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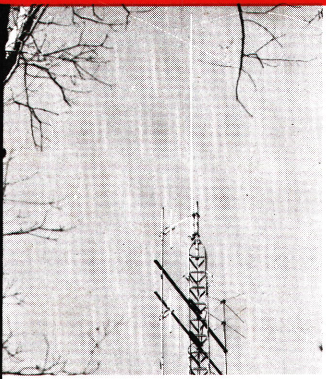
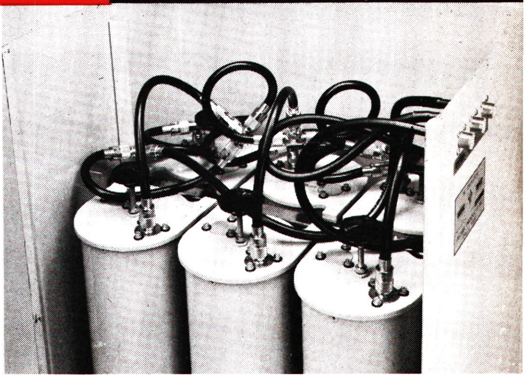
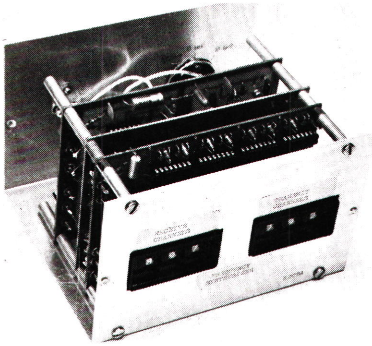
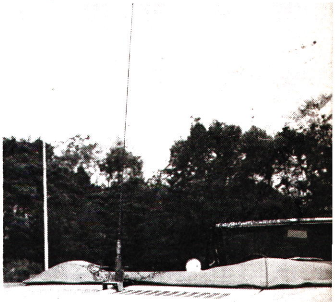
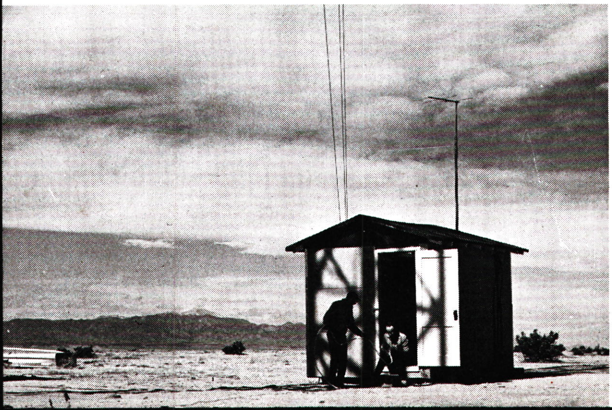
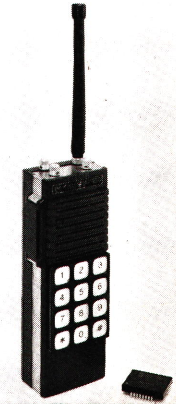

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FM and REPEATERS for the Radio Amateur

By the ARRL Headquarters Staff

Thomas McMullen, W1SL
Editor

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Foreword

The surge of amateur fm mobile activity on vhf, using repeaters, has been as spectacular as any other milestone in our history. In that portion of the spectrum, fm/repeaters are changing the shape of things as much as did the hf transition from spark to cw, or the shift from a-m to sideband.

True, fm has been around us a long time. Repeaters are not really new. And two meters has long been a vhf mainstay. So why the sudden change?

The catalyst sparking dramatic growth was the decision of the Federal Communications Commission to reduce permissible bandwidths in the commercial land mobile services just above 150 MHz. This caused thousands of "obsolete" police, taxi, etc., two-way fm units to appear on the used equipment market – ideal for hams to revamp for 144-MHz operation.

Long accustomed to roaming within bands at will, amateurs were obliged to adapt to limited-channel availability offered by most surplus units. The "restriction" was turned to an advantage – by allocation of vhf band segments as to spots for repeater input, output, and direct communication channels. Hams thus no longer need be envious of the Citizens Radio Service for the one "plus" they held in potentially efficient communications – channelization. And in amateur radio it was voluntary, not decreed by regulation.

The market was not long ignored by industry, and shortly manufacturers tooled up for the new field, adding those participants more interested in operating than soldering-iron projects of modification of surplus.

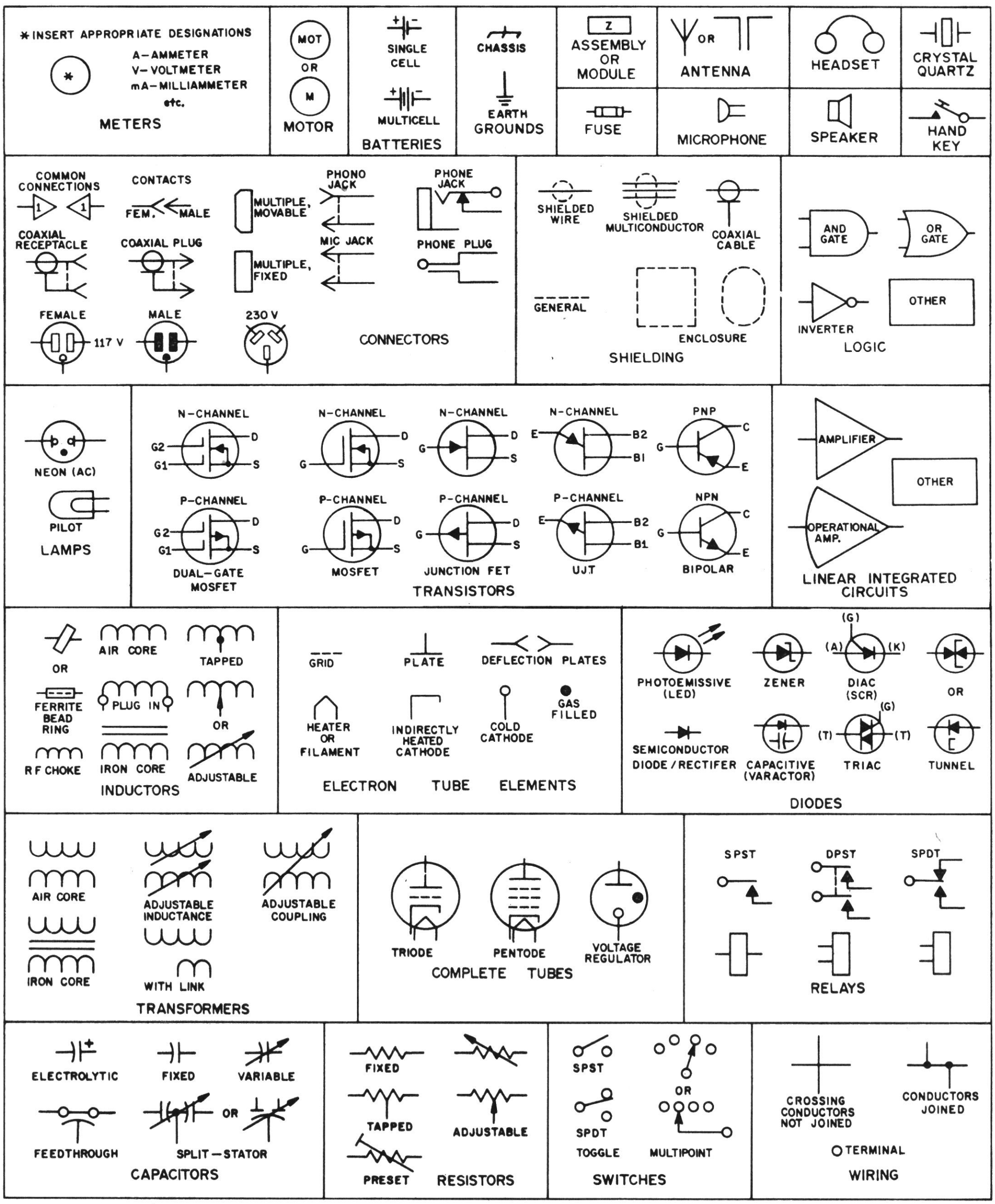
This manual has been produced by the Hq. staff in response to membership desires as collated and crystallized by the Board of Directors. It has attempted to choose the "best" of material published earlier in ***QST*** when still appropriate for the purpose. Yet many months of lab work, writing, rewriting and editing were required to get the publication ready for production. Its appearance was intentionally delayed, however, until FCC put the final touches on proposed new regulations for the repeater field, which has now been accomplished.

As in the case of all League publications, but particularly for this first edition of a new work, the Hq. staff would appreciate comment and criticism so that future editions may more fully meet the needs of amateur radio.

JOHN HUNTOON, W1RW
General Manager, ARRL,

Newington, Conn.

SCHEMATIC SYMBOLS USED IN CIRCUIT DIAGRAMS



CONTENTS

FM—Past and Present

IT HAS BEEN SAID, with some justification, that if modern fm techniques had been available before amplitude modulation became thoroughly entrenched, fm would have established itself as the basic mode of voice communication in the vhf spectrum, if not on all frequencies where voice is used. This is an over-simplification of a complex picture, but it does help to explain the long struggle that fm advocates have had to wage to gain acceptance for their chosen mode.

The origins of fm go back a very long way, probably to the earliest attempts at voice communication of any kind. Frequency modulation was dealt with in solid technical terms as far back as 1922, when Carson[1] analyzed modulation systems mathematically, and proved that (with any detection method then known) fm was inferior to a-m, in respect to both the bandwidth and distortion of the received signal.

This just about took care of fm, for that early time, except as an unwanted byproduct of other modulation schemes. The paper brought its author some unjust criticism when practical fm detection was developed later, but his statements were true as gospel in 1922, and for more than a decade after. No less an advocate than the late Major Edwin H. Armstrong devoted several pages of his classic 1936 paper on fm[2] to a recital of its failures, originating with a frequency-shift keying system for the Poulsen Arc. His references, going back to 1912, confirm the Carson analysis. But Armstrong went on to show the ways to handle the well-documented weaknesses of fm.

Probably few readers of these lines have access to *IRE Proceedings* of 1936, so it may be desirable to quote verbatim from Armstrong on what it takes to make fm competitive with other systems:

> The conditions which must be fulfilled to place a frequency-modulation system on a competitive basis with an amplitude-modulated one are the following:
>
> 1. It is essential that the frequency deviation shall be about a fixed point. That is, during modulation there shall be a symmetrical change in frequency with respect to this point, and over periods of time there shall be no drift from it.
>
> 2. The frequency deviation of the transmitted wave should be independent of the frequency of the modulating current, and directly proportional to the amplitude of that current.
>
> 3. The receiving system must have such characteristics that it responds only to changes in frequency, and that for maximum change of frequency at the transmitter (full modulation) the selective characteristic of the system responsive to frequency changes shall be such that substantially complete modulation of the current therein will be produced.
>
> 4. The amplitude of the rectified or detected current should be directly proportional to the change in frequency of the transmitted wave, and independent of the rate of change thereof.
>
> 5. All the foregoing should be carried out by the use of aperiodic means.

Could it be said any better today? Armstrong then described the methods by which he achieved the noise-free high-fidelity signal that is the hallmark of fm broadcasting as we know it today. Basically, this meant introducing into the transmitted signal a characteristic not present in disturbances of natural origin and most man-made noise, and then making a receiver that would not respond to amplitude variations such as these. Modern-style frequency modulation of a stable carrier and the limiter-discriminator type of fm receiver thus first found their way into print.

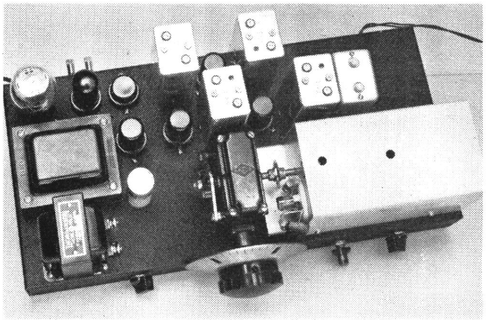
Crosby, W2CSY,[3] would soon show that, *above a certain improvement threshold* which was related to the deviation ratio, frequency modulation was demonstrably superior to amplitude in signal-to-noise ratio when Armstrong's numbered criteria, above, were satisfied.

The battle for acceptance of fm was still far from won, however. Particularly in the amateur radio field, the close tie-in between transmitter deviation and receiver bandwidth, and the need for a receiver designed for this mode alone, were to hold back many who might have otherwise become quick converts to fm. We have compatibility with other modes in narrow-band fm today, but full realization of the advantages of fm still requires meeting Armstrong's five requirements. The receiving devices to do this, which are not required for other modes, still represent a stumbling block to some potential users of fm.

It is of interest to note that while the fm pioneering of Armstrong and others was going on, rapid strides were being made in reducing the destructive effects of noise in other forms of communication. Crosby emphasized this, citing two amateur contributions to this end in cw and voice communication, reported in *QST*.[4]

FM in QST

The principles of modern fm were first set forth for *QST* readers in 1939, by Professor Daniel E. Noble, W1CAS,[5] of Connecticut State College, later to become the University of Connecticut, at Storrs. Noble had worked closely with Armstrong, and had designed two experimental 43-MHz fm



This 112-MHz receiver, possibly the first complete unit designed specifically for amateur vhf fm reception, was described by Grammer and Goodman in *QST* for January, 1940. The acorn-tube front end (aluminum assembly at the right) was salvaged from an earlier vhf receiver by Ross Hull. Its 5-MHz output fed an i-f system using specially-built transformers in its amplifier and limiter-discriminator stages.

broadcasting stations, one at Storrs and the other on West Peak, in Meriden.

Professor Noble was also a prime mover in an experimental project with the Connecticut State Police, which resulted in the first practical two-way vhf communications system for mobile use.[6] His concept of statewide vhf communications with fm and repeaters was the forerunner of the vast networks of fm mobile communications, commercial, governmental, and amateur, that we know today. Noble's part in this would have assured him an honored place in fm's hall of fame, but he is perhaps better known as a long-time engineer and official of Motorola, Inc.

Other farsighted amateurs were realizing the potential of fm. Grammer and Goodman described a complete 112-MHz fm station in *QST*, early in 1940.[7] No less than seven feature articles on fm were in *QST* that year, and mentions of fm activity began to appear in the fledgling vhf column, "On The Ultrahighs." Its conductor, W1HDQ, built his first fm receiver to listen to the Grammer-Goodman rig, used occasionally at W1INF, ARRL headquarters in West Hartford.

There were no deviation standards for amateur fm, but it was generally conceded that optimum noise reduction was possible only with a deviation ratio of 5 or more. Audio frequencies up to 15,000 Hz were transmitted in fm broadcasting, so a deviation of 75 kHz was required, and is still used. Receiver components were designed for 150-kHz bandwidth, so amateurs were more-or-less tied to it, unless they made their own i-f transformers, which not many did. The F. W. Sickles Company, an early supplier, made it possible for amateurs to get into the fm receiver field soon after suitable i-f transformers became available.

Incidental FM

Broadcasting's bandwidth turned out to be fine for a receiver called upon to handle signals from modulated-oscillator transmitters, then in common use on the 112-MHz band. Modulating the supply voltage of a vhf oscillator results in plenty of deviation before appreciable amplitude modulation occurs, so if the transmitter operator held his audio down his signal sounded fine on a wide-band fm receiver. This simple approach to vhf fm was applied successfully by W1CTW many years later,[8] and it still has potential for use on 1215 MHz and the higher bands, where there is room for it.

Narrower Bandwidths

It was clear that, with no useful information in voice frequencies above 5000 Hz, even hi-fi voice communication required no more than 25-kHz deviation. The i-f systems in amateur fm receivers described toward the end of 1940 were designed with this in mind.[9] Commercial and police communication systems, using 3000 Hz, maximum, in their audio circuits were set up for 15-kHz deviation around this same time. This was still wide-band fm (deviation ratio of 5) and still incompatible with other voice modes used in the amateur bands, with the selective receivers then coming into general use for a-m and cw.

Because of this incompatibility, fm of any kind was illegal for amateur frequencies below 112 MHz. To promote use of wide-band fm on other amateur frequencies where there was room for it, FCC, acting on an ARRL request, made wide-band fm usable above 29.25 MHz in the 10-meter band,

This cover picture from February, 1940, *QST* shows the rf portion of a 112-MHz fm transmitter built by Goodman. The tubes at the left are the frequency-modulated oscillator-doubler and second doubler. The single RK-34, right foreground, is a pushpull tripler to 112 MHz. The single 6L7 reactance modulator is in an aluminum shield, just in back of the tank circuit.

and above 58.5 MHz in the old 5-meter band. The latter assignment was changed to above 52.5 MHz, when the band was changed to 50 to 54 MHz, after World War II.

This resulted in some movement to fm in the vhf bands. Proponents of fm organized demonstrations at hamfests and conventions, both before and after World War II, showing clearly the benefits of the system. Their audiences were sold easily on all aspects of fm, save one: the need for a special receiver to reproduce those beautiful signals. "Incompatibility" was to become the epitaph for wide-band fm, for all practical purposes, until the windfall of cheap and plentiful fixed-frequency transceivers from military and commercial services, in the mid 1950s. But narrow-band fm was soon to enjoy considerable popularity – for reasons not related to the success of fm in broadcasting or commercial-mobile service.

The Narrow-Band FM Era

Because there is no amplitude change in the output of an fm transmitter, whatever the deviation, the mode is an almost perfect cure for audio-related interference problems that plague the vhf enthusiast in densely settled areas. This panacea probably converted more 6- and 2-meter men than the more advertised advantages of fm. It also attracted the attention of some voice operators on lower frequencies, for audio-rectification problems are not the scourge solely of vhf men.

Even before the war era there had been some interest in narrow-band fm. It had been observed that, with careful matching of the receiver bandwidth and the transmitter deviation, an fm signal could be copied fairly well on a selective communications receiver, tuned slightly to either side of the center of the signal. "Slope detection" didn't offer the other advantages of fm, but it pointed the way to a compatible system – and a major relief from interference problems.

The real potential of narrow-band fm was first spelled out by Grammer, in *QST* for October, 1946.[10] Whitaker, W2BFB, of the Hammarlund Company, had worked up a narrow-band fm phone rig for the amateur market, just before the World War II closedown. Essential details of his reactance modulator for crystal-controlled transmitters were given by Shuart, W2AMN, in November, 1946, *QST*.[11]

All this suggested a careful check of the interference potential of narrow-band fm in a crowded voice band. With special FCC authorization, the ARRL headquarters station, W1AW, began tests on 3920 kHz with W2GDG, in the fall of 1946. These quickly proved that if the deviation ratio was held below 0.75, as recommended earlier by Grammer,[10] two stations could work only 2 kHz apart, with less interference than would result from use of a-m of the same power on the same frequencies. W2GDG, meanwhile, described a phase modulation exciter for 29 MHz, with provision for use on lower frequencies when and if the mode was made legal there.[12]

The W1AW-W2GDG tests, continued through the spring of 1947, showed that the two modes were compatible, and nfm was authorized by FCC, on a one-year trial basis in band segments 3850-3900 kHz, 14,200-14,250 kHz, 28.5 to 29 MHZ and 51 to 52.5 MHZ. Soon the nfm authorization was extended to all amateur voice frequencies, provided that ". . . the peak deviation is limited to a value equal to or less than the maximum modulation frequency."

QST and ARRL encouraged fm in every practical way thereafter. Between 1946 and 1950, 16 *QST* articles featured fm in one form or another. Special multipliers were given fm users in vhf contests. Almost every vhf transmitter in *QST* and the *Handbook* had a reactance or phase modulator. There were numerous articles on fm receivers, and on adapters to provide good fm reception with existing communications receivers. Several manufacturers brought out nfm adapters as plug-in accessories, but these options were not widely picked up by amateurs.

"Sideband" Takes Over

Frequency modulation continued in the role of a neglected stepchild, as far as most amateurs were concerned, despite its many good points. Then, in the early 1950s, came ssb, and whatever wide acceptance of fm may have been in prospect for the lower frequencies disappeared in the cloud of dust stirred by the new and obviously far more efficient voice techniques.

Once more, fm was relegated to the vhf bands, and used there mainly as an interference-preventing device. As such it has had some strong advocates, especially in urban areas, where any other voice mode triggered almost insurmountable neighbor problems. But the very real communications advantages of fm were largely ignored by the majority of hams, mainly because their communications receivers, as purchased, were not particularly effective in dealing with the mode.

Meanwhile, on commercial and public-service frequencies in the vhf range, where fixed channels could be set up and transmitter deviation and receiver bandwidth carefully matched, fm quickly became the accepted standard after World War II. Dozens of electronics manufacturers entered the field, producing equipment that offered reliable and effective radio communication to nontechnical users everywhere. Within the space of a few years, available frequencies filled to the overflowing, requiring drastic measures to make room for countless new users who wanted to take full advantage of this superb solution to the communications problems of work vehicles operating far from their home bases.

There were no more frequencies available; the obvious step was to cut down bandwidth, transmitting and receiving, to make room for more channels. This was done by FCC edict, requiring all vhf fm users other than amateur to convert from a maximum deviation of 15 kHz to 5, progressively by services. Beginning in 1960, it continued on the basis of the priority of the service concerned, over the next ten years or more.

Several factors made starting over with completely new equipment preferable to conversion of existing gear to the narrower bandwidth. Development of new or improved techniques had been rapid in the 1950s. Conversion to solid-state circuitry was imminent. Miniaturization was becoming practical. So, much of the existing gear for fm communications, designed for frequencies near our 50-, 144- and 420-MHz bands, was simply discarded in favor of completely new models, creating a surplus market in used fm equipment that would become a potent force in converting thousands of hams to a "new" mode of communication.

Though this reversed the traditional role of amateur pioneering, and a good many amateurs were not overly receptive to the idea at first, vhf fm communications with equipment salvaged from commercial users gradually gained a foothold. K9OJV pointed the way in a 1960 *QST* article,[13] which generated so much interest that the author was soon forced into the production of a book of conversion information.[14] "Two-meter fm" was on its way, and in the next ten years it would work a change in amateur radio operating habits on a par with such historic conversions as spark to cw in the Twenties, and a-m to ssb in the Fifties.

Also inherited from the commercial services were equipment and methods for extending the reliable operating range of vhf mobile stations through use of repeaters. Like fm itself, the fm repeater idea caught on slowly at first, but once started it began to mushroom. As pointed out in our historical summaries, both fm and repeaters date back to the earliest days of vhf communication. Neither got very far in ham radio by itself. Together they have changed the whole amateur radio game in a major way. "The World Above 50 Mc." will never be quite the same again.

FM REPEATERS, OLD AND NEW

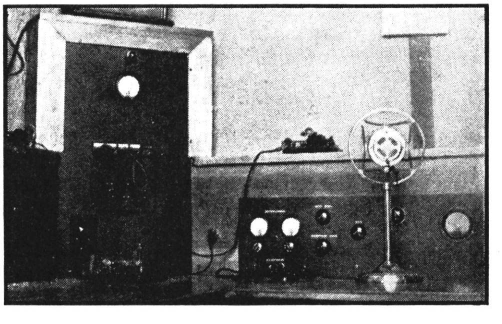
Today's fm advocates tend to think of the repeater as a recent development, but relaying of various kinds has been a part of amateur radio from its earliest days. The fm repeater is popular because it provides the best means yet for extending the reliable range of low-powered portable and mobile stations. In this role the repeater has great potential for the good of the game. But *new* it is not!

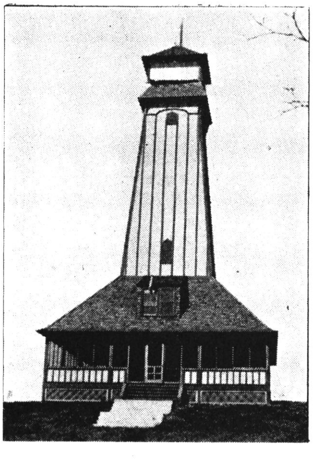
Greybeards of the vhf scene fondly recall working far beyond their usual horizons, through the cooperation of 5-meter relay stations of the early 1930s. With the kind of gear available in those days, we *needed* help. And an obsession with the line-of-sight idea caused most of us to assume there was no chance of working farther than across town, unless we could get up on a mountain with portable gear. Work on 5 meters was thus almost wholly confined to weekends, when hams had the time required to set up for business in the high spots.

All used simple low-powered transmitters, and super-regenerative receivers. With separate antennas these devices were soon found to offer the capability of "duplex phone." It was a short step from working duplex to retransmitting the other fellow's signals, and this suggested a special role for mountaintop stations. They weren't called "vhf repeaters," but they performed services not unlike those of today's more sophisticated relay stations.

An early 5-meter station,W1AWW, operating from a 90-foot wooden lookout tower overlooking the eastern slope of the Connecticut Valley, near Springfield, Mass., was probably the first regular practitioner of this art. Later licensed as W1HMO, this station was repeating 5-meter stations to one another over distances up to 100 miles or so, as long ago as 1932. Except that this required an operator on duty, how many repeaters do better today?

This was even an fm repeater, in practical effect if not by intent. Modulating the simple oscillator rig made more fm than a-m, though it was the fashion in that day to have plenty of both, in order to assure high audio recovery with the simple "rushbox" receivers then in universal use. It mattered little that this was not exactly a narrowband system. Who else was using any frequency above 30 MHz or so, in the early Thirties? The





The first vhf repeater? W1AWW, later W1HMO, installed part way up in a 90-foot wooden lookout tower, near Springfield, Massachusetts, began 5-meter relaying in 1932. By 1934, when these pictures appeared in *QST*, the station boasted several vhf receivers, each on a separate antenna, and a telephone-type patch panel for connecting any receiver output to the 100-watt transmitter. Retransmission of signals from as far away as New York and Boston was achieved before 1935.

operator simply tuned up his transmitter around 61 MHz or so and told the stations waiting to work through him to move down around 54 MHZ, or wherever it might be necessary to go to avoid blocking effects. "The band" was whatever you needed, in those days.

There were other stations doing much the same thing, but this one, at least, is part of vhf history in *QST.*[15] As we look back on those happy days we can feel that the W1AWW-W1HMO gang experienced most of the pleasures and pains that reward and afflict operators of vhf repeaters 40 years later. They had the satisfaction of seeing 5-meter activity spring up early, both in the swarms of portables on summer weekends and in gradually increasing home-station operation, for the stay-at-homes also found new pleasures in 5-meter work "through the mountain." Such instant and deserved popularity also brought problems. Repeater operators of the Seventies will find this part of the first time around all too familiar.

With more stations wanting to be relayed than there was time for, there developed elements of the inevitable strife that results from overuse of a good idea. There were also 5-meter operators who felt that they could eventually work out from ordinary home locations, without the aid of mountaintop facilities. This was a big joke to most of the relay-happy gang, but that didn't stop the optimists. Ross Hull became their patron saint when, in the fall of 1934, he proved that with big antennas and better equipment a 5-meter station could, indeed, do very well on its own from other than a high mountain site.[16]

Will history repeat itself here, too? Will the thousands of today's users of push-to-talk boxes and 19-inch whips rediscover the fact that a repeater is not an absolute prerequisite to interesting activity on the 2-meter band? We hope that they will, while recognizing full well the worth of the modern vhf repeater in providing highly reliable and almost interference-free communication between mobile and portable stations, far beyond their normal service areas.

FM and Repeaters — the Perfect Marriage

It should not be inferred from the foregoing that the repeater idea was ever totally abandoned. Since the earliest vhf communication, there have always been repeaters. Some of them became quite sophisticated remotely controlled devices, in the years after World War II, but before the current fm boom. K6GWE in the Bay Area, and K6MYK and K6JCC in Southern California, were notable a-m repeaters of the 1950s. Others were scattered around the country, particularly in mountainous areas, where mobile work was rather ineffective without a strategically located repeater to help the cause along. How to set up vhf repeaters, legally and technically, was described by K6QNY in *QST*[17] when vhf mobile work was still almost entirely a-m oriented.

But frequency modulation has certain characteristics that make its mating with the vhf repeater a highly effective solution to many of the problems of reliable local communication with mobile and portable gear. How these characteristics come about in an fm system will be discussed in detail in later chapters. We only point them out, here. Perhaps the most important is the nature of fm reception. With receivers specifically designed for fm, the strongest signal on a given channel has a marked "capture effect." With only a few dB difference in level, any weaker signal is not heard. Heterodyne interference, the plague of a-m communication in crowded voice frequencies, hardly exists with modern fm gear.

Allied with this factor is the agc effect (limiting) inherent in fm reception. Once the signal level is sufficient to quiet the receiver noise, the audio output of the receiver (for a given transmitter deviation) changes very little, virtually eliminating the effects of "mobile flutter" that prove so annoying in reception of other modes.

Finally, there is the noise-free quality of fm when well-designed receivers are used. Especially for ears unaccustomed to the racket that is part of voice communication with a-m and ssb, a good fm system provides much more pleasant listening. Add to all this an effective squelch system and the reliable nature and extended range of communication through a well-run repeater, and you have a "way of life" that has great appeal for the ham who must spend a lot of time in his car. You also have a communications system of unparalleled worth in time of local emergency.

Transmitter design factors with fm are important, too. Rf circuits are simple. Linearity problems that can so easily ruin the quality of an a-m or ssb signal are gone with fm. With no amplitude changes involved in the modulation process, the fm transmitter can be operated at maximum cw ratings, if need be, and reduction of power, for reduction of interference or for long battery life, is a very simple process involving no critical transmitter adjustments.

Audio equipment is elementary. No audio power is required. The modulation process is taken care of early in the transmitter lineup, usually in the oscillator section, and no later stage has any bearing on the signal quality. Unlike other voice modes, adjustment of exciter and amplifier stages in the fm rig is a simple "tune for max" process.

In view of these special characteristics it is easy to see why modern fm and the vhf repeater combine so well. Each is a very old idea. Each had its advocates, from the earliest days of communication above 30 MHz, but neither set the world on fire on its own. But now combined, and with specialized techniques developed to improve their effectiveness together, fm and repeaters have brought about a major revolution in amateur radio operating habits.

You can enjoy the fruits of this revolution without ever learning more than how to work the push-to-talk switch on your microphone. But, as with any aspect of amateur radio, you'll enjoy it more and do a much better job of it if you learn all you can of the how-and-why of fm and repeaters. To help you along this intriguing route is the main objective of this book.

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Chapter 2

The FM Concept

THE ADVANTAGES of frequency modulation (fm) were discovered many years ago as was pointed out in Chapter 1 of this manual. One of the primary reasons for the popularity of fm, then and now, can be related to the comparative freedom from man-made and natural noise pulses external to an fm receiver. Though methods for blanking out noise pulses in ssb, cw, and a-m receivers have been developed in recent years, and with good effect, the complexity of receivers for those modes, when effective noise-blanking circuits are employed, somewhat exceeds that of a good fm receiver. Though hi-fidelity audio is not necessarily a requisite for good communications it is desired by some amateur operators, and fm makes it easier to obtain "broadcast quality." Because of the foregoing, many amateurs prefer to use fm for local communications.

Perhaps a reason for the recent upswing in fm popularity among amateurs is the widespread availability of surplus tube- and transistor-type two-way fm gear that has been retired by the land-mobile services. The availability of this equipment at very low prices has made it possible for amateurs with the most modest of budgets to get on fm, and with reliable transmitting and receiving gear designed to meet rigid commercial specifications. Another reason for the success of fm and repeaters can be related directly to the comradeship which is peculiar to vhf work on a local level. The extended vhf fixed-station and mobile coverage afforded by repeater stations assures regular contact between operators who might not otherwise have the occasion to communicate within a relatively small geographic area.

FM DEFINED

The carrier amplitude of an fm transmitter remains at a constant level with or without modulation. However, when modulation is applied the carrier frequency is varied above and below the **center frequency** (unmodulated carrier frequency) in accordance with the audio voltage applied to the transmitter modulation. An illustration of the swing in transmitter frequency is given in Fig. 2-1. The amount of swing from center frequency is solely dependent upon the peak value of the modulating voltage rather than upon its frequency. The frequency of the audio energy will, however, govern the rate at which the changes in carrier frequency occur. Thus, the greater the modulating-voltage level the more pronounced will be the frequency swing of the carrier.

The **bandwidth** of an fm signal is dependent upon the **frequency** of the audio voltage as well as its amplitude. **Fm sidebands** are formed during the modulation process, and these are separated from one another by an amount equal to the audio frequency. This means that if a 600-Hz tone were introduced at the modulator input, fm sidebands would exist 600 Hz apart (above and below center frequency of the carrier). The amplitude of the sidebands would diminish progressively as they occurred farther and farther from center frequency. If the amplitude of the 600-Hz modulating voltage was great enough to cause, say, ten **significant sidebands** (five above and five below center frequency) the bandwidth of the fm signal would be 10 × 600, or 6 kHz. Because both the amplitude and frequency of the modulating voltage determine the actual bandwidth of the transmitted signal, it is necessary to adjust the deviation controls of some fm transmitters to one operator's voice. The exception to this rule is when the speech system of an fm transmitter is equipped with an audio clipper or limiter which is located ahead of the level control used to establish the deviation amount (Fig. 2-2). Since no two human voices exhibit the same frequency and amplitude characteristics, their effects on the fm transmitter signal bandwidth will be decidedly different. Perhaps the greatest contrast can be seen when comparing the components and level of a woman's voice against those of a man. By employing a clipper/filter in the speech amplifier circuit the

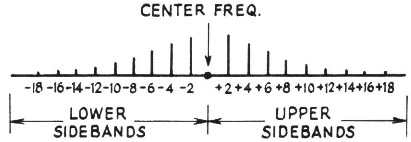


Fig. 2-1 — Illustration of how the fm sidebands are spaced above and below the center frequency of the carrier. This display shows a group of sidebands resulting from the application of a 2-kHz tone to the transmitter modulator. The sidebands farthest from center frequency are the lowest in amplitude. The sidebands nearest to center frequency can be considered the *significant sidebands*, their amplitudes being fairly great.

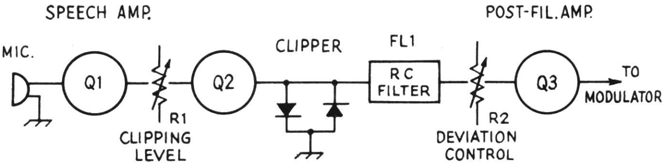


Fig. 2-2 – Block diagram of a typical fm-transmitter speech amplifier/clipper. R1 sets the clipping level and R2 is adjusted for the desired amount of deviation. FL1 filters out the harmonic energy developed during the clipping process, thus minimizing distortion.

foregoing effect is nullified, though the average audio level supplied to the modulator will be lower with voices of lower intensity and less low-frequency range. If the voice is so "thin" that clipping does not occur, the deviation can drop to some level below that for which the transmitter was originally set, but it will never exceed that amount regardless of how robust the speaker might be.

The human voice has many components indeed, and numerous fm sidebands occur at varying levels during the formation of any complex sound or word. For this reason the sidebands at a given instant will be spaced differently and will be significant in number only as a function of their amplitude at that precise moment.

Comparing Frequency and Phase Modulation

The end result is the same whether frequency or phase modulation techniques are applied. The more classic "frequency modulator" is generally regarded as that system used to shift the crystal frequency, or pull it, during the modulation cycle. This method is popular mostly in solid-state transmitters whose current drain must be kept low to provide extended battery life. The usual means of shifting the oscillator frequency above and below the desired center frequency is to insert a voltage-controlled variable capacitor in series with the crystal (CR1 in Fig. 2-3A). Varactor diodes (sometimes called Varicaps or Epicaps) are generally used for this purpose, though the junctions of bipolar transistors can be employed to provide the same effect. Audio voltage is impressed across the voltage-variable modulator diode. The positive and negative excursions of the af waveform cause the diode junction capacitance to vary above and below a mean value. This change in capacitance shifts the oscillator frequency in accordance with the voice frequencies and their amplitudes at a particular instant, thereby providing frequency modulation. Unless an amplitude limiter is used after the modulated stage of the transmitter there is likely to be a resultant mixture of a-m and fm in the transmitted signal. However, the a-m component will normally be small in comparison to the fm characteristic of the signal and will therefore be of little concern in amateur work.

It must be remembered that the amount of frequency modulation occurring at the oscillator is dependent upon the multiplication factor of the crystal frequency versus the carrier frequency of the transmitter. If one wishes to have a deviation of 5 kHz at 146 MHz, and the oscillator crystal frequency is, for example, 6.1 MHz, the oscillator frequency must be shifted approximately 100 Hz above and below center frequency. Since the basic frequency multiplication factor in this example is 24 (6.1 MHz × 24 = 146.4), the deviation value is governed by the same factor. Thus 100 Hz × 24 = 2.4 kHz. Therefore, 2.4 kHz × 2 = 4.8 kHz (a 2.4-kHz swing above and below center frequency), is the total *significant bandwidth* of the signal. We have kept the numbers simple in this example. To obtain the full 5-kHz deviation the oscillator would have to be swung ± 104.16 Hz (104.16 Hz × 24 = 2.49984 kHz). It can be seen from this that the

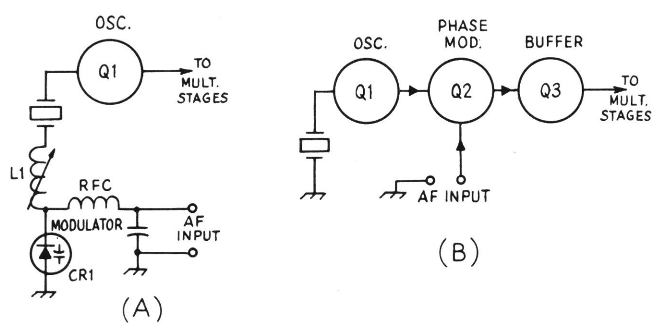


Fig. 2-3 – Illustration A shows how a voltage-variable diode can be used to generate direct fm by pulling the crystal frequency above and below center frequency when af voltage is applied. At B, a block diagram of a phase-modulation system.

higher the crystal frequency the lower will be the frequency multiplication factor, thereby requiring greater amounts of frequency swing at the oscillator to acquire the desired deviation. As the operating frequency of the oscillator is increased, more difficult becomes the task of obtaining wide amounts of deviation. This results from a need to swing the crystal frequency as much as several kHz under modulation, a condition which can cause the oscillator to stop working on peaks of audio voltage. Additionally, the crystal must be made rather "rubbery" by introducing VXO techniques, and this in turn can lead to poor frequency stability of the transmitter.

Phase modulation (pm) produces the same end result obtained when employing **direct frequency modulation**. The mechanics of pm involve vectors and phase, and a thorough technical explanation of the subject would be somewhat lengthy. The reader is referred to Kiver's excellent treatment of fm in his book, *FM Simplified*, Chapter 2 (Van Nostrand Co.). In essence, however, the modulating audio-frequency voltage is used to shift the phase angle of the carrier from its reference value (value when no modulating voltage is present) by an amount proportional to the instantaneous value of the modulating sine wave.

The phase modulator is located after the oscillator stage of the transmitter (Fig. 2-3B), and functions at the crystal frequency. A buffer/amplifier or frequency multiplier normally follows the modulator. Reactance modulators are sometimes used to obtain pm from VFO-controlled transmitters, and when used are connected to the VFO tuned circuit. Since only the frequency and phase of the carrier wave is altered in pm and fm work, any class of amplifier can be used to increase the power of the signal. A linear amplifier is neither necessary or desirable, though it can be used for the purpose. Class C operation is preferable because the efficiency of the latter is superior to that of linear amplification, Class AB or B.

FM RECEPTION AND ITS ADVANTAGES

A well designed fm receiver has the characteristic ability to reject amplitude-modulation energy. Since noise pulses external to the receiver are sometimes rather great in magnitude, especially during mobile operation, and because noise pulses are bursts of a-m energy, the fm receiver will not reproduce them at its output. Fm receivers contain stages called "limiters." **Limiters** are used after the last i-f stage, just ahead of the detector (Fig. 2-4). Any a-m pulses that reach the limiter or limiters will cause the tube or transistor used to be driven into saturation, at which point it ceases to amplify. The fm signal being received is not adversely affected by the limiting action of the receiver. Within reasonable limits, various levels of input signal to an fm receiver produce a constant output from the limiter, thus providing good immunity to noise pulses and other forms of a-m. The limiting action also establishes an agc characteristic in the receiver. A typical fm receiver might produce the same af output voltage to the speaker at any input-signal level between, say, 1 and 10,000 μV.

Since most fm receivers are equipped with a muting system (squelch) that silences the audio channel when no signal is present, ham operators and their families tend to prefer fm for fixed-station and mobile work. One does not have to listen to irritating hiss noise coming from the loudspeaker when the frequency being monitored is not in use.

Another significant advantage to mobile operation offered by fm is one of *driver safety*. Most mobile transceivers are crystal controlled, thereby not requiring that the operator look at dials or tune a transceiver LMO, VFO, or PTO. The latter is common to hf-band mobile operation when using modes other than fm. The fm operator needs only to move a crystal-selector switch and push a microphone transmit button, either of which can be done while in motion, and without looking at his radio equipment.

Why a Repeater?

Why, if fm is so effective a communications mode, should repeaters be necessary? The answer is simple: A repeater serves as an extension of an amateur's fixed and mobile stations. Because repeaters are generally located on high buildings or land masses, line-of-sight communications are more

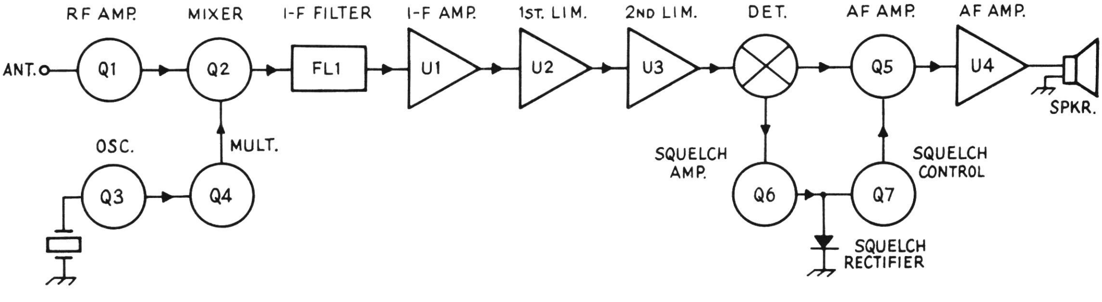


Fig. 2-4 — Block diagram of a simple fm receiver showing the manner in which the stages are organized. The arrows indicate the direction of travel for the signal.

effective in terms of distance than if the communicating stations were operating simplex (direct) from some lower elevation. Also, the repeater transmitter can provide the focal point that attracts many operators to a common frequency, thus making it easier to locate the person one wishes to communicate with. Also, this form of "channel" sharing enhances the likelihood of being able to "raise" another station in time of emergency, since many operators listen "on channel" many hours each day.

During times of local emergency or disaster the repeater makes possible long-range communications between on-the-scene handi-talkies and distant base or mobile stations, and can provide phone patching to various nonradio equipped points from areas where mobile or hand-held transceivers are in use.

Receivers for FM

A HIGH-QUALITY fm receiver is a complex device. Selectivity and stability – the desirable characteristics of any receiver – are needed in an fm unit. In addition, the fm receiver should respond only to frequency-modulated signals – any traces of amplitude modulation on a signal should not be detected. Because the fm signals used in amateur communications are broader than a-m or ssb transmissions, careful design is needed in the i-f portion of the receiver to assure that the overall bandwidth is wide enough to allow detection without distortion, but not so wide that adjacent-channel interference becomes troublesome.

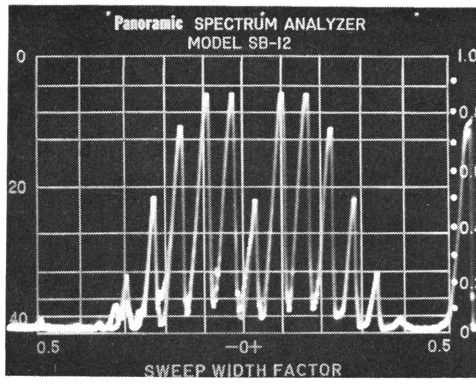


Fig. 3-1 – Output wave form of a narrow-band fm transmitter modulated by a 1-kHz tone.

THE FM RECEIVER

Block diagrams of an a-m/ssb and an fm receiver are shown in Fig. 3-2. Fundamentally, to achieve a sensitivity of less than one microvolt, an fm receiver requires a gain of several million – too much total gain to be accomplished with stability on a single frequency. Thus, the use of the superheterodyne circuit has become standard practice. Three major differences will be apparent from a comparison of the two block diagrams. The fm receiver employs a different detector, and has a limiter stage added between the i-f amplifier and the detector. Otherwise the functions, and often the circuits, of the rf, oscillator, mixer and audio stages will be the same in either receiver.

In operation, the noticeable difference between the two receivers is the effect of noise and interference on an incoming signal. From the time of the first spark transmitters, "rotten QRM" has been a major problem for amateurs. The limiter and discriminator stages in an fm set can eliminate a good deal of impulse noise, except that noise which manages to acquire a frequency-modulation characteristic. Accurate alignment of the receiver i-f system and phase tuning of the detector is

A-M RECEIVER

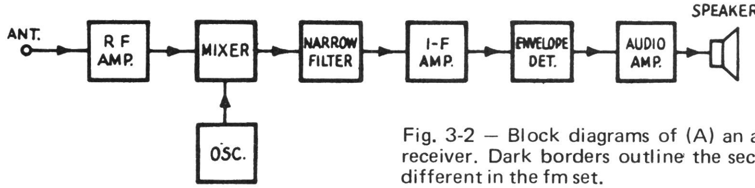
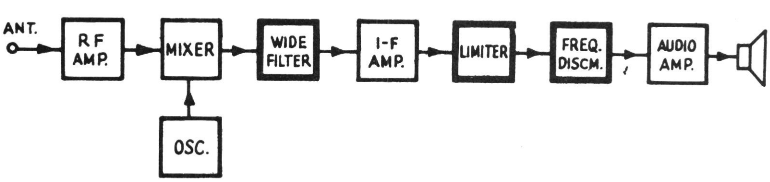


Fig. 3-2 – Block diagrams of (A) an a-m (B) an fm receiver. Dark borders outline the sections that are different in the fm set.

F M RECEIVER



required to achieve good noise suppression. Fm receivers perform in an unusual manner when QRM is present, exhibiting a characteristic known as the *capture effect*. The loudest signal received, even if it is only two or three times stronger than other stations on the same frequency, will be the only transmission demodulated. By comparison, an S9 a-m or cw signal can suffer noticeable interference from an S2 carrier.

FM RECEIVER DESIGN

Until recently, fm receivers have followed the design shown in block-diagram form in Fig. 3-3. One or two rf amplifier stages and a double conversion frequency scheme were used. Greater band occupancy has inspired both commercial and amateur receiver designers to work on the dynamic range and strong-signal handling capabilities of fm receivers. As cross-modulation and overload effects are primarily caused by the rf amplifier and first mixer, a good deal of research has gone into the application of various solid-state devices for use in receiver front ends. The result of this work has been a vast improvement in fm receiver signal-handling capability.

Two devices, the FET and the hot-carrier diode, are responsible for the revolution in front-end circuits. Both devices can be operated to provide square-law response as mixers. The sensitivity of either type is such that the rf amplifier can be eliminated in many cases. Although the hot-carrier diode has been used by the amateur fraternity, the device hasn't been popular with fm receiver designers for two reasons. To assure linear mixing, the level of oscillator injection to a diode mixer must be at least 10 dB above the strongest signal to be received. Even with a balanced bridge of hot-carrier diodes, the power required from the local oscillator is considerable. Also, the diode mixer must be followed by a low-noise i-f preamplifier for best overall receiver noise figure, introducing a new area for cross-modulation effects to appear. FET devices exhibit a slightly better noise figure (by 1 to 3 dB), and thus, are usually chosen over hot-carrier diodes.

The first field-effect transistors to gain wide acceptance were the junction types (JFET). Though still the leader in the low-noise-figure competition, the JFET also requires a rather large amount of power from the oscillator chain when used as a mixer. Early metal-oxide semiconductors (MOSFET) were easily damaged by static charges and voltage spikes, and were considered too delicate for mobile service. However, the development of the diode-protected dual-gate models has made the MOSFET as hardy as the bipolar transistor. Only one volt of oscillator injection is required to the high-impedance gate 2 of a typical dual-gate MOSFET mixer, which eliminates the high injection level necessary for a JFET.

The designer has a choice of two basic approaches to the layout of a new fm receiver. He can use single conversion (Fig. 3-3B). But, to provide sufficient gain before the limiter, he must employ an rf amplifier, and worse, use a bipolar-transistor mixer to achieve high conversion gain. Even with an rf amplifier stage, getting sufficient i-f gain with stability can be a problem. Alternatively, a dual-conversion scheme can be employed where sufficient overall gain can be obtained in the i-f stages. With this design, Fig. 3-3C, the rf stage can be eliminated if sufficient rf selectivity can be achieved before the first mixer, without seriously degrading the sensitivity of the receiver.

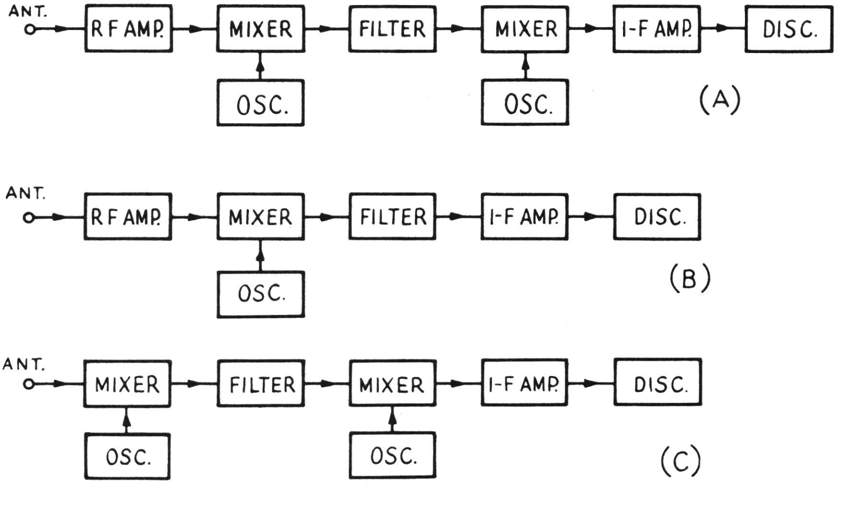


Fig. 3-3 — Block diagrams of the fm receiver designs discussed in the text.

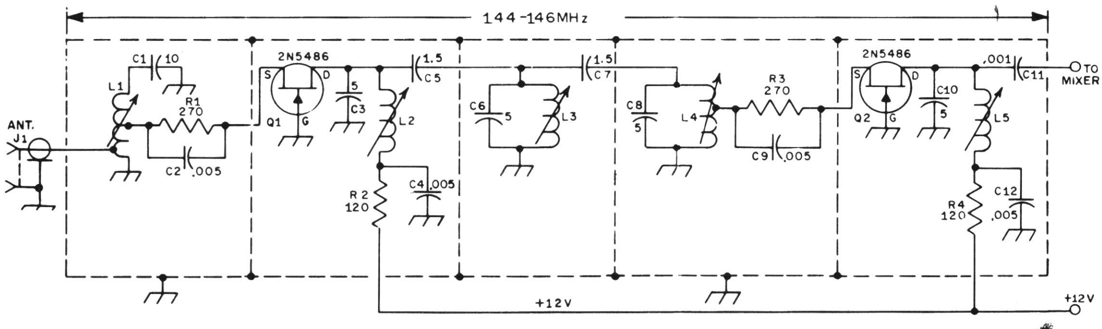


Fig. 3-4 – Schematic diagram of the high-performance front end. Resistors, unless noted otherwise, are 1/2-watt carbon. Dashed lines denote shielding.
C5, C7 – Silver-mica type.
J1 – Chassis-mount coax fitting, type BNC.
L1-L5, incl. – 4-1/2 turns No. 22 tinned-copper wire. Space one wire dia between turns. Wind on 1/4-in. dia ceramic form with brass slug (J.W. Miller 46A013-5 form. Address: 19070 Reyes Ave., Compton, CA 90224). L1 tapped at 1 (ant.) and 2 (source) turns above ground. L4 tapped at 2 turns. See text.

Front-End Design

The weakest point in any receiver is the front end. Fm rigs, especially those used in mobile stations, are required to operate with incoming signal levels that vary from very weak to very strong. Also, the receiver is exposed to strong out-of-band signals which it must reject. As outlined above, a high-quality receiver front end should have sufficient sensitivity to hear signals, sufficient selectivity to reject out-of-band energy, and sufficient dynamic range so that very strong signals will not cause overload.

RF selectivity at vhf and uhf is difficult to achieve. Many lumped-constant tuned circuits are usually needed for even a moderate degree of rf selectivity; several tuned circuits before the first active stage (rf amplifier or mixer) will have sufficient loss to limit the sensitivity of the receiver. If lumped-constant tuned circuits are employed, FET rf amplifiers can be interspaced between the *LC* elements to make up losses in tuned circuits. High gain is not required, so the transistors may be operated grounded gate, as shown in Fig. 3-4.

Junction FETs are used in a cascaded common-gate rf amplifier, Fig. 3-4. Source bias (R1 and R2) is used in each rf stage to reduce overloading in the presence of strong signals. The JFETs are able to sustain up to 80 volts pk-pk from gate to source before junction damage occurs. Therefore, protective diodes aren't needed at the antenna input if a good changeover relay is used for antenna switching. The rf stages are unconditionally stable in the common-gate mode, thus eliminating the need for neutralization circuits. A properly-adjusted common-gate rf amplifier (one stage) can provide up to 16 dB of gain and have a low noise figure.

The antenna is tapped down on L1 for lowest noise figure. The source of Q1 is tapped near the center of L1 to effect an impedance match. A 3-section bandpass tuned circuit, lightly coupled, is used between Q1 and Q2 to establish a 2-MHz passband (146 to 148 MHz). Inductors L1 through L5 are stagger-tuned to provide a uniform response across that range. Shield compartments separate the tuned circuits to prevent mutual coupling, and to discourage input-output coupling at Q1 and Q2. The latter condition could cause instability of the rf amplifiers. Networks R2-C4 and R4-C12 prevent unwanted ac coupling between the stages via the 12-volt line. The combined gain of the rf amplifiers (after coupling losses through the tuned circuits) is approximately 18 dB.

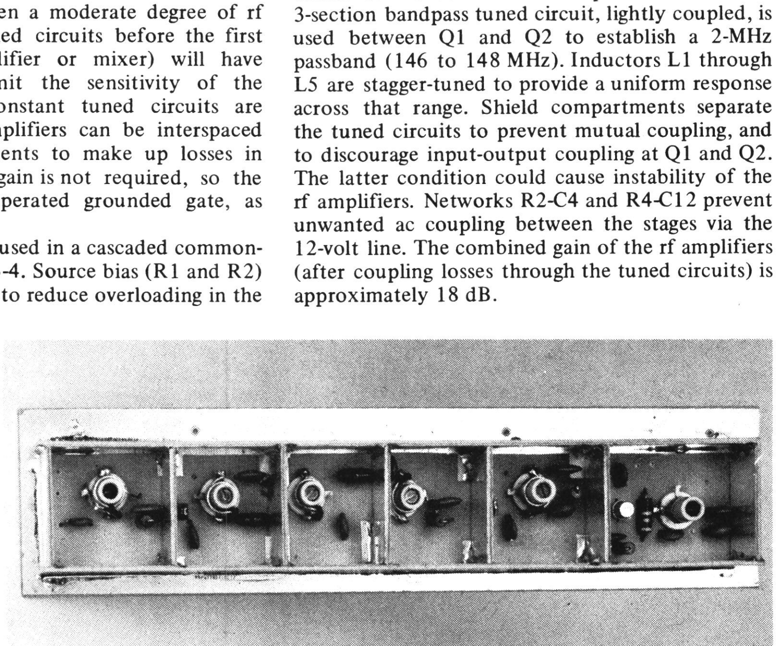


Fig. 3-5 – Interior view of the rf amplifier. The input stage is at the far left, and a mixer compartment has been added at the extreme right. Double-sided pc board is used to make the shield box and its compartment dividers. The main pc board is also double-sided.

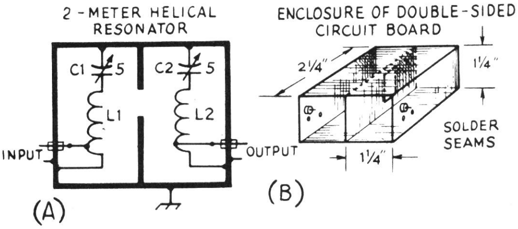


Fig. 3-6 — Circuit of the helical resonator. Double-sided pc board is used for the box walls, and is soldered along each seam by means of a pencil-type iron. E. F. Johnson silver-plated air-variable capacitors (No. 189-563) were used in this model, but high-dielectric piston trimmers can be substituted. Coils L1 and L2 consist of 4-1/2 turns of No. 12 copper wire, 3/4 inch in diameter, and 3/4 inch long. Each coil is centered in its compartment and tapped 1/4 turn from ground to obtain a bilateral 50-ohm impedance. A 3/8 × 5/8-inch aperture is cut in the center divider, and is opposite the second and third turns of each coil. C1 and C2 are tuned for peak signal response with the resonator connected between the receiver input and the feed line. The bottom end of the assembly need not be enclosed. Ideally, the enclosure should have no soldered seams, and both it and the coils should be silver plated. This suggests the use of large-diameter copper tubing for the outer shield if maximum *Q* is desired.

A better approach is to use *helical resonators* – a device which consists of lumped-constant elements housed in a small cavity. Helical resonators can be built exhibiting *Q* of 1000 or more at vhf and uhf. Because the *Q* is so high, front-end tuned circuits can be designed using helical resonators which provide a high degree of selectivity with low insertion loss. The inductance value in a helical resonator should be made as large as possible, and capacitance kept to a minimum, for best performance. Probe, loop tap, or aperture coupling may be employed. The walls of the cavity should be seamless, if possible. The current practice in fm receivers is to use two or more resonators slightly overcoupled to provide a 1-MHz or wider bandpass characteristic. A typical 146-MHz helical resonator is shown in Fig. 3-6.

A second example of a helical resonator, used in the Johnson 504 transceiver, is shown in Fig. 3-7. The 504 resonators consist of 5-3/4 turns of No. 12 wire contained in a rectangular 1 × 1 × 2-inch cavity. Both the coil and enclosure are silver plated. The coil is 5/8 inch inside diameter and 5/8 inch long, tuned with a 7-pF miniature air-variable capacitor. The 50-ohm input tap is at 1/4 turn from the ground end of the coil, an indication of the high impedance achieved. Coupling between individual resonators is through a 1/2 × 1/4-inch aperture, or "window." A front-end design using two sets of resonators is given in Fig. 3-8.

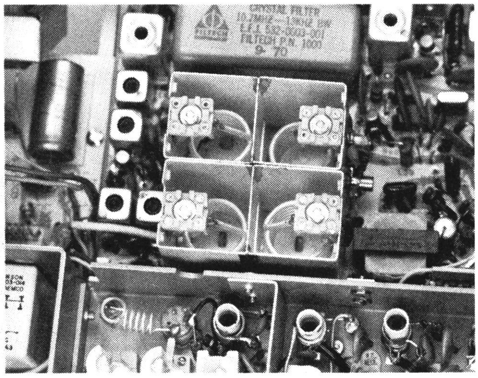


Fig. 3-7 — Close-up view of the helical resonators, with the covers removed. The rf amplifier stage is constructed on the outside wall of the upper-right-hand resonator. Details are given in the text.

Modern JFET mixer devices can be used in fm receiver designs where the rf amplifier stage is eliminated. Such a circuit, from the Collins 718V receiver, is shown in Fig. 3-9. Four helical resonators provide rf selectivity. A pair of 2N4416 transistors are employed in the balanced mixer. T1 is a balun transformer which provides balanced feed to the gates of the two mixer transistors. Local-oscillator energy is applied to the source connections of Q1 and Q2 via a second balun transformer, T2. Output signal from the mixer is fed to a high-frequency crystal filter. While the Collins circuit is not as sensitive as those shown in Figs. 3-4 and 3-8, its ability to reject out-of-band signals and its freedom from overload are far better. The 718V sensitivity of 0.5μV for 20 dB of quieting is adequate for vhf communication.

Local Oscillator

Most fm receivers employ crystal control. The local-oscillator/multiplier chain must provide sufficient injection voltage for the mixer and some form of crystal switching is needed if the receiver is to function on more than one channel. The local oscillator may be complex in a high-quality re-

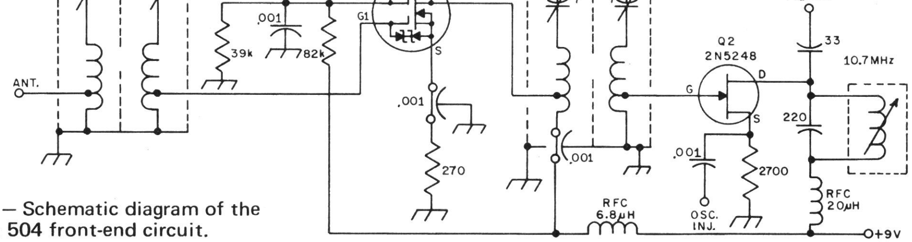


Fig. 3-8 — Schematic diagram of the Johnson 504 front-end circuit.

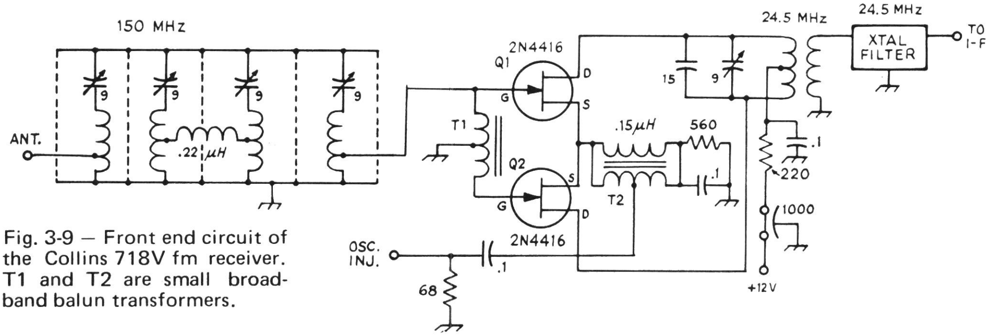


Fig. 3-9 — Front end circuit of the Collins 718V fm receiver. T1 and T2 are small broadband balun transformers.

ceiver while a single-transistor circuit will suffice for simple rigs. The techniques outlined below to reduce the level of spurious responses can be applied to improve the performance of commercially made receivers.

Injection to the mixer should be provided by a single path – the intended one. The wave form being suppied to the mixer should be pure. Some oscillator/mixer sections rely on a diode multiplier after the oscillator, and output from the multiplier is fed to the mixer without benefit of selective circuits. Other circuits feed the oscillator output into a transistor multiplier, and then to the mixer . . again without filtering. When this is done many frequencies are contained in the mixer injection voltage. This can result in birdies and poor mixer performance. Furthermore, when the injection is taken from a doubler or tripler it is often too low in level (at the desired frequency) to provide suitable mixer performance.

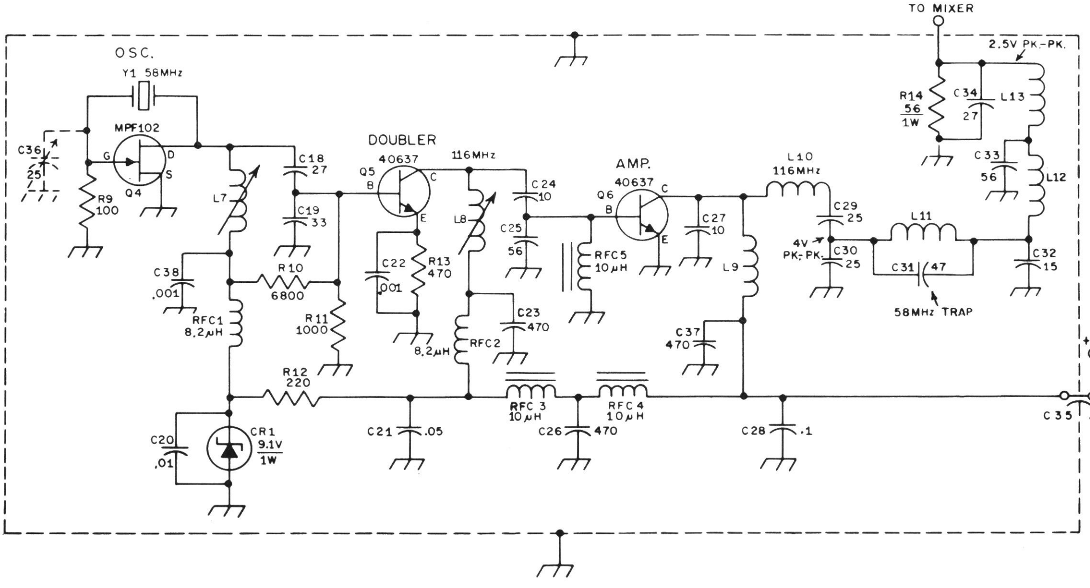


Fig. 3-10 — Circuit of the oscillator/multiplier module. Resistors, unless noted otherwise, are 1/2-watt carbon. Dashed lines denote shielding.

C31 — Silver-mica type.
C29, C30 — 5- to 25-pF ceramic trimmer (Erie 557 with phenolic flange trimmed off).
C35 — .001-μF feedthrough capacitor mounted on wall of shield compartment.
C36 — 25-pF miniature air variable or ceramic trimmer (Erie 557 NPO suitable).
CR1 — 9.1-volt 1-watt Zener diode.
L7 — 7-1/2 turns No. 26 enam. wire, close-wound at base end of Miller 46A013-4 form.
L8 — 4-1/2 turns No. 22 enam., close-wound at base of Miller 46A013-4 form.
L9 — 16 turns No. 22 enam., close-wound, self-supporting, 3/16-in. dia.
L10 — 6 turns No. 20 tinned copper wire, 3/8-in. dia x 5/8 in. long.
L11 — 6 turns No. 22 enam., 3/16-in. dia, close-wound. See text.
L12, L13 — 4 turns No. 22 enam., 3/16-in. dia, close-wound. See text.
R13 — Select value to provide required output from Q6. See text.
RFC1, RFC2 — 8.2-μH rf choke (James Millen J300-8.2 or equiv.).
RFC3, RFC4 — 10-μH rf choke. 4 turns No. 30 enam. wire looped through Amidon ferrite bead (Amidon Assoc., 12033 Otsego St., N. Hollywood, CA 91607).
S1 — Spst toggle.
Y1 — 58-MHz 3rd-overtone crystal. (International Crystal type GP.) Case style F-605. International Crystal pc-board socket F-605.

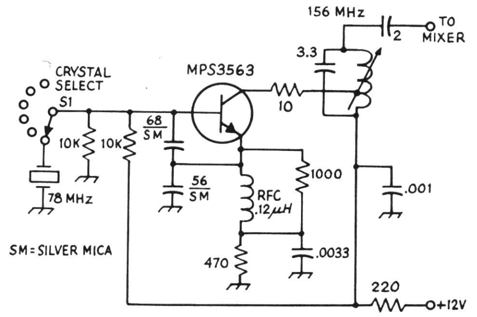


Fig. 3-11 — Oscillator/doubler circuit developed by Pearce-Simpson. S1 is a multiposition rotary switch.

The oscillator chain in Fig. 3-10 was designed for high performance. It has more output capability than is needed, the output waveform is pure, and there are no spurious oscillations in the circuit. The strip is contained in its own shielded enclosure to prevent coupling to the rf and mixer stages of the converter by stray paths.

Oscillator Q4 operates in the third-overtone mode. An optional frequency-trimmer capacitor, C36, is shown in dashed lines. Those wishing to place the oscillator dead on frequncy may add this component. The crystal should be a high-accuracy commercial-standard type if this is done, and should be ground for a load capacitance of 20 pF. Capacitor C36 can be an NPO ceramic trimmer, mounted on the side wall of the oscillator box near Y1.

Zener-diode regulation of the oscillator supply voltage is provided by CR1. The forward bias to Q5 is also regulated by CR1. Regulation of this part of the supply is desirable if the main 12-volt source is unregulated. This will help to keep the oscillator on frequency.

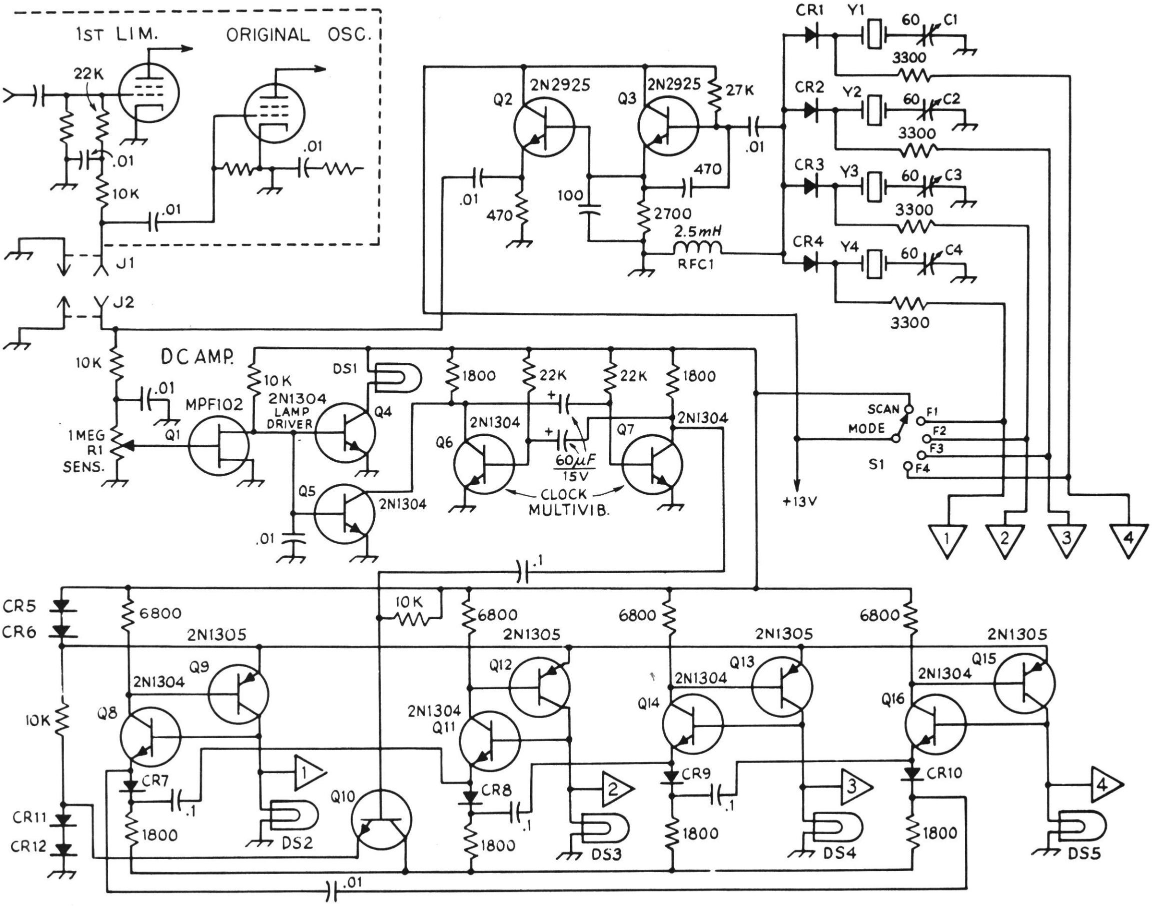


Fig. 3-12 — K2CBA's seanner adapter. Resistors are 1/2-watt composition and capacitors are disk ceramic, except those with polarity marked, which are electrolytic.

DS1-DS5, incl. — No. 327 miniature lamp.
CR1-CR12, incl. — Any silicon switching diode.
R1 — Linear-taper composition control.
RFC1 — Miniature rf choke.
S1 — Sp5t rotary switch.
Y1-Y4, incl. — Crystal from original receiver oscillator.

A simple circuit (developed by Pearce-Simpson) that would be ideal for use in a hand-held transceiver because few parts are used is shown in Fig. 3-11. This circuit uses 78-MHz crystals; output from the oscillator is taken at the second harmonic, 156 MHz. If the leads are kept very short, and a low-capacitance switch is used, 12 or more crystals can be included.

A Scanner Oscillator

A system of periodic electronic crystal switching is often used in fm receivers. Such a device is called a *scanner*. A scanner receiver automatically monitors one channel, then a second, and so on. The process goes on until a channel is selected with an incoming signal. The scanning process then stops and the channel is monitored for as long as a signal is being received. A simple scanner circuit, designed by K2CBA, can be added to most tube fm receivers. This circuit, shown in Fig. 3-12, features manual selection of four channels by means of S1, in addition to the scan feature.

The time that each channel is monitored in the scan mode is determined by the period of a multivibrator, Q6 and Q7. The multivibrator will stop when first-limiter current appears at the gate of Q1. Timing pulses are fed through the counter stages which, in turn, connect crystals to the oscillator, which consistof Q2 and Q3. Oscillator output is fed to the receiver via a short length of RG-58A/U cable. The same cable carries dc voltage from the first-limiter stage back to the scanner adaptor.

Bandwidth

An fm signal swings above and below a center frequency with voice modulation. The amount of peak swing allowed in the fm transmitter is called the *deviation*. Three deviation amounts are now standard practice: 15, 5 and 2.5 kHz, which in the current vernacular of fm users, are known as wide band, narrow band, and sliver band, respectively. The 2.5-3 kHz deviation (called nbfm by OTs) was popular for a time on the vhf bands and 10 meters after World War II. Deviation figures are given for the frequency swing in one direction. The bandwidth required in an fm receiver is approximately 2.4 times the deviation - 36 kHz for wide band and 13 kHz for narrow.

Most fm receivers are dual-conversion designs. The second mixer should be located after a high-selectivity filter if spurious and image responses are to be kept to a minimum. The requirements for the second mixer and second conversion oscillator are not stringent – low-cost bipolar transistors such as shown in Fig. 3-13 may be employed. The circuit at Fig. 3-13 is designed for i-fs of 10.7 MHz and 455 kHz, a popular combination in fm receivers.

Most fm sets that use tubes achieve i-f selectivity by using a number of overcoupled transformers. The wide bandwidth and phase-response characteristic needed in the i-f system dictate careful design and alignment of all interstage transformers. For those experimenters willing to take on a difficult challenge, the design procedure for fm i-f transformers is covered in *The Radiotron Designer's Handbook*.

For the average ham, the use of a high-selectivity filter in a homemade receiver offers some simplification of the alignment task. Following the techniques used in ssb receivers, a crystal or ceramic filter should be placed in the circuit as close as possible to the antenna connector – at the output of the first mixer, in most cases. Fig. 3-14 lists a number of suitable filters that are available to amateurs, and sources for the various units. Prices for these filters are in the range of $10 to $30. Experimenters who wish to "roll their own" can use surplus hf crystals, as outlined in ARRL's *Single Sideband for the Radio Amateur*.

One item of concern to every amateur fm user is the choice of i-f bandwidth for his receiver, as both 15- and 5-kHz deviation are now in common use on the amateur bands. A wide-band receiver can receive narrow-band signals, suffering only some loss of audio in the detection process. However, a wideband signal will be badly distorted when received on a narrow-band rig. At this point it seems reasonable to assume that increasing fm activity and continued production of commercial narrow-band transceivers will shift amateur operation to a 5-kHz deviation standard. But, as with the a-m operators, the wide-band enthusiasts will be around for some time to come, lured by inexpensive surplus wide-band gear.

Limiters

When fm was first introduced, the main selling point used for the new mode was the noise-free reception possibilities. The circuit in the fm receiver that has the task of chopping off noise and amplitude modulation from an incoming signal is

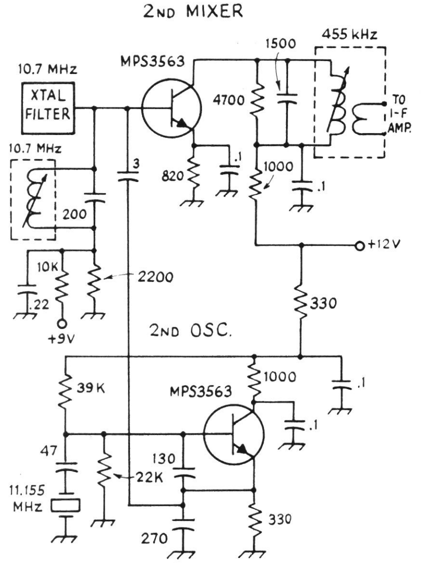


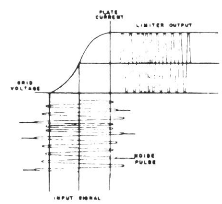
Fig. 3-13 – Typical circuit for the second oscillator and second mixer of an fm receiver.

FM FILTERS

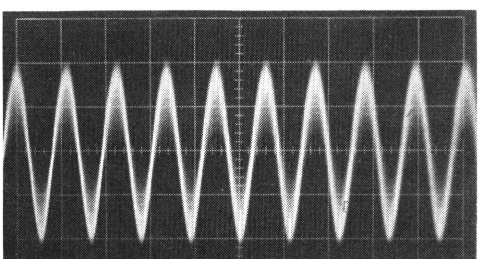
Manufacturer	Model	Center Frequency	Nonimal Bandwidth	Ultimate Rejection	Impedance (r) In	Impedance (r) Out	Insertion Loss	Crystal Discriminator
KVG (1)	XF-9E	9.0 MHz	12 kHz	90 dB	1200	1200	3 dB	XD9-02
KVG (1)	XF-107A	10.7 MHz	12 kHz	90 dB	820	820	3.5 dB	XD107-01
KVG (1)	XF-107B	10.7 MHz	15 kHz	90 dB	910	910	3.5 dB	XD107-01
KVG (1)	XF-107C	10.7 MHz	30 kHz	90 dB	2000	2000	4.5 dB	XD107-01
Heath Dynamics (2)	–	21.5 MHz	15 kHz	90 dB	550	550	3 dB	–
Heath Dynamics (2)	–	21.5 MHz	30 kHz	90 dB	1100	1100	2 dB	–
E.S. (3)	FB-6D	10.7 MHz	15 kHz	80 dB	950	950	2 dB	AB-1C
E.S. (3)	10-MA	10.7 MHz	30 kHz	80 dB	2000	2000	4 dB	AB-1C
E.S. (3)	EL-3A	11.5 MHz	36 kHz	70 dB	50	50	4 dB	AL-1
E.S. (3)	DR-9	21.4 MHz	20 kHz	40 dB	750	750	5 dB	AR-10
Clevite (4)	TCF4-12D3CA	455 kHz	12 kHz	60 dB	40k	2200	6 dB	–
Clevite (4)	TCF4-18G45A	455 kHz	18 kHz	50 dB	40k	2200	6 dB	–
Clevite (4)	TCF6-30D55A	455 kHz	30 kHz	60 dB	20k	1000	5 dB	–

Fig. 3-14 — A list of fm-bandwidth filters that are available to amateurs. Manufacturer's addresses are as follows.

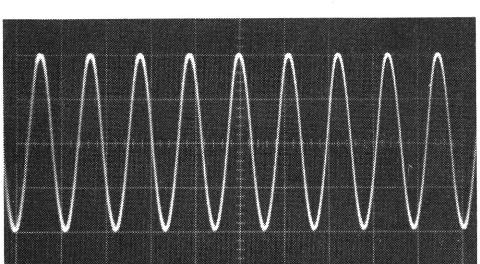
1) Spectrum International, P. O. Box 87, Topsfield, MA 01983.
2) Heath Dynamics, Inc., 6050 N. 52nd Avenue, Glendale, AZ 85301.
3) E. S. Electronic Labs, 301 Augustus, Excelsior Springs, MO 64024.
4) Semiconductor Specialists, Inc., P. O. Box 66125, O'Hare International Airport, Chicago, IL 60666. (Minimum order $5.00.)



(A)



(B)



(C)

the *limiter*. Most types of fm detectors respond to both frequency and amplitude variations of the signal. Thus, the limiter stages preceding the detector are included to "cleanse" the signal so that only the desired frequency modulation will be demodulated. This action can be seen in Fig. 3-15B and C.

Limiter stages can be designed using tubes, transistors, or ICs. For a tube to act as a limiter, the appied B voltages are chosen so that the stage will overload easily, even with a small amount of signal input. A sharp-cutoff pentode such as the 6BH6 is usually employed with little or no bias applied. As shown in Fig. 3-15A the input signal limits when it is of sufficient amplitude so that diode action of the grid and plate-current saturation clip both sides of the input signal, producing a constant-amplitude output voltage.

Obviously, a signal of considerable strength is required at the input of the limiter to assure full clipping, typically several volts for tubes, one volt for transistors, and several hundred millivolts for ICs. Limiting action should start with an rf input of 0.2 μV or less, so a large amount of gain is required between the antenna terminal and the limiter stages. For example, the Motorola 80D has eight tubes before the first limiter, and the solid-state MOTRAC receivers use nine transistor stages to get sufficient gain before the first limiter. The new ICs offer some simplification of the i-f system as they pack a lot of gain into a single package, but the fm equivalent of the "super-regen", has yet to be developed.

Fig. 3-15 — (A) Representation of limiter action. Amplitude variations on the signal are removed by the diode action of the grid- and plate-current saturation. (B) Input wave form to a limiter stage shows a-m and noise. (C) The same signal, after passing through two limiter stages, is devoid of a-m components.

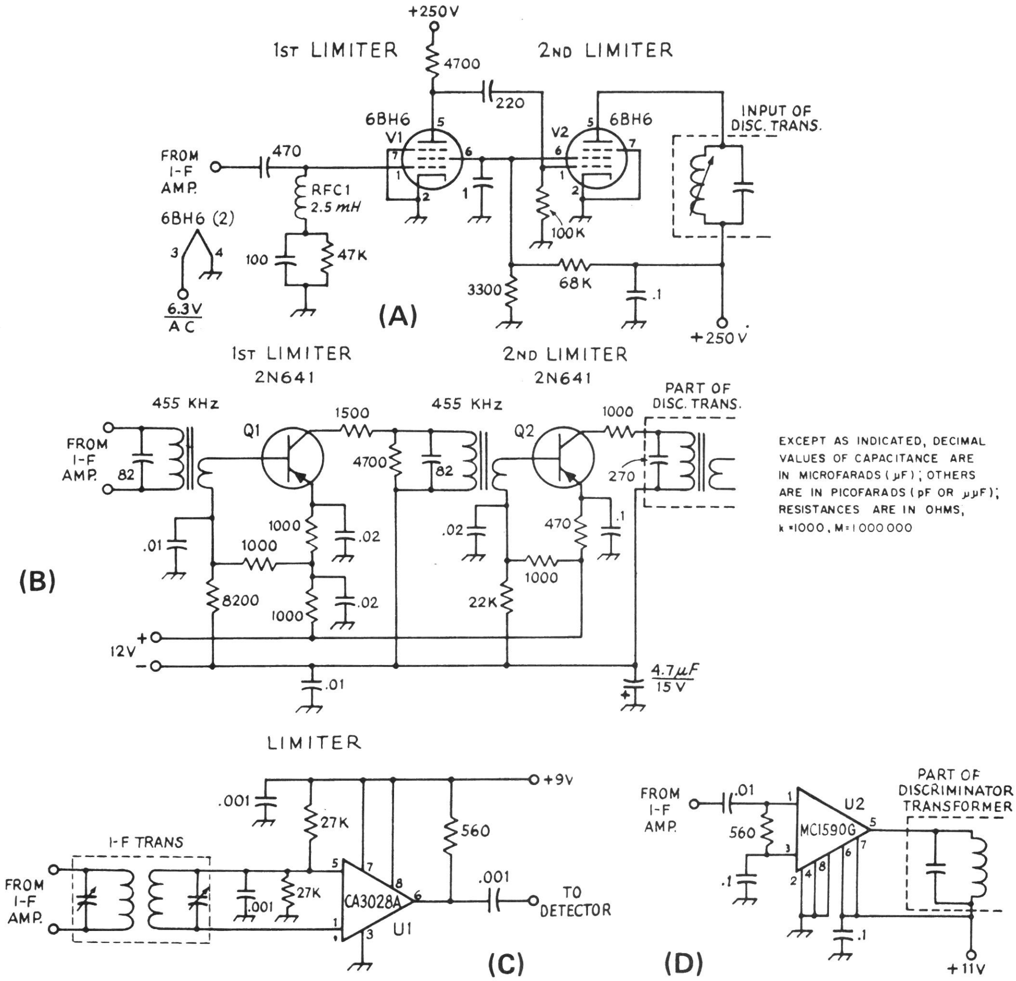


Fig. 3-16 – Typical limiter circuits using (A) tubes, (B) transistors, (C) a differential IC, (D) a high-gain linear IC.

The high gain used in fm receivers accounts for another requisite, an audio squelch. With 140 dB or more of amplification before the detector, a blast of noise emits from the fm-set speaker when no signal is being received. To allow monitoring for long periods without having one's wife and children leave home, a squelch is employed to quiet the avalanche of noise until a signal is heard.

When sufficient signal arrives at the receiver to start limiting action, the set *quiets* – that is, the background noise disappears. The sensitivity of an fm receiver is rated in terms of the amount of input signal required to produce a given amount of quieting, usually 20 dB. Current practice using the newer solid-state devices can produce receivers which achieve 20 dB quieting with 0.115 to 0.5 μV of input signal.

A single tube or transistor stage will not provide good limiting over a wide range of input signals. Two stages, with different input time constants, are a minimum requirement. The first stage is set to handle impulse noise satisfactorily while the second is designed to limit the range of signals passed on by the first. At frequencies below 1 MHz it is useful to employ untuned *RC*-coupled limiters which provide sufficient gain without a tendency toward oscillation.

Fig. 3-16A shows a two-stage limiter using sharp-cutoff tubes, while 16B has transistors in two stages biased for limiter service. The base bias on either transistor may be varied to provide limiting at a desired level. The input-signal voltage required to start limiting action is called the *limiting knee*, referring to the point at which collector (or plate) current ceases to rise with increased input signal. Modern ICs have limiting knees of 100mV for the circuit shown in Fig. 13-16C, using the CA3028A or MC1550G, or 200μV for the Motorola MC1590G of Fig. 3-16D. Because high-gain ICs such as the CA3076 and MC1590G contain as many as six or eight active stages which will saturate with sufficient input, one of these devices provides superior limiter performance compared to a pair of tubes or transistors.

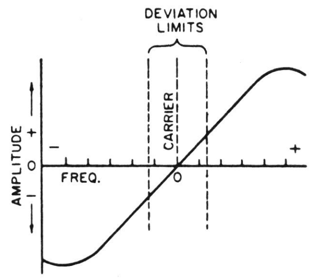


Fig. 3-17 — The characteristic of an fm discriminator.

Detectors

The first type of fm detector to gain popularity was the frequency discriminator. The characteristic of such a detector is shown in Fig. 3-17. When the fm signal has no modulation, and the carrier is at point O, the detector has no output. When audio input to the fm transmitter swings the signal higher in frequency, the rectified output increases in the negative direction. Over a range where the discrimination is linear (shown as the straight portion of the line), the conversion of fm to a-m which is taking place will be linear.

A practical discriminator circuit is shown in Fig. 3-18. The fm signal is converted to a-m by transformer T1. The voltage induced in the T1 secondary is 90 degrees out of phase with the current in the primary. The primary signal is introduced through a center tap on the secondary, coupled through a capacitor. The secondary voltages combine on each side of the center tap so that the voltage on one side leads the primary signal while the other side lags by the same amount. When rectified, these two voltages are equal and of opposite polarity, resulting in zero-voltage output. A shift in input frequency causes a shift in the phase of the voltage components that result in an increase of output amplitude on one side of the secondary, and a corresponding decrease on the other side. The differences in the two changing voltages, after rectification, constitute the audio output.

In the search for a simplified fm detector, RCA developed a circuit that has now become standard in entertainment radios and which eliminated the need for a preceding limiter stage. Known as the *ratio detector*, this circuit is based on the idea of dividing a dc voltage into a ratio which is equal to the ratio of the amplitudes from either side of a discriminator transformer secondary. With a detector that responds only to ratios, the input signal may vary in strength over a wide range without causing a change in the level of output voltage — fm can be detected, but not a-m. In an actual ratio detector, Fig. 3-19, the dc voltage required is developed across two load resistors, shunted by an electrolytic capacitor. Other differences include the two diodes, which are wired in series-aiding rather than series-opposing, as in the standard discriminator circuit. The recovered audio is taken from a tertiary winding which is tightly coupled to the primary of the transformer. Diode-load resistor values are selected to be lower (5000 ohms or less) than for the discriminator.

The sensitivity of the ratio detector is one half that of the discriminator. In general, however, the transformer design values for Q, primary-secondary coupling, and load will vary greatly, so the actual performance differences between these two types of fm detectors are usually not significant. Either circuit can provide excellent results. In operation,

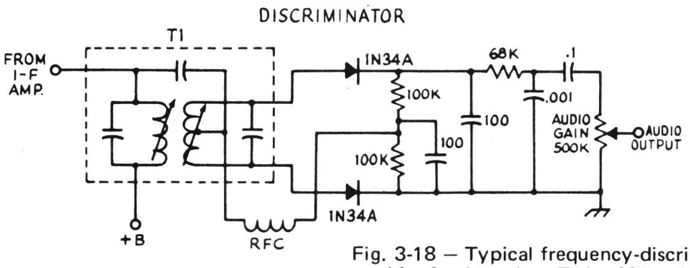


Fig. 3-18 — Typical frequency-discriminator circuit used for fm detection. T1 is a Miller 12-C45.

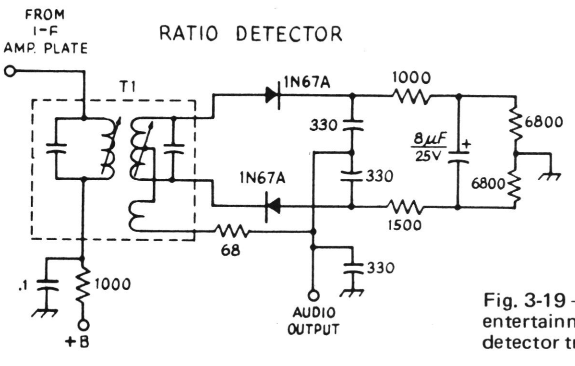
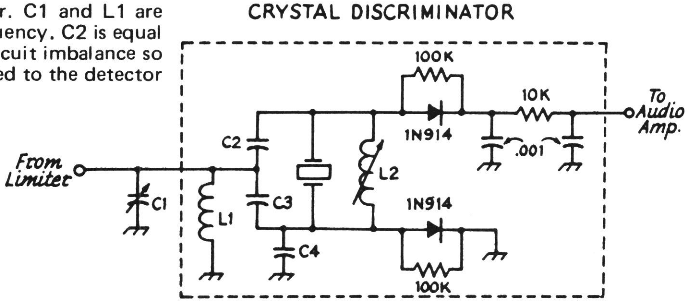


Fig. 3-19 — A ratio detector of the type often used in entertainment radio and TV sets. T1 is a ratio-detector transformer such as the Miller 1606.

Fig. 3-20 – Crystal discriminator. C1 and L1 are resonant at the intermediate frequency. C2 is equal in value to C3. C4 corrects any circuit imbalance so that equal amounts of signal are fed to the detector diodes.



the ratio detector will not provide sufficient limiting for communications service, so this detector also is usually preceded by at least a single limiting stage.

New Detector Designs

The difficulties often encountered in building and aligning LC discriminators have inspired research that has resulted in a number of adjustment-free fm detector designs. The *crystal discriminator* utilizes a quartz resonator, shunted by an inductor, in place of the tuned-circuit secondary used in a discriminator transformer. A typical circuit is shown in Fig. 3-20. Some commercially made crystal discriminators have the input-circuit inductor, L1, built in (C1 must be added) while in other types both L1 and C1 must be suppied by the builder. Fig. 3-20 shows typical component values; unmarked parts are chosen to give the desired bandwidth. Sources for crystal discriminators are listed in Fig. 3-14.

Little information has been published about crystal-discriminator design. A practical receiver using an inexpensive surplus crystal discriminator is to be described later in this chapter.

Transformerless Discriminator

Another interesting fm-detector circuit designed for telemetry use has been described by Kubo. Using active circuits to provide the phase shifts usually accomplished in a discriminator transformer, the circuit (illustrated in Fig. 3-21) will work up to 1 MHz. Ideally, R1 should equal R2, but Kubo reports that the slight loading of R3 and an inequality of the h_{FE} of the two transistors, Q1A and Q1B, require that R1 be varied to achieve circuit balance. The expensive MD6100 can be replaced by two transistors of closely-matched characteristics; an IC array such as the RCA CA3018 would be a good choice. Component values are quite critical, if the best performance is to be obtained. Resistors should be 5-percent tolerance, and capacitors 10 percent.

Another popular discriminator circuit which does not require a special transformer is shown in Fig. 3-22. Often called the Travis discriminator, this arrangement uses two tuned circuits, one set above the i-f center frequency and the other set below by the same offset amount, feeding separate detectors. The outputs of the two detectors are combined by R1, which is adjusted for maximum a-m rejection. Because it can be built for any i-f, the Travis discriminator is useful as an fm detector for the Heath SB-series receivers, ARC-5s and others with nonstandard i-fs.

Bridge Discriminator

With the advent of stereo and other subcarrier transmissions, engineers working to develop radios have had to reduce the level of phase distortion produced in receiver circuits. Otherwise, mixing of the subcarrier and main-channel signals limits the

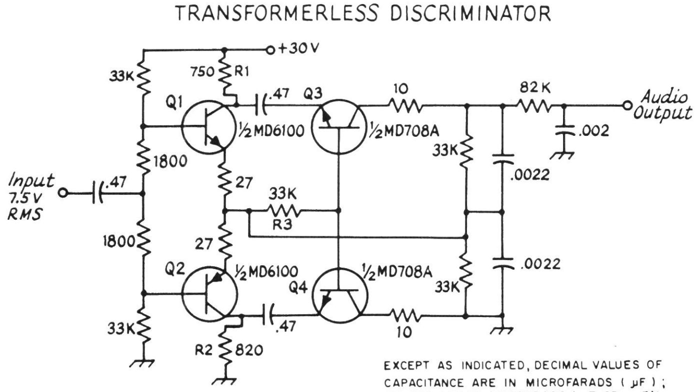


Fig. 3-21 – Transformerless discriminator.

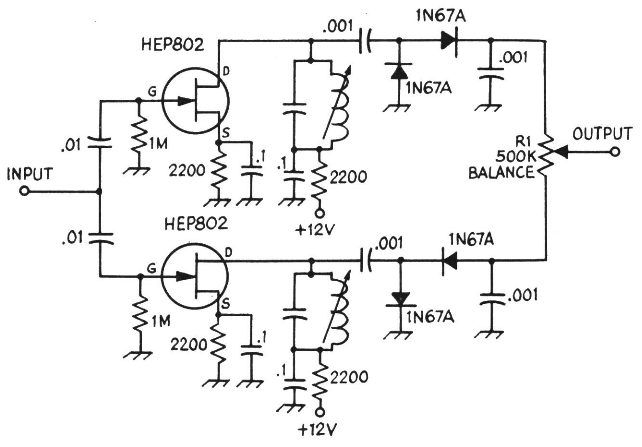


Fig. 3-22 – The Travis discriminator.

audio performance. One product of this research is the *bridge discriminator*, a circuit that can produce nearly distortion-free demodulation of fm signals. This detector, shown in Fig. 3-23 consists of a balanced transmission-line bridge. The physical dimensions of the coaxial lines limit its use to the middle and upper vhf region.

The input resistors (R1 and R2), which are chosen to realize a desired input impedance, and the transmission-line sections form a Wheatstone bridge. The voltages developed at points A and B vary with frequency in such a way that the difference between the two is a straight-line function. By using diode a-m detectors attached to points A and B, the difference between the two detector outputs, developed across a common load resistor (R4), is a duplicate of the modulating signal. R3 sets the detector balance. A pi-section output filter removes any trace of the i-f energy, leaving only the recovered audio. To align a bridge discriminator, a cw signal centered in the i-f passband is injected into the limiter, and R3 is adjusted for zero voltage at point C.

Entertainment Fm ICs

The TV manufacturers represent a large potential market for IC producers. So, several limiter/detector/audio-preamplifier packages have been designed for use in entertainment products. Although developed for very wide-band fm detection (75-200 kHz deviation), these ICs are usable in amateur receivers. Design changes are necessary in a receiver to make up for the low level of recovered audio obtained when receiving 5- to 15-kHz deviation.

IC fm-detector packages fall into two general categories. A typical IC from the first group requires an external transformer to accomplish the fm-to-a-m conversion. This unit consists of a multistage limiter, all of the components for a frequency discriminator except the transformer, and an audio preamp. A circuit example (using the RCA CA3043) is shown in Fig. 3-24A. Input sensitivity of this detector for 20 dB of quieting is about 100 μV. A three-stage amplifier provides 80 dB of i-f gain. With an IC this "hot," parts positioning and circuit-board ground return paths become critical, if stability is to be maintained. A sample in Fig. 3-24B, provides proper ground returns.

The limiter section of the '3043, Fig. 3-24C consists of a differential amplifier, Q10 and Q11, fed from a constant-current source, Q12. Both inputs of the differential amplifier are used to insure equal limiting of the positive and negative

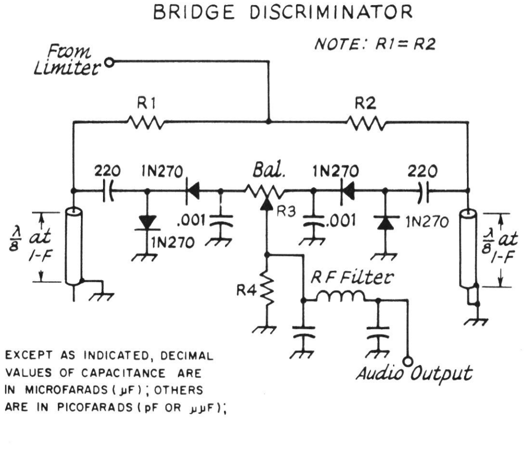


Fig. 3-23 – Bridge discriminator. Labeled components are noted for text reference.

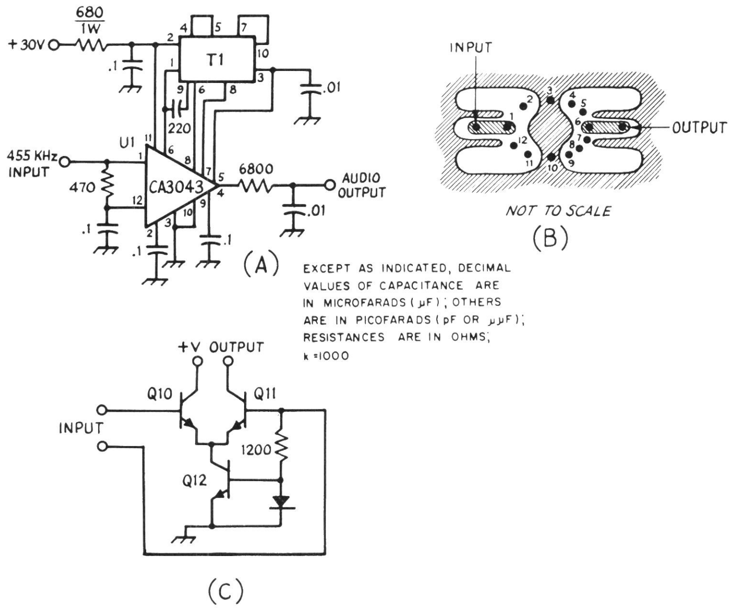


Fig. 3-24 — Circuit diagram (A), circuit-board layout for minimum feedback (B), and partial schematic (C) for the CA3043. T1 is a J. W. Miller 8806 miniature discriminator transformer.

signal excursions. Powering the "diff amp" from a current source that remains constant assures a "hard" limiting characteristic. A-m rejection is typically 60 dB when using the CA3043, an indication of the limiting ability of this monolithic IC.

The other approach to a TV fm detector also includes a multistage limiter but uses a *quadrature* or *envelope detector* to simplify the alignment task. A quadrature detector includes a phase detector, usually consisting of four to eight transistors which are part of the IC, and a phase-shift

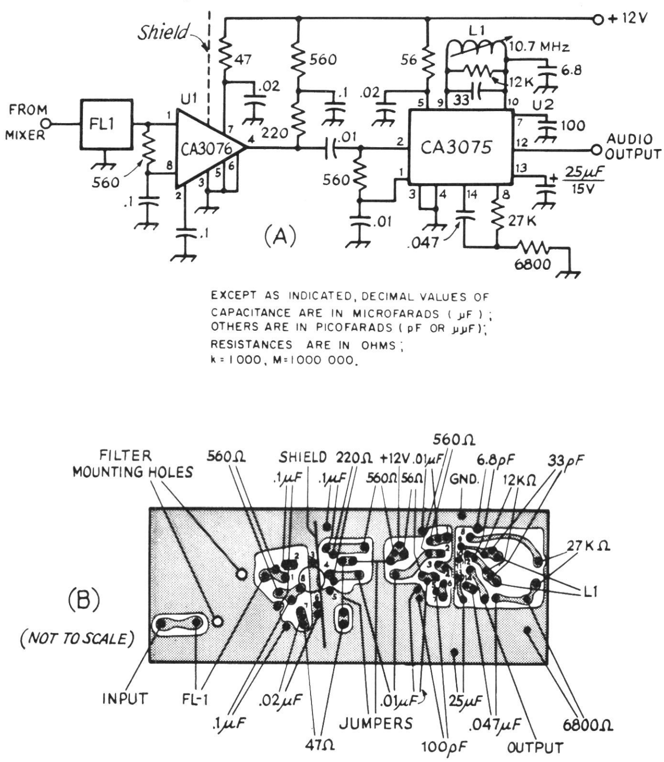


Fig. 3-25 — (A) Schematic diagram of the IC i-f amplifier/detector. L1 is a 4.24-5.20-μH variable inductor (J. W. Miller 46A476CPC) and FL1 is a KVG XF-107B for narrow band, or XF-107C for wide band. (B) Circuit-board layout and parts placement.

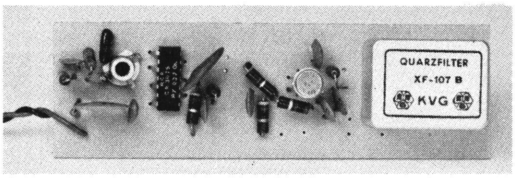


Fig. 3-26 – Breadboard version of the i-f amplifier using a KVG filter, CA3076 and CA3075.

network comprised of an external *LC* circuit. A few esoteric models have been developed which use active components throughout and, thus, require no external parts. The envelope detector, also known as the *differential peak detector* is a newcomer which also utilizes an external *LC* circuit, as shown in Fig. 3-25A. Two peak-signal detectors are employed; the output of each is fed to a difference amplifier/combiner, providing linear fm to a-m conversion.

Quadrature and envelope fm detectors recover very little audio, even from wide-band signals. And, the amount of audio detected drops as deviation is decreased. A multistage audio preamplifier is included on the TV-type chips, providing about 20 dB of audio gain. Even with this preamplifier, however, high gain is required of the receiver audio amplifier. A breadboard version of the circuit (Fig. 3-25A) was constructed using a CA3076 i-f amplifier in addition to the CA3075 detector. Audio output from the detector measured 0.1 volt (after 25 dB of audio amplification within the IC) when detecting a signal having 15-kHz deviation. The '3075 circuit proved to be easy to work with and align. But, the '3076 was quite another matter, as this integrated circuit requires careful attention to ground-return paths if stable operation is to be achieved. The circuit-board foil pattern displayed in Fig. 3-25B is recommended.

The ULN2111, developed by Sprague, is the most popular limiter/detector IC. Rated for operation over the range from 5 kHz to 50 MHz, an input of 400 µV is needed for limiting action to start. A typical circuit shown in Fig. 3-27; Q1 and Q2 provide an impedance transformation to match input characteristic of the ULN2111. The IC detector is tuned by an *LC* circuit. Typical values for many of the popular receiver i-fs are given in Fig. 3-27. The detector tuned circuit should be housed in a shielded enclosure, and the decoupling capacitors for pins 5,6 and 12 should have short leads. The connection for pin 4 should be as far removed from the connections for pins 9, 10 and 12 as possible. To adjust the detector, inject an fm signal and tune L1 for maximum recovered audio.

The PLL

Now that the *phase-locked loop* (PLL) has been reduced to a single IC package, this circuit is destined to revolutionize some facets of receiver design. The complexity of the PLL has, no doubt, prevented a head-long rush by amateurs to experiment with this unusual circuit. However, the introduction by Signetics of a PLL in a single flat-pack IC, followed by Motorola and Fairchild (who are making the PLL in separate building-block ICs), allows a builder to get to work with a minimum of bother.

A basic phase-locked loop (Fig. 3-28) consists of a phase detector, a filter, a dc amplifier, and a voltage-controlled oscillator (VCO). The VCO runs at a frequency close to that of an incoming signal. The phase detector produces an error voltage if any difference in frequency exists between the VCO and the i-f signal. This error voltage is applied to the VCO. Any changes in the frequency of the incoming signal are sensed at the detector and the error voltage readjusts the VCO frequency so that it remains locked to the intermediate frequency.

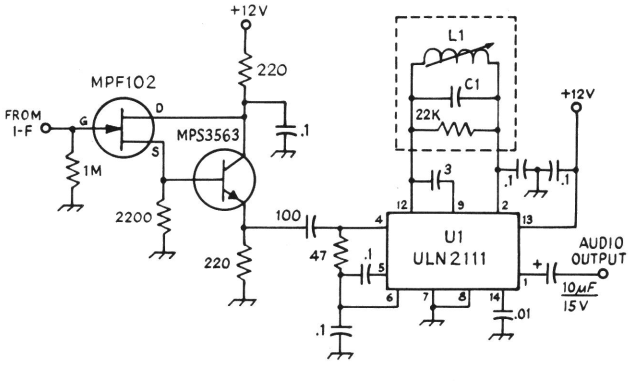
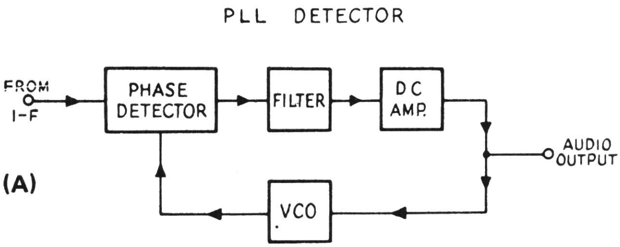


Fig. 3-27 – Diagram of the ULN2111 limiter/detector circuit.

C1 – For 10.7 MHz, 120 pF; for 4.5 MHz, 180 pF; for 3.3 MHz, 180 pF for 455 kHz, 680 pF.

L1 – Slug-tuned inductor; for 10.7 MHz, 2.1 µH; for 3.3 MHz, 13 µH; for 455 kHz, 180 µH.

U1 – Signetics IC.



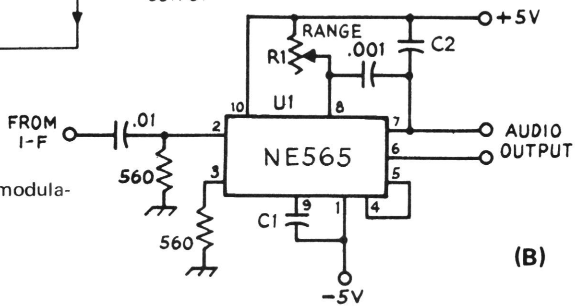


Fig. 3-28 — (A) Block diagram of a PLL demodulator. (B) Complete PLL circuit.

The bandwidth of the system is determined by a filter on the error-voltage line.

Because the error voltage is a copy of the audio variations originally used to shift the frequency of the transmitter, PLL functions directly as an fm detector. The sensitivity achieved with the Signetics NE565 PLL is good – about 1 mV for the circuit shown in Fig. 3-28B. No transformers or tuned circuits are required. The PLL bandwidth is usually two to ten percent of the i-f for fm detection. Components R1-C1 set the VCO to near the desired frequency. C2 is the loop-filter capacitor which determines the capture range – that range of frequencies over which the loop will acquire lock with an input signal, initially starting out of lock. The equations for determining these component values are:

$$\textit{VCO free-running frequency } (f_o) \textit{ in Hz} = \frac{1.2}{4R1C1}$$

(Note: R1 should be between 2000 and 20,000 ohms, with 4000 ohms about optimum.)

$$\textit{Lock frequency range } (f_L) \textit{ in Hz} = \pm \frac{8f_o}{Vcc}$$

$$\textit{Capture range } (f_C) = \pm \frac{1}{2\pi} \ldots \sqrt{\frac{2\pi f_L}{RC_2}}$$

The NE565 has an upper frequency limit of 500 kHz; for higher frequencies, the NE561, which is usable up to 30 MHz, can be employed.

The other use of a phase-locked loop in fm reception is to generate the dozens of frequencies which are now in use by 2-meter fm enthusiasts. To equip a rig with crystals for all of the popular 146-MHz channels is expensive enough to warrant serious investigation of a PLL frequency synthesizer, which would require only one crystal. This subject is covered in Chapter 4, where a practical frequency synthesizer for receiving and transmitting is described. Readers wishing to experiment in this area will find additional basic design data and sample circuits in the manufacturer's application notes listed below:

Signetics Corporation, 811 East Arques Avenue, Sunnyvale, CA 94086.

1) Grebene, "A Monolithic Phase-Locked Signal Conditioner/Demodulator."
2) "General Description of the NE560B/NE561B Phase Locked Loops," Application Memo D-66.
3) "A New Phase Locked Loop with High Stability and Accuracy," Applications Memo D-147.

Motorola Semiconductor Products, Inc. Technical Information Service, Box 20912, Phoenix, AZ 85036.

1) "An Integrated Circuit Phase-Locked Loop Digital Frequency Synthesizer," AN-463.
2) "Phase-Locked Loop Design Fundamentals," AN-535.
3) "MTTL and MECL Avionics Digital Frequency Synthesizer," AN532.
4) Nash, "Locking in on Phase-Locked Loops." *Motorola Monitor*, Vol. 8, No. 2, 1970.

Fairchild Semiconductor, 313 Fairchild Drive, Mountain View, CA 94041.

1) "A Digital Frequency Synthesizer for an A-m and Fm Receiver," TP-53.
2) "TV Receiver Tuning Systems of the Future," TP-52.
3) "A Navigation Receiver That Uses a Digital Frequency Synthesizer," App-178.
4) "Frequency Synthesizer for a 27-MHz Citizens Band Transceiver," APP-144.

Squelch Considerations

Squelch circuits are generally classified as carrier operated and noise operated. Early commercial fm squelch designs used the noise-operated circuit, while later models in tube receivers combined the carrier- and noise-operated squelch in an effort to achieve extra sensitivity. Carrier signal levels were sensed by the voltage change produced across the grid-return resistor of the limiter stage. However, the excellent quieting sensitivities of solid-state receivers have allowed a return to the noise-operated squelch, which can reliably be opened by a 0.1-μV rf signal when the receiver designer employs the latest techniques.

A number of squelch circuits were described by Danz in *QST* for September 1969. One popular type of transistorized squelch circuit is that used

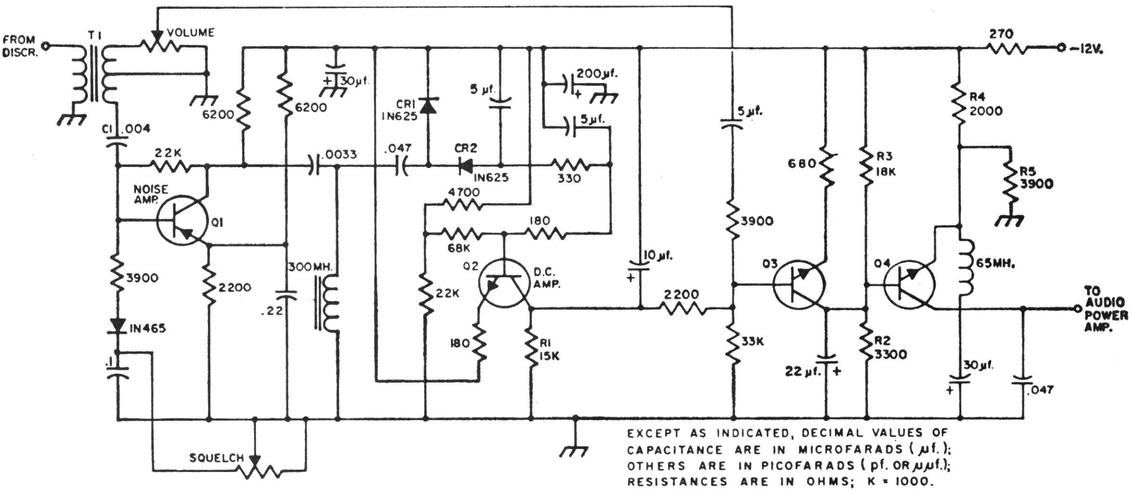


Fig. 3-29 — General Electric solid-state squelch circuit for fm receivers. Transistor complement is as follows:
Q1 – 2N450. Q2 – GE A4003-428-1. Q3, Q4 – 2N169.

by General Electric for its transistorized Progress Line receiver, type ER-31. It not only is more sensitive, but also is more complicated than many other circuits. Fig. 3-29 shows the schematic of this circuit.

The audio signal from the discriminator is fed to an impedance-matching transformer with a split secondary (T1). One half of the secondary supplies normal audio to the volume control. The other half supplies audio to the noise amplifier, Q1. Note that the audio is applied through C1, a .004-µF capacitor which acts as a high-pass filter. The squelch control acts by controlling the gain of Q1. Diodes CR1 and CR2 rectify the noise-amplifier output. The dc voltage from the diodes determines the base bias for Q2, a dc amplifier.

Q2 is an npn transistor and will be cut off when the negative output of the rectifiers is applied to its base. Conversely, when the voltage output of the noise rectifiers goes to zero (as is the case when a signal is being received), Q2 will conduct because of the positive bias it receives. The voltage drop across R1, the collector load resistor for Q2, is applied as bias to Q3. Q3 already is biased in such a way that a drop in positive bias caused by Q2 conduction cannot cause Q3 to be cut off. It does, however, go from saturation (no-signal condition) to partial conduction (signal condition). Going from saturation to partial conduction causes a reduction in the voltage drop across R2. This voltage drop is the bias appied to the base of Q4.

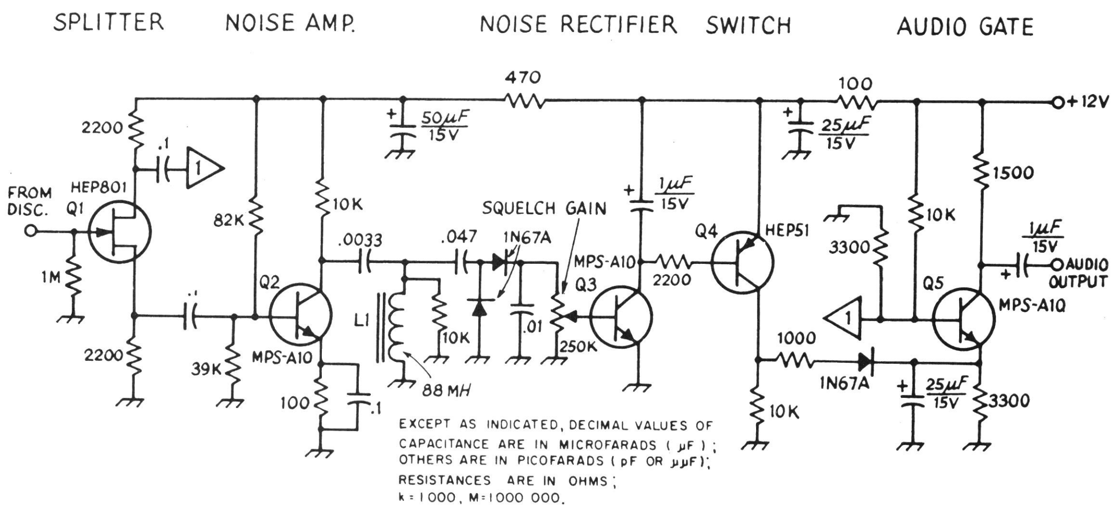


Fig. 3-30 — Diagram of the high-sensitivity squelch. L1 is an 88-mH telephone loading coil.

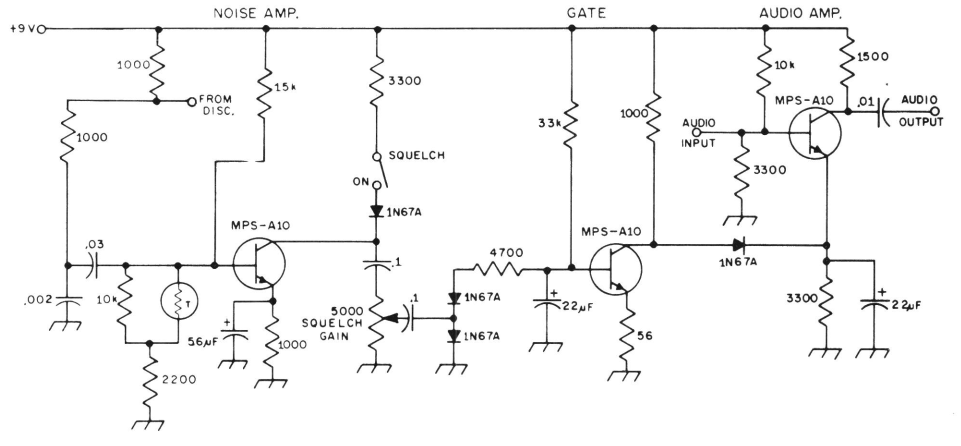


Fig. 3-31 – Squelch circuit used in the 540 hand-held portable.

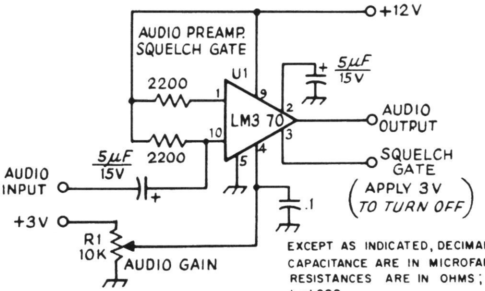
Under a no-signal condition, Q3 is saturated and negative bias is applied to Q4. Q4 emitter bias, from R4, will be considerably less (toward zero) than −12 volts dc because of bleeder R5. The base bias can be made to overcome this emitter bias and swing more negative because of the voltage-dividing resistors R3 and R2 and the collector current of Q3. In this way, Q4 is cut off completely and the receiver audio is squelched.

When a signal is being received, Q3 is only partially conducting, which results in less of a voltage drop across R2. This reduced bias on Q4 allows it to conduct, opening the receiver audio circuit. Many of the newer detectors require a squelch circuit with high gain, such as shown in Fig. 3-30. Here, the output from the detector is split into two components by Q1, one of which is fed to the audio gate while the other is amplified by Q2. Only the noise component of the audio signal (frequencies above 5 kHz) is passed by L1–C1 to the noise rectifier. The dc output of the noise rectifier is amplified by Q3. When noise is present, Q4 and Q5 will be held on by the output from Q3. When the receiver quiets, Q4 and Q5 will shut off, opening the audio gate. Duration of the squelch "tail" – the length of time that the audio gate remains open after the input signal disappears – is determined by C1.

The bandwidth of the noise amplifier does not have to be sharp – in fact, a broad frequency response is better. Manufacturers now tend to choose active *RC* circuits in place of more costly *LC* filters for tuning the noise-amplifier stage. For amateur applications the ever-popular telephone loading coils can be employed. Active filters can be constructed so that they take up very little space, but the toroid coils offer simplicity that is hard to beat.

The bulky inductors used in most squelch circuits to tune the noise amplifier would take up far too much room in a hand-held transceiver. The Johnson 540 rig uses a simple squelch circuit similar to that shown in Fig. 3-31. *RC* coupling components are chosen to pass only audio above 5 kHz, eliminating the need for a tuned noise-amplifier stage. The squelch is activated by applying collector voltage to Q9. The output of this stage is rectified and filtered, and the resulting dc voltage is fed to Q10, the squelch gate. When no signal is being received, Q10 is "on" which upsets the biasing of the first audio amplifier, Q8, holding this stage "off." When an input signal quiets the receiver sufficiently, Q10 will turn "off," allowing Q8 to amplify the audio output from the discriminator.

Fig. 3-32 – An audio preamplifier/squelch gate using the LM370.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF) ; RESISTANCES ARE IN OHMS ; k = 1 000

For applications where high gain is required in both the squelch noise amplifier and audio preamp, a stereo preamp such as the RCA CA3048 and CA3053, Motorola HEP592, or PA239 can be employed. These ICs consist of two high-gain, wide-band audio amplifiers. One amplifier channel can be used as a tuned noise amplifier in the squelch circuit while the other section amplifies the audio signal. Another audio IC with obvious applications in fm receivers is the National Semiconductor LM370 (Fig. 3-32). Providing about 40 dB audio gain, the '370 has an electronic attenuator built in so that the gain of the device can be controlled by a dc voltage applied to pin 4. This arrangement is ideal for trunk-mount rigs, as only dc voltage needs to be fed to the remote-control head. For squelch control of the preamp, a dc voltage (3 V) applied to pin 3 will attenuate the audio passing through the IC by 70 dB.

PRE- AND DE-EMPHASIS

To reduce the amount of noise in some fm communications systems, an audio shaping network called *pre-emphasis* is added at the transmitter to proportionally attenuate the lower audio frequencies, giving an even spread to the energy in the audio band. This results in an fm signal of nearly constant energy distribution. The reverse is done at the receiver, called *de-emphasis*, to restore the audio to its original relative proportions. Sample circuits are shown in Fig. 3-33.

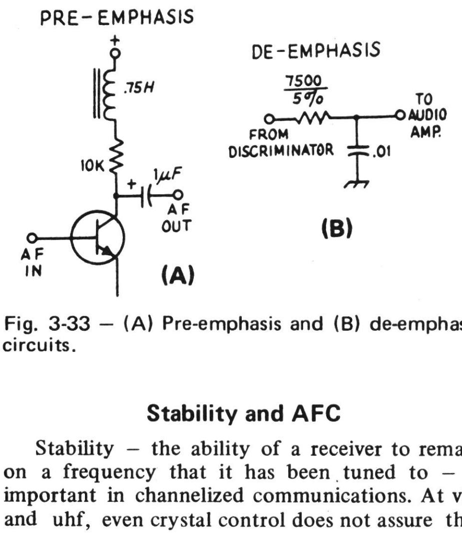


Fig. 3-33 – (A) Pre-emphasis and (B) de-emphasis circuits.

Stability and AFC

Stability – the ability of a receiver to remain on a frequency that it has been tuned to – is important in channelized communications. At vhf and uhf, even crystal control does not assure that temperature changes and component aging will not change a receiver's frequency. The considerations for crystal selection, temperature compensation and the use of ovens are covered in Chapter 4.

At uhf, the difficulty of keeping a receiver "on channel" is manifest. Most of the tube-type 450-MHz receivers were designed with *automatic frequency control* (afc) to offset the changes in receiver frequency caused by temperature changes. In an afc system, a sample of the voltage output from the discriminator is applied to a variable capacitance element – usually a Varactor diode – which is part of the local-oscillator circuit. When the incoming signal is centered in the i-f, output from the discriminator will be zero. If the signal is off frequency in either direction, an "error" voltage will be produced at the discriminator which will, when applied to the oscillator, produce enough shift in frequency to tune the receiver to the signal frequency. In effect, the receiver automatically tunes itself on channel. An example of an afc system applied to a tunable receiver is given in Chapter 11.

When aligning a receiver with afc, the afc function should be disabled. Once the receiver has been set on channel, the afc can be turned back on. The "lock" range of an afc system is much wider than its capture range. Lock range refers to the frequency change over which the afc correction voltage can tune the receiver, while the capture range is the amount off frequency that the receiver can drift and still have the afc control function when a signal is first received.

FM RECEIVING ADAPTERS

To put the older tube receivers such as the 75A, HRO, and Super Pro models into fm service, the receiving adapter shown in Fig. 3-35 was designed. Filament and plus B voltages are taken from the companion receiver. Obviously, the better the basic receiver, the better will be the performance of the fm receiving system. For this application sets with high-gain i-f amplifier sections and a broad-band selectivity position (such as the SP-400, SP-600, SX-73, and R-390) are excellent choices. Receivers that have only a 6-kHz or narrower bandwidth may need an extra i-f amplifier stage in the fm adapter in order to tap the receiver i-f at the output of the second mixer. Of course, a converter will also be required with the basic receiver to copy vhf fm signals.

A sample of the receiver i-f signal is passed to T1, a 455-kHz i-f transformer, which feeds amplifier/limiter V1. A low screen voltage and signal bias enhance the limiting characteristic of the tube. Further "hard" limiting action is provided by the two sections of V2, a 12AT7. A sample of the grid current of V2A is available at TP1, a test point used during alignment. A commercially made discriminator transformer converts the fm signal to a-m; the a-m is detected by CR1 and CR2. An RC de-emphasis network is included to match the standard pre-emphasis used on fm transmitters.

Audio amplification is provided by V3 – in some receivers with high-gain audio systems this stage may not be necessary.

The adapter is constructed on an aluminum channel which is 11 inches long, 2 inches wide, and 1 3/4 inches high. A 1/4-inch lip is included on one side as a mounting foot. A Minibox or a standard chassis is also suitable as a base. The layout of the stages should be kept in a straight line so that rf feedback paths can be avoided. Point-to-point wiring is used throughout.

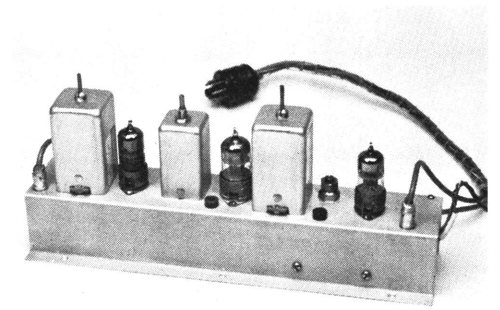
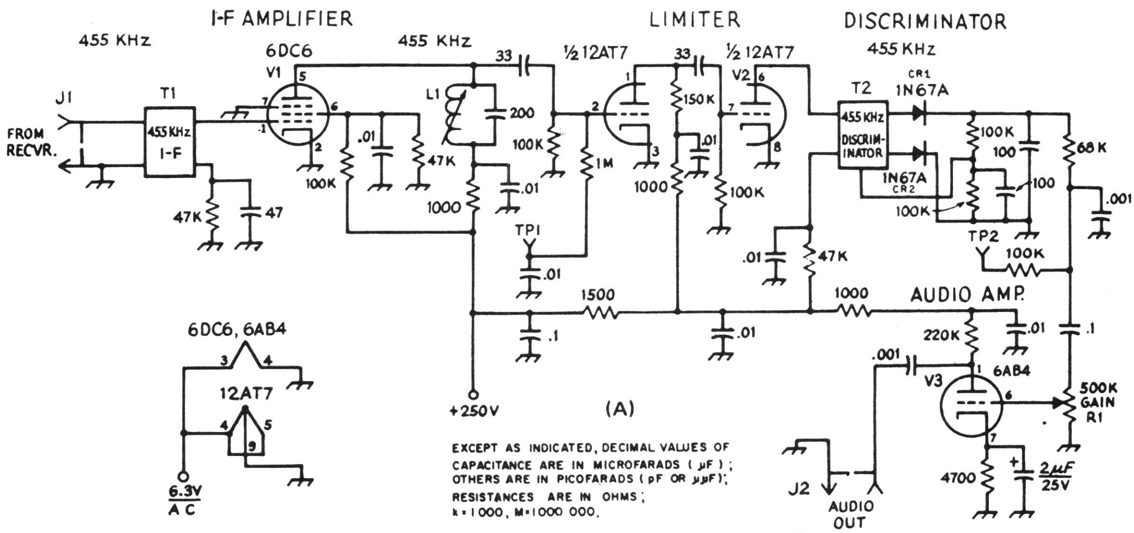


Fig. 3-34 – The fm adapter, wired for connection to a Collins 75A2.

Alignment

"Lining up" the adapter takes time and test equipment. A VTVM or microammeter plus a signal generator are required. Good alignment cannot be accomplished by ear; if the necessary test instruments aren't available, they should be borrowed.

To start, check the alignment of the communications receiver, following the manufacturer's instructions, to be sure that the rf and i-f stages are "peaked" before the fm adapter is installed. Two simple internal modifications are required in the receiver, as shown in Fig. 3-34B. If the receiver has a wide i-f bandwidth, a sample of the i-f signal can be taken from the plate of the last i-f stage. Otherwise, the tap should be made at the plate of the first i-f amplifier, and an extra stage, a duplicate of V1, included in the adapter. Short



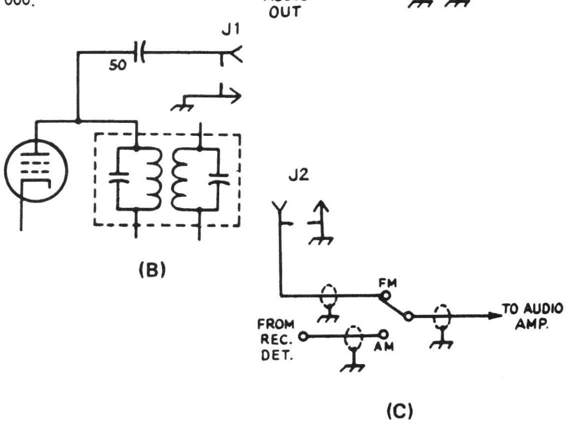


Fig. 3-35 – (A) Schematic diagram of the 455 kHz fm adapter. Resistors are 1/2-watt composition; capacitors are disk ceramic, except those with polarity marked, which are electrolytic.
J1, J2 – Phono jack, panel mount.
L1 – 430-850-µH slug-tuned variable inductor (J. W. Miller 42A684CBI).
R1 – Audio-taper composition control.
T1 – I-f transformer, 455 kHz (J. W. Miller 913-C1).
T2 – Discriminator transformer, 455 kHz (J. W. Miller 913-CD).
TP1, TP2 – Tip jack (E. F. Johnson 105-XX).
(B) Diagram of the connections to use the fm adapter with a communications receiver. The tap to the i-f stage is through a 50-pF disk-ceramic capacitor. If the receiver has a wide-band i-f systemm the connection should be made to the last intermediate-frequency amplifier; for narrow i-fs, tap the first i-f stage. (C) Audio connections.

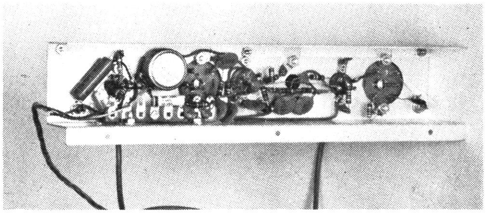


Fig. 3-36 — In this bottom view, the input transformer is to the right followed by the i-f amplifier, limiter and detector. On the far left are the audio amplifier stage and gain control.

lengths of shielded cable are used to carry the i-f signal to the adapter and to return audio to the receiver – see Fig. 3-34C. Some units (75A2, HRO-50) which have provision for fm adapters already have a front-panel switch wired for this purpose.

Connect the signal generator to the receiver, and set the generator to produce an S9 reading on the receiver signal-strength meter. The receiver crystal filter should be switched to its most selective position to assure that the incoming signal is being heterodyned to exactly 455 kHz. Then, with a voltmeter or microammeter connected to TP1, adjust both sections of T1 and L1 for maximum limiter current. The receiver i-f stage being "tapped" should also be aligned to compensate for the capacitance of the adapter cable.

To align the discriminator, set the receiver selectivity at the broad position, and connect the voltmeter to TP2. Voltage at this test point will swing both plus and minus, so a zero-center meter or VTVM with a lead-reversing switch should be employed. Set the secondary of the discriminator transformer for a zero-voltage indication on the meter. Then vary the signal-generator frequency plus or minus 15 kHz. Going off center frequency in one direction will produce positive voltage at TP2, while going in the other direction generates negative voltage. The primary of the transformer must be set so that, for example, if a shift down in frequency by 5 kHz produces plus 2 volts, then, a change of 5 kHz in the other direction should produce minus 2 volts. Unfortunately, the two adjustments on the discriminator transformer are interlocking, so considerable experimentation is required. Also, the tuning of the preceding stages, if not centered on 455 kHz, will affect the discriminator linearity. The first time around, a half hour or more of alignment and realignment is usually required to achieve *equal* swings in output voltage for *equal* swings in frequency – a linear response.

One further check of the discriminator is required. An impulse-generating device, such as an electric shaver, should be switched on, and the receiver, set for a-m detection, tuned to a point in the spectrum where the noise is strong. Then, switch to the fm adapter and adjust the discriminator transformer for best suppression of the noise pulses. If the alignment with the signal generator has been completed properly, only a half turn or so of the slugs will be needed to complete the phase tuning of the discriminator.

A SOLID-STATE ADAPTER

The fact that the main station receiver is an old favorite with tube-type circuitry should not dictate that only adapters using tubes be connected to it. A solid-state adapter will bring the station a bit closer to being "state-of-the-art" and at the same time help the constructor to become familiar with ICs and other miniature components.

Power for a solid-state adapter can be borrowed from the receiver without overloading the receiver's supply. Many receivers have a husky resistor in the cathode circuit of the audio output stage. The potential developed across this resistor is a very convenient source of the low voltage and current required by adapters such as the one described here.

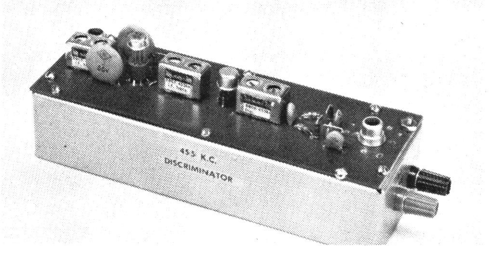


Fig. 3-37 — The solid-state fm adapter is constructed on a 6 × 2-inch etched-circuit board, mounted on a homemade chassis.

Tubes are seldom used in current designs. For those builders who prefer to be "up with the times," a solid-state version of the 455-kHz adapter was constructed. Using IC limiter/amplifier, and miniature i-f transformers, the unit requires only 25 mA at 12 V for power. See Fig. 3-38. The Motorola MC1590G provides 70 dB gain, and hard limiting action superior to that obtained with the tube version.

The unit is built on a 2 × 6-1/2-inch circuit board; a template is given in Fig. 3-38B. Because of the high gain of the IC stage, a shield is required across pins 4 and 6 to isolate the input from the output. Alignment and installation are the same as for the tube version. The bandwidth of the miniature transformers restricts this adapter to narrow-band reception. However, builders wishing a wideband version can use the J. W. Miller 8811 miniature coils combined with a 12-pF coupling capacitor to form a wide-band transformer.

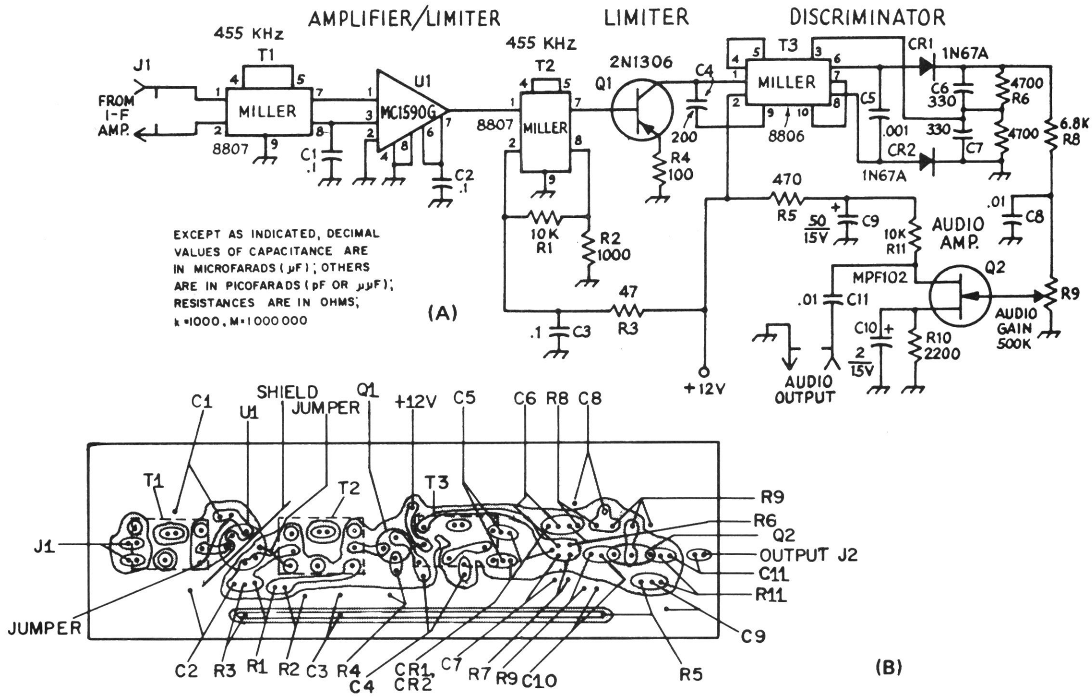


Fig. 3-38 – (A) Diagram of the 455-kHz narrow-band adapter. Resistors are 1/4- or 1/2-watt composition and capacitors are disk ceramic, except those with polarity marked, which are electrolytic. Components with reference numbers that are not listed below are noted for circuit-board location.

J1, J2 – Phono receptacle, panel mount.
R1 – Miniature 1/2-watt composition control.
T1 – Miniature 455-kHz i-f transformer (J. W. Miller 8807).
T2 – Miniature discriminator transformer, 455 kHz (J. W. Miller 8806).
U1 – Motorola MC1590G.
(B) Template for the solid-state adapter (not to scale).

AN FM RECEIVER FOR 29 AND 52 MHz

A block diagram of the receiver is outlined in Fig. 3-40. The front-end circuit uses 40673 dual-gate MOSFETs for the rf amplifier and mixer. Toroid coils were chosen for the signal circuits because of their self-shielding properties. A crystal-controlled JFET oscillator provides injection voltage for Q2. Trimmer C3 is included to move the oscillator frequency "on channel."

A single-conversion scheme using a high i-f was chosen for simplicity, although having 120 dB of gain at 11.5 MHz requires careful layout and good bypassing techniques to assure stability. Three Motorola MC1590Gs are used, although two can achieve the required gain. Three stages, each with resistive loading, exhibited far better stability than two '1590s running "flat out."

The i-f amplifier circuit board uses extensive shielding. The finished product looks more like a piece of vhf gear than an i-f amp., but with high gain special precautions are necessary. The front end and i-f amplifier proved to be easy to build and adjust. The squelch circuit was a bother from the beginning. The basic circuit used for the noise-operated squelch is borrowed from Motorola MO-TRAC series. Output from the crystal discrimina-

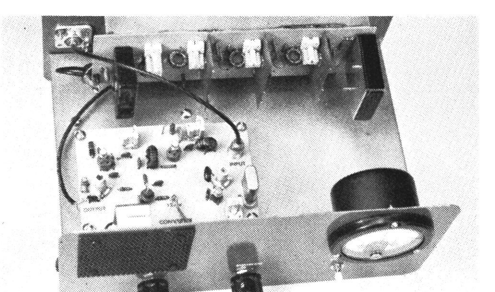


Fig. 3-39 – Top view of the receiver. The etched circuit board containing the front-end components is at the lower left, while the i-f amplifier/detector circuit board is bolted to the rear wall of the cabinet.

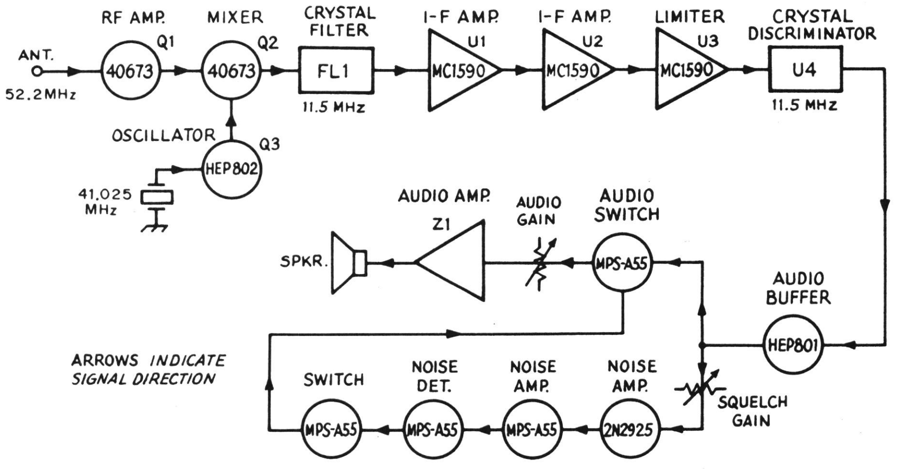


Fig. 3-40 – Block diagram of the 10-meter fm receiver using a crystal discriminator.

tor proved to be quite a bit lower in level than would be obtained from an equivalent *LC* discriminator. Also, Z1 (Fig. 3-42) wants to "look into" an impedance of 100,000 ohms or more. The first version of the squelch circuit had far too little gain, so a redesign was required. The final version of the circuit is shown in Fig. 3-42. The voltages noted at the audio gate, Q8, are critical; any variation from the indicated values will cause a full squelch condition where the audio gate will not open, or, no squelch operation at all.

A commercial amplifier module was chosen for the audio-output section. It delivers two watts (rms) to an 8-ohm load when using a 12-volt supply. Sufficient audio output is available for comfortable copy of weak stations when operating mobile. An inexpensive imported 0.5-watt audio amplifier may be substituted if the receiver will be used only in a ham shack. Power requirements for the receiver are 12 volts at 70-mA drain (squelch engaged) and 200mA (at full audio output). Since automobile electrical systems can have voltages as high as 16 volts, a series regulator should be included for mobile operation.

Alternative values for the rf and oscillator coils are given for 6-meter operation. To set the receiver

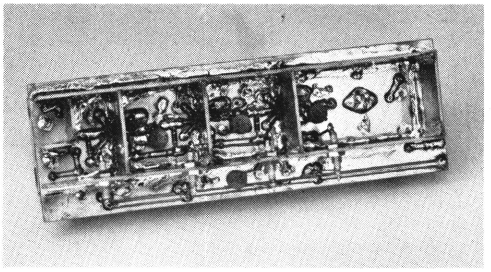


Fig. 3-41 – The bottom view of the i-f board shows the shielding and filtering used.

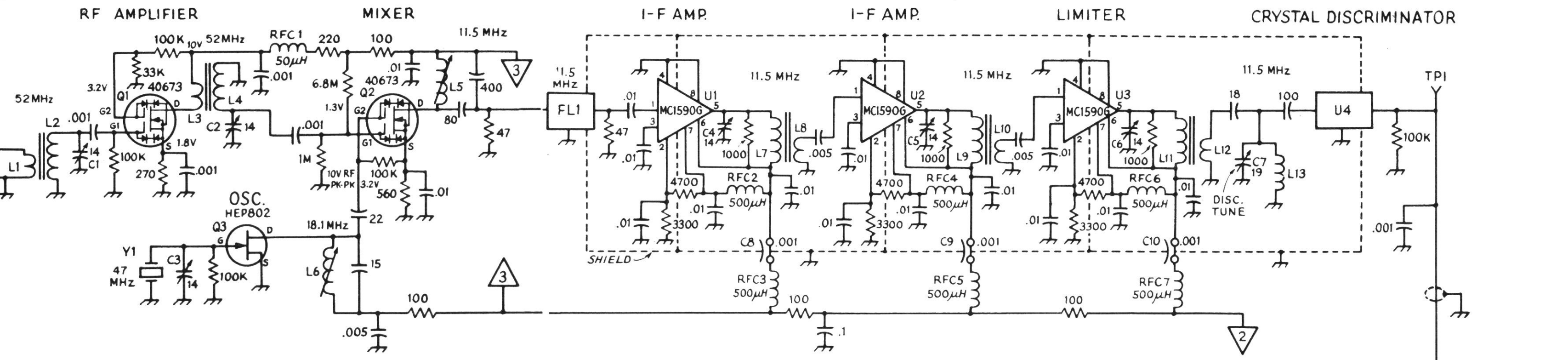
for the 6-meter frequency, 52.525 MHz, a 41.025-MHz crystal is required. When built for 29.6 MHz, this unit can be used for 2-meter reception by adding any 144- to 148-MHz converter, having 10-meter i-f output, ahead of the fm receiver. Suitable designs are shown in the *Handbook* and *VHF Manual*. With a converter i-f of 28 to 32 MHz, a 19.44-MHz crystal would be needed in the 10-meter receiver for reception of 146.94 MHz.

Alignment

A signal generator and a VTVM are required for receiver alignment. The VTVM should be connected to terminal TP1 and set to read 0-3 V dc. The generator should be set to about 29.6 MHz, and connected to J1 on the receiver. Rotate R1 fully counterclockwise, and you should hear noise in the speaker. If no noise is heard, place your finger on the input terminal of Z1. If the audio module is working, a loud hum will be heard. No noise output indicates that the squelch may be locked up. Check the voltages given in Fig. 36 against those found on the audio gate.

With a cw input signal, adjust C4, C5 and C6 for a maximum reading on the VTVM. Then set C1 and C2 for maximum indicated output voltage. Set the signal to 29.585 and note the VTVM reading. Then set the generator to 29.615 MHz and adjust C7 for a VTVM reading of the same magnitude, but opposite polarity, from that obtained on the "low side" of 29.6 MHz. Repeat the procedure several times to assure a correct adjustment.

With the basic alignment completed, inject a 29.600-MHz signal – the output of a 100-kHz calibrator will do. Then set C3 so that the VTVM reads zero voltage. This completes the rf and i-f alignment. Connect an antenna and advance the squelch control, R1, until the backround noise disappears. The squelch should close the audio gate at one-third to one-half scale rotation of R1.



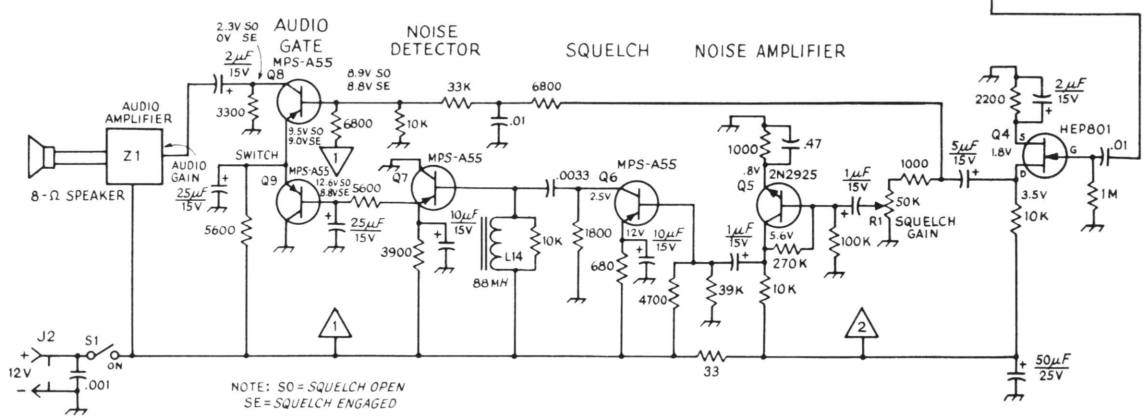


Fig. 3-42 — Schematic diagram of the fm receiver. Unless otherwise noted, resistors are 1/2-watt composition and capacitors are disk ceramic, except those with polarity marked, which are electrolytic.

C1-C6, incl. — Miniature air variable (E. F. Johnson 189-507-5).

C7 — Miniature air variable (E. F. Johnson 189-509-5).

C8-C10, incl. — Feedthrough type.

FL1 — For a wide-band 11.5MHz i-f, ESEL MEL-3A; narrow-band 11.5-MHz i-f, ESEL DL-11A; wide-band 10.7-MHz i-f, KVG XF-107D; narrow-band 10.7-MHz i-f, KVG XF-107B. If 10.7-MHz i-f is used, add 15-pF ceramic capacitors across L5, L7, L9, L11, and L13.

J1, J2 — Phono type, panel mount.

L1 — 5 turns No. 22 enam. over L2 for 29 MHz; use 2 turns for 52 MHz.

L2 — 21 turns No. 22 enam. on Amidon T-50-6 toroid core (yellow code) for 29 MHz; use 11 turns for 52 MHz (Amidon Associates, 12033 Otsego Street, North Hollywood, CA 91607).

L3 — 8 turns No. 22 enam. on L4 for 29 MHz; use 4 turns for 52 MHz.

L4 — 13 turns No. 22 enam. on Amidon T-50-6 (yellow code) for 29 MHz; use 6 turns for 52 MHz.

L5 — 2.96-3.14-μH variable inductor (J. W. Miller 46A336CPC).

L6 — For 18-MHz crystals (10-meter operation), 1.99-2.42-μH variable inductor (J. W. Miller 46A226CPC); for 41-MHz crystals (6-meter operation) 0.37 to 0.47-μH variable inductor (J. W. Miller 46A397CPC).

L7, L9, L11 — 36 turns No. 26 enam. on Amidon T-50-2 (red code) core.

L8, L10, L12 — 16 turns No. 26 enam. over L7, L9, and L11 respectively.

L13 — 24 turns No. 22 enam. on Amidon T-50-2 (red code) core.

L14 — 88-mH surplus telephone loading coil

Q1, Q2 — RCA dual-gate MOSFET.

Q3 — Motorola rf JFET.

Q4 — Motorola audio JFET.

Q5 — GE audio bipolar.

Q6-Q9, incl. — Motorola audio bipolar.

R1 — Linear-taper composition control.

RFC1 — 50-μH miniature choke (James Millen 34300).

RFC2-RFC7, incl. — 500-μH miniature choke (J. W. Miller 70F504A1).

S1 — Spst miniature toggle.

TP1 — Vector T2.8 terminal.

U1-U3, incl. — Motorola IC.

U4 — ESEL AL-1A for 11.5-MHz i-f, KVG 107-01 for 10.7 MHz.

Y1 — International Crystal type EX.

Z1 — 2-watt audio amplifier, 1-volt sensitivity (Amperex PCA-1-14).

A TUNABLE 440-MHz FM RECEIVER

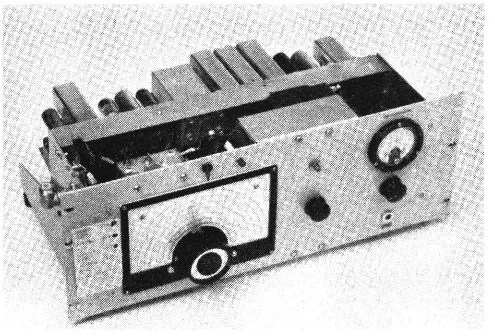


Fig. 3-43 — Panel view of the K1ZJH 440-MHz fm receiver. The vernier dial drives the tuning shaft of a converted uhf TV front end. At the rear is a 450-MHz Motorola fm receiver, the i-f system of which takes the output of the converted TV tuner. The meter can be connected in the limiter or discriminator circuit.

Though originally intended for checking signal paths between proposed uhf fm sites, this receiver also provides convenient eavesdropping on local 440-MHz fm activity, and monitoring of commercial frequencies adjacent to the high end of our 420-MHz band. It or something quite similar to it is readily put together, and can be assembled quite inexpensively. Though a duplicate can be built from the information suppied here, the reader should treat this discourse mainly as a collection of ideas. The exact units used for the receiver may not always be available, so other components may have to be adapted to the job.

In most modern TV receivers the uhf tuner is solid-state, designed to feed the 43-MHz TV i-f strip directly. The mixer output is untuned, so it is apparent that any intermediate frequency can be accommodated, depending solely on the frequency range of the tuner oscillator. One advantage of the 43-MHz i-f is the great number of low-band fm monitor receivers for this frequency range available at low cost.

It is best to avoid the narrow-band monitors that won't accept more than 5 kHz deviation. Tuning will be too sharp for the stability and tuning rate of uhf converters, and most amateur fm in the 420-MHz band is still wide-band deviation. The wide-band receiver will not be bothered seriously by any drift in the TV tuner.

The uhf TV tuner used here is a Sickles Model 228. Many tuners use the same basic electrical and mechanical layout, the only differences being in the dial-drive arrangement made for a particular TV receiver. These tuners do not have trimmer capacitors for alignment, such as were used in earlier uhf converters. Alignment is done with specialized test equipment by precisely bending the rotor plates in the tuner. Most tuners are linear within plus or minus one TV channel, over the entire uhf TV spectrum, when they leave the factory.

Uhf Tuner Modifications

Getting this type of tuner to cover the upper 10 MHz of the amateur band is best done by adding trimmer capacitors across the tuner circuits. The sketch of the tuner as modified, Fig. 3-44, should help to make clear how this is done. Start by removing one of the two rotor plates in the

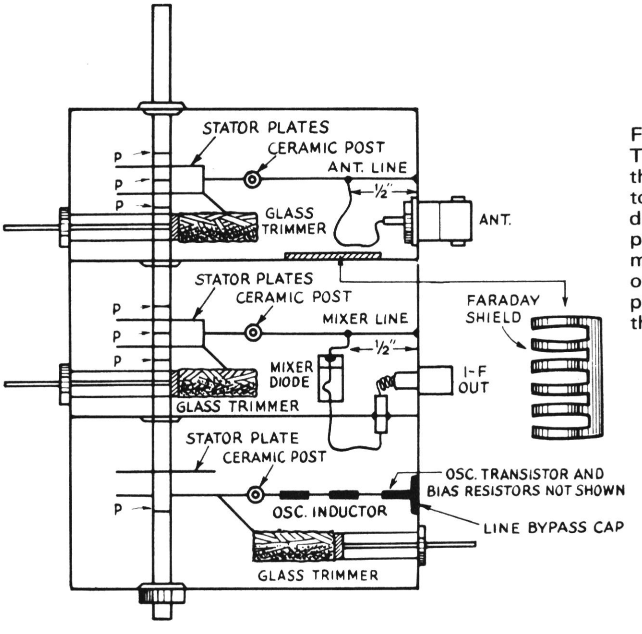


Fig. 3-44 — Bottom view of the uhf TV converter, as modified for use in the 420-MHz band. Only the oscillator circuit is tuned by the vernier dial, all rotor plates in the mixer and preselector circuits having been removed. One rotor plate is left in the oscillator section. Positions of the plates to be removed are indicated by the letter P.

oscillator compartment. The mixer and antenna circuits will not require tuning across our small intended frequency range, so the rotor plates in the two upper sections of the tuner can all be removed.

Mount three 16-pF glass trimmers on the tuner walls, parallel to the three lines and as close as possible to them. See Fig. 3-44. Connect the short trimmers to their respective lines with short pieces of heavy wire or copper strip. By bending the one oscillator rotor plate away from its stator carefully, the tuning range can be reduced to as little as 15 MHz.

Remove the 300-ohm connector and coupling loop from the antenna section by drilling out the mounting rivets in its insulating support. Enlarge the hole and mount a phono jack or a BNC fitting for antenna connection. Run a 1/8-inch copper strip from a point on the antenna line, 1/2 inch from the wall,down to as close to the coupling port to the mixer compartment as possible, then up to the connector, as shown in Fig. 3-44. If the port is not merely an open hole in the wall separating the sections, but is a Faraday shield, as in the 228 tuner, remove the Faraday shield to improve interstage coupling. This shield is not visible in the tuner photo. If used, it is a comb-like insert in the port, as shown in enlarged form in Fig. 3-44.

One lead of the mixer diode in the 228 tuner runs through a small port between the oscillator and mixer sections. The other diode lead, barely visible in the tuner photo, is parallel to the mixer line and is connected to the right-hand wall of the tuner. Cut it at this point and solder the lead to the mixer line, about 1/2 inch from the wall, as shown in Fig. 3-44. In some of the better tuners the mixer diode is reverse biased, and does not go directly to ground in the mixer section. This was done for improved noise figure and should be left the way it is.

Most tuners are designed to terminate in an i-f input circuit which is at dc ground potential. If the receiver to be used does not provide a dc path, a 50-MHz rf choke should be connected from the tuner i-f output to ground to provide a dc path for the mixer crystal current. The ground end of the choke can be lifted to measure crystal current, which should be at least 100 μA.

In the receiver shown here the tuner feeds the 75-MHz i-f of a Motorola 450-MHz crystal-controlled fm receiver. The two 6AK5 frequency multipliers which provide injection to the first mixer, the front-end rf tubes and afc tube were removed to conserve power, since they are not used in this application. A National vernier dial drives the two-plate tuning capacitor in the tuner, through a shaft extension and a flexible coupling. If there is backlash in the drive system it is not evident in the operation of the receiver. Signals tune in smoothly and easily.

A meter indicates limiter current, for signal strength observation, and as an aid in adjusting antenna systems and beam headings in fm work. The nature of fm reception makes small changes in signal level undetectable by ear. The discriminator is also metered, for ease of station tuning. Supply voltage for the tuner is dropped from the receiver B-plus line, and is regulated with a Zener diode.

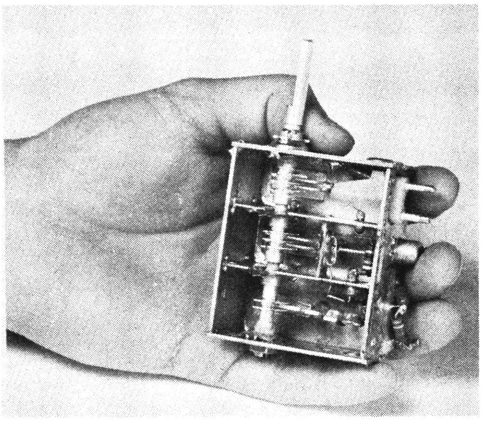


Fig. 3-45 – Typical uhf TV tuner similar to the one used in the fm receiver described by K1ZJH. This is the original condition, before modification.

Visible in the upper left portions of the photographs of the complete receiver is a grounded-base uhf preamplifier using a TIXM101 transistor. A preamp suitable for this purpose is shown in Chapter 11.

The tuning range of this receiver is roughly 440 to 454 MHz. No images or other spurious responses are heard. Tuning is smooth, and stations are easily "zeroed" on the discriminator meter.

The sensitivity is adequate for monitoring on line-of-sight paths, but not for weak-signal DX work such as is commonly done around 432 MHz. The TV tuner alone is very poor – on the order of 10 microvolts for 10-dB quieting. If one wishes to be able to hear the weak ones, a much better mixer is needed, and should be preceded by a good low-noise rf amplifier.

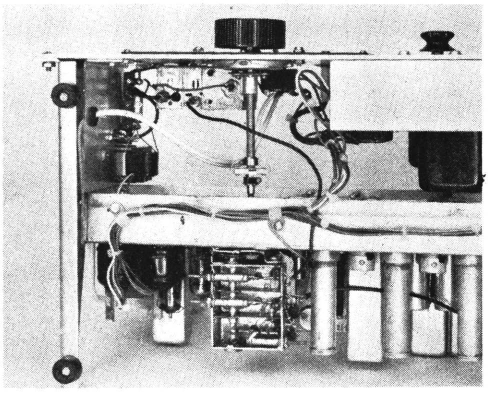


Fig. 3-46 – Looking into the bottom of the tunable 440-MHz fm receiver shows the converted TV tuner below the vernier dial. A transistorized rf preamplifier, also built into a TV tuner case, is visible just to the left of the tuning shaft.

A COMPACT CONVERTER FOR 220-MHz

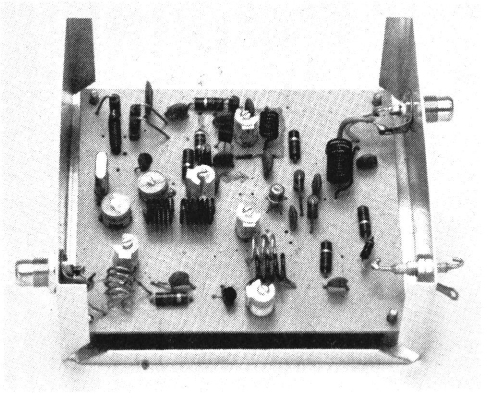


Fig. 3-47 – The 220-MHz converter is mounted in a box made from sheet aluminum. A phono jack at the lower left is the input connection. Another jack at the upper right is the output to the receiver. The i-f output coil shown here is for use with a low-band receiver. Changes necessary to work into a 2-meter receiver are explained in the parts list and text.

With the recent increase in repeater planning and, in some cases, activity on 220 MHz, there is a need for receiving systems on that frequency. Many past designs for 220-MHz converters have suffered from bulkiness in size, and complexity of circuits, that has made them unattractive for most mobile installations. The converter described here is small enough to be mounted in most mobile receivers.

One decision that must be made when designing a converter is what frequency to use as an i-f. For fm use the field is narrowed somewhat by the availability of surplus equipment. Much of this equipment is in the "low-band" range of 30 to 50 MHz, or in the "high-band" range of 148 to 170 MHz. It has been common practice to convert these rigs to work in the amateur 6- or 2-meter bands. Therefore, a most useful converter design would be one that could be adapted to use either of these bands as an i-f. This converter can be constructed for either i-f with only small component changes.

Circuit Considerations

One of the important features of this converter is the crystal oscillator and the multiplier stage that follows it. As shown in Fig. 3-48. Q3 is the oscillator and quadrupler. By using a crystal frequency of 19.25 MHz, and tuning the collector circuit to 77 MHz, the transistor stage provides the injection voltage to the mixer for an i-f of 147 MHz, or high-band. For a low-band i-f, only one more stage is needed – a frequency doubler. With a crystal frequency of 21.5 MHz, the output of Q3 is 86 MHz. Q4 doubles this to 172 MHz, which is the injection frequency for an i-f of 52 MHz. The foregoing figures assume an input or signal frequency of 224 MHz. Crystal frequencies for other input or output frequencies can be calculated as follows:

$$\text{For a low-band i-f, } f_o = \frac{f_s - f_1}{8}$$

$$\text{For a high-band i-f, } f_o = \frac{f_s - f_1}{4}$$

Where f_o is the crystal frequency, f_s is the signal frequency to be received, and f_1 is the i-f. If the receiver to be used has several channels, an extra one can be set up for use with the converter. Where the choice of channels is limited, the one with least likelihood of feedthrough interference will depend on the sensitivity of the receiver, shielding, grounding of the chassis, and the strength of the repeater or direct (simplex) signal.

A 40673 dual-gate MOSFET is used for the mixer, with the gate-2 connection tapped on the input-frequency coil. Gate 1 obtains injection voltage via a 5-pF capacitor from the output of the oscillator multiplier chain. The i-f output circuit is connected to the drain of the MOSFET. This circuit is fixed-tuned for simplicity's sake. It can be peaked for maximum output by squeezing or stretching the coil.

The rf amplifier uses an MPF102 or 2N5486 JFET in a grounded-gate configuration. The latter device will give slightly better performance. A word of advice when using these transistors in such a circuit: The gate must be connected to ground with the *shortest* possible lead length. A stubborn case of self-oscillation in the converter described here was cured by leaning the 2N5486 over so that the gate lead was just long enough to reach through the board and connect to the ground foil.

Construction

The converter is built on a piece of glass-epoxy board, 8.8-cm wide by 9.9-cm long. In inches, that works out to be just under 3-7/16 × 4. An aluminum box, 9-cm wide, 10-cm long, and 5-cm high was constructed as a housing. If the converter is to be installed inside a receiver, the box may not be necessary. However, care should be taken to assure that the converter is not mounted close to circuits that would couple unwanted signals into it. Such circuits might be the oscillator, multiplier, or rf amplifier stages of the i-f receiver.

Metal stand-off posts at each corner of the board serve to mount the converter and provide a good ground to the chassis. Phono connectors are used for input and output. The 12-volt dc supply is connected to a feedthrough capacitor on the wall of the box. A silicon diode in the supply lead offers protection against damage caused by reversing the polarity, although in most mobile installations this should not be a problem.

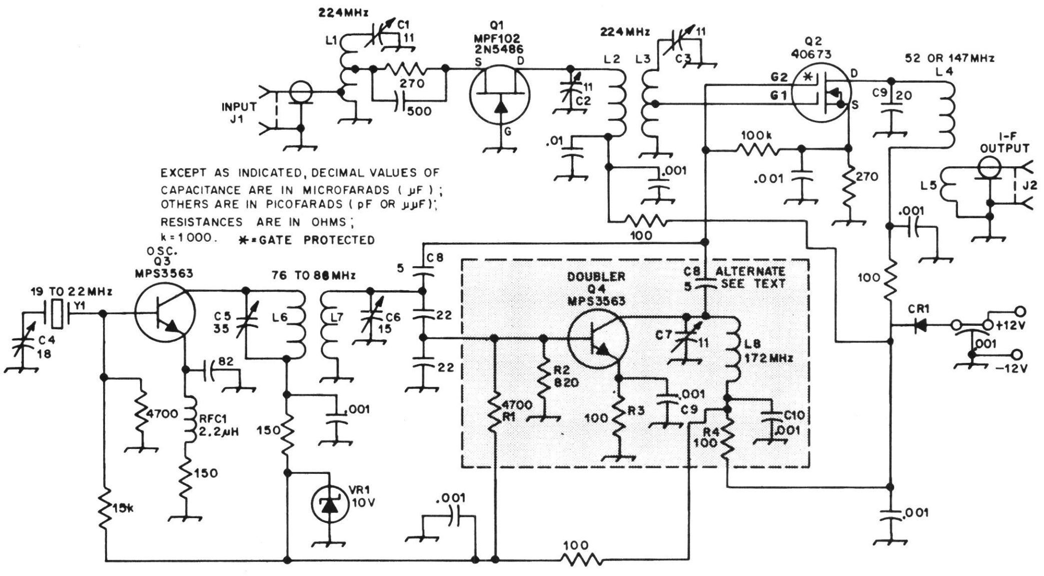


Fig. 3-48 — Schematic diagram of the 220-MHz converter. The components shown in the shaded area are the frequency-doubler circuit and can be omitted if the converter is built for use with a 2-meter receiver. Note that the connection point for C8 is also changed for a high-band i-f.

C1, C2, C3, C7 — 1.7- to 11-pF miniature variable (E. F. Johnson 187-0106-105).

C4 — 5.5- to 18-pF ceramic trimmer (Erie 538-002A-5.5-18 or equiv.).

C5 — 9- to 35-pF ceramic trimmer (Erie 538-002D-9-35 or equiv.).

C6 — 1.9- to 15.7-pF miniature variable (E. F. Johnson 187-0109-105).

C8 — 5-pF ceramic (see text).

CR1 — Silicon diode, 50 PRV, 200 mA or greater.

J1, J2 — Coaxial connector, phono or other type.

L1 — 4 turns No. 20 tinned wire, 1/4-in. ID × 3/8-in. long, tapped 1-1/2 and 2-1/4 turns from ground end.

L2 — 4 turns No. 18 enam. wire, 1/4-in. ID × 1/2-in. long.

L3 — 3 turns No. 20 tinned wire, 1/4-in. ID × 3/8-in. long, tap 1-1/2 turns from ground end.

L4 — For 52 MHz, 9 turns No. 20 enam. wire, 1/4-in. ID × 5/8-in. long; for 146 MHz, 5 turns No. 20 enam. wire, 1/4-in. ID × 3/8-in. long.

L5 — For 52 MHz, 3 turns No. 20 enam. wire, 1/4-in. ID, closewound; for 146 MHz, 2 turns No. 20 enam. wire, 1/4-in. ID, closewound.

L6 — 6 turns No. 20 enam. wire, 1/4-in. ID × 1/2-in. long.

L7 — 7 turns No. 18 enam. wire, 1/4-in. ID × 1/2-in. long.

L8 — 5 turns No. 18 enam. wire, 3/16-in. ID × 3/8-in. long.

RFC1 — 2.2 µH Choke, (J. W. Miller 70F225A1).

Y1 — Crystal, 19- to 22-MHz fundamental (International Crystal type CS or equiv.). The etched-board layout will accept either 0.486 or 0.275 pin spacing.

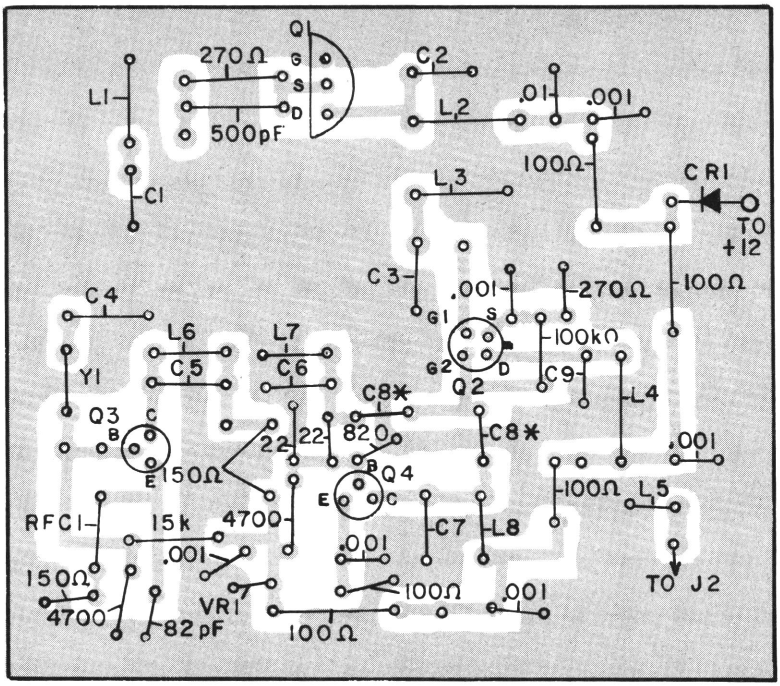
The circuit board has been designed to include parts placement for either high- or low-band i-f. For an output at 147 MHz, the injection coupling capacitor, C8, is connected from the top of L7 to gate 1 of the 40673. For a 52-MHz i-f, Q4 is added to the board, along with its associated resistors, capacitors, and L8. When the doubler is used, C8 must be connected in the alternative position (from the top of L8 to gate 1) to provide injection voltage.

All of the coils are wound with wire large enough to be self-supporting. Vibration should not be a problem, but a few drops of coil dope can be applied to each winding for further stiffening. Some of the resistors are installed flat and some are upright, depending on the space available. Power consumption of each stage is low enough that 1/4-watt resistors can be used, resulting in a more neat-appearing board.

Tuneup and Performance

As with most construction projects of this type, a grid-dip oscillator is an almost indispensable tool to aid in getting the tuned circuits on the correct frequency. A good quality crystal should be used for Y1. There is no oven to keep the crystal at a constant temperature, so a good commercial-grade crystal is worth the price. If the oscillator has a low output or shows a reluctance to start, it might need a feedback capacitor connected from emitter to base. Something in the range from 10 to 30 pF should do – but use the smallest value that will assure oscillation. Most of the transistors tried in this circuit did not require extra feedback. The oscillator performance should be checked to assure that its output is on the 4th harmonic of the crystal, and not the third or fifth.

After the frequency multipliers are tuned for maximum injection to the mixer, the converter can



* CONNECT C8 ACCORDING TO TEXT

Fig. 3-49 – Scale drawing of the pc-board pattern for the 220-MHz converter. Foil side shown.

be connected to the input of a receiver. If a transceiver is to be used, the converter must be ahead of the receiver portion only. Accidental keying of a transmitter with the converter connected to it can ruin several hours work! The rf amplifier and mixer stages can be peaked up on a signal while monitoring the limiter current in the receiver. The spacing between L2 and L3 should be adjusted a small amount at a time, and each circuit retuned for maximum limiter current. The ultimate in adjustment requires a calibrated signal generator and an audio-output meter to measure the amount of quieting that a given signal will provide. When this converter was used ahead of a Motorola strip on 52 MHz, sensitivity was such that 0.28-microvolt into the converter produced the sought-after 20 dB of quieting. Under these conditions 0.1 microvolt would open the squelch of the receiver. Performance like this makes the converter equal to many of the two-meter receivers now in use, and better than some. Image rejection was more than 70 dB.

An i-f amplifier was not needed with the strip used to test the converter. If the receiver needs a bit of help in the sensitivity department, it is an easy matter to add a small amplifier. Single-stage preamplifiers for 6 or 2 meters should be adequate. Examples of such amplifiers can be found in Chapter 11.

A SINGLE-CONVERSION 2-METER FM RECEIVER

The single-conversion solid-state fm receiver described here is intended as a mate for the fm transmitter described in Chapter 4, this book. This design makes use of a $3.65 multifunction IC, the CA3089E. Circuit simplicity, good performance, and low cost are the keynotes in this project. Construction costs should not exceed $50 if all parts are purchased new, in single-lot quantity. Those lucky enough to have fertile junk boxes should be able to duplicate the receiver for less than $25.

Circuit Highlights

A JFET was chosen for rf amplifier Q1, Fig. 3-51. Neutralization is unnecessary provided the gate and drain elements are tapped down on their respective tuned circuits. For simplicity's sake only two tuned circuits are used ahead of the mixer, a dual-gate MOSFET. The combination of FETs Q1 and Q2 assure low IMD and provide good immunity to overloading. Output from the mixer is supplied to FL1. This is a four-pole 10.7-MHz i-f

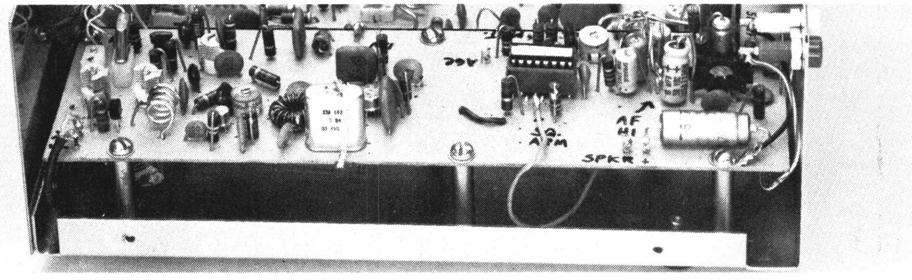


Fig. 3-50 — This photo shows the final breadboard version of the fm receiver. Some of the bypass capacitors are located on the foil side of the pc board in this example. The template and parts-layout sheet provide for topside mounting of the capacitors. The differences between the receiver shown here and the final model are quite minor. Numbered components not in parts list are identified for pc-board layout purposes only.

filter which is fed from a 900-ohm tap point on tuned circuit C9-C10-L3.

The oscillator/multiplier stage, Q3, is a copy of that used by Pearce-Simpson in their Gladding 25 fm transceiver. It is one of the simplest circuits one can use, yet it performs well. Injection to the mixer is supplied at 157 MHz (10.7-MHz i-f plus the frequency of the received signal). The oscillator crystal frequency is one half the injection frequency – 78 MHz in this example. No netting trimmers are necessary if crystals designed for the Gladding circuit are used. Frequency doubling from 78 MHz is accomplished in the collector circuit of Q3.

I-f amplifier U1 is a CA3028A wired for cascode operation. FL1 connects to input terminal 2 through a .01-μF blocking capacitor. Terminating resistor R7 is selected for the characteristic impedance of the filter used. The KVG filter has a 910-ohm bilateral impedance, so if precise matching is desired one can use a 910-ohm resistor in place the 1000-ohm unit at R7. Output from U1 is fed to multifunction chip U2, across R11.

Audio output from U2 is amplified by Q4 before being routed to U3, a transformerless 1-watt output IC. Though the MC1454 is designed to work into a 16-ohm speaker, good results can be had when using an 8-ohm speaker.

Construction

How the receiver is packaged can best be decided by the builder. Two choices are offered – dividing the board in two parts and stacking one section above the other on standoff posts. If this is done it will be necessary to cut the board midway between U1 and U2. If compactness is not necessary the constructor can follow a one-piece-assembly format, keeping the board at its 8 × 2-11/16-inch size.

Those who desire additional crystal positions can make the board slightly longer. This will provide room for more crystal sockets, but will require that a switch with more positions be used for S1.

It is recommended that transistor and IC sockets be avoided except at Q4 and U3. The rf circuits must be built to assure stable operation. Short leads between the bodies of the devices and the pc board must be maintained to prevent unstable operation. The use of sockets will cause instability unless low-profile receptacles are used. Similarly, the pigtails on the bypass capacitors should be kept as short as possible in all parts of the rf circuit.

The wiring which connects the audio and squelch controls to the circuit board should be of the shielded variety. If the board is cut into two sections, as mentioned earlier, use shielded cable between U1 and U2, routing the i-f signal from pin 6 of U1 to pin 1 of U2. *Don't leave out C16!*

The leads from S1 to the crystal sockets must be kept as short as possible – less than 1 1/2 inches each. As a further aid to circuit stability mount the pc board on a metal cabinet wall or chassis by means of 4 or 6 metal standoff posts. This technique is beneficial in reducing rf ground loops.

Checkout and Alignment

It should be stressed that there is no simple way to align an fm receiver. A stable signal generator will be required, preferably one with fm capability. Initial alignment cannot be properly effected by using off-the-air signals. A weak-signal source can be built by using the modulator and crystal oscillator stage of the transmitter described in Chapter 4. Whatever method is used, make certain that the test signal is no farther off frequency than 200 Hz from the desired frequency of reception. Ideally, the signal source should be *exactly* on the chosen input frequency of the receiver.

Connect the signal generator to J1. Attach a meter across J2 and J3. Make certain that a speaker is hooked to the output of U3. If an ohmmeter check shows no shorted or open circuits in the completed assembly, connect a 12-volt dc supply to the receiver. With the squelch turned off (maximum hiss noise) adjust C2, C4, and C44 for an upward deflection of the relative-signal-strength meter (at J2 and J3). Next, adjust C10 for maximum meter reading. Repeat these steps two more times. All tuning adjustments should provide fairly sharp peaks when the circuits are tuned to resonance.

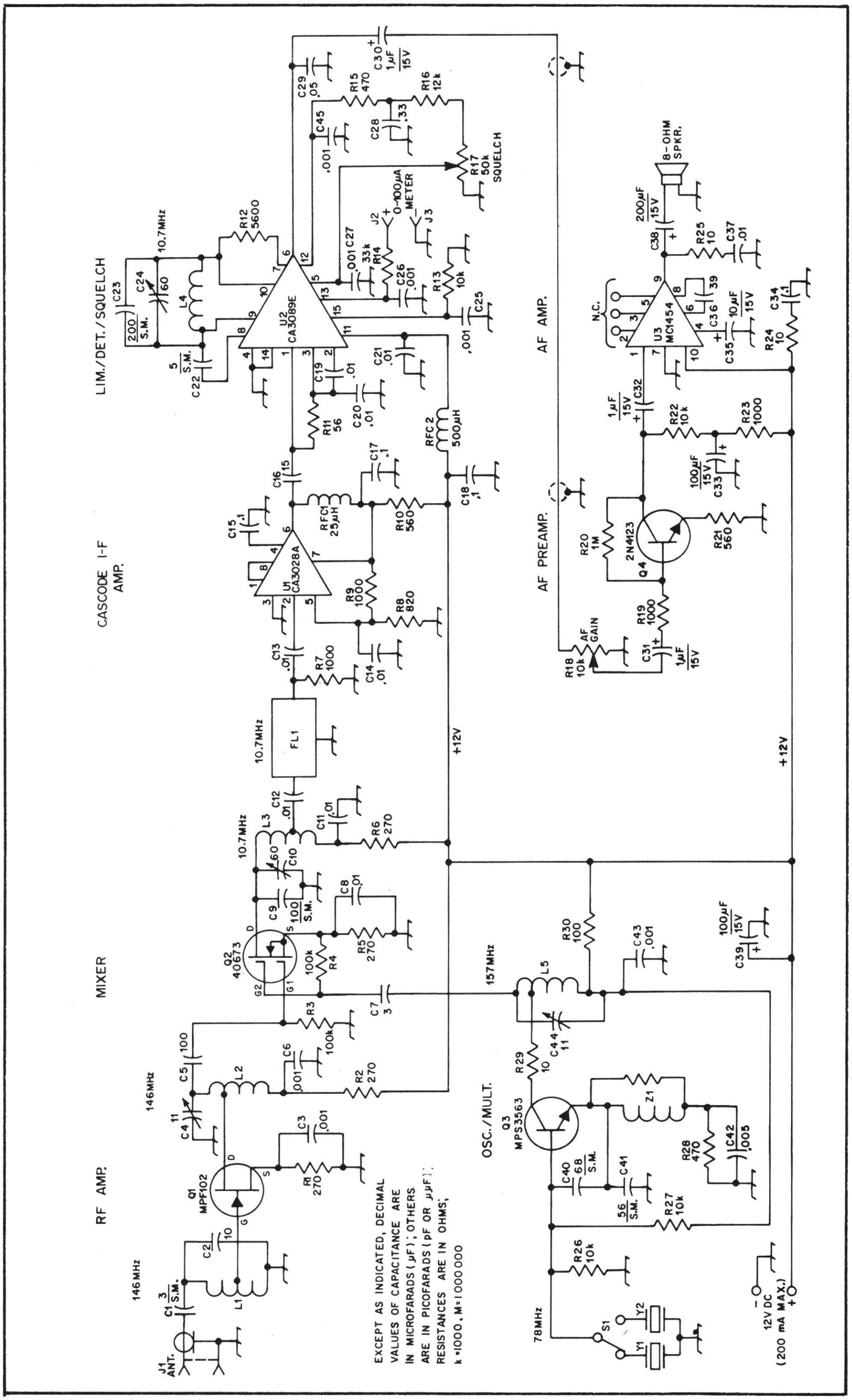

RF AMP.
MIXER
CASCODE I-F AMP.
LIM./DET./SQUELCH
AF PREAMP.
AF AMP.
OSC./MULT.
EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF); OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS; k=1000, M=1000000
12V DC (200 mA MAX.)

Fig. 3-51 – Schematic diagram of the fm receiver. Fixed-value capacitors are disk ceramic unless otherwise noted. Polarized capacitors are electrolytic. Fixed-value resistors are 1/2-watt composition types.

C1 – 3-pF silver mica. For precise matching substitute a 10-pF trimmer for the fixed-value capacitor.
C2, C4, C44 – 11-pF pc-mount miniature air variable (E. F. Johnson 187-0106-005, avail. from Newark Electronics).
C10, C24 – Subminiature ceramic trimmer, 15 to 60 pF (Erie 538-011F-15-60, avail. from Newark Electronics, or surplus from Reliance Merchandising, 2223 Arch St., Phila., PA 19103).
FL1 – See text and footnotes.
J1 – Coax receptacle of builder's choice.
J2, J3 – Binding posts or pin jacks.
L1 – 5 turns No. 18 tinned bus wire, 1/4-inch ID × 1/2-inch long. Tap gate of Q1 at 2-1/2 turns from hi-*Z* end.
L2 – 4 turns No. 18 tinned bus wire, 1/2-inch ID × 1/2-inch long. Tap drain of Q1 at 1 turn from hi-*Z* end.
L3 – 16 turns No. 22 enam. wire to occupy entire circumference of Amidon T-50-2 toroid core. Tap at 6 turns from hi-*Z* end for FL1.
L4 – 1-μH high-*Q* inductor, unloaded *Q* 150 or greater. 18 turns No. 24 enam. wire to occupy entire circumference of Amidon T-37-2 toroid core (Amidon Assoc., 12033 Otsego St., N. Hollywood, CA 91607).
L5 – 5 turns No. 18 tinned bus wire, 1/4-inch ID × 1/2-inch long. Tap collector via R29 at 1 turn from hi-*Z* end.
Q1, Q3, Q4 – Motorola transistor.
Q2 – RCA MOSFET.
R17 – 50,000-ohm linear-taper composition control
R18 – 10,000-ohm audio-taper composition control
RFC1 – 25-μH choke (James Millen J300-500 or equivalent).
RFC2 – 500-μH choke (James Millen J300-500 or equivalent).
S1 – Spdt miniature slide or wafer switch, nonshorting.
U1, U2 – RCA integrated circuit.
U3 – Motorola integrated circuit.
Y1, Y2 – International Crystal Co. receiving crystal ground to Pearce-Simpson Gladding 25 specs. Nylon crystal sockets avail. from International Crystal Co.
Z1 – Rf choke consisting of 8 turns No. 24 enam. wire, close-wound on body of 1000-ohm 1/2-watt carbon resistor. Solder coil leads to resistor pigtails.

A frequency-modulated signal will be required for on-the-nose adjustment of the detector (L4 and C24). C24 should be adjusted slowly until the point is found where best audio quality occurs. Audio recovery will be the lowest at this point, creating the illusion of reduced receiver sensitivity. If no fm signal is available for this part of the alignment, tune the detector for minimum hiss noise as heard in the speaker. After the detector is aligned, readjust C10 for best audio quality of a received fm signal. It may be necessary to go back and forth between C10 and C24, carefully tweaking each capacitor for the best received-signal audio quality. The detector should be adjusted while a strong signal (100 μV or greater) is being supplied at J1.

Adjustment of the squelch control should provide complete muting of the hiss noise (no signal present) at approximately midrange in its rotation. If the audio channel is functioning properly one should find that plenty of volume occurs at less than a midrange setting of R18.

Performance

In two models built both identical to the circuit of Fig. 3-52, sensitivity checked out at approximately 0.8 μV for 20 dB of quieting. This sensitivity figure is by no means spectacular, but is quite ample for work in the primary signal contour of any repeater. The addition of a dual-gate MOSFET preamplifier, such as described in Chapter 11, ahead of Q1 resulted in a sensitivity of 0.25 μV for 20 dB of quieting. The barefoot receiver requires approximately 0.5 μV of input signal to open the squelch. A more elaborate circuit would have provided greater sensitivity, but at increased cost and greater circuit complexity.

Hard limiting occurs at signal input levels in excess of 10 μV, with 3 dB of limiting exhibited at 1 μV. Addition of an outboard preamplifier will greatly improve the limiting characteristics, and this would benefit whose who are dealing primarily with weak signals.

A KVG XM 107S04 i-f filter (FL1) is used in the circuit of Fig. 1.[1] However, any 10.7-MHz filter with suitable bandwidth characteristics for amateur fm reception can be substituted for the unit specified. During the development period a Piezo Technology comline filter was used at FL1.[2] The model tried was a PTI 2194F, which sells for $10 per unit in single lots. Club groups may wish to take advantage of the 5 to 9 price break, $5.95 each. The PTI 2194F gave performance similar to that of the KVG unit.

Each brand of filter has its own characteristic impedance, so if substitutions are made it will be necessary to change the tap position on L3 to assure a proper match between Q2 and FL1. Similarly, the ohmic value of R7 will have to be changed to 2700 or 3300 ohms.

A scale-size template with parts-placement guide can be obtained for this project by sending a large self-adressed, stamped envelope and 50 cents to the ARRL. A ready-made pc board can be ordered if the builder does not wish to etch his own.[3]

[1] The filter sells for $15.95 and can be ordered from Spectrum International, Box 87, Topsfield, MA 01983.

[2] Piezo Technology Inc., Box 7877, Orlando, FL 32804.

[3] Inquire concerning availability and price by writing to Spectrum Research Laboratory, Box 5824, Tucson, AZ 85703, or D. L. McClaren, W8URX, 19721 Maplewood Ave., Cleveland, OH 44135.

Chapter 4

Transmitters for FM

IN THE AREA of transmitter construction, the amateur builder can practice his technique to a great degree. With the possible exception of antennas, building and testing a transmitter for fm use will require the least in the way of exotic equipment. It can be said that almost any circuit that can generate and amplify a radio frequency signal can be made to work as a transmitter for fm. As long as the devices that are used, either tubes or transistors, operate within their dissipation and frequency ratings, the design need not be complex. The demand for auxiliary equipment is minimal, since a simple power supply will suffice in most instances. The audio requirements are also quite relaxed since only a few volts are needed to modulate an fm transmitter to the full extent. Indeed, the builder can start with the very first stage of the transmitter and test each one as it is completed. It is not necessary to have the entire sequence of frequency multipliers and amplifiers finished to ascertain how the signal will sound. The harmonics of the oscillator and modulator can be observed with the aid of a hf or vhf receiver. Each stage that is added along the way is a stepping stone that can be completely checked out before proceeding to the next one.

TUBE OR TRANSISTOR

The choice between building a solid-state transmitter or sticking to the more familiar tube type construction must be made by the builder according to his experience or desires. Certainly there are few areas where the choice could make any great difference in the end result. One such area is in the low-power transmitter class. The lack of a dual voltage requirement for filament and plate supplies makes the transistor an ideal candidate for portable and mobile work. Most of the early stages of a transmitter can be constructed around inexpensive transistors. Recent improvements in the manufacturing process have brought the prices of power amplifier transistors within the reach of many amateurs.

Tube-type transmitters do have the advantage of being basically "cleaner" with respect to spurious output and so-called white noise. This is an important consideration for those who contemplate building equipment for use as a repeater. Another plus for the tube type of transmitter is their willingness to forgive mistakes on the part of the builder. Voltage spikes and switching transients that would "wipe out" a transistor are usually ignored by vacuum tubes.

Unlike many other modes of communication, when using fm it is not necessary to build a high-power final amplifier to extend the range of the transmitter. Thanks to the remote "final" that is in operation at the repeater site, a very modest rig will provide that "arm-chair" copy at quite a distance. In addition there is an immeasurable satisfaction to be derived from having built a rig, complex or simple, with which to talk to other amateurs.

FREQUENCY AND PHASE MODULATION

It is possible to convey intelligence by modulating any property of a carrier, including its frequency and phase. When the frequency of the carrier is varied in accordance with the variations in a modulating signal, the result is **frequency modulation (fm)**. Similarly, varying the phase of the carrier current is called **phase modulation (pm)**.

Frequency and phase modulation are not independent since the frequency cannot be varied without also varying the phase, and vice versa.

The effectiveness of fm and pm for communication purposes depends almost entirely on the receiving methods. If the receiver will respond to frequency and phase changes but is insensitive to amplitude changes, it will discriminate against most forms of noise, particularly impulse noise such as is set up by ignition systems and other sparking devices. Special methods of detection are required to accomplish this result.

Modulation methods for fm and pm are simple and require practically no audio power. There is also the advantage that, since there is no amplitude variation in the signal, interference to broadcast reception resulting from rectification of the transmitted signal in the audio circuits of the bc receiver is substantially eliminated.

Frequency Modulation

Fig. 4-1 is a representation of frequency modulation. When a modulating signal is applied, the carrier frequency is increased during one half cycle of the modulating signal and decreased during the

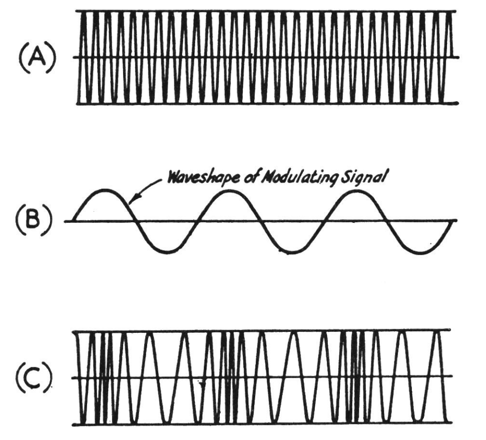


Fig. 4-1 — Graphical representation of frequency modulation. In the unmodulated carrier at A, each rf cycle occupies the same amount of time. When the modulating signal, B, is applied, the radio frequency is increased and decreased according to the amplitude and polarity of the modulating signal.

half cycle of opposite polarity. This is indicated in the drawing by the fact that the rf cycles occupy less time (higher frequency) when the modulating signal is positive, and more time (lower frequency) when the modulating signal is negative. The change in the carrier frequency (**frequency deviation**) is proportional to the instantaneous amplitude of the modulating signal, so the deviation is small when the instantaneous amplitude of the modulating signal is small, and is greatest when the modulating signal reaches its peak, either positive or negative.

As shown by the drawing, the amplitude of the signal does not change during modulation.

Phase Modulation

If the phase of the current in a circuit is changed there is an instantaneous frequency change during the time that the phase is being shifted. The amount of frequency change, or deviation, depends on how rapidly the phase shift is accomplished. It is also dependent upon the total amount of the phase shift. In a properly operating pm system the amount of phase shift is proportional to the instantaneous amplitude of the modulating signal. The rapidity of the phase shift is directly proportional to the frequency of the modulating signal. The latter represents the outstanding difference between fm and pm, since in fm the frequency deviation is proportional only to the amplitude of the modulating signal.

FM and PM Sidebands

The sidebands set up by fm and pm differ from those resulting from a-m in that they occur at integral multiples of the modulating frequency on either side of the carrier rather than, as in a-m, consisting of a single set of side frequencies for each modulating frequency. An fm or pm signal therefore inherently occupies a wider channel than a-m.

The number of "extra" sidebands that occur in fm and pm depends on the relationship between the modulating frequency and the frequency deviation. The ratio between the frequency deviation, in Hertz, and the modulating frequency, also in Hertz, is called the **modulation index**. That is,

$$\textit{Modulation index} = \frac{\textit{Carrier frequency deviation}}{\textit{Modulating frequency}}$$

Example: **The maximum frequency deviation in an fm transmitter is 3000 Hz either side of the carrier frequency. The modulation index when the modulating frequency is 1000 Hz is**

$$\text{Modulation index} = \frac{3000}{1000} = 3$$

At the same deviation with 3000-Hz modulation the index would be 1; at 100 Hz it would be 30, and so on.

In pm the modulation index is constant regardless of the modulating frequency; in fm it varies with the modulating frequency, as shown in the above example. In an fm system the ratio of the *maximum* carrier-frequency deviation to the *highest* modulating frequency used is called the **deviation ratio.**

Fig. 4-2 shows how the amplitudes of the carrier and the various sidebands vary with the modulation index. This is for single-tone modulation; the first sideband (actually a pair, one above and one below the carrier) is displaced from the carrier by an amount equal to the modulating frequency, the second is twice the modulating frequency away from the carrier, and so on. For example, if the modulating frequency is 2000 Hz and the carrier frequency is 29,500 kHz, the first sideband pair is at 29,498 kHz and 29,502 kHz, the second pair is at 29,496 kHz and 29,504 kHz, and the third at 29,494 kHz and 29,506 kHz, etc. The amplitudes of these sidebands depend on the modulation index, not on the frequency deviation.

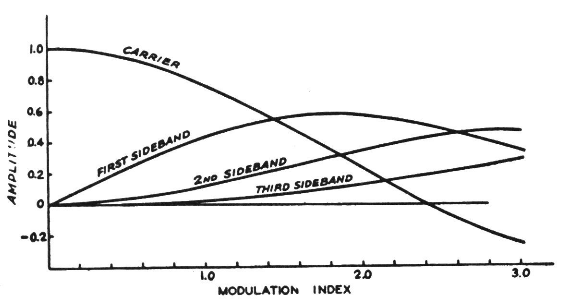


Fig. 4-2 — How the amplitude of the pairs of sidebands varies with the modulation index in an fm or pm signal. If the curves were extended for greater values of modulation index it would be seen that the carrier amplitude goes through zero at several points. The same treatment also applies to the sidebands.

Note that as shown by Fig. 4-2, the carrier strength varies with the modulation index. (In amplitude modulation the carrier strength is constant; only the sideband amplitude varies.) At a modulation index of approximately 2.4 the carrier disappears entirely. It then becomes "negative" at a higher index, meaning that its phase is reversed as compared to the phase without modulation. In fm and pm the energy that goes into the sidebands is taken from the carrier, the *total* power remaining the same regardless of the modulation index.

Since there is no change in amplitude with modulation, an fm or pm signal can be amplified without distortion by an ordinary Class C amplifier. The modulation can take place in a very low-level stage and the signal can then be amplified by either frequency multipliers or straight-through amplifiers.

If the modulated signal is passed through one or more frequency multipliers, the modulation index is multiplied by the same factor that the carrier frequency is multiplied. For example, if modulation is applied at 6 MHz and the final output is at 144 MHz, the total frequency multiplication is 24 times, so if the frequency deviation is 500 Hz at 6 MHz it will be 12,000 Hz at 144 MHz. Frequency multiplication offers a means for obtaining practically any desired amount of frequency deviation, whether or not the modulator itself is capable of giving that much deviation without distortion.

If the modulation index (with single-tone modulation) does not exceed 0.6 or 0.7, the most important extra sideband, the second, will be at least 20 dB below the unmodulated carrier level, and this should represent an effective channel width about equivalent to that of an a-m signal. In the case of speech, a somewhat higher modulation index can be used. This is because the energy distribution in a complex wave is such that the modulation index for any one frequency component is reduced as compared to the index with a sine wave having the same peak amplitude as the voice wave.

Three deviation amounts are now standard practice: 15, 5, and 2.5 kHz, which, in the current vernacular of fm users, are known as wide band, narrow band, and sliver band, respectively. The 2.5-3 kHz deviation (called nbfm by OTs) was popular for a time on the vhf bands and 10 meters after World War II. Deviation figures are given for the frequency swing in one direction. The rule-of-thumb for determination of bandwidth requirements for an fm system is:

$$2\,(\Delta F) + F_{\mathrm{Amax}}$$

where ΔF is one half of the total frequency deviation, and F_{Amax} is the maximum audio frequency (3 kHz for communications purposes). Thus, for narrow-band fm, the bandwidth equals (2) 5 + 3 or 13 kHz. Wide-band systems need a 33-kHz receiver bandwidth.

Comparison of FM and PM

Frequency modulation cannot be applied to an amplifier stage, but phase modulation can; pm is therefore readily adaptable to transmitters employing oscillators of high stability such as the crystal-controlled type. The amount of phase shift that can be obtained with good linearity is such that the maximum practicable modulation index is about 0.5. Because the phase shift is proportional to the modulating frequency, this index can be used only at the highest frequency present in the modulating signal, assuming that all frequencies will at one time or another have equal amplitudes. Taking 3000 Hz as a suitable upper limit for voice work, and setting the modulating index at 0.5 for 3000 Hz, the frequency response of the speech-amplifier system above 3000 Hz must be sharply attenuated, to prevent excess splatter. Also, if the "tinny" quality of pm as received on an fm receiver is to be avoided, the pm must be changed to fm, in which the modulation index decreases in inverse proportion to the modulating frequency. This requires shaping the speech-amplifier frequency-response curve in such a way that the output voltage is inversely proportional to frequency over most of the voice range. When this is done the maximum modulation index can only be used to some relatively low audio frequency, perhaps 300 to 400 Hz in voice transmission, and must decrease in proportion to the increase in frequency. The result is that the maximum linear frequency deviation is only one or two hundred Hz, when pm is changed to fm. To increase the deviation for narrow band requires a frequency multiplication of 8 times or more.

METHODS OF FREQUENCY MODULATION

Direct FM

A simple and satisfactory device for producing fm in the amateur transmitter is the reactance modulator. This is a vacuum tube or transistor connected to the rf tank circuit of an oscillator in such a way as to act as a variable inductance or capacitance.

Fig. 4-3A is a representative circuit. Gate 1 of the modulator MOSFET is connected across the oscillator tank circuit, C1L1, through resistor R1 and blocking capacitor C2. C3 represents the input capacitance of the modulator transistor. The resistance of R1 is made large compared to the reactance of C3, so the rf current through R1C3 will be practically in phase with the rf voltage appearing at the terminals of the tank circuit. However, the voltage across C3 will lag the current by 90 degrees. The rf current in the drain circuit of the modulator will be in phase with the grid voltage, and consequently is 90 degrees behind the current through C3, or 90 degrees behind the rf tank voltage. This lagging current is drawn through the oscillator tank, giving the same effect as though an inductance were connected across the tank. The frequency increases in proportion to the amplitude of the lagging plate current of the modulator. The audio voltage, introduced through a radio-frequency choke, varies the transconductance of the transistor and thereby varies the rf drain current.

The modulated oscillator usually is operated on a relatively low frequency, so that a high order of carrier stability can be secured. Frequency multipliers are used to raise the frequency to the final frequency desired.

A reactance modulator can be connected to a crystal oscillator as well as to the self-controlled type as shown in Fig. 4-3B. However, the resulting signal will be more phase-modulated than it is frequency-modulated, for the reason that the frequency deviation that can be secured by varying the frequency of a crystal oscillator is quite small.

The sensitivity of the modulator (frequency change per unit change in grid voltage) depends on the transconductance of the modulator transistor. It increases when R1 is made smaller in comparison with C3. It also increases with an increase in L/C ratio in the oscillator tank circuit. However, for highest carrier stability it is desirable to use the largest tank capacitance that will permit the desired deviation to be secured while keeping within the limits of linear operation.

A change in *any* of the voltages on the modulator transistor will cause a change in rf drain current, and consequently a frequency change. Therefore it is advisable to use a regulated power supply for both modulator and oscillator.

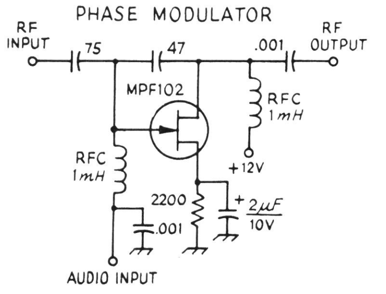


Fig. 4-4 — The phase-shifter type of phase modulator.

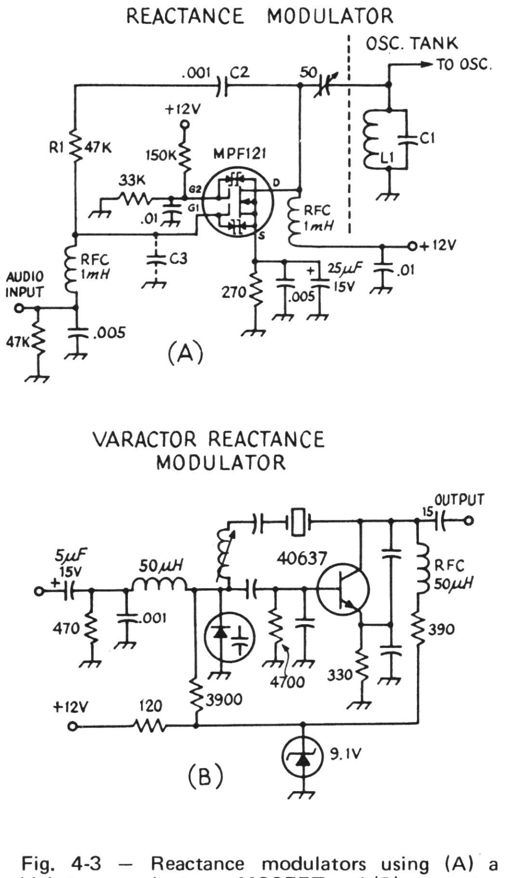


Fig. 4-3 — Reactance modulators using (A) a high-transconductance MOSFET and (B) a varactor diode.

Indirect FM

The same type of reactance-tube circuit that is used to vary the tuning of the oscillator tank in fm can be used to vary the tuning of an amplifier tank and thus vary the phase of the tank current for pm. Hence the modulator circuit of Fig. 4-3A or 4-4 can be used for pm if the reactance transistor or tube works on an amplifier tank instead of directly on a self-controlled oscillator. If audio shaping is used in the speech amplifier, as described above, fm instead of pm will be generated by the phase modulator.

The phase shift that occurs when a circuit is detuned from resonance depends on the amount of detuning and the *Q* of the circuit. The higher the *Q*, the smaller the amount of detuning needed to secure a given number of degrees of phase shift. If the *Q* is at least 10, the relationship between phase shift and detuning (in kHz either side of the resonant frequency) will be substantially linear over a phase-shift range of about 25 degrees. From the standpoint of modulator sensitivity, the *Q* of the tuned circuit on which the modulator operates should be as high as possible. On the other hand, the effective *Q* of the circuit will not be very high if the amplifier is delivering power to a load since the load resistance reduces the *Q*. There must therefore be a compromise between modulator sensitivity and rf power output from the modulated amplifier. An optimum figure for *Q* appears to be about 20; this allows reasonable loading of the modulated amplifier and the necessary tuning variation can be secured from a reactance modulator without difficulty. It is advisable to modulate at a low power level.

Reactance modulation of an amplifier stage usually results in simultaneous amplitude modulation because the modulated stage is detuned from resonance as the phase is shifted. This must be eliminated by feeding the modulated signal

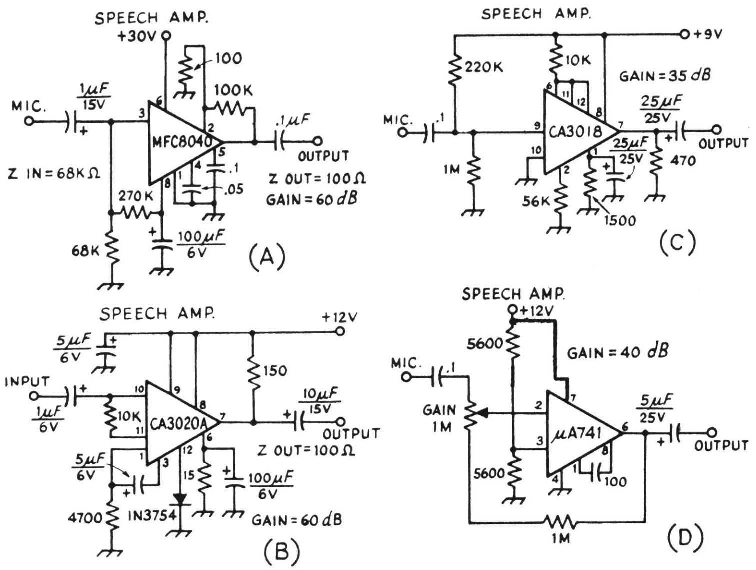


Fig. 4-5 – Some examples of speech amplifiers using integrated circuits.

through an amplitude limiter or one or more "saturating" stages – that is, amplifiers that are operated Class C and driven hard enough so that variations in the amplitude of the input excitation produce no appreciable variations in the output amplitude.

For the same type of reactance modulator, the speech-amplifier gain required is the same for pm as for fm. However, as pointed out earlier, the fact that the actual frequency deviation increases with the modulating audio frequency in pm makes it necessary to cut off the frequencies above about 3000 Hz before modulation takes place. If this is not done, unnecessary sidebands will be generated at frequencies considerably away from the carrier.

SPEECH PROCESSING FOR FM

The speech amplifier preceding the modulator follows ordinary design, except that no power is taken from it and the af voltage required by the modulator grid usually is small – not more than 10 or 15 volts, even with large modulator tubes, and only a volt or two for transistors. Because of these modest requirements, only a few speech stages are needed; a two-stage amplifier consisting of two bipolar transistors, both resistance-coupled, will more than suffice for crystal ceramic or hi-*Z* dynamic microphones. Integrated circuits can be used to make speech amplifiers as shown in Fig. 4-5.

Several forms of speech processing produce worthwhile improvements in fm system performance. It is desirable to limit the peak amplitude of the audio signal applied to an fm or pm modulator, so that the deviation of the fm transmitter will not exceed a preset value. This peak limiting is usually accomplished with a simple audio clipper which is placed between the speech amplifier and modulator. The clipping process produces high-order harmonics which, if allowed to pass through to the modulator stage, would create unwanted sidebands. Therefore, an audio low-pass filter with a cut-off frequency between 2.5 and 3 kHz is needed at the output of the clipper. Excess clipping can cause severe distortion of the voice signal. An audio processor consisting of a clipper and filter is given in Fig. 4-6.

To reduce the amount of noise in some fm communications systems, an audio shaping net-

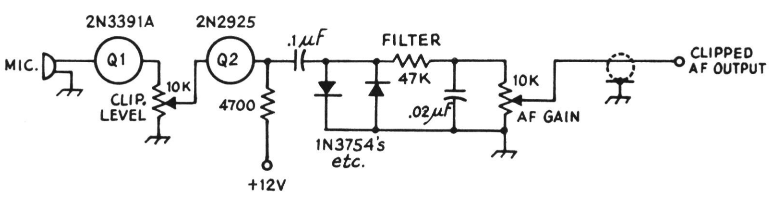


Fig. 4-6 – A speech clipper with an *RC* filter to eliminate high frequency components generated by the clipping action.

work called **pre-emphasis** is added at the transmitter to proportionally attenuate the lower audio frequencies, giving an even spread to the energy in the audio band. A circuit for this purpose is shown in Fig. 4-7. This results in an fm signal of nearly constant energy distribution. The reverse is done at the receiver, called **de-emphasis**, to restore the audio to its original relative proportions. Sample circuits are shown in Chapter 3.

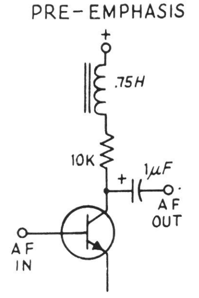


Fig. 4-7 — A simple form of pre-emphasis that can be used with an fm modulator.

FM EXCITERS

Fm exciters and transmitters take two general forms. One, shown in Fig. 4-8A, consists of a reactance modulator which shifts the frequency of an oscillator to generate an fm signal directly. Successive multiplier stages provide output on the desired frequency, which is amplified by a PA stage. This system has a disadvantage in that, if the oscillator is free running, it is difficult to achieve sufficient stability for vhf use. If a crystal-controlled oscillator is employed, unless the amount that the crystal frequency is changed is kept small, it is difficult to achieve equal amounts of frequency swing.

The indirect method of generating fm shown in Fig. 4-8B is currently popular. Shaped audio is applied to a phase modulator to generate fm. As the amount of deviation produced is very small, a large number of multiplier stages is necessary to achieve wide-band deviation at the operating frequency. In general, the system shown at A will require a less complex circuit than that at B, but the indirect method (B) often produces superior results.

OSCILLATORS AND STABILITY

One basic requirement for oscillators that are to be used in fm equipment is that they should be stable enough to remain on channel over long periods of time. In a mobile rig, the temperature extremes in many parts of the country can impose some severe operating conditions on the equipment. There are many schemes to overcome the problem of frequency drift caused by temperature changes. A popular circuit in tube type equipment uses ovens that enclose the crystal, with a built-in thermostat to keep the temperature near some pre-set value. Other equipment uses a "warmer" that becomes operative only when the surrounding air temperature drops to a pre-determined value. A warmer has the advantage of not imposing any additional drain on the automotive electrical system except during the colder seasons of the year, and for that reason is used in solid-state equipment. Some manufacturers depend on the inherent stability of the crystal to maintain its frequency over a wide temperature swing. The crystals that will do this are more accurately calibrated and special care is taken in their manufacture. Their cost is proportional to their accuracy.

The prospective builder must take into account the type of service and the temperature extremes his equipment will most likely encounter. A base station or repeater that is to be located in a temperature controlled environment will not likely require ovens or heaters to keep the crystals on frequency. A mobile rig should have some provision for temperature control. It can be as simple as an extra piece of heater air duct placed so as to direct a flow of warm air over the equipment in winter-time, or cool air in the summer.

No matter what system is used to keep the temperature of the crystal nearly constant, the use of high accuracy crystals is recommended wherever possible. These crystals, in addition to their better calibration, usually have more activity and in some circuits will provide more drive to the following stages than will a bargain-type crystal.

Base or repeater stations, in particular, should maintain a high order of frequency stability. Portable and hand-held equipment with little or no reserve power that can be used for ovens, must depend on good crystals and well-designed circuits to remain on channel.

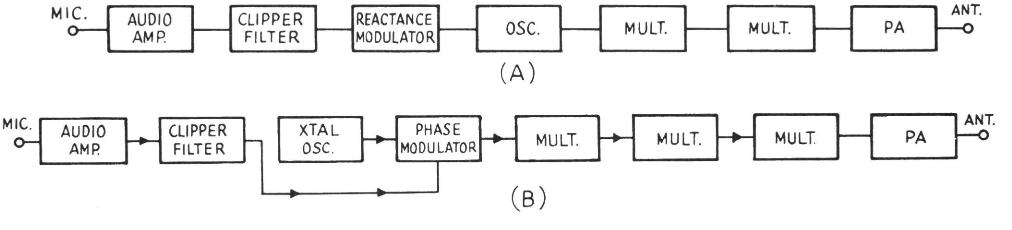


Fig. 4-8 — Block diagrams of typical fm exciters.

FREQUENCY MULTIPLIERS

Single-tube Multiplier

Output at a multiple of the frequency at which it is being driven may be obtained from an amplifier stage if the output circuit is tuned to a harmonic of the exciting frequency instead of to the fundamental. Thus, when the frequency at the grid is 6 MHz, output at 12 MHz, 18 MHz, and 24 MHz, etc., may be obtained by tuning the plate tank circuit to one of these frequencies. The circuit otherwise remains the same as that for a straight amplifier, although some of the values and operating conditions may require change for maximum multiplier efficiency.

A practical limit to efficiency and output within normal tube ratings is reached when the multiplier is operated at maximum permissible plate voltage and maximum permissible grid current. The plate current should be reduced as necessary to limit the dissipation to the rated value by increasing the bias and decreasing the loading.

Multiplications of four or five sometimes are used to reach the bands above 28 MHz from a lower-frequency crystal, but in the majority of lower-frequency transmitters, multiplication in a single stage is limited to a factor of two or three. Screen-grid tubes make the best multipliers because their high power-sensitivity makes them easier to drive properly than triodes.

Since the input and output circuits are not tuned close to the same frequency, neutralization usually will not be required. Instances may be encountered with tubes of high transconductance, however, when a doubler will oscillate in tuned-plate, tuned-grid fashion.

Frequency multipliers using tubes are operated Class C, with the bias and drive levels adjusted for plate-current conduction of less than 180 degrees. For maximum efficiency, a doubler requires a plate-conduction angle of about 110 degrees, while a tripler needs 100 degrees, a quadrupler 80 degrees, and a quintupler 65 degrees. For higher orders of multiplication increased bias and more drive are needed.

A typical circuit using a 6CL6 pentode tube is shown in Fig. 4-9A. The input circuit is tuned to the driving frequency while the output tank is set for the desired harmonic.

Push-Push Multipliers

A two-tube circuit which works well at even harmonics, but not at the fundamental or odd harmonics, is known as the **push-push** circuit. The grids are connected in push-pull while the plates are connected in parallel. The efficiency of a doubler using this circuit approaches that of a straight amplifier.

Push-Pull Multiplier

A single- or parallel-tube multiplier will deliver output at either even or odd multiples of the exciting frequency. A push-pull stage does not work as a doubler or quadrupler but it will work as a tripler.

Transistor Multipliers

A transistor develops harmonic energy with good efficiency, often causing harmonic-output problems in straight-through amplifiers. Two harmonic-generating modes are present, parametric multiplication and multiplication caused by the nonlinear characteristic presented by the base-collector junction. Transistors may be used in single-ended, push-pull, or push-push circuits. A typical push-pull tripler is shown in Fig. 4-9B. A small amount of forward bias has been added to the bases of the 2N2102s to reduce the amount of drive required. If a high level of drive is available, the bias circuit may be omitted.

A number of integrated circuits can be employed as frequency multipliers. The circuit at C

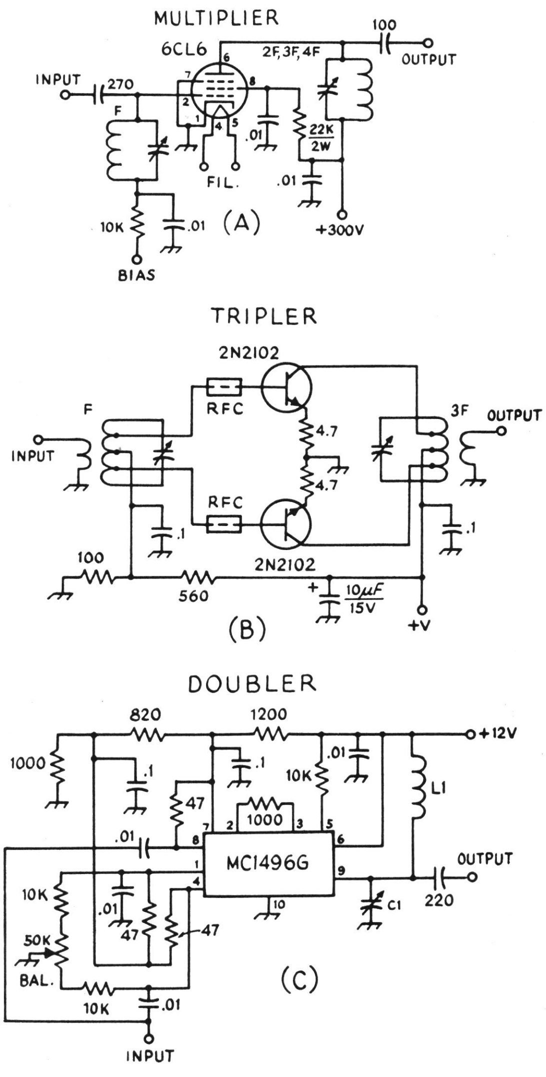


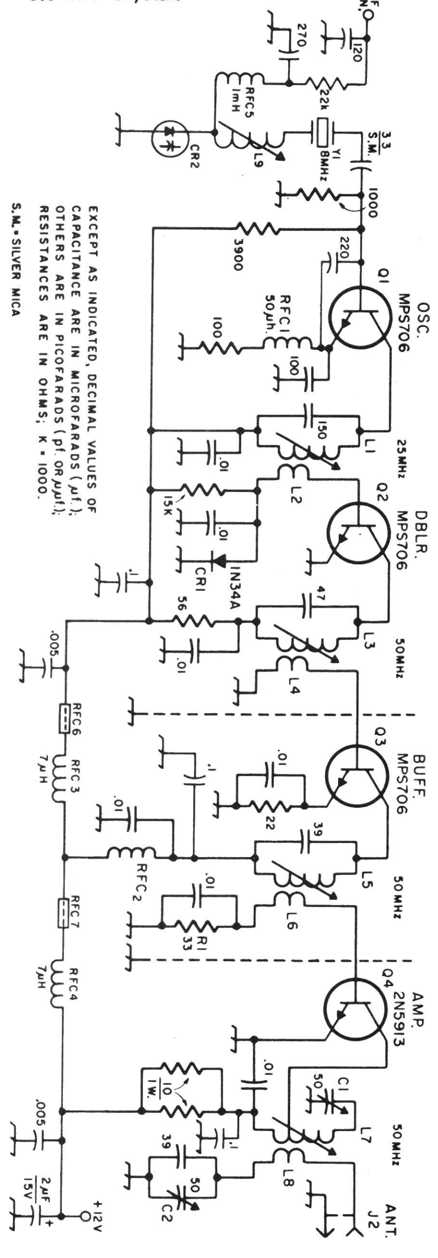
Fig. 4-9 — Frequency multiplier circuits.

uses a Motorola MC1496G (or the Signetics S5596, or Fairchild μA796) as a doubler. The input signal is balanced out in the IC, so only the desired second harmonic of the input frequency appears at the output. With suitable bypass capacitors this doubler can be used from audio to vhf.

A SOLID-STATE 50-MHz FM TRANSMITTER

Fig. 4-10 — Schematic of the four-transistor 6-meter strip. Decimal-value capacitors are 50-volt disk ceramics. Resistors are 1/2-watt composition unless noted otherwise.

C1, C2 — 8 to 50-pF trimmer.
CR2 — Motorola MV839.
J2 — Phono jack.
L1 — 5 turns No. 24 enam. on 1/4-inch dia slug-tuned ceramic form. Space wind coil one wire diameter between each turn (Miller 4500-2 form).
L2 — 1 turn No. 22 insulated wire over B+ end of L1.
L3, L5 — 5 turns No. 24 enam. space wound to occupy 3/8 inch on same type form as L1.
L4, L6 — 1-1/2 turns insulated No. 22 wire over cold ends of L3 and L5 respectively.
L7 — 6 turns No. 20 tinned solid wire, 1/2-inch dia 1 inch long. Tap 1-1/4 turns from bottom end.
L8 — 2 turns No. 22 insulated wire, 1/2-inch dia. Insert in B+ end of L7.
L9 — 2.4- to 4.1-μH slug-tuned inductor (J. W. Miller 23A336RPC).
R1 — See text.
RFC1 — 50-μH rf choke.
RFC2-RFC4, incl. — 7-μH rf choke (48 inches No. 24 enam. scramble-wound on 100,000-ohm, 1-watt resistor).
RFC5 — Subminiature rf choke.
RFC6, RFC7 — Ferrite bead.
Y1 — 8.3-MHz crystal.



The four-transistor unit shown in Fig. 4-10 can be used as an exciter, or as a 1-watt transmitter. It operates from 12 volts dc, and can be modulated by the audio clipper/filter shown in Fig. 4-25.

The circuit is built on a small Minibox. Transistor sockets are used to provide for point-to-point wiring. Layout should follow the same pattern used with vhf vacuum-tube transmitters – short, direct connections.

Checkout should be done one stage at a time, starting with the oscillator. The remainder of the transistors should be removed from their sockets and a No. 49 lamp connected across L2. A faint glow should show when L1 is peaked at 25 MHz. Check each stage in the same manner, terminating the output link of each stage with the dummy lamp. A No. 47 lamp will be needed at L8 because of the higher power at the transmitter output. Full brilliance should be noted on the No. 47 lamp if all stages are working properly. Finally, tune each stage for maximum transmitter output. Power output from this transmitter is approximately 1 watt.

Once the transmitter has been adjusted for maximum output, the modulator should be connected. The check-out procedure for the modulator section is contained in the description of the 1-watt, 220-MHz transmitter which appears later in this chapter. Once the modulator is functioning properly, adjust R23 of the audio board for the desired deviation. The Bessel-function method or a deviation meter (both described in Chapter 10) can be used to set the amount of frequency swing.

A SOLID-STATE FM TRANSMITTER FOR 146 MHz

In an effort to shrink the dimensions of the solid-state fm transmitter treated earlier in *QST*, and in the 1972 *ARRL Handbook*, it became necessary to eliminate one stage of the rf section, and to reduce the size of the speech amplifier and clipper. The product of that effort is shown schematically in Fig. 4-11.

A slightly different electrical approach was taken, wherein the oscillator was called upon to deliver a fair amount of power. The increased output from Q1 permitted the deletion of a driver stage ahead of the PA. The change made it necessary to pay particular attention to the design of all networks between stages, providing adequate selectivity to assure suppression of unwanted output frequencies. The criterion was met, as evidenced by a spectral display of the output energy. The MK-II version is as clean as was the MK-I model.

A logical approach to reducing the area occupied by the speech amplifier and clipper was the employment of a transistor-array IC as opposed to the use of discrete components. The latter technique was used in the MK-I example.

Circuit Highlights

Generally, the circuit of Fig. 4-11 follows the classic sonobuoy format given in RCA's *Power Circuits, DC to Microwaves.*[1] Some of the circuit changes made are radical; others are subtle. The boiled-down version is based on amateur-band performance criteria and the more commonly available supply voltage of 12. Emphasis has been placed on good frequency stability, narrow-band deviation (up to 6 kHz), and relative freedom from spurious output.

Low-cost transistors are used at Q1 and Q2. A ballasted transistor (mismatch protected) is used at Q3 to prevent burnout resulting from temporary open- or short-circuit conditions in the antenna system. The current OEM price (single lot) for the 2N5913 is $3.63. Over-the-counter prices will be slightly higher, but it is recommended that builder use the '5913 if he wishes to have the circuit perform as specified here. Substitutes for any of the devices used in the circuit should be employed only by those who are experienced in semiconductor work. The wrong choice can lead to dismal results with the circuit – instability, low output, or destruction of one or more of the transistors.

Ferrite beads are used generously in the circuit, for decoupling of the dc bus and as rf chokes.[2] The beads provide low-*Q* impedances and are superior to solenoid-wound inductors in preventing circuit instability caused by tuned-base-tuned-collector conditions. A further aid to stability is provided through the use of high and low values of capacitance (combined) in various parts of the circuit. This standard technique helps to assure stability at hf and vhf, and is necessary because of the high f_T of the transistors used.[3]

Transistor sockets should not be used at Q1, Q2 or Q3. The additional lead lengths resulting from the use of sockets could lead to instability problems. Those wishing to use a socket at U1 may do so by redesigning the pc board to allow a socket to be installed (bringing the twelve holes for the IC closer together). Alternatively, one might employ an IC socket which has fairly long lugs, bending the lugs outward to mate with the holes in the pc-board.

Speech Amplifier

U1 consists of four bipolar transistors on a common substrate. Two of the transistors are connected for use as a Darlington pair. The remaining two are separate from one another. In the circuit of Fig. 4-11 the Darlington pair serves as a preamplifier for a high-impedance crystal, ceramic, or dynamic microphone. One of the separate transistors is used as a diode in the clipper circuit (an outboard silicon diode is used to clip the opposite side of the af sine wave), and the remaining transistor amplifies the clipped audio after it is filtered by an *R-C* network. Deviation is set by adjustment of a pc-board potentiometer, R17.

The processed audio is fed to CR1, the varactor diode modulator. Some reverse bias is used on CR1 to assure greater linearity of modulation (3 volts dc taken from the junction of R3 and R4). As the audio voltage is impressed across CR1, the junction capacitance of the diode shifts above the steady-state value which exists when no af voltage is present. The change in capacitance shifts the crystal frequency above and below its nominal value to provide fm.

Construction

There are no special instructions provided the builder follows the template pattern offered.[2] However, it is worth mentioning that the *QST* model was built on glass-epoxy circuit board. Those attempting to use phenolic or other types of pc board may encounter difficulty in obtaining proper circuit performance. The dielectric properties of the various board materials are different, thereby causing different values of capacitance to exist between pc-board foil strips. The condition can cause instability, unwanted coupling, and tuned circuits that will not hit resonance. Some builders of the MK-I transmitter learned this the hard way!

Transistors Q2 and Q3 require fairly hefty heat sinks if good efficiency and longevity of the devices is to be realized. Homemade sinks are shown in the photo. Each consists of a piece of 1/16-inch thick aluminum (brass or copper is ok) formed over a drill bit slightly smaller in diameter than a TO-5 transistor case. The aluminum can be crimped in a bench vise until it fits snugly around the drill body. Silicone grease should be used to coat the transistor bodies prior to installation of

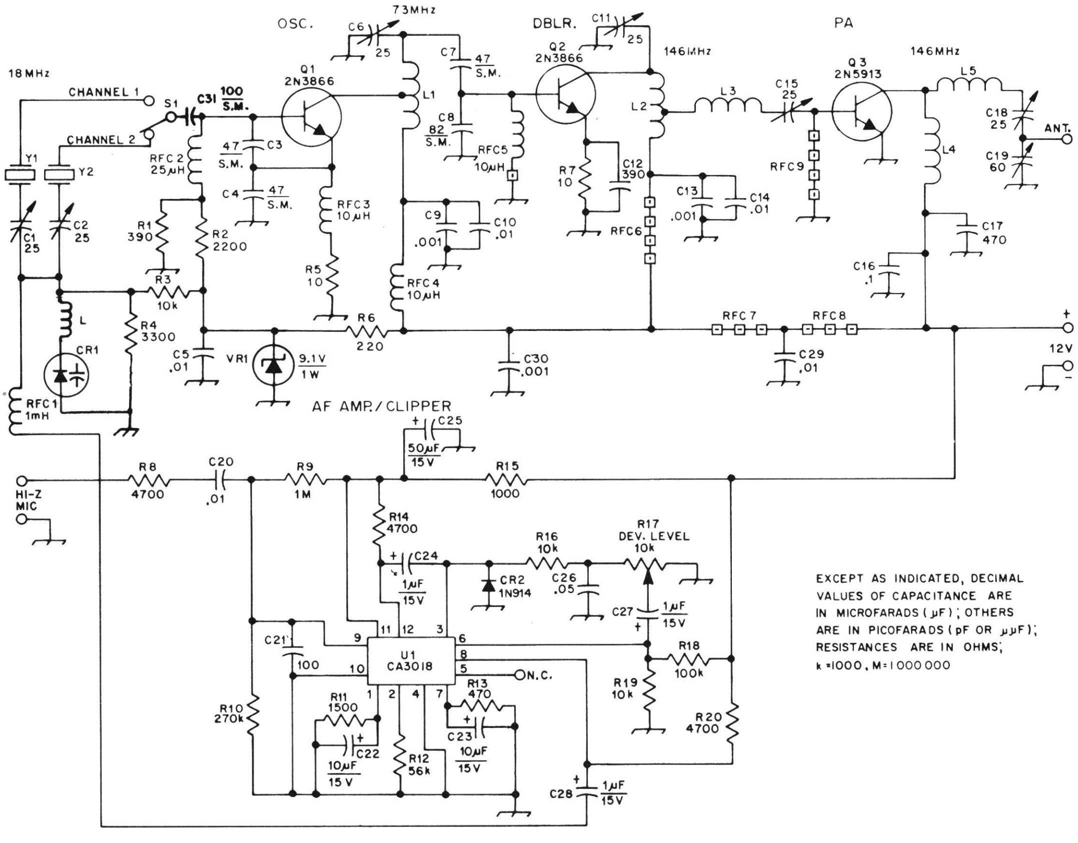


Fig. 4-11 – Schematic diagram of the 2-meter fm transmitter. Fixed-value capacitors are disk ceramic unless otherwise marked. Polarized capacitors are electrolytic. Fixed-value resistors are 1/2-watt composition. Numbered components not appearing in parts list are so numbered for pc-board layout purposes only. Use crown type heat sink on Q1, larger style on Q2 and Q3.

C1, C2, C6, C11, C15, C18 – 7- to 25-pF miniature ceramic trimmer (Erie 538-002B-7-25 or equiv. Avail. new from Newark Electronics. Avail. surplus from Reliance Merchandising Co., Phila., PA).
C19 – 15- to 60-pF miniature ceramic trimmer (Erie 538-002F-15-60 or equiv.).
C31 – 100-pF silver mica.
CR1 – Varicap diode MV839.
CR2 – High-speed silicon switching diode.
L – 1 to 2 μH inductor. 20 turns No. 30 enam. close-wound on 100,000 ohm, 1-watt resistor.
L1 – 5 turns No. 16 tinned bus wire, 1/4-inch ID X 5/8 inch long. Tap at 1-1/2 turns from 12-volt end.
L2 – 3 turns No. 16 tinned bus wire, 1/4-inch ID X 3/8 inch long. Tap at 1/2 turn from C13 end.
L3 – 4 turns No. 22 enam. wire, close-wound, 1/4-inch ID.
L4 – 25 turns No. 28 enam. wire, close-wound on body of 100,000-ohm, 1-watt resistor. Use resistor pigtails as anchor points for ends of winding.
L5 – 5 turns No. 16 tinned bus wire, 5/16 ID X 1/2 inch long.
Q1-Q3, incl. – RCA transistor.
R17 – 10,000-ohm pc-board carbon control, linear taper (Mallory MTC 14L1 or equiv.).
RFC1 – 1-mH miniature rf choke (Millen J300-25).
RFC3, RFC4 – 10-μH miniature rf choke (Millen J300-10).
RFC5 – 10-μH miniature rf choke (Millen J300-10) with one Amidon ferrite bead over ground-end pigtail.
RFC6, RFC9 – 4 Amidon ferrite beads on 1/2-inch length of No. 24 wire (Amidon Associates, 12033 Otsego St., No. Hollywood, CA 91607).
RFC7, RFC8 – Same as RFC6 but with three beads on 3/8-inch length of wire.
S1 – Spdt slide or rotary switch.
U1 – RCA integrated circuit.
VR1 – 9.1-volt, 1-watt Zener diode.
Y1, Y2 – 18-MHz crystal (International Crystal Co. ground for 20-pF load capacitance. HC-25/U holder. Use International FM-2 pc-board crystal socket). High accuracy .002 percent temperature-tolerance crystal recommended.

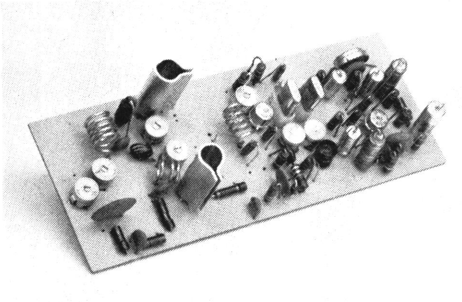


Fig. 4-12 – Top side of the fm transmitter. This view shows the prototype version. Some of the components indicated in Fig. 4-13 are located on the foil side of this model. The template includes a few changes in layout which permit all parts to be mounted on the non-foil side of the board. The two models are otherwise identical. The large metal cylinders at the other end of the board are the homemade heat sinks for Q2 and Q3. The audio section of the circuit is assembled on the opposite end of the board. Smaller sinks (3/4 inch high) can be used if the builder wishes to reduce the vertical profile of the assembly.

the heat sinks. The height of the sinks is 1 inch. The ID is approximately 1/4 inch.

Lead lengths of the wires going from the pc board to S1 should be kept short – preferably less than 1-1/2 inches long. Coaxial cable (50-ohm impedance) should be used between the antenna terminals on the pc board and the antenna connector. The shield braid must be grounded at each end of the cable. Similarly, shielded cable should be employed between the microphone jack and the audio-input terminals on the pc board.

Checkout and Use

Initial checkout should be undertaken at reduced supply voltage. Apply a voltage of between 6 and 12, making certain that a dummy load of approximately 50 ohms is connected to the output of Q3. A 56-ohm 2-watt resistor or a No. 47 pilot lamp will suffice. Using a wavemeter tuned to 73 MHz, adjust the collector tank of Q1 for a peak reading on the wavemeter. Next, set the wavemeter for operation at 146 MHz and adjust the collector tuned circuit of Q2 for maximum meter indication. The tank circuit of Q3 should be adjusted for maximum power output as observed on an rf wattmeter or Monimatch-type SWR indicator. A rough check can be made by using a No. 47 lamp as a load, adjusting for maximum bulb brilliancy. The next step is to raise the supply voltage to 12 and repeat the tweaking procedure outlined above. If all stages are functioning normally, a No. 47 lamp should illuminate to slightly more than normal brilliance. Power output into a 50-ohm load should be between 1-1/2 and 2 watts. Current drain will be between 200 and 250 mA, speech amplifier included.

Adjustment of the transmitter frequency and deviation can best be done while using a vhf frequency counter and deviation meter. Alternatively, one can put the transmitter in service and ask one of the other fm operators in the area to observe his receiver's discriminator meter while you adjust your crystal trimmer for a zero reading. Deviation can be set reasonably close to the desired

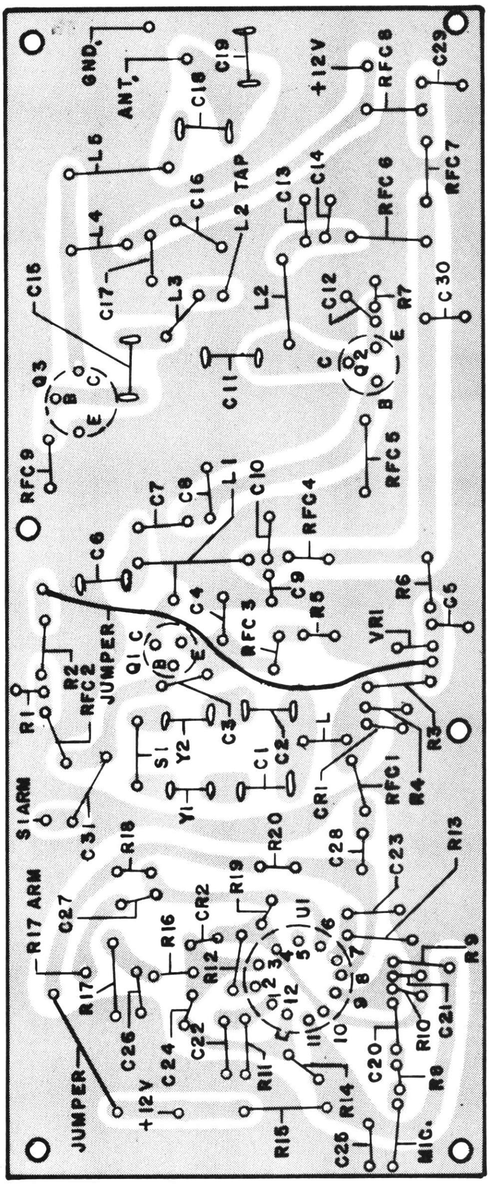


Fig. 4-13 – Template and parts layout for the transmitter, drawn to scale. Foil-side view.

amount by comparing your modulation against that of other local stations, having a third operator report the comparisons.

This transmitter is well suited as a companion unit to the fm receiver described in Chapter 3, and in *QST*.[4] The two units can be packaged to form a trans-receiver for portable, mobile, or fixed-state use. The transmitter can be used to drive a high-power solid-state 2-meter amplifier, described later in this chapter, if one wishes to put on a pair of "boots."[5]

A scale-size template is available from ARRL for 50 cents and a large s.a.s.e. Ready-made pc boards may be available from Spectrum Research Laboratory.[6]

References

[1]Recommended for amateur libraries. Order from local radio store, or write RCA Electronic Components, Harrison, NJ 07029. Price: $2.

[2]See parts list for ordering information.

[3]The higher the f_T (upper-frequency rating) of a transistor, the greater will be its gain capability at lower frequencies, thus giving rise to unwanted hf or lf oscillations.

[4]DeMaw, "A Single-Conversion 2-Meter FM Receiver, *QST*, August 1972.

[5]Hejhall, "Some 2-Meter Solid-State RF Power-Amplifier Circuits," *QST*, May 1972, p. 40.

[6]Write: Spectrum Research Laboratory, Box 5824, Tucson, AZ 85703.

SOLID-STATE POWER AMPLIFIERS FOR 144 MHZ

The majority of the commercially made 2-meter fm transceivers available today have rf power-output levels of 1 to 15 watts. There are many occasions when it is desirable to have a little more output to be able to work over greater distances. Here is a 50-watt output amplifier for the 2-meter band which will add more "muscle" to a signal. The amplifier uses a single transistor and operates directly from a 13.6-volt vehicular electrical system. The amplifier was described by K7QWR in *QST* for May, 1972.

Circuit Description

The amplifier circuit shown in Fig. 4-15 utilizes a single 2N6084 transistor operated in a Class-C, zero-bias configuration. This mode of operation has the advantages of high collector efficiency at full output and zero dc current drain when no rf driving signal is applied. The reader should note that zero-bias operation yields an amplifier that is not a "linear." It is designed for fm (or cw) operation only, and would produce objectionable distortion and splatter if used to amplify either a-m or ssb signals.

The input- and output-tuned circuits are designed to match the impedances of the transistor to a 50-ohm driving source and to a 50-ohm antenna system, respectively. Since both the input and output impedances of the transistor are extremely low (in the 1- to 5-ohm region), the matching networks employed are somewhat different than those used with tubes. The networks chosen for the amplifier of Fig. 4-15 are optimized for low-impedance matching, and they perform their tasks efficiently.

The elaborate decoupling network used in the collector dc feed is for the purpose of assuring amplifier stability with a wide variety of loads and tuning conditions. Fig. 4-17 shows a power-output-versus-power-input plot for the amplifier. The 2N6084 transistor is conservatively rated at 40 watts output (approximately 60 watts dc input). The amplifier can readily be driven to power output levels considerably higher than 40 watts, but it is recommended that it be kept "throttled back" to not more than 50 watts output. If your transmitter or transceiver has greater than 10 watts output, an attenuator should be used at the amplifier input to keep the output from the amplifier below 50 watts.

The discussion of power levels thus far has focused on rf power *output*. This is the practice in commercial service and the custom has come into common usage for 2-meter fm rigs, probably because of the large number of converted commercial rigs in use. When delivering 40 watts rf output, this amplifier has a dc power input of 63

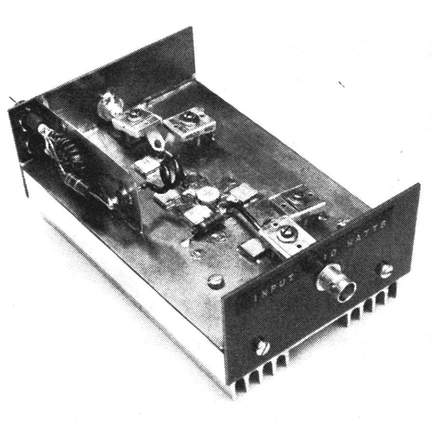


Fig. 4-14 — An end view of the breadboard version of the 50-watt 2-meter amplifier. The input circuit is at the lower right, and the output network is at the upper left.

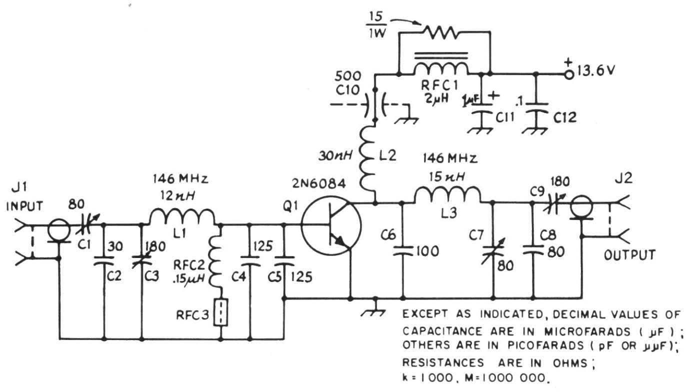


Fig. 4-15 – Diagram of the amplifier which provides 40 to 50 watts output. Capacitors are mica unless otherwise noted. The resistor is a composition type. The heat sink is a Thermalloy 6169B (Allied Electronics No. 957-2890).

C1, C7 – 5- to 80-pF compression trimmer (Alco 462 or equiv.).
C2, C4-C6, incl., C8 – Mica button (Underwood J-101).
C3, C9 – 9- to 180-pF compression trimmer (Arco 463 or equiv.).
C10 – Feedthrough type.
C11 – Tantalum.
C12 – Ceramic disk.
J1, J2 – Coaxial connector, panel mount.
L1 – 12 nH, No. 10 tinned wire, 1-1/4-inch long straight conductor.
L2 – 30 nH, 1-3/4 turns, No. 10 tinned wire, 3/8 inch ID, 3/4 inch long.
L3 – 15 nH, No. 14 tinned wire, 3/4-inch long straight conductor.
Q1 – Motorola silicon power transistor.
RFC1 – 17 turns, No. 16 enam. wire wound on Amidon T-80-2 toroid core.
RFC2 – Molded rf choke (J. W. Miller 9250-15).
RFC3 – Ferrite bead (Ferroxcube 56-590-65/3B or equiv.).

watts – the number which the FCC requires to be entered in the log.

Construction Details

Construction of the amplifier is straightforward. The usual precautions that must be observed when building a solid-state final amplifier are followed. These precautions include proper mechanical mounting of the transistor, emitter grounding, heat sinking, and decoupling of the supply-voltage leads. Most of the components used are conventional items which are readily available, with two exceptions. The fixed mica capacitors, Underwood type J-101, are a special mica unit designed for high-frequency applications. The core for RFC1 and the rf bead used for RFC3 are available only from one source. (See Appendix A)

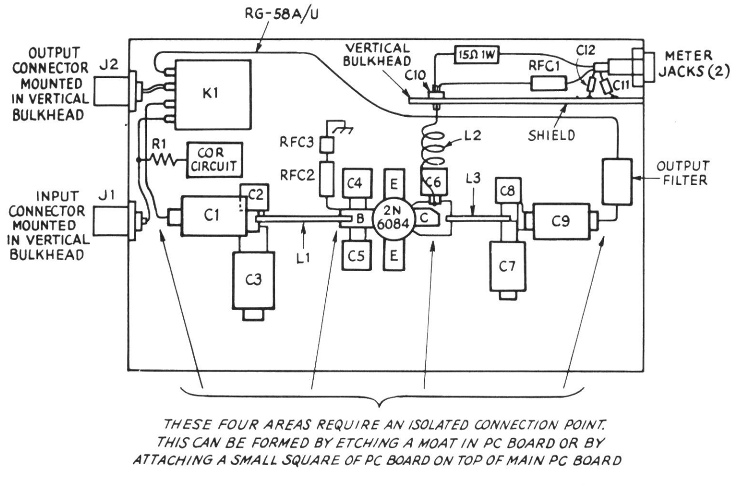


Fig. 4-16 – Parts layout diagram for the 50-watt amplifier (not to scale). A 4 X 6-inch pc board is used as the base.

The amplifier is constructed on a pc board which is bolted to a heat sink. A few islands can be etched on the board for tie points, at the builder's discretion; a complex foil pattern is not required. In the amplifier shown in the photo, islands were etched only for input and output tie points. Circuit-board islands may also be etched for the transistor base and collector leads. However, an interesting alternative method was used in this particular amplifier. The base and collector islands were formed by attaching small pieces of pc board to the top of the main board. This procedure added a few tenths of a pF of capacitance at the connection points, so if the islands are etched directly on the main board the value of C6 should be increased slightly. (The values of C4 and C5 are not critical.)

A word about the care of a stud-mount rf power transistor: Two of the most important mounting precautions are (1) to assure that there is no upward pressure (in the direction of the ceramic cap) applied to the leads, and (2) that the nut on the mounting stud is not overtightened. The way to accomplish item 1 is to install the nut *first* and solder the leads to the circuit later. For item 2, the recommended stud torque is 6 inch-pounds. For those who don't have a torque wrench in the shack, remember that it is better to under tighten than to over tighten the mounting nut.

The transistor stud is mounted through a hole drilled in the heat sink. A thermal compound, such as Dow Corning 340 heat-sink grease, should be used to decrease the thermal resistance from transistor case to heat sink.

Series impedance in the emitter circuit can drastically reduce the gain of the amplifier. Both transistor emitter leads should be grounded as close to the transistor body as is practical.

The wiring for the dc voltage feeder to the collector should have extremely low dc resistance. Even a drop of one volt can significantly reduce the power output of the amplifier. A good goal is less than 0.5 volt drop from the car battery to the transistor collector. With operating currents of several amperes, a total dc resistance of only a fraction of an ohm is needed. A standard commercially made heat sink is used for the 50-watt amplifier, and it is adequate for amateur communications. Forced-air cooling across the heat sink should be used for any application requiring long-term key-down operation at 40 watts or more of output.

Tune-up Procedure

There are no convenient dc indicators for tuning the output tank of a transistor final, such as the classic tune-for-a-plate-current-dip instruction popular with the tube circuits. Generally, the best way to tune a transistor final is for maximum rf power output. If this approach results in exceeding the power ratings of the transistor, then the power output should be reduced by reducing the drive-level, not by detuning the final. In the case of an outboard PA stage, such as described here, both the input and output networks can be tuned for maximum rf output, if the driving source has an output impedance of approximately 50 ohms. However, a better procedure consists of tuning the output tank circuit for maximum rf output and tuning the input circuit for minimum SWR as measured between the exciter and the final amplifier. This tune-up procedure has the added advantage of assuring that the amplifier presents a 50-ohm load to the exciter. A dc ammeter to check collector current is a useful tune-up aid.

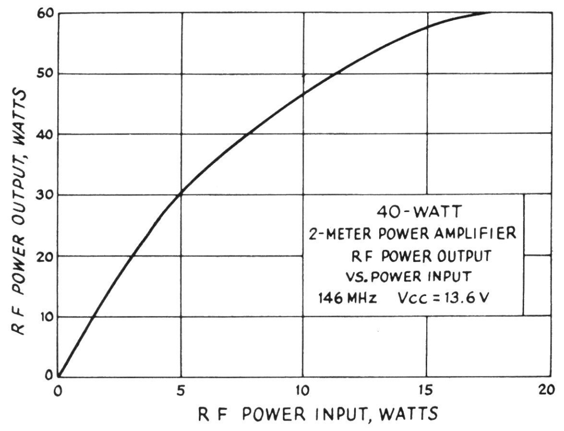


Fig. 4-17 — Output power obtained from the amplifier shown in Fig. 4-15.

A Monimatch-type SWR bridge is adequate for the job of tuning for maximum output. Also, the wattmeter described by W1SL in *QST* for April, 1972, and in Chapter 10, would be an excellent choice. The best tuning procedure is to monitor simultaneously both output power (absolute or relative) and input SWR.

With dc voltage applied and no rf drive, no collector current should flow. A low level of rf drive can be applied – perhaps 25 percent or less of the rated 10 watts maximum drive – and the input network tuned for maximum indicated collector current. The networks may not tune to resonance at this low drive level, but there should be at least an indication of proper operation by smooth tuning and lack of any erratic behavior in the collector-current reading. Drive should be increased, while retuning, until the rated 7-10 watts input and 40- to 50-watts output are obtained.

There is danger of low-frequency oscillations with most transistor amplifiers. A scope of 5-MHz or more bandwidth connected to the dc feeder at point A makes an excellent indicator of any low-frequency oscillation. This amplifier was completely stable over a wide range of power levels and tuning conditions, but one should always be looking for signs of instability when adjusting a solid-state stage. It is possible to have signal output on all hf and vhf amateur bands and all TV channels, simultaneously, when a bad case of parasitic oscillation occurs. For those who may have access to one, the best indicator of parasitic oscillation is a wide-band spectrum analyzer.

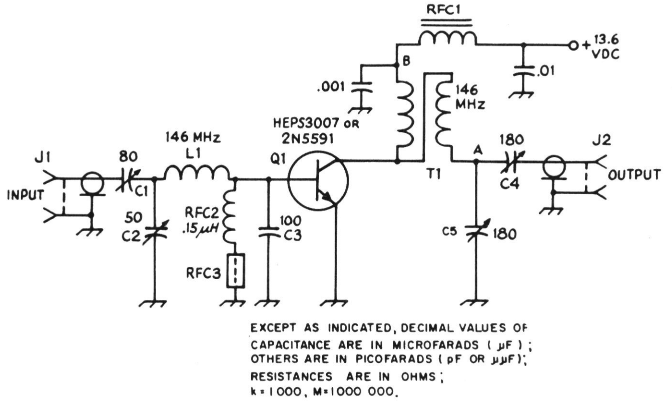


Fig. 4-18 — Circuit diagram of the 25-watt amplifier. Capacitors are disk ceramic unless otherwise noted.

C1 — 5- to 80-pF compression trimmer (Arco 462 or equiv.).
C2 — 2- to 50-pF compression trimmer (Arco 461 or equiv.).
C3 — Button mica (Underwood J-101).
C4, C5 — 9- to 180-pF compression trimmer (Arco 463 or equiv.).
J1, J2 — Coaxial connector, panel mount.
L1 — 1-inch length of No. 14 tinned wire.
Q1 — Motorola silicon power transistor (2N5591 or HEP S3007 for 25 W output, 2N5590 or HEP S3006 for 10 W output).
RFC1 — Ferroxcube VK200-19/4 ferrite choke.
RFC2 — Molded rf choke (J. W. Miller 9250-15).
RFC3 — Ferrite bead (Ferroxcube 56-590-65/3B or equiv.).
T1 — See Fig. 4-20.

Additional Designs

For those who own a low-power fm transceiver, an intermediate amplifier stage or a final amplifier providing 10 to 25 watts may be desired. The circuit of Fig. 4-18 is suitable for the 2N5591 or HEP S3007 transistors (25 watts), and the 2N5590 or HEP3006 transistors (10 watts). An unusual feature of this circuit is the use of a transmission-line transformer in the output network. Details of this transformer are given in Fig. 4-20. A driver stage which delivers up to 3 watts is shown in Fig. 4-19. A 2N5589 or HEP S3005 can be employed in this driver stage. The construction and tune-up procedures for the amplifiers of Figs. 4-18 and 4-19 are similar to those described earlier for the 50-watt amplifier.

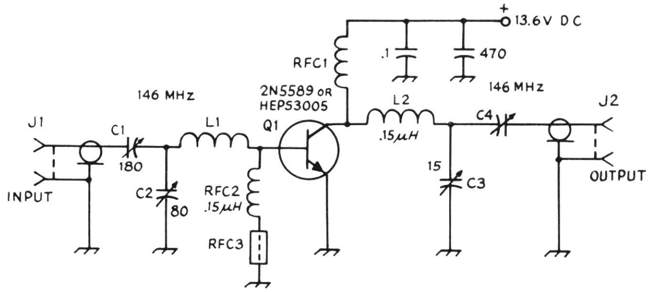


Fig. 4-19 — Circuit of the 3-watt amplifier. The resistor is 1/2-watt composition and capacitors are disk ceramic, unless otherwise noted.

C1 — 9- to 180-pF compression trimmer (Arco 463 or equiv.).
C2 — 5- to 80-pF compression trimmer (Arco 462 or equiv.).
C3, C4 — 1.5- to 15-pF compression trimmer (Arco 460 or equiv.).
J1, J2 — Coaxial connector, panel mount.
L1 — 25 nH, 1 turns, No. 18 tinned wire, 3/16 inch dia.
L2 — 0.15-µH molded choke (J. W. Miller 9250-15).
Q1 — Motorola silicon power transistor.
RFC1 — 10 turns, No. 20 enam. wire wound over 510-ohm, 1/2-watt composition resistor.
RFC2 — Molded rf choke (J. W. Miller 9250-150).
RFC3 — Ferrite bead (Ferroxcube 56-590-65/3B or equiv.).

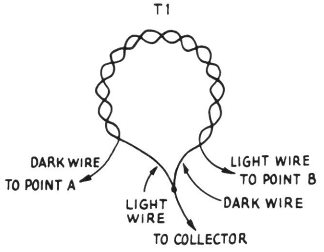


Fig. 4-20 — Transmission-line output transformer consisting of 2 4-inch long conductors, No. 20 enam. wire, twisted to 16 crests per inch, using an electric drill. The conductors should be color coded, one with one color and one with a second color. Form the twisted pair into a 1/2-inch dia circle. Unwind the leads so that only the portion of the pair forming the circle remains twisted. Connect the leads of each color as shown.

Accessories

When an amplifier stage is used with an fm transceiver, a method of automatic transmit/receive switching is needed. A simple carrier-operated relay (COR), such as shown in Fig. 4-7A, can be employed for the amplifiers described here. The level of input rf required to operate the COR is determined by the value of R1. One to two watts of 2-meter energy will operate K1 when a 4700-ohm resistor is employed. The rf signal is rectified by two-high-speed switching diodes; the dc output from the rectifier is applied to Q1, a Darlington-connected transistor pair. When sufficient current is developed in the base circuit, Q1 will turn on, activating K1. A transient-suppression diode is included across the relay coil to prevent voltage-spike damage to Q1.

The switching circuits needed to take the amplifier in and out of the circuit are somewhat complex, as can be seen in Fig. 4-7A. The cost of four coaxial relays would be prohibitive. But, an open-frame relay can cause sufficient loss at 146 MHz to severely degrade the sensitivity of the associated receiver. To get around this problem, an inexpensive relay was modified as detailed in Fig. 4-7B. The long leads to the wiper arms were removed and discarded. Two shorting bars were added, as shown in the drawing. External connections were made only to the stationary contacts. Received signal loss through the modified relay measured 0.4 dB – an insignificant amount.

Second-harmonic output from the 50-watt amplifier measured 34 dB down from the level of the 146-MHz energy. Thus, the computer-design output network compares favorably with the pi-section tank circuits often used in hf transmitters. To assure that harmonic energy will not cause a problem to other services, a simple pi-section output filter (Fig. 4-22) was added. This filter is designed for 50-ohm input and output impedances; it can be used with any two-meter amplifier. The insertion loss of the filter at 146 MHz is 0.2 dB, while it provides 46 dB attenuation at 292 MHz and 25 dB at 438 MHz.

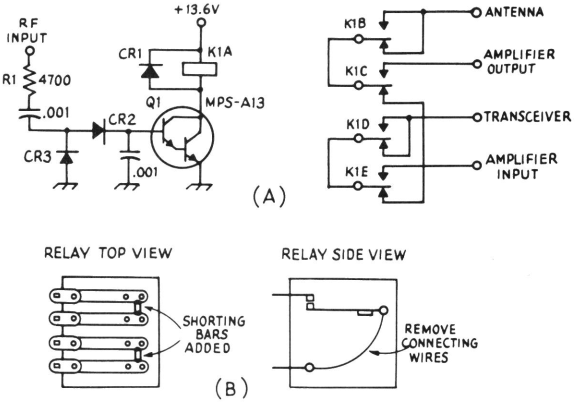


Fig. 4-21 — (A) COR circuit. Capacitors are disk ceramic.

CR1 — 100-PRV or more, 500-mA or more silicon diode (Motorola 1N4001 or equiv.).

CR2, CR3 — High-speed, low-capacitance 100-PRV silicon diode (Motorola MSD7000 dual package used here).

K1 — 4pdt open-frame relay, 12-V contacts (Comar CRD-1603-4S35 or equiv., Sigma 67R4-12D also suitable), modified as described below.

Q1 — Npn silicon Darlington transistor, h_{FE} of 5000 or more (Motorola MPS-A13 or equiv.).

(B) The COR relay is modified by removing the connecting wires from all four wiper arms and adding two shorting bars, as shown. Only the stationary-contact connectors are used.

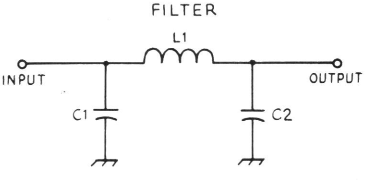


Fig. 4-22 — Pi-section output filter. C1 and C2 are 39-pF mica capacitors (Elmenco 6ED390J03 or equiv.), and L1 consists of 2 turns of No. 18 tinned wire, 1/4 inch ID, 0.2 inch long (approximately 44 nH).

Appendix A

1) Amidon toroid cores are available from Amidon Associates, 12033 Otsego Street, No. Hollywood, CA 91607.

2) Ferroxcube components can be purchased from Elna Ferrite Laboratories, Inc., 9 Pine Grove Street, Woodstock, NY 12498.

3) J. W. Miller chokes are available from distributors, or directly from J. W. Miller, 19070 Reyes Ave., Compton, CA 90224.

4) Underwood mica capacitors must be ordered directly from the manufacturer, Underwood Electric and Manufacturing Company, Inc., P. O. Box 188, Maywood, IL 60153. Price for the J-101 units specified here is approximately \$1.20 each (specify the value – in pF – desired).

5) A circuit board for the 50-watt amplifier will be available from Spectrum Research Labs, P. O. Box 5824, Tucson, AZ 85703.

AN FM TRANSMITTER FOR 220 MHz

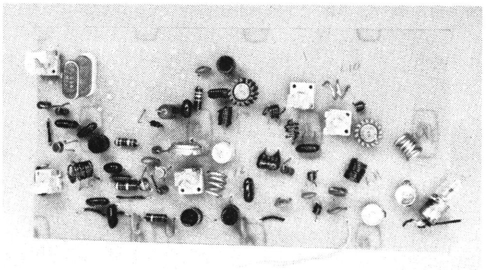


Fig. 4-23 – Top view of the solid-state 1-W transmitter for 220 MHz. Y2 through Y4 and C26 through C28 have not been mounted although provisions for them have been made on the board.

Whether you're a would-be fm-er, or a person who has already explored the world of fm and repeaters, this little 2-watt solid-state transmitter can be the key to new operating enjoyment. No need to scoff at the QRP aspect of this project, because here we have a piece of gear that can be operated from the 12-volt automotive system, a dry-battery pack (10 size-D flashlight batteries in series, or a 12-volt lantern battery), or a simple ac-operated 12-volt dc supply. This feature makes possible a variety of amateur applications, and noteworthy among them, emergency/portable operation.

Rf Circuit

Four low-cost bipolar transistors are used in the circuit of Fig. 4-24. Q1 is the oscillator, which uses 18-MHz fundamental crystals ground for a load capacitance of 20 pF. Output from the first stage is taken at 55 MHz, a frequency multiplication of 3. The second stage, Q2, doubles the frequency to 110 MHz. Q3 doubles to 220 MHz. The remaining stage operates as an amplifier at 220 MHz.

Frequency modulation is effected by applying audio to a voltage-variable diode (Varicap) CR1. As the amplitude of the audio varies, the junction capacitance of CR1 changes, and this change pulls the crystal frequency above and below its preset frequency to provide fm. The amount of deviation, or swing, is determined by the audio level impressed across CR1. Normally, this will be set for 5- or 15-kHz deviation, depending upon the bandwidth in vogue for a given area. Approximately 1.5 volts of reverse bias is developed within the circuit and appears across CR1. This eliminates the need to provide back bias from the 12-volt line.

Crystals Y1 through Y4 are adjusted to the desired frequency by means of trimmer capacitors. Regulated voltage is supplied to Q1 (and to the bias line of Q2) by means of Zener diode CR2. This measure helps insure against oscillator instability.

A drive control, R9, is connected in the emitter lead of Q2 to permit the operator to reduce power to the minimum amount needed. This measure helps to prolong the life of dry batteries during portable operation.

The Modulator

Only a few peak-to-peak volts of audio are needed to provide fm. A two-stage audio channel is shown in Fig. 4-25. This circuit amplifies the microphone output to a suitable level for clipping at diodes CR3 and CR4. A small amount of forward bias is used on the diodes to permit clipping action at relatively low audio level. The 10,000-ohm resistor and .05-μF capacitor used after the clipper diodes serve as a filter to reduce the harmonics caused during clipping. Output stage Q6 amplifies the clipped audio to a maximum level of 20 volts peak to peak. The deviation control, R23, is adjusted to provide the amount of frequency swing needed.

Construction Data

Anyone who has built a commercial kit can assemble this transmitter easily. Circuit-board templates for the transmitter and modulator are available from ARRL for 50 cents and a *large* self-addressed, stamped envelope. A parts-placement overlay is included in the package.

Some of the inductors are wound on 3/16-inch diameter phenolic rod. Any low-loss rod material (Plexiglas or polystyrene) can be used, or the coils can be wound on a 3/16-inch form, slipped off and used as air-wound inductors. If this is done, put a drop of coil dope on each inductor to hold the turns in place. The large air-wound coils can be wound over a drill bit of appropriate size. Ferrite beads are used as cores for chokes RFC7 and 8. Each choke has four turns of No. 30 enameled wire looped through its ferrite bead. The chokes, after being installed on the circuit board, are glued in place with china cement.

Glass-epoxy circuit board is a must for the rf module. Low-cost phenolic board is suitable for the modulator. Poor-quality circuit board can cause problems in the rf module.

Heat sinks should be used on transistors Q3 and Q4. Small clip-on types are suitable. Wakefield Engineering Co. makes a wide variety of these devices. They are listed in most mail-order catalogs. Alternatively, homemade sinks can be made from 16-gauge aluminum or brass stock.

The transmitter can be housed in any metal box that suits the builder's fancy. The transmitter board measures 3 × 7-1/2 inches. The modulator dimensions are 1-3/4 × 4-1/2 inches.

Tune-Up

Connect the modulator output to the audio input terminals on the transmitter board. Use shielded audio cable or small-diameter coax. At-

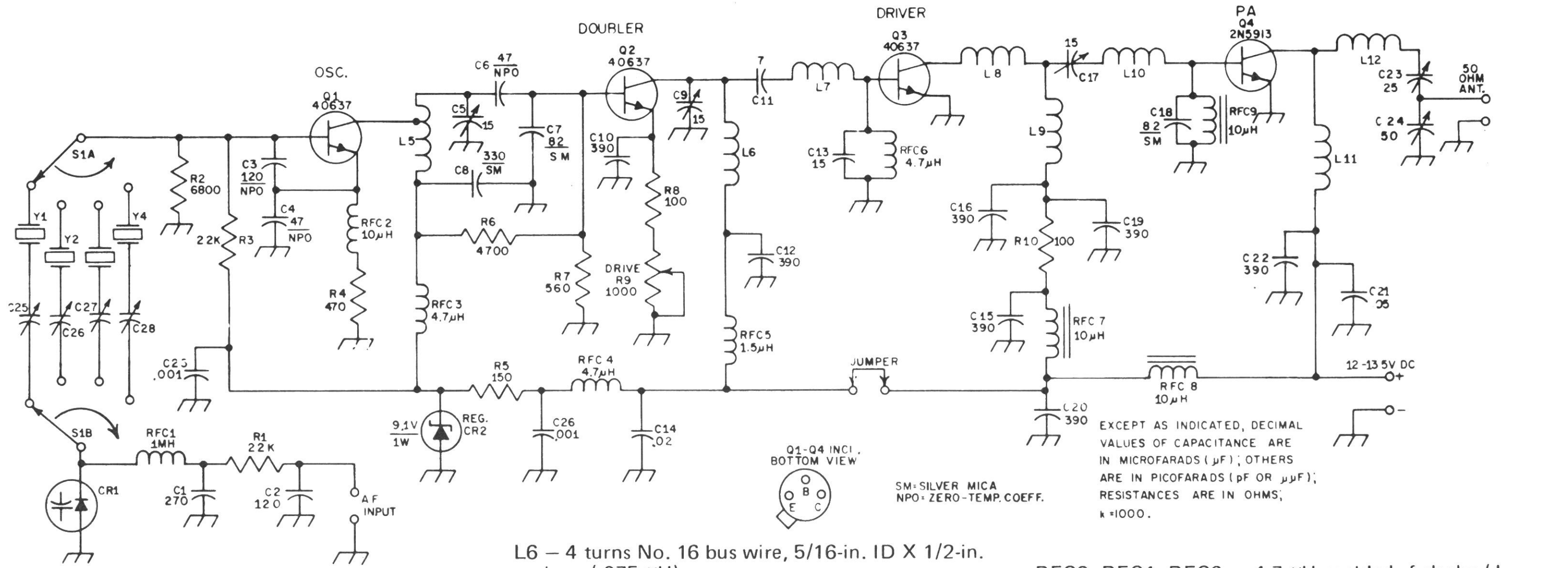


Fig. 4-24 – Schematic diagram of the rf section of the transmitter. Most of the parts are available from Allied Industrial Electronics (Catalog No. 710), Chicago, IL. Numbered components not given in the parts list are so labeled for circuit-board identification. Fixed-value capacitors are disk ceramic unless noted differently. Fixed-value resistors are 1/2-watt carbon.

C5, C9, C17 – 1.7- to 14.1-pF pc-type air variable (Johnson 189-505-5). Compresssion trimmers or ceramic padders can be substituted.

C11, C25-C28, incl. – Miniature ceramic trimmer.

C23, C24 – Phenolic-base ceramic padder (Erie type 557 or equiv.). Cut off phenolic flange.

CR1 – Varicap diode, 82-pF nominal capacitance, 73.8- to 90.2-pF total range (Motorola MV839 or nearest equiv.).

CR2 – Zener regulator diode (Motorola HEP-104 or equiv.).

L5 – 8 turns No. 16 bus wire, 5/16-in. ID X 5/8-in. long. Tape 1-1/2 turns from C5 end (0.11 μH).

L6 – 4 turns No. 16 bus wire, 5/16-in. ID X 1/2-in. long (.075 μH).

L7 – 9 turns No. 22 enam., closewound, 3/16-in. dia. See text.

L8 – 5 turns No. 22 enam., 3/16-in. ID, closewound.

L9 – 3 turns No. 22 enam., 3/16-in. dia, spaced to occupy 3/8-in. on form (.06 μH).

L10 – 2 turns No. 16 bus wire, 5/16-in. ID X 1/4-in. long.

L11 – 10 turns No. 22 enam., closewound 3/16-in. dia (0.435 μH).

L12 – 5 turns No. 16 bus wire, 5/16-in. ID X 1/2-in. long (0.14 μH).

Q1-Q4, incl. – RCA bipolar transistor. Substitutes should have equal or higher voltage, wattage, and f_T ratings.

R9 – 1000-ohm linear-taper pc-board carbon control (IRC type X-201, R102B or equiv.).

RFC1 – 1-mH pc-board rf choke (James Millen J302-1000).

RFC2 – 10-μH molded rf choke (J. W. Miller 9310-36). See text.

RFC3, RFC4, RFC6 – 4.7-μH molded rf choke (J. W. Miller 9310-28). See text.

RFC5 – 1.5-μH molded rf choke (J. W. Miller 9310-16). See text.

RFC7, RFC8 – 10-μH low-Q rf choke. 4 turns No. 30 enam. wound on Amidon miniature ferrite bead (Amidon Assoc., 12033 Otsego St., N. Hollywood, CA 91607).

RFC9 – 4 Amidon miniature ferrite beads on a short length of hookup wire.

S1 – 2-pole, 4-position nonshorting pheonolic or ceramic rotary switch.

Y1-Y4, incl. – 18-MHz fundamental crystal cut for 20-pF load capacitance. International Crystal Co., .0025 percent commercial standard, FI-4 holder. High-accuracy .0025 percent type preferred for best stability. FI-4 pc-board sockets used in this transmitter. Crystals from other manufacturers may work satisfactorily if ground for 20-pF load. (International Crystal Mfg., Inc., 10 North Lee, Oklahoma City, OK 73102.)

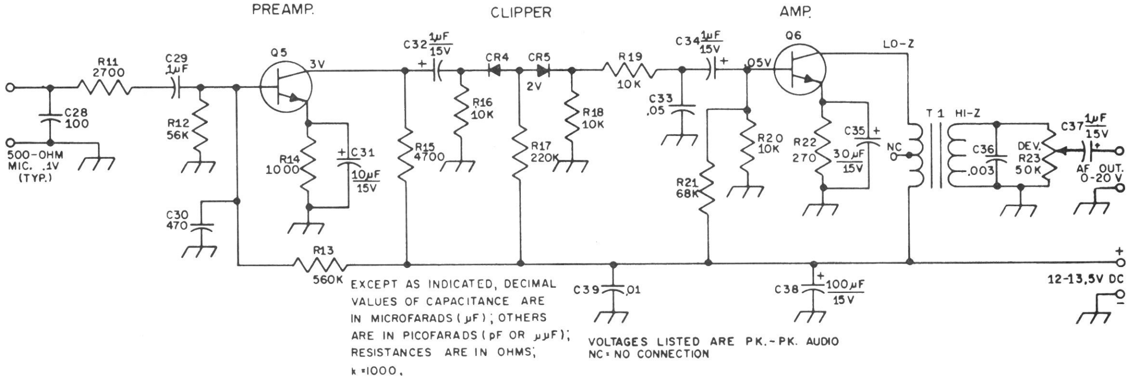


Fig. 4-25 — Schematic diagram of the clipper/modulator. Numbered components not listed below are for circuit-board identification. Capacitors are disk ceramic or paper. Polarized capacitors are electrolytic. Fixed-value resistors are 1/2-watt carbon.

CR4, CR5 — Silicon diode. 1N914 or top-hat rectifier suitable.

Q5, Q6 — Audio-type npn bipolar transistor. RCA 40231 or equiv. Also, Motorola 2N4123 or MPS-A10 suitable.

R11 — See text.

R23 — 50,000-ohm linear-taper carbon control. Pc-board type IRC X-201, R503B.

T1 — Miniature audio transformer, 10,000-ohm primary, 2000-ohm secondary, ct not used. Radio Shack/Archer 273-1378 or equiv. Connect low-*Z* winding to Q6 collector.

tach a No. 47 pilot lamp across the transmitter output jack. This will serve as a visual-indicator dummy load of approximately 50-ohms impedance. Adjust the drive control to nearly full resistance (low power). Plug in a crystal and apply +12 volts to the B-plus terminal of the transmitter module (negative lead to ground foil). Couple a wavemeter to L5 and adjust C5 for a maximum reading at 55 MHz.

The next step is to set the wavemeter for 110 MHz and couple it to tank coil L6. Tune C9 for maximum output indication. The same technique is used to adjust the tuned circuits of Q3 and Q4. Now, advance the drive control to obtain maximum power. The dummy load should light at this point. Retune each stage for maximum lamp brilliance. Alternately adjust the tune and load trimmers, C23 and C24, for maximum glow of the lamp. Normal operation should cause the lamp to light to full brightness or slightly more. At 13.5 volts one should be able to obtain above-normal lamp brilliance. Couple a wavemeter to the output tank and check for second-harmonic energy. Choose a setting for C23 and C24 that provides maximum rf output at 220 MHz with the lowest possible reading at the second harmonic. The wavemeter response at 440 MHz should be very low, but some energy will be present.

Modulator Checkout

The circuit of Fig. 4-25 is designed for a low-impedance dynamic microphone (500 to 1000 ohms). If a high-impedance microphone is to be used, replace R11 with a 100,000-ohm unit. This will reduce the audio drive to Q5, thus preventing saturation of that stage. Also, the high-value resistor will give the high-impedance microphone a more suitable impedance to look into. Adjust R23 for the amount of deviation required. This can be done best by checking with another amateur who has an fm receiver of the desired bandwidth. The crystal can be rubbered to the desired frequency by adjusting its series capacitor.

A final word of caution: *Never operate this transmitter into a highly reactive load.* The SWR should be no higher than 2:1 to prevent damage to PA stage Q4. The output circuit of Q4 is designed to work into a 50- to 75-ohm load.

Suitable substitutes for Q1, Q2, and Q3 are 2N4427 and 2N3866.

AN AMPLIFIER FOR 220 MHz

While the exciter just described will give a fair accounting of itself on a power versus coverage basis, there is still room for improvement. To be comparable with the performance of many solid-state rigs now in use on 144 MHz, a transmitter for 220 MHz should have an output in the vicinity of 10 watts. The amplifier that is shown in Fig. 4-26 was built with that comparison in mind.

There are many transistors available that will do a fine job in this amplifier, although some will require different values of *L* and *C* in the input and output matching networks. The one chosen, a 2N3632, has been offered at bargain prices by several supply houses and dealers in surplus. For those who are power-hungry, there is a good selection of transistors that will provide an output of 40 to 50 watts, but which require 5 to 10 watts of drive to realize full output. This amplifier will be an ideal intermediate stage in such a lineup.

Construction

The amplifier is constructed on a piece of pc board with small islands etched out for connection of the capacitors and inductances. It is possible to construct the amplifier by using the technique of fastening small pieces of pc board on top of the main board. The transistor is mounted between the board and the heat sink (chassis), with the pins projecting through holes to make connection to the foil. At the power level this amplifier is capable of, there is no need for an additional heat sink other than the aluminum enclosure. The edges of the pc board are soldered to grounding lugs that are held in place by the hardware used to mount the input and output connectors. This method of grounding the board provides a direct rf path to the coaxial fittings, without relying on the chassis.

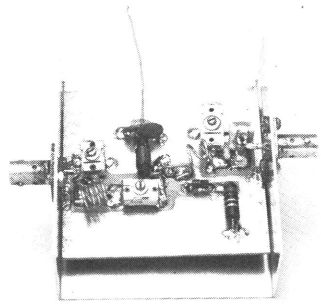


Fig. 4-26 — The amplifier is mounted in a shield box bent from sheet aluminum. The transistor is located under the board, near the center. Connection to the 12-volt supply is via the lead from the junction of RFC2 and the two disk ceramic capacitors. J1, the input connector, is on the right.

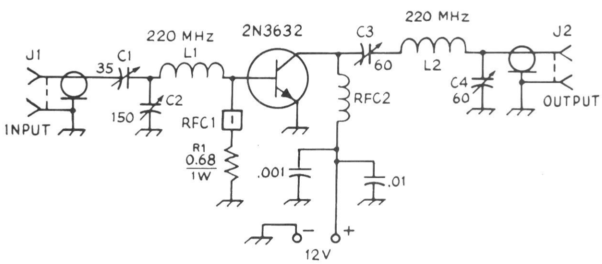


Fig. 4-27 — Circuit diagram of the 220-MHz amplifier. Capacitors are disk ceramic unless otherwise noted.

C1 — 3- to 35-pF compression trimmer (Arco 403 or equiv.).
C2 — 14- to 150-pF compression trimmer (Arco 424 or equiv.).
C3, C4 — 8- to 60-pF compression trimmer (Arco 404 or equiv.).
J1, J2 — Coaxial connector, BNC, panel mount.
L1 — 2 turns No. 16 tinned wire, 1/4-inch ID X 1/2-inch long.
L2 — 4 turns No. 16 tinned wire, 1/4-inch ID X 5/8-inch long.
Q1 — Motorola transistor.
RFC1 — 2 ferrite beads on 1/2-inch length No. 20 enam. wire (Amidon Assoc., N. Hollywood, CA).
RFC2 — 12 turns No. 22 enam. wire, close-wound on 3/16-inch dia plastic rod.

Tune-Up

Tune-up of the amplifier is so easy that a description of the procedure would seem almost superfluous. It is merely a matter of adjusting the input tuning capacitors for minimum SWR to the exciter and adjusting the output capacitors for maximum power output. The drive from the exciter should not be so high as to cause the amplifier to draw more than its rated collector current. Spurious signals from the exciter will cause the collector current to be unnecessarily high. To eliminate any such unwanted signals from the exciter, a helical-resonator filter was installed between the exciter and the amplifier. The turns of L2 can be squeezed or stretched slightly to make a small adjustment in the output network. Any increase in output power with a corresponding decrease, or no change, in collector current is a step in the right direction.

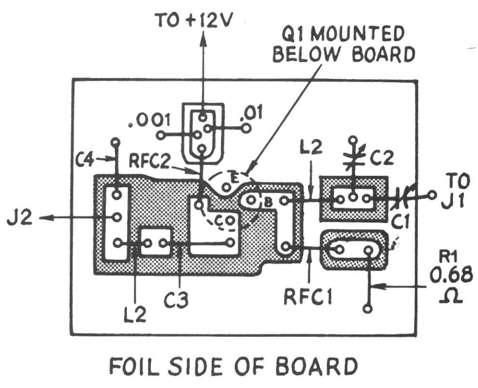


Fig. 4-28 — Parts location for the amplifier. The pc board is 3-1/8 inches long and 3 inches wide. Portions of the board that are etched away are shown as shaded areas.

Results

Power output from the amplifier was in the range of 5 to 8 watts with many of the transistors tried. One "enthusiastic" 2N3632 provided 9 watts output while using a 12.5-volt supply. Some 2N3375s were tried in the circuit and the output power was similar to that obtained from the '3632s, but the lack of smoothness in output tuning indicated that the matching networks were not optimum for that transistor. For safe operation of an amplifier using the 2N3375 the emitter should be above ground by 0.1 to 0.2 ohm, with a good rf bypass. Such construction would involve slightly different connections to the pc board.

A VARACTOR TRIPLER FOR 420 MHz

It is indeed fortunate that the 420-MHz band is related harmonically to the 144-MHz band, since a simple exciter or transmitter for the lower frequency can be pressed into service as an exciter for the higher band as well. Discussions and designs using varactor diodes as frequency multipliers have been seen in printed form many times, and all have pointed out the ease of obtaining output at the second, third, fourth or higher order of multiplication.

Many of the designs had some drawbacks that prevented their acceptance to other than the avid experimenter; the simple circuits had too many unwanted frequencies in the rf output and the "clean" designs were large physically. The tripler presented in Fig. 4-29 is a step toward overcoming some of these deficiences.

The Circuit

The input circuit for this varactor multiplier was chosen because it does its job well, and of no less importance, it is not as confusing in schematic form. L1 is the input-coupling link and its reactance is tuned out by C1. L2-C2 form a conventional series-resonant circuit tuned to the input frequency. The combination of these circuits, then, becomes the familiar tuned circuit with link-coupled input. The link is coupled to the cold end of L2 and the amount of coupling is adjustable by changing the position of L1. It is easier to visualize the end of L2 as being "cold" by remembering that the varactor diode is a low impedance device.

L3-C3 is the series-tuned idler circuit that is necessary for efficient harmonic generation, and L4-C4 is a series-tuned circuit for the output frequency. L5 and C6 is resonant at the output frequency also, with a small capacitor, C5, to provide coupling to the diode output circuitry.

Construction

Double-sided pc-board material was used as a housing for the tripler, shown in Fig. 4-30. J1, C1, C2 and C3 are all mounted on one end of the box. The diode is mounted on the bottom of the enclosure, fastened in place by means of a nut on the outside. A small piece of aluminum sheet, used as a heat sink, is placed over the diode mounting stud before the nut is secured. The heat sink need be only two or three inches square for drive levels up to five or six watts. For higher input power, the heat sink should be larger; three or four inches on a side of finned aluminum will be needed if the diode is pushed to its rated limit. L4 is a copper strip with one end connected directly to the diode. C4 is mounted at the end of L4 opposite the varactor. L5 is likewise a strip of copper, and is tuned by C6. The ground end of L5 connects to a shield that isolates the input circuitry from the rest of the compartment. Another shield is placed lengthwise in the box to separate L4 and L5. The

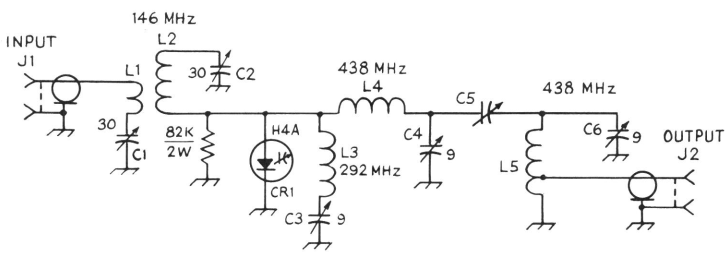


Fig. 4-29 — Schematic for the varactor tripler.

C1, C2 — 2.2- to 34-pF miniature variable (E. F. Johnson 190-0010-001).
C3 — 1.4- to 9.2-pF miniature variable (E. F. Johnson 189-563-001).
C4, C6 — 1.4- to 9.2-pF miniature variable (E. F. Johnson 189-563-005).
C5 — Copper strip 1-in. long X 1/4-in. wide. Bend one end up to form a tab 3/8-in. long. Spacing between tabs approx. 1/8 inch.
CR1 — Varactor diode (Amperex H4A or equiv.).
J1, J2 — Coaxial connector. Type BNC suitable.
L1 — 3 turns No. 16 enam., 3/8-in. ID X 3/8-in. long.
L2 — 6-1/2 turns No. 16 tinned bus wire, 3/8-in. ID X 7/8-in. long.
L3 — 3-1/2 turns No. 16 tinned bus wire, 3/8-in. ID X 1/2-in. long.
L4 — Copper strip, 3-1/4-in. long X 3/8-in. wide. Space 1/2-in. above ground.
L5 — Copper strip, 3-3/8-in. long X 3/8-in. wide. Space 1/2-in. above ground. Tap 1-3/8 in. from ground end.

coupling capacitor, C5, is made from two small tabs of copper strip bent into an L shape. Coupling is adjusted by bending the tabs slightly. Output is taken from a tap connection near the ground end of L5.

Adjustment

Tune-up of the tripler is not difficult if a few pieces of test gear are available. An SWR indicator will be needed for the input, and an output-power indicator should be connected to J2. A grid-dip meter is also of great help. The first step should be to tune the input, L1-C1 and L2-C2, to resonance as indicated by the dip meter. Likewise, the idler circuit should be tuned to the second harmonic of the intended input frequency, 292 MHz if the input is 146 MHz. Not many of the currently available dip meters will tune to 440 MHz, but a pilot-lamp dummy load should provide an indication of output when L4-C4 is tuned while low driving power is applied to J1.

The input circuits should be tuned for minimum reflected power at J1, and then the output circuits adjusted for maximum output as shown by a lamp load or power meter. The copper tabs of C5 can be bent toward or away from each other by means of an insulated tuning tool. Overcoupling is indicated by the tuning of C4 and C6 becoming quite broad or even out of range of their adjustments.

Efficiency of the tripler can be as high as 70-percent, but it is recommended that the tuning be set to a condition where the most stable output results. If there is a sudden step, either up or down, in power output as the circuits are adjusted, the input coupling, or the capacitance of C5, should be increased slightly to alleviate this critical condition. With all circuits adjusted properly, the efficiency will be in the vicinity of 60 percent. Moderate temperature changes will have little effect on the output. Spurious signals should be 45 dB below the desired output.

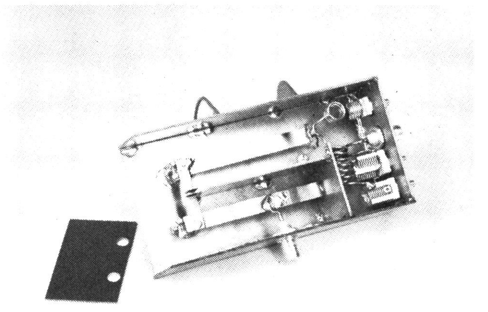


Fig. 4-30 – The varactor tripler is assembled in a box made from double-sided pc board. Input is at the left. The idler coil, L3, is mounted at right angles to L1 and L2 to prevent undesired coupling. The copper strips tune to the output frequency. Two tabs of copper provide coupling between the strips. Output is taken from J2, at the bottom center. A piece of pc board with holes for access to C4 and C6 should be soldered to the end of the enclosure. Other pieces can be soldered to the top to provide complete shielding, if desired. The box is 3-in. wide X 5-1/4 in. long and 1-1/2 in. high.

A 75-WATT AMPLIFIER FOR 420 MHz

Much of the fm activity on the 420- to 450-MHz band involves the use of surplus units retired from commercial service. This equipment certainly has a record of long and excellent performance. However, from a power consumption standpoint they leave much to be desired. The many tubes needed for frequency multiplication and power amplification impose a heavy load on any mobile installation.

An increasingly popular method of generating rf output on this uhf band is to use a varactor tripler driven by a low- or medium-power transmitter. The driver can thus do double duty by being used on 146 MHz as well. Varactor diodes that will withstand more than a few watts of drive are somewhat expensive, hence the output from most multipliers of this type is in the order of two to ten watts.

As manufacturing techniques improve, transistors that will provide increased power output at uhf are becoming available – and at attractive prices. The following is an example of construction techniques using two Motorola uhf power transistors. It was built by K2OVS and first appeared in *QST* in October, 1972.

Circuit Description

The basic design as shown in Fig. 4-31 is a two-stage amplifier with capacitive interstage coupling. Inductors L1, L2, and L3 are strip-line components which are etched or cut into the main printed wiring board. Capacitors C1 through C5 are ARCO type 420 compression trimmers. Other types can be used instead, with the precaution that the lengths of the strip-line inductors may have to be adjusted to obtain impedance matching at each stage. The coupling capacitor, C6, is a high-*Q* porcelain or leadless ceramic type. A disk ceramic or mica type in its place will have a severe effect on the performance of the amplifier, possibly decreasing the output. Miniature connectors are used for input and output to fit the small space available. BNC connectors can be used if more mounting space is provided.

Since the transistors are biased for Class C, removing the drive causes the collector current to

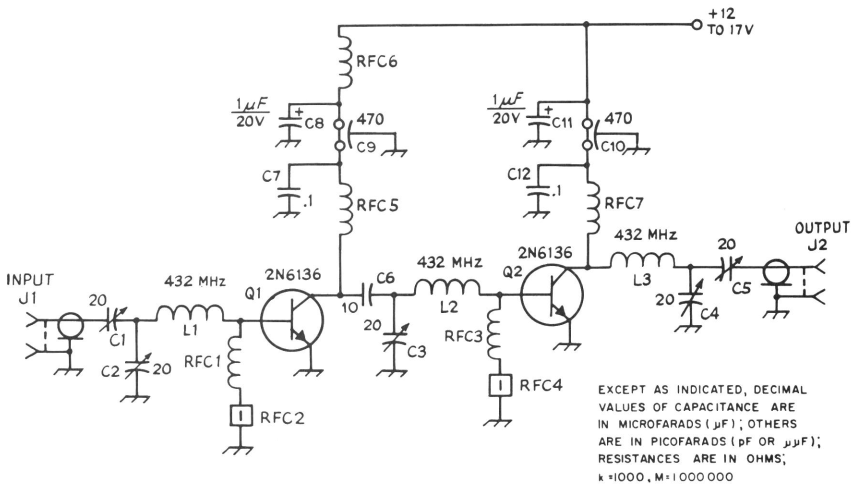


Fig. 4-31 — Circuit diagram of the two-stage amplifier.

C1-C5, Incl. — 1- to 20-pF compression trimmer (Arco 420 or equiv.).

C6 — 10-pF microwave ceramic capacitor (ATC-100-B100MC, available from American Technical Ceramics, Inc., 1 Norden Lane, Huntington Station, NY 11746).

C7, C12 — 0.1-μF, 20-volt disk ceramic.

C8, C11 — 1-μF, 20-volt tantalum electrolytic.

C9, C10 — 470-pF feedthrough.

J1, J2 — Coaxial connectors, type BRM or BNC.

L1, L2, L3 — Strip line inductors (see text and drawing).

Q1, Q2 — Motorola 2N6136 transistor.

RFC1, RFC3 — 0.15-μH molded miniature choke.

RFC2, RFC4 — Ferrite bead slipped over lead at cold end of RFC1 and RFC3.

RFC5, RFC7 — 5 turns No. 20 enam. wire, close wound, 3/16-inch ID.

RFC6 — 0.2-μH molded choke (Ferroxcube VK200 or equiv.).

decrease to nearly zero and no heat is generated during standby periods.

Both dc and rf decoupling is provided on the supply voltage leads. Good quality capacitors and chokes are essential to prevent instability. Working with semiconductors that exhibit high gain at uhf requires some care in choosing decoupling component values which will prevent the amplifier from oscillating at hf and vhf, where the transistors usually have very high gain.

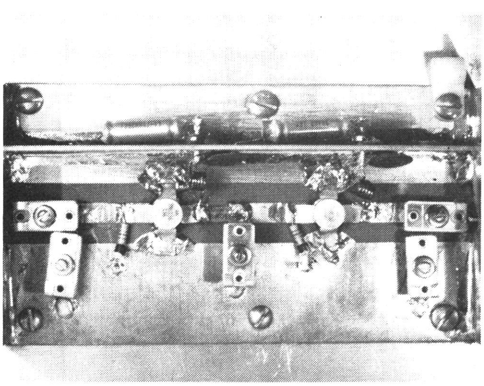


Fig. 4-32 — A two-transistor amplifier that can provide up to 40 watts output on 432 MHz. In this top view, the input is at the left. A shield partition and the two end pieces are fabricated from double-sided pc board material, as is the strip line circuit components. The assembly is bolted to a large heat sink by the six screws along the top and bottom edge of the amplifier.

PC Board Construction

The entire amplifier is constructed on a single piece of pc board, 5-3/4 inches long by 3-1/4 inches wide. The dielectric material is Teflon, 1/16-inch thick, with one-ounce copper cladding on both sides. The board layout is shown in Fig. 4-33. Glass-epoxy or paper-base pc board material is much too lossy at uhf and should not be used for this amplifier. The dimensions shown should be followed to within 1/64 of an inch, especially the width of the base and collector striplines.

The layout is so simple that the board could be constructed without etching at all; transfer the layout to the board with a pencil and carefully cut through the top layer of copper with a sharp knife. The copper to be removed can be peeled off of the Teflon base material in two strips by lifting the end of a strip and pulling it at right angles to the board. A piece of single-sided Teflon board could be used for construction by fabricating the ground surfaces and strip lines from adhesive-backed copper foil.

The thickness of the dielectric has a great effect on the impedance and resonant frequency of the strip line, therefore the 1/16-inch thick board should be used. The width of the board can be changed to fit other sizes of heat sink, but it should not be less than 3 inches to provide an adequate ground area. After the strip lines are constructed, all holes can be drilled and the heat sink prepared.

Heat Sink

The heat sink, shown in Fig. 4-32, is constructed from a section of finned aluminum material approximately 7-11/32 inches long by 5-inches wide. The fins are 2 inches high and .090 inch thick. This represents a surface area of about 300 square inches to radiate heat. A single flat plate of aluminum, bent into a U shape, could be used but its overall size would have to considerably larger to provide the same surface area.

After the heat sink is cut to size, the holes for mounting the pc board can be drilled and tapped. Clearance holes for the transistor mounting studs can be drilled through the heat sink and the fins must be cut away around these holes to allow installation of the mounting nuts.

Adequate heatsinking is extremely important. Most uhf power transistors will destroy themselves rapidly if their junction temperature is allowed to exceed 125 degrees C. Heat sinks are only effective if the heat generated by the transistor is efficiently dissipated. For this reason, a thermal-conductive grease must be applied to the transistor mounting stud before it is installed in the heat sink.

Shielding and Final Assembly

Three pieces of double-sided pc board material are cut and soldered in place to provide shielding between the rf and dc sections of the amplifier. These partitions provide a convenient place to mount the input and output connectors and the dc filtering components. The rf connectors should be mounted on the end shields before the shields are assembled to the strip-line board.

All components with the exception of the transistors may now be mounted to the strip-line board and shields as shown in Fig. 4-32. All component lead lengths must be as short as possible. A minimum amount of heat should be used when soldering to the base and collector lines to prevent them from lifting off the board; a small 25-watt soldering iron is best here. The emitter grounding ribbons can be installed to connect the two sides of the pc board together as shown in Fig. 4-34.

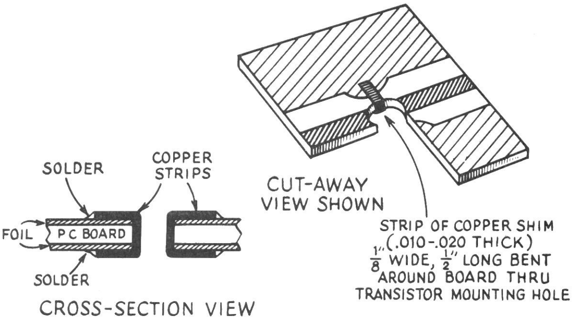


Fig. 4-34 — The copper foil on both sides of the board is bonded together by means of copper strips through the transistor mounting holes.

The strip-line assembly can be placed on the heat sink to check the alignment of all mounting holes. This is extremely important; misalignment of the board may overstress the leads on the transistors and crack their top caps. The flat bottom portion of the transistor mounting stud should fit firmly against the heat sink without placing any stress on the transistor leads. When the alignment is correct, thermal grease can be applied to the mounting studs and the transistors bolted to the heat sink. A torque of six inch-pounds should be applied to the nut to provide proper thermal contact to the heat sink. As the last step, the board mounting screws should be tightened and the transistor leads can be soldered to the board. Again, use only the minimum amount of heat necessary to make a connection.

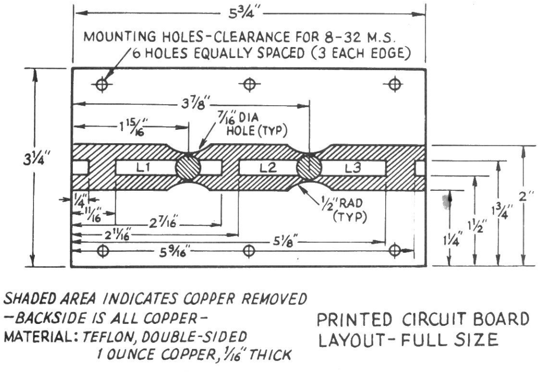


Fig. 4-33 — Layout for the pc board. The dielectric material is Teflon, 1/16-inch thick. Dimensions should be followed within 1/64th inch.

Power Requirements

A power supply providing between 12 and 17 volts at 5 amperes is required for operation. A regulated supply is preferred, though it will not be necessary if the voltage never exceeds 17. When the amplifier is supplied with the 12 to 13 volts that is available in most mobile installations the output will be 25 to 30 watts.

A suitable power supply with output regulation and short-circuit protection is shown in Fig. 4-35. This power supply, with the exception of the transformer and the regulating transistors, may be assembled on one small pc board.

Cooling Requirements

The heat sink described above will provide adequate cooling if it is mounted where air can circulate freely around it. If the amplifier is to be enclosed in a cabinet, the heat sink can serve as the back or top panel with the fins outside. If the amplifier is to be mounted in a closed area, some air flow from a small fan will be required to keep the transistor case temperature down.

At the full dc input of 75 watts, the case temperature of the output transistor should not exceed 200 degrees F. However, when the output is not matched properly extra power will be dissipated as heat in the last transistor.

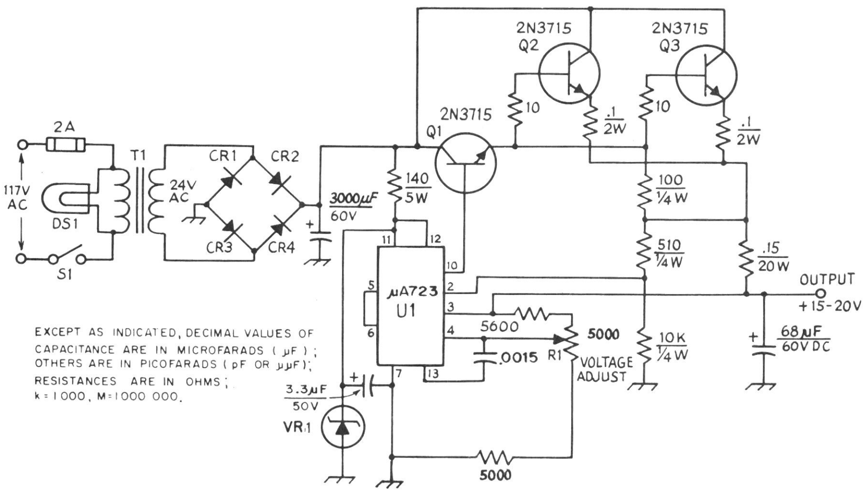


Fig. 4-35 – A regulated power supply suitable for use with the amplifier. The output is in the range of 15 to 20 volts at 5 A. Resistances are 1/2-watt unless otherwise specified.
CR1-CR4, incl. – 50 PRV, 5-A silicon diodes.
R1 – 1000-ohm linear-taper composition control.
T1 – 117-V primary; secondary 24 volts at 5 A (Stancor P-6378 or equiv.).
U1 – µA723 voltage regulator.
VR1 – 36-volt, 10-watt Zener diode (1N2991B or equiv.).

Tune-Up

Initial tune-up is performed with the full collector voltage applied and between 1/2- and 1-watt of drive from an exciter or varactor multiplier. Changing the voltage from the supply will drastically affect tuning by causing the junction capacitances of the transistors to vary. C1 and C2 should be adjusted for minimum SWR between the exciter and the amplifier input. Next, C3, C4 and C5 can be adjusted for maximum output. The rf input power should be increased gradually and the adjustments repeated, monitoring the current from the power supply at all times. Any sudden jump or oscillation of the collector current indicates instability and all bypassing and decoupling components should be checked before proceeding.

Performance

Despite the fact that the amplifier is biased for Class C, the output power is a fairly linear function of the rf input applied. As little as 1 watt of drive will produce about 10 watts of output. The measured overall efficiency at an input of 75 watts was 52 percent. Almost 40 watts of output can be realized at that dc input level.

Spurious outputs were checked on a spectrum analyzer and all were at least 34 dB down. The highest output observed was at 864 MHz. The 144-MHz feedthrough from a varactor multiplier was at least 60 dB below the 432-MHz energy out of the amplifier.

FREQUENCY SYNTHESIZERS FOR TRANSMITTING AND RECEIVING

Because of the channelized operation that makes fm and repeaters so attractive to mobile operators, keeping the equipment supplied with just the right crystals can become a problem. If the operator moves around a great deal in an area heavily populated with repeaters, it soon taxes his imagination to find space for more channels in the transmitter or receiver. Several ingenious methods have been set forth to solve the problem. One of the most promising devices for this use is the frequency synthesizer. In their present state of complexity they do not represent an economical answer to the dilemma, but in terms of access to the greatest number of channels, synthesizers are very attractive.

SYNTHESIZER TYPES

Early attempts at frequency synthesis were along the lines of a series of oscillators and frequency multipliers, wherein the appropriate set of frequencies was generated to be combined in a mixer to produce the desired output frequency, or some submultiple thereof. While such a system does work, the filtering needed to eliminate the unwanted products of the multiplier and mixer

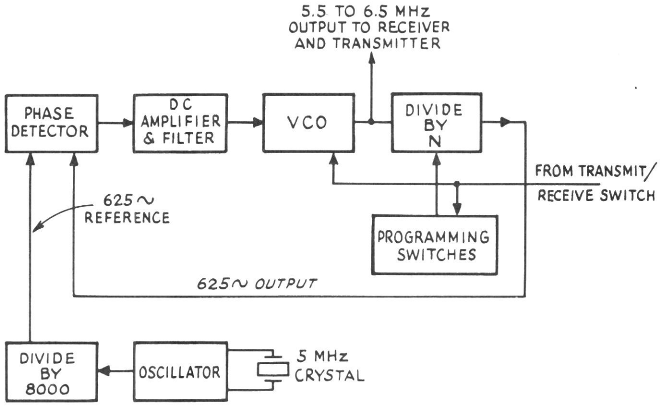


Fig. 4-36 – Block diagram of the synthesizer described in the text.

stages can become formidable. Called **direct synthesis**, this method was used in some military and commercial applications. Because of the size and circuit complexity of the filtering network required for more than just a few channels, this system has not found favor with many amateur fm enthusiasts.

Another method of synthesis that is beginning to be explored by a few experimenters is called **digital table look up.** This system requires that all the information required to generate a sine wave be stored in a memory. The readout or access circuit is programmed to select the proper information from the memory to "build" a wave of the desired frequency. This method of synthesis has several good points, among them being very fast frequency-changing capability and the use of digital techniques almost entirely. The slow speed of presently available sampling devices limits this type of synthesizer to only a few megahertz. Even so, it offers great possibilities to the experimenter.

A third type of circuit is called **phase-locked-loop synthesis** (PLL). This method has been investigated by several amateurs, and with varying degrees of success. Among the problems that they have faced are noise in the reference source and power supply causing the output to occupy a wide spectrum, slow lockup time, and temperature and vibration instability.

Most of the builders of a PLL synthesizer have found that the problems of noise on the signal and slow lockup time are interrelated. Noise can be reduced by the addition of filtering components to the reference-frequency and phase-detector circuits. However, the additional filtering also slows down the response of the detector. In the end result, a compromise must be made between speed of lock and purity of emission. Temperature and mechanical instability can be overcome by using commonly accepted good practices for VFO construction.

A PRACTICAL SYNTHESIZER

With so many amateurs working toward developing a synthesizer for use on 146-MHz fm, it is inevitable that the results are beginning to appear, each showing the builder's unique approach to the aforementioned problems. One practical synthesizer, contributed by K2CBA, represents a basic PLL circuit with a minimum of frills. The compromise between lockup time and spectral purity is a good one. It takes less than 0.5 second to lock to a new channel or to switch from transmit to receive. Spurious responses on the carrier are better than 35 dB down as seen on a spectrum analyzer. By using programming switches that do not read directly in frequency, considerable circuit complexity and expense is avoided. The output provides 15-kHz steps at 146 MHz, which allows working through a repeater input or "splitting the channel" to find a spot for simplex. Receiving and transmitting frequencies are selected independently by the use of separate thumbwheel switches.

The output frequency for transmitting is in the 6-MHz range, which is compatible with many of the surplus transmitters available. For receiving,

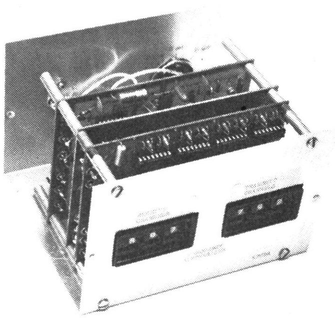


Fig. 4-37 – Two sets of thumb-wheel switches are used to select transmitting and receiving frequencies independently. The pc boards are fastened to the front panel and to each other by means of threaded metal spacers. A blank pc board is mounted between the front and rear boards to provide shielding.

the output is near 5.5 MHz as required for the RCA Carfone equipment for which the synthesizer was designed. Other makes of receivers might require modification of their local oscillator and frequency multiplication circuitry to work with this synthesizer.

Circuit Features

A block diagram of the PLL synthesizer is shown in Fig. 4-36. It consists of a crystal-controlled oscillator and frequency-divider chain from which a reference frequency is derived, a voltage-controlled oscillator whose output fre-

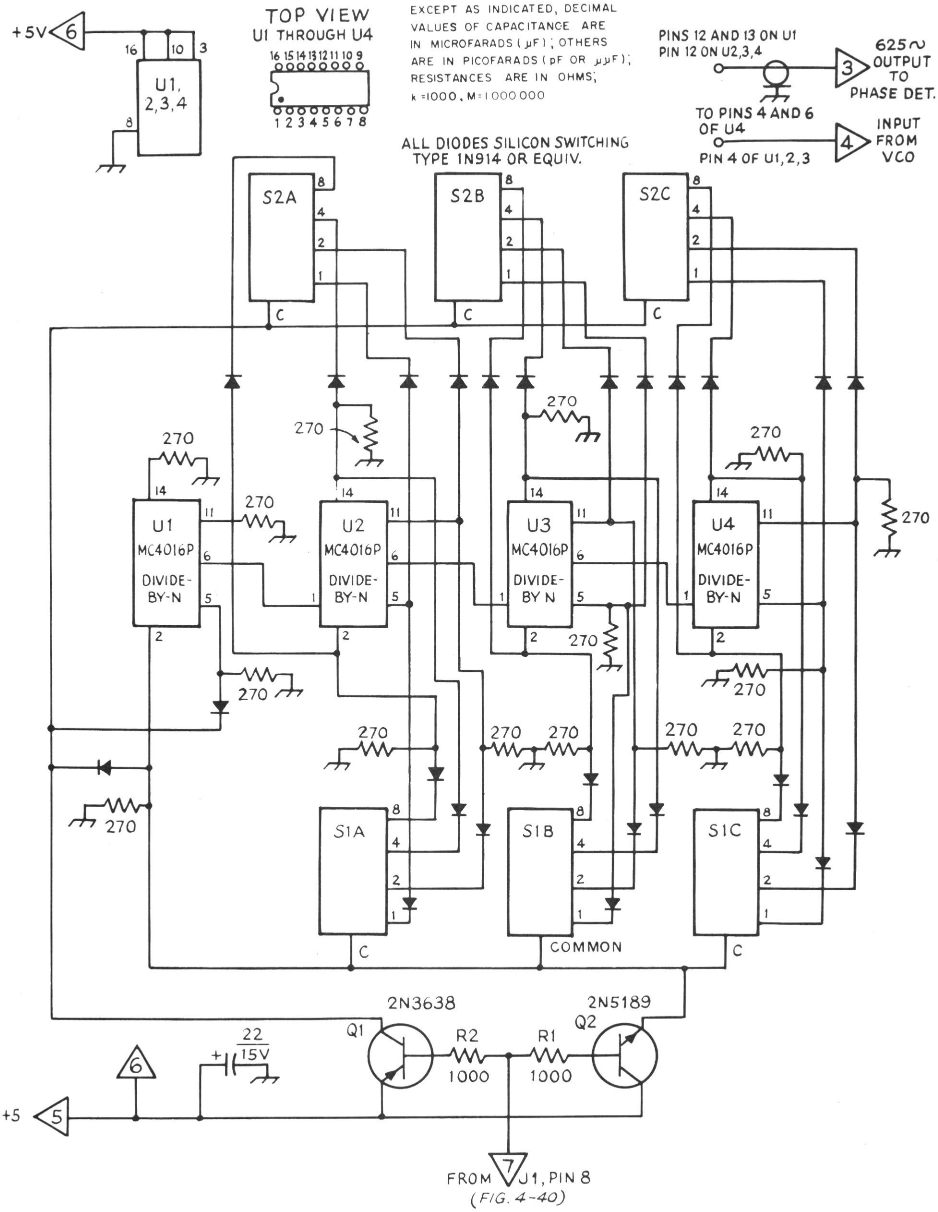


Fig. 4-38 — Schematic of the divide-by-N portion of the synthesizer. Resistors may be 1/4- or 1/2-watt composition.

S1, S2 — Printed-Circuit thumb-wheel switch, 10-position, BCD, single-pole, EECo type 1776 or equiv.

U1-U4, incl. — TTL programmable modulo-N decade counter IC, Motorola MC4016P or equiv.

quency is divided by programmable circuits, and a phase detector that compares the resultant signals from the divider chains and develops a correction voltage for the VCO.

The crystal oscillator generates a 5-MHz signal, which is divided by 8000 to produce a 625-Hz reference signal. A total of six ICs perform the oscillator and division functions. The VCO operates in the 5.5- to 6.5-MHz range and the output frequency of the VCO is divided down to 625 Hz to be compared with the output from the crystal-controlled source. Four programmable (divide-by-*N*) ICs are used following the output of the VCO. Thumbwheel switches are used to program the frequency-dividing circuit.

A single IC is used to compare the phase of the two 625-Hz signals, and, with the help of an external transistor, develops a voltage that is proportional to the phase difference between these signals. This voltage is applied to the VCO in such a manner as to cause a frequency change in the direction that will reduce the phase difference.

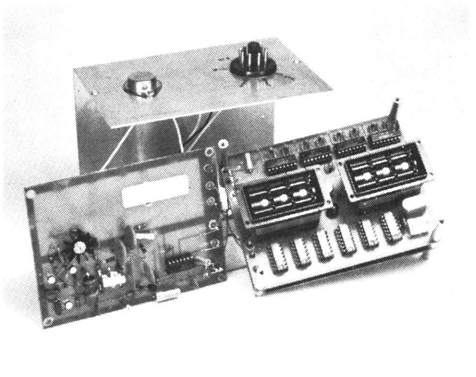


Fig. 4-39 — The two boards are shown removed from the minibox, although still attached by the leads to the 9-pin plug and the voltage regulator. On the VCO board, left, can be seen the phase-detector IC. The transistor with the heat sink is Q6, a 2N3866. L1 is wound on a two-watt resistor which appears just below Q6. C1 is immediately to the right of L1. The right-hand board contains the reference oscillator and its divider chain (bottom row of ICs). The top row of ICs is the divide-by-*N* circuit. Q1 and Q2 can be seen just between the thumb-wheel switches.

VCO Circuit

The circuit for the VCO is shown in Fig. 4-40. It is simply a series-tuned Colpitts VFO with CR1 providing the variable capacitance to adjust the frequency. The capacitance of this diode varies with a change in voltage applied to it, causing a corresponding change in the frequency of oscillation. Two small chokes, L2 and L3, along with C2 and C3, filter the correction voltage from the phase detector circuit. The value of this *LC* filter network influences the lockup time of the VCO, in addition to reducing the amplitude of any 625-Hz energy present. Values for L1 and CR1 are selected so as to cause Q4 to oscillate on the frequency needed for transmitting, in this case 6 MHz.

A trimmer capacitor, C1, is added to the circuit to adjust the oscillator to the frequency needed for receiving. In the receive mode, a positive voltage is applied to CR2, causing it to conduct and effectively place C1 in parallel with CR1. This lowers the frequency of oscillation to 5.5 MHz, which is multiplied by external circuits to the frequency needed for receiver mixing. At the same time that a voltage is applied to CR2, the divide-by-*N* counter is reprogrammed to provide a 625-Hz signal for comparison with the reference, thus keeping the VCO stabilized. Q5, Q6, and Q7 are buffers to isolate the oscillator from any load and to provide two output connections. Output from Q7 is connected to the divider chain. Q6 provides output to the frequency multipliers in the transmitter or receiver.

Frequency Dividers

A stable 625-Hz reference signal is derived from the 5-MHz oscillator and a frequency divider chain, as shown in Fig. 4-41. A hex inverter, SN74H04, is used as a crystal controlled oscillator. C5 is a trimmer capacitor to provide a means of adjusting the frequency to zero beat with WWV. The oscillator is followed by three divide-by-10 stages, then a divide-by-4 and a divide-by-2 stage for a total division of 8000. The 625-Hz output from this circuit is applied to one input of the phase detector.

The 5.5- to 6.5-MHz output from the VCO buffer, Q7, is divided by four programmable stages, called divide-by-*N*. The divisor, *N*, is selected by setting the thumbwheel switches to the proper positions. These switches have the necessary binary-coded output connections to program the divided circuits. Two separate sets of thumbwheel switches are connected to the divider chain through isolating diodes. A positive voltage, applied to Q2, causes the diodes to conduct, thereby connecting the receive thumbwheel to the chain. When there is no voltage applied to Q2 and the transmit-receive bus is grounded, Q1 will conduct, causing the transmit channel selector switches to be connected to the divider chain. The 625-Hz output from the divide-by-*N* circuit is connected to the remaining input of the phase detector.

Phase Detector

A circuit to compare the phase of the two 625-Hz signals is provided in a single IC, in this case a Motorola MC4044P. As shown in Fig. 4-40, the signals are applied to the inputs of the phase detector, U5. Any phase difference is detected and a dc voltage that is proportional to this difference is developed. A dc amplifier is built into the IC to bring the voltage up to a useful level. Q3, with R3, R4, R5, and C4 forms an active filter that helps to eliminate any tendency to lock up on harmonics of the input frequencies. The correction voltage is filtered additionally by L2 and L3 in the VCO circuit.

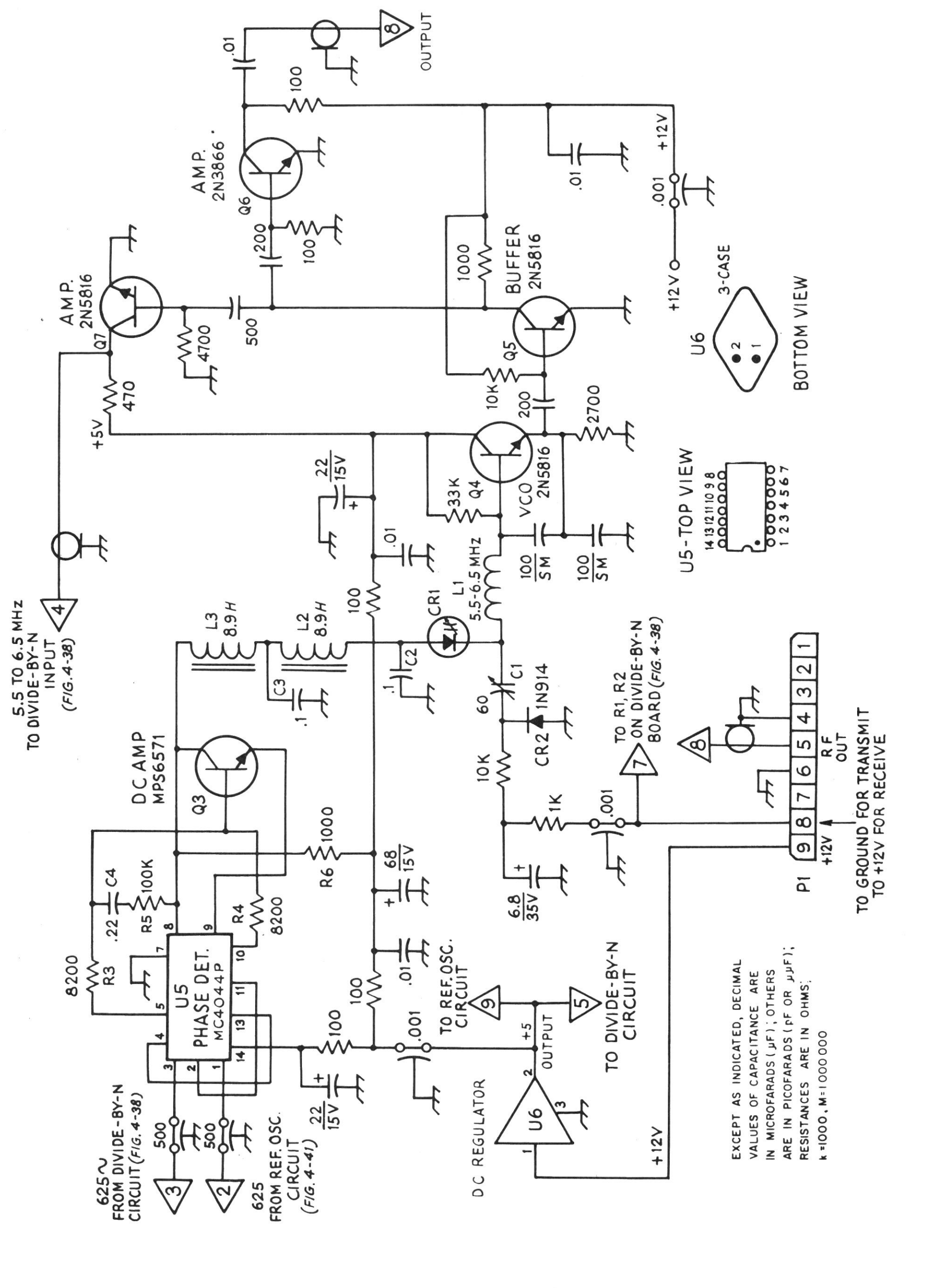


Fig. 4-40 — Circuit of the VCO and PLL portion of the synthesizer. Resistors can be either 1/4 or 1/2 watt composition.

C1 — 9- to 60-pF compression trimmer (ARCO 404 or equiv.).

CR1 — 15- to 60-pF voltage-variable capacitance diode. Motorola MV2205 or MV2209 suitable.

L1 — 15 μH nominal. Approx. 40 turns No. 28 enam. closewound on high-value 2-watt resistor. Miller 4506 slug tuned inductor also suitable.)

L2, L3 — 8.9 H miniature audio choke. Aladdin 86-101 or equiv.

P1 — 9-pin chassis-mount connector, male.

U5 — Phase-frequency detector IC, Motorola MC4044P or equiv.

U6 — 5-volt regulator IC, 1A, National Semiconductor LM309K or equiv.

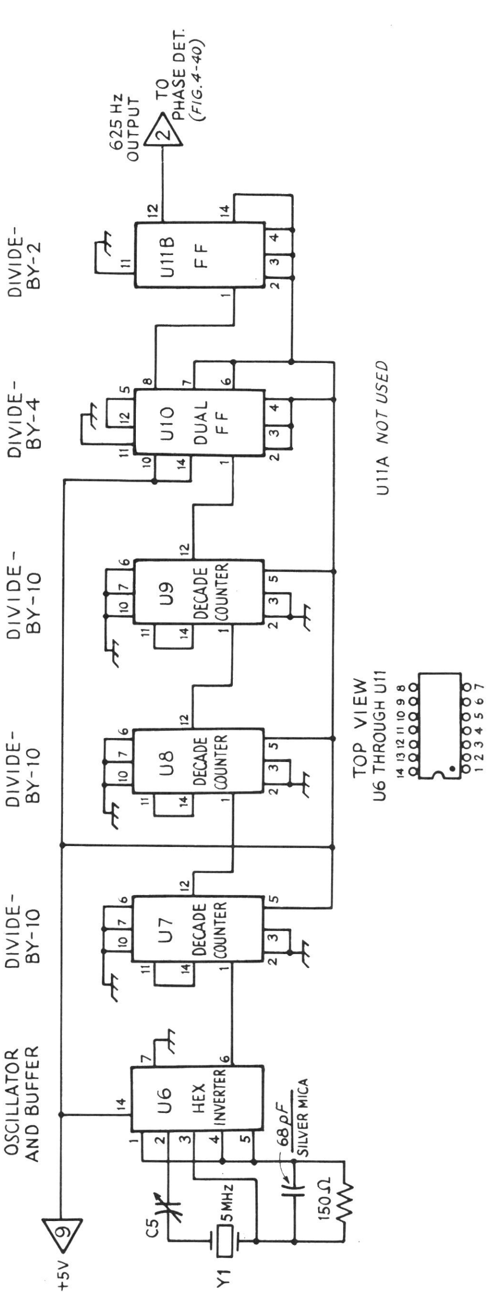


Fig. 4-41 — The reference oscillator and divider chain.

C5 — 9- to 60-pF compression trimmer (Arco 404 or equiv.).
U6 — TTL high-speed hex-inverter IC, Texas Instrument SN74HO4N or equiv.
U7, U8, U9 — TTL decade-counter IC, Texas Instr. SN7490 or equiv.
U10 — TTL dual *J-K* master-slave flip-flop, Texas Instr. SN7473 or equiv.
U11 — Same as U10 but one section not used.
Y1 — 5-MHz crystal, calibrated for 32-pF load capacitance.

Construction

Construction practices with any VFO call for extremely rigid mechanical assembly, and very good filtering and shielding techniques. With a VFO that will be used with several stages of frequency multiplication for an output on 144 MHz, the importance of the aforementioned practices cannot be overstressed. The coil, voltage-variable capacitor, and the trimmer capacitors associated with the frequency-determining parts of the circuit should be mounted securely to eliminate microphonic effects. The leads carrying dc supply voltages should be well filtered and shielded. Since it takes only millivolts of change to cause a wide excursion of frequency, the leads carrying the correction voltage to the VCO should be well shielded against hum and noise.

In the model described here, the VCO coil, L1, is wound on a 2-watt resistor of high ohmic value, thus obtaining a mechanically rigid mount. Dipped silver-mica capacitors are used in the oscillator circuits for temperature stability. All dc and correction voltages are connected to the pc boards via feedthrough capacitors of the solder-in variety. A blank copper-clad board, to provide shielding, is mounted between the frequency divider board and the one containing the VCO and phase detector. The boards are fastened securely to each other and to the chassis by threaded metal posts at the corners.

Adjustment and Operation

As complex as the circuitry for the synthesizer is, there are not many adjustments associated with its operation. The 5-MHz oscillator can be set to zero beat with WWV by adjusting C5. If the reference-oscillator divider chain is working properly, a check with an oscilloscope or audio oscillator should show that a 625-Hz signal is present on pin 1 of the phase detector. The VCO should be oscillating at approximately 6 MHz with the correction voltage removed from L3. If it is not, turns may be added or removed from L1 to correct the frequency. A small trimmer could be installed between the bottom of L1 and ground for exact frequency correction, but it will limit the effectiveness of CR1 in maintaining lockup. C1 is adjusted to set the oscillator to the correct frequency for receiving.

The thumbwheel switches set the programming for the divide-by-*N* counters. S1 sets the division necessary for receiving, and S2 sets that needed for transmitting. With the particular switches used in this unit, the numbers are *not* channel numbers or the output frequency, but rather, are the *divisor* numbers that are applied to the frequency out of the VCO. Direct-frequency readout would require a much more complex circuit and it was felt desirable to keep things as simple as possible. In either case, transmitting or receiving, the first digit of the four-number divisor is preprogrammed into the counter, with the last three numbers being selected by the thumbwheels. As an example, the

VCO frequency required for transmitting on 146.34 MHz is 6097.5 kHz. To obtain 625 Hz for comparison with the reference, it is necessary to divide 6097.5 kHz by 9756. The 756 part of the divisor is set by the switches with the 9 part being preset in the wiring of the divide-by-*N* circuit.

For use in receiving, the output of the VCO is near 5.5 MHz. The equipment that this synthesizer was designed to work with requires a local-oscillator injection frequency in the 130-MHz range for the first mixer. To receive 146.94 MHz, the output from the VCO must be 5561.875 kHz. Reducing this to 625 Hz requires a division of 8899. The 8 part of the divisor is preset in the wiring and the 899 part is set by the thumbwheel switches.

For receivers that require a different injection frequency, it will be necessary to adjust the VCO output frequency and change the programming of the divide-by-*N* counters to obtain the correct combination. Additional information concerning the counters is available in the data sheets for the Motorola MC4016P Programmable Modulo-N decade counter. Motorola application notes AN438 and AN532A are suggested reading for those who would like to learn more about active filters and frequency synthesizers using the MC4044P phase detector.

To keep the noise problem to a minimum, it is not recommended that modulation be applied directly to the synthesizer. A phase modulator stage following the output buffer will provide good results. Many of the commercially manufactured units with which the synthesizer can be used will have such a phase modulator as part of their original circuitry.

Mobile and Portable Equipment

MANY PUBLICATIONS that have appeared in the past 15 to 20 years have contained information on the astonishing growth in the number of mobile operators. If the increase was considered surprising during that period, certainly it can be said that it *really* skyrocketed during the last few years. The advent of repeaters, channelized operation with its increased reliability and driver safety, surplus equipment, and imported and domestic equipment of solid-state design, all have given to mobile operators the inducement to become the most prevalent users of repeaters, which is as it should be.

Home stations, by-and-large, can have improved range with relative ease. A larger – or higher – antenna, more powerful amplifiers, low-noise preamplifiers, and low-loss transmission line, all contribute to an advantageous situation for the fixed-station operator. The mobile enthusiast, however, is faced with limited space, somewhat limited power-supply capabilities, and a relatively low antenna site.

The mobile operator, then, needs a repeater as a means to overcome the handicap of his environment. A repeater, in turn, needs mobile stations to remain useful and to justify its continued existence. The growth in number of repeaters and mobile stations has been a parallel phenomenon because of this inter-dependence.

The potential that exists with this combination of a highly mobile (and this includes portable) station and a remote "output stage" with excellent terrain and equipment advantages extends far beyond the mere satisfaction of one operator being able to talk to another over greater distances than before. These operators have already given invaluable assistance in times of emergency, both local and widespread. Earthquakes, floods, tornados, and hurricanes have all brought out the fm-ers with their mobile rigs and hand-held equipment to do their stint in the awesome aftermath of such disasters. On a more personal level, numerous highway hazards and accidents have been the subject of calls through the machine for assistance or a "phone-patch" to police or fire departments.

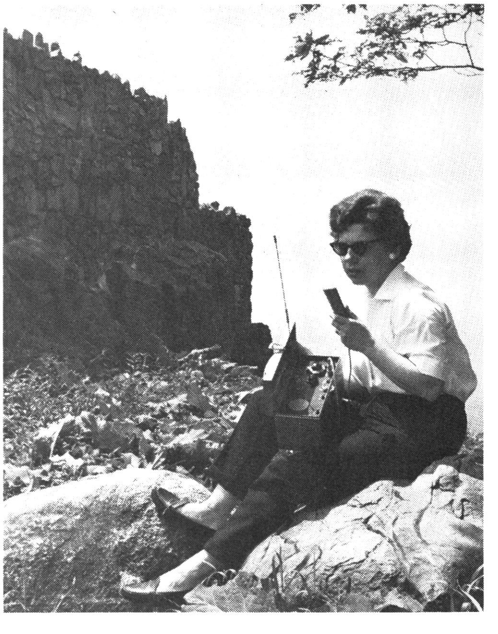


Fig. 5-1 – Mobile or portable operation from mountain-top locations can be fun. Here is W1CKK with a transistorized, battery-powered 2-meter rig.

MOBILE INSTALLATIONS

The theme of the following pages can best be set by quoting from the foreword of the ARRL *Mobile Manual for Radio Amateurs*, fourth edition: "In few other phases of amateur radio is departure from standard so much a matter of necessity, rather than choice, as it is in the field of mobile work. Unlike fixed-station equipment, one design will seldom satisfy the requirements as to space, power, and frequency coverage, of more than a small portion of the many who engage in this fascinating activity."

Certainly no one publication could ever cover the vast number of different rigs that are available to the would-be fm enthusiast. Multiply the number of such rigs by the number of different vehicles, and again by the number of operators – each with his own idea, and the possibilities stagger the imagination. The most useful thing that can be done, therefore, is to offer a few suggestions that will help the beginner to avoid some of the pitfalls, frustrations, or failures that can beset the eager neophyte.

INSTALLATION TIPS

A mobile installation should be planned just as carefully as is a home station, or perhaps even more so. The hazards of driving on today's congested, high-speed highways will not be decreased by a poorly planned layout. Even the adage that one should pull over and stop while using the rig is no cure-all, since it is often more hazardous (or even impossible) to stop along one of these concrete ribbons than to keep moving with the flow of traffic.

Operator safety should be the first item of concern when planning the installation. Such items as the control head, microphone hanger, Touch-Tone pad, should all be fastened temporarily in place with tape or clamps to see if they can be reached by the driver without the need of changing his position or detracting his attention from the road. Cords and wires should be routed so that they will not entangle ones feet or interfere with the operation of braking or steering. The microphone cord in particular, should be checked both when the microphone is in its hanger and when it is in use. Anyone who expects to be more than an occasional mobile operator should consider adapting the rig to accept one of the "headset" type of microphones, thereby leaving both hands free for driving. The stares received from passing motorists will be offset by the feeling of increased safety as the communicator goes his merry way.

Many of the rigs that have been retired from commercial use are of the tube type, and the audio output was measured in watts. The speaker could be tucked away in some recess, out of sight, or where it would not interfere with the leg room of the passengers in the vehicle, and still produce enough sound to blast through the ambient noise level in many cars and trucks. Not so with some of the solid-state rigs that are currently available. Many have a self-contained speaker and an audio output stage that has to work hard to produce one or two watts. Some of these packages have the speaker on the top, where the proximity of the mounting bracket and the dash board of the car can effectively muffle the audio. If at all possible, an external speaker should be connected to rigs of this type. The speaker should be positioned where the operator can get the full benefit of whatever audio power is available. It is not always a good idea to use the speaker that is in the bc set in the car. Many of these speakers provide the dc return to ground for the output transistor, and the transistor could be damaged by turning on the set while the speaker is disconnected.

Drilling

Whether the rig to be installed in the vehicle is a surplus unit requiring space in the trunk, or a compact rig that will fit under the dash, it is almost a certainty that some holes will have to be drilled to accommodate it. Before taking drill in hand, the operator would be well advised to see what is on the other side of the chosen site.

Automobile manufacturers seem to have as many areas in which to place such things as fuel tanks, brake lines, and electrical cables as amateurs have ideas about where to install their equipment. With many of the more compact cars, almost any spot that one picks to drill a hole will have something on the other side of it. Even if the area behind the intended hole seems clear, the drill bit should have a piece of metal tubing slipped over it to limit the penetration. Drills can attach themselves to small wires, insulation, or fabric, and create quite a shambles before the finger can release the trigger.

Even so seemingly innocent a location as the hump in the floor over the drive shaft should be suspect. Some manufacturers have placed the wiring harness for all stop and tail lights along that convenient route, in the form of a flat cable that defies detection until the floor mat is lifted for a look.

Cable Routing

One of the more frustrating aspects of a mobile installation can be finding a route for the cables that must traverse the vehicle, especially for the older, trunk-mount type of rig. A pair of heavy cables is required to supply high current from the battery to the equipment. These heavy cables should be protected by a grommet wherever they pass through a wall or partition. A fuse should be mounted near the point of connection to the battery or electrical system. If the cable must be run outside the car, such as along the frame or under the floor, it should be protected by a heavy plastic sleeve. Clamps should be installed wherever needed to prevent the wires from swaying or chafing on any of the underparts of the vehicle.

There are many routes one can use to install cables that connect trunk-mounted equipment with the control head under the dash. Trim can be removed to expose channels under the doors or around windows. While use of these channels does allow a more aesthetically pleasing installation, the operator may not be too happy when the time comes to remove the equipment. Perhaps the best solution is to lift the floor mat and let the cables lie along the corner formed by the floor and the sill, or near the drive-shaft hump. With proper smoothing of the mat and the felt cushion, such installations are not unsightly. Removal of the equipment in the excitement of obtaining a new car or a new rig is then less of a chore.

ELECTRICAL-NOISE ELIMINATION

One surprise that may come to the beginner on fm is when he discovers that electrical noise, and particularly ignition noise, can be a problem while using a mode that has been touted as virtually noise free. What was overlooked is the use of the word *virtually* instead of *completely*.

Under weak-signal conditions, ignition noise can, and often does, interfere with reception, even though the limiter is doing its job well. A noise impulse can be limited in amplitude to the extent that it does not override the received signal. However, it has still "punched a hole" in the incoming information, and this hole can be just as annoying to an fm-er as to his a-m counterpart. Noise-reducing schemes such as Motorola's "Extender," the Hallett "Message Master," and others, have not been widely successful because, while they do cancel the noise impulse, they cannot fill in the hole with the information that was obscured by that impulse.

Ignition noise and alternator/generator whine can enter the receiver directly via the dc supply cables. With modern solid-state equipment designed to operate from the vehicle storage battery, this type of noise can be very difficult to eliminate. Because of the extreme sensitivity of solid-state devices to low-level signals at their input, brute-force filtering, even using massive components, may not be effective in all cases. The first step is to clean up the *noise source* itself, then utilize the receiver's built-in noise-reducing circuit as a last measure to reduce any noise pulses from passing cars, or from other man-made sources.

Spark-Plug Noise

Spark-plug noise is perhaps the worst offender when it comes to ignition noise. There are three methods of eliminating this type of interference – resistive spark-plug suppressors, resistor spark plugs, or resistance-wire cabling. By installing Autolite resistor plugs a great deal of the noise can be stopped. Tests have proved, however, that suppressor cable between the plugs and the distributor, and between the distributor and ignition coil, is the most effective means of curing the problem. Distributed-resistance cable has an approximate resistance of 5000 ohms per foot, and consists of a carbon-impregnated sheath followed by a layer of insulation, then an outer covering of protective plastic sheathing. Some cars come equipped with suppressor cable. Those which do not can be so equipped in just a matter of minutes. Automotive supply stores sell the cable, and it is not expensive. It is recommended that this wiring be used on all mobile units. A further step in eliminating plug noise is the addition of shielding over each spark-plug wire, and over the coil lead. It should be remembered that each ignition cable is an antenna by itself, thus radiating those impulses passing through it. By fitting each spark-plug and coil lead with the shield braid from a piece of RG-59/U coax line, grounding the braid at each end to the engine block, the noise reduction will be even greater. An additional step is to encase the distributor in flashing copper, grounding the copper to the engine block. This copper is quite soft and can be form-fit to the contour of the distributor. (Commercially manufactured shielded ignition cable kits are also available.) The shield braid of the spark-plug wires should be soldered to the distributor shield if one is used. Also, the ignition coil should be enclosed in a metal shield since the top end of many of these coils is made of plastic. A small tin can can often be used as a top cover for the coil or distributor. It should be soldered to the existing metal housing of the coil. Additional reduction in spark-plug noise can be effected by making certain that the engine hood makes *positive* contact with the frame of the car when it is closed, thus offering an additional shield over the ignition system. The engine block should also be bonded to the frame at several points. This can be done with the shield braid from coax cable. Feedthrough (hi-pass) capacitors should be mounted on the coil shield as shown in Fig. 5-2 to filter the two small leads leaving the assembly.

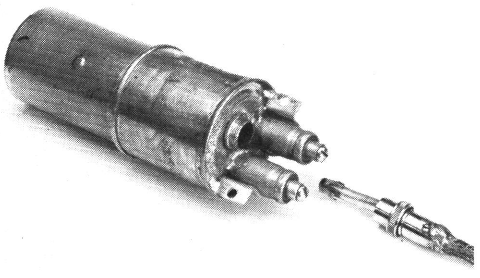


Fig. 5-2 – The automobile ignition coil should be shielded as shown here. A small tin can has been soldered to the metal coil case, and coaxial feedthrough capacitors have been soldered to the top of the can. The "hot" lead of the coil enters the shield can through a modified audio connector.

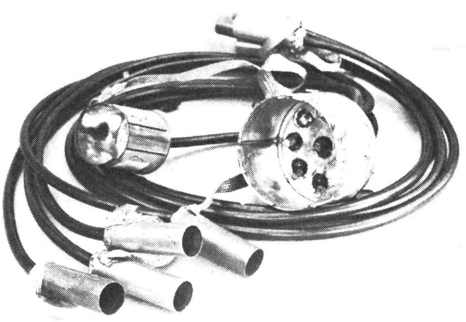


Fig. 5-3 – A typical homemade shielding kit for an automotive ignition system. Tin cans have been put to use as shields for the spark coil and distributor. Additional shields have been mounted on the plug ends of the wires for shielding the spark plugs. The shield braid of the cabling protrudes at each end of the wires and is grounded to the engine block.

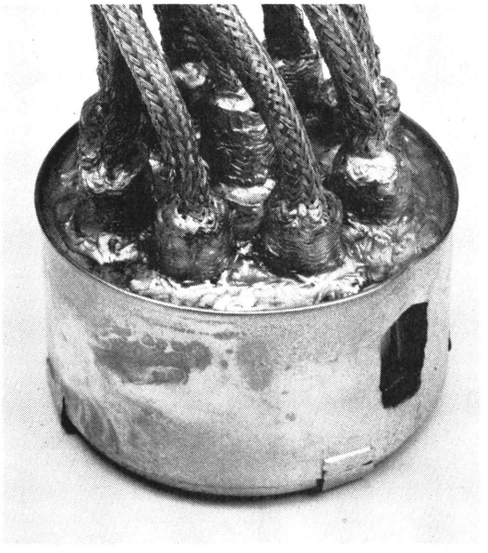


Fig. 5-4 – A close-up view of the distributor shield can. The shield braid over each spark-plug wire is soldered to the top of the can, and the can is grounded to the engine block.

Other Electric Noise

The automotive generator system can create an annoying type of interference which manifests itself as a "whine" when heard in the receiver. This noise results from the brushes sparking as the commutator passes over them. A dirty commutator is frequently the cause of excessive sparking, and can be cleaned up by polishing its surface with a fine grade of emery cloth. The commutator grooves should be cleaned out with a small, pointed instrument. A coaxial feedthrough capacitor of 0.1- to 0.5-μF capacitance should be mounted on the generator frame and used to filter the generator *armature* lead. In stubborn cases of generator noise a parallel L/C tuned trap can be used in place of the capacitor, or in addition to it, tuned to the receiver's operating frequency. This is probably the most effective measure used for curing generator noise.

Voltage regulators are another cause of mobile interference. They contain relay contacts that jitter open and closed when the battery is fully charged. The noise shows up in the receiver as a ragged, "hashy" sound. Coaxial feedthrough capacitors can be mounted at the *battery* and *armature* terminals of the regulator box to filter those leads. The *field* terminal should have a small capacitor and resistor, series-connected, from it to chassis ground. The resistor prevents the regulator from commanding the generator to charge constantly in the event the bypass capacitor short-circuits. Such a condition would destroy the generator by causing overheating.

Alternators should be suppressed in a similar manner as dc generators. Their slip rings should be kept clean to minimize noise. Make sure the brushes are making good contact inside the unit. A coaxial feedthrough capacitor and/or tuned trap should be connected to the output terminal of the alternator. Make certain that the capacitor is rated to handle the output current in the line. The same rule applies to dc generators. *Do not connect a capacitor to the alternator or generator field terminals.* Capacitor values as high as 0.5 μF are suitable for alternator filtering.

Some alternator regulator boxes contain solid-state circuits, while others use single or double contact relays. The single-contact units require a coaxial capacitor at the *ignition* terminal. The double-contact variety should have a similar such capacitor at the *battery* terminal. If noise still persists, try shielding the field wire between the regulator and the generator or alternator. Ground the shield at both ends.

Instrument Noise

Some automotive instruments are capable of creating noise. Among these gauges and senders are the heat- and fuel-level indicators. Ordinarily, the addition of a 0.5-μF coaxial capacitor at the sender element will cure the problem.

Other noise-producing accessories are turn signals, window-opener motors, heating-fan motors and electric windshield-wiper motors. The installation of a 0.25-μF capacitor will usually eliminate their interference noise.

Frame and Body Bonding

Sections of the automobile frame and body that come in contact with one another can create additional noise. Suspected areas should be bonded together with flexible leads such as those made from the shield braid of RG-8/U coaxial cable. Trouble areas to be bonded are:

1 – Engine to frame.
2 – Air cleaner to engine block.
3 – Exhaust lines to car frame and engine block.
4 – Battery ground terminal to frame.
5 – Steering column to frame.
6 – Hood to car body.
7 – Front and rear bumpers to frame.
8 – Tail pipe to frame.
9 – Trunk lid to frame.

Wheel and Tire Static

Wheel noise produces a ragged sounding pulse in the mobile receiver. This condition can be cured by installing static-collector springs between the spindle bolt of the wheel and the grease-retainer cap. Insert springs of this kind are available at automotive supply stores.

Tire static has a ragged sound too, and can be detected when driving on hard-surface highways. If the noise does not appear when driving on dirt roads it will be a sure indication that tire static exists. This problem can be resolved by putting antistatic powder inside each tire. This substance is available at auto stores, and comes supplied with an injector tool and instructions.

MOBILE ANTENNAS

Antennas in general are covered in Chapter 6 of this manual. Many of them were designed with mobile use in mind; others can be adapted for that purpose. The mobile antenna will, in most cases, be vertically polarized in keeping with the practice of most repeater operators; many of the antennas for repeaters are revamped models designed for commercial service.

In the primary coverage area of a repeater, the mobile antenna need not be anything special. The usual quarter-wave whip will suffice to keep the repeater saturated with a full-quieting signal. However, for simplex operation or on the outskirts of a repeater coverage area, a very good antenna installed in the best possible location is a requisite to good communication. Knowledge of the antenna radiation pattern, use of the proper coaxial cable, and carefully installed fittings on that coax, will help the mobile operator to realize a successful installation.

ANTENNA LOCATION

Some typical radiation patterns are shown in Fig. 5-5. It is apparent that the best omnidirectional coverage can be expected when the antenna is placed on the roof at the center of the vehicle. Other locations can contribute to lobes and nulls in the pattern, which can explain why the repeater sounds fine from one direction but becomes choppy from another. If the antenna chosen is of the shortened style, with a lumped inductance to tune it to resonance, the roof-top location is strongly recommended.

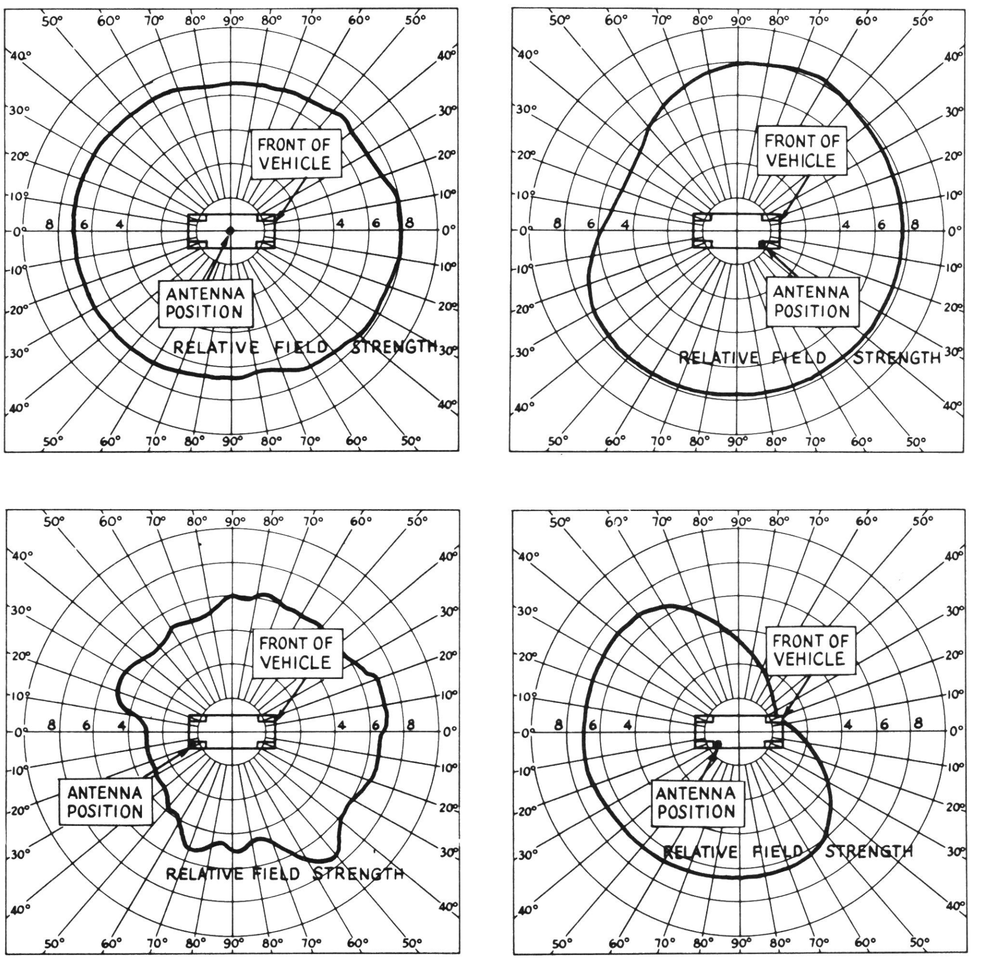


Fig. 5-5 — Radiation patterns versus placement of the antenna of the vehicle. The antenna patterns are based on the use of a 1/4-wave whip.

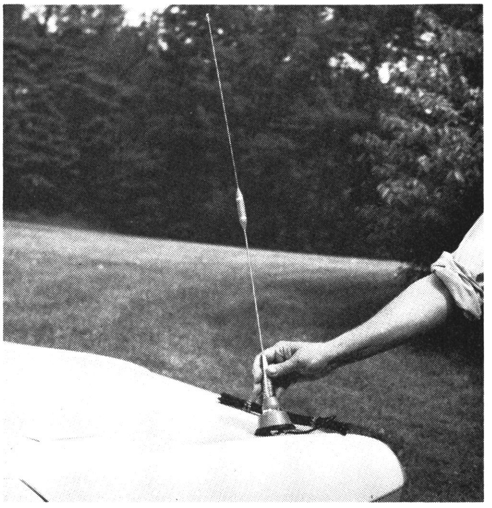


Fig. 5-6 — One type of antenna for the 420-MHz band that can be mounted without the need for drilling holes. A C-shaped clamp will fit over the edge of the trunk lid. The skirt at the base of the mount has a soft plastic ring to prevent marring the surface. This gain antenna, by Antenna Specialists, will provide good coverage from a mobile installation.

For those who shudder at the thought of drilling a hole in such an obvious spot as the center of the roof, there are several methods of mounting the antenna *without* holes. One such installation makes use of a flat sheet of thin metal, held in place with tape or straps. The antenna may be mounted on a small can or bracket that is attached to the center of the flat sheet.

Another aid to antenna installation is a magnetic mount. It consists of a low-profile enclosure for the base of the antenna, and some small but powerful magnets to attach the enclosure to the car body. A mount of this type could be fabricated by the amateur, using an aluminum box and some of the magnetic latches that are commonly used to keep cabinet doors closed. The box should be four or five inches on a side, and one to two inches high. A small box will be adequate to support a shortened antenna or a quarter-wave whip for 146, 220, or 420 MHz. Larger antennas might tend to tip over at high speeds because of their increased wind resistance. The feed line from the antenna may be routed to a window or door opening and held in place by means of tape. Colored tape, such as Mystic, will help to maintain an acceptable appearance.

ANTENNA GAIN

Mobile operators using the hf bands have become accustomed to using antennas that have no gain, or perhaps even a loss, when compared to the usual reference dipole. However, at vhf the wavelengths are such that the construction of an antenna with gain is feasible while staying within the bounds of practicality.

Type	*Gain dB*
1/4λ Ground Plane	−1.8
1/2λ Dipole	Unity
5/8λ Ground Plane	+1.2

Fig. 5-7 — Gain comparison of the three most popular mobile antennas.

Fig. 5-7 shows a comparison of three of the most popular types of mobile antennas. It is easy to see why better results can be obtained when using the 5/8-wavelength whip.

A 6-METER ROOFTOP ANTENNA

It was pointed out earlier that the rooftop is the best place to mount an antenna from the performance standpoint. Those who like to operate on 6 meters, however, might not care to have such a large antenna on top of their cars for several reasons. The average whip for that band is large and quite stiff and the antenna or roof could be damaged from the frequent contact with overhead obstructions. The antenna shown in Fig. 5-8 has a whip portion of a more springy material than the usual quarter-wave antenna, which will minimize any problems from tree limbs or garage doors. The spring section between the whip and the matching transformer at the base will add still more to the mechanical flexibility of the antenna. The bottom of the transformer section contains a PL-259 fitting, thereby allowing a variety of mounting possibilities. The base section was not made to be taken apart, but it can be assumed that it contains a tuned circuit, with the coaxial center conductor and the antenna tapped on at the correct points. Some adjustment of resonance is possible by sliding the whip in and out of the adapter at the top of the spring.

QUICKIE ANTENNA FOR 2 METERS

A low-cost 2-meter mobile antenna can be made from a Millen 37001 high-voltage connector and a 19-inch length of small-diameter brass rod, such as brass welding rod, as shown in Fig. 5-9. Once the whip has been soldered to the male connector, epoxy cement can be used to fill the top of the cap, making the unit quite rugged. The antenna can be mounted any place on the car and will be weatherproof as long as a rubber gasket is placed between the Millen fitting and the car body. This scheme is particularly useful for center-roof installations. Brass screws are recommended for securing the mount so that rust will not form. When desired, the antenna can be unscrewed from its mount and stored inside the car.

COLLINEAR ANTENNA FOR 2-METER MOBILE

Here is an antenna hint for 2-meter mobile operators who want something better than the conventional quarter-wave roof-mounted rod. The idea, a brainchild of W2RUI, with WN2ALR's car and rig for the guinea pig, is shown schematically in Fig. 5-10. The usual quarter-wave rod is made of stiff material so that it will support the phasing section and half-wave radiator above it. The phasing section and radiator are made as a detachable unit that can be screwed onto the top of the rod when the added coverage they provide is needed. The phasing line can be formed into a circle to cut down its over-all dimensions.

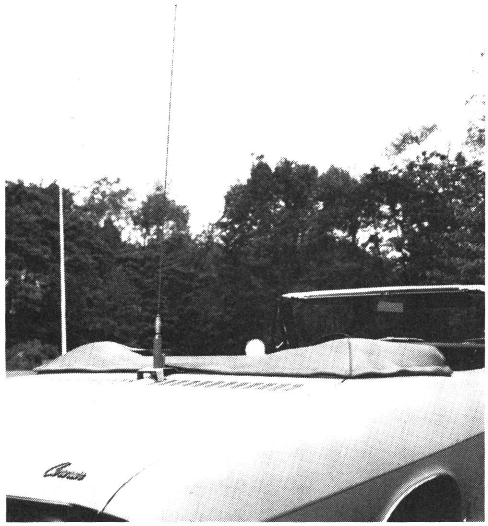


Fig. 5-8 — A base-loaded, six-meter whip that can be mounted in a roof-top location. A PL-259 fitting, part of the base assembly, makes this antenna easy to adapt to several styles of roof-top or rear-deck mount.

COAXIAL FITTINGS

The importance of properly installing the connectors on the coaxial cable is often overlooked in the rush to get that new rig installed in the car for a try at the repeater. Of course, most amateurs know that there should not be a short between the inner and outer conductors, and that there should be continuity from one end to the other. A quick check with the ohmmeter is often used to confirm these conditions. What many do not realize, however, is that as much as 10-dB loss can be introduced into the system by an improperly installed fitting which will pass the continuity test. Fig. 5-11 shows the proper method of assembling coax fittings of the PL-259 variety, and Fig. 5-12 gives this information for the BNC types. These two styles are the ones most prevalent in mobile use.

Troubles to watch for in assembling the connectors would include deformed coax caused by overheating the fitting during soldering the braid or center conductor, poorly soldered connections, and poorly positioned center pins or adapter sleeves in the connector body.

Deformed cable can introduce an impedance bump in the system that will cause a loss, as

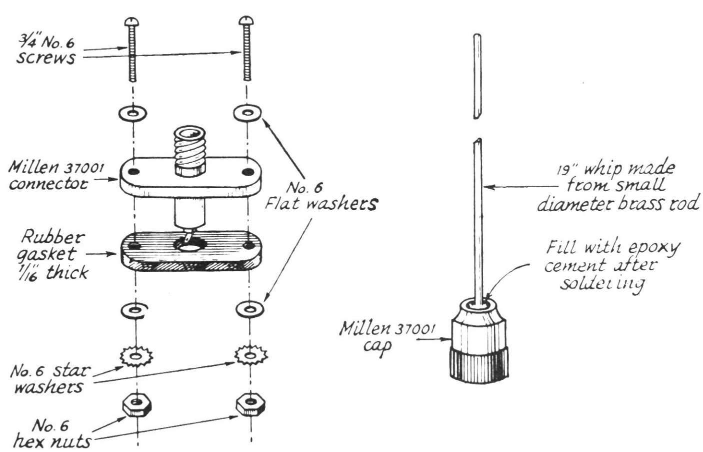


Fig. 5-9 — Construction Details for the Quickie 2-Meter antenna.

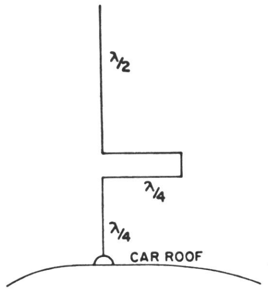
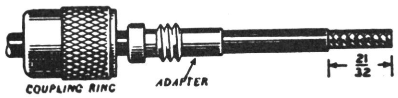
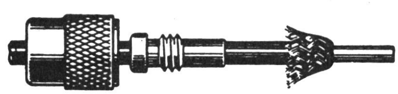


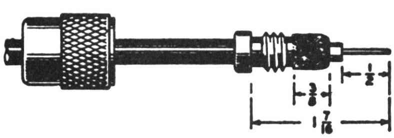
Fig. 5-10 — Electrical circuit of the 2-meter collinear mobile antenna.



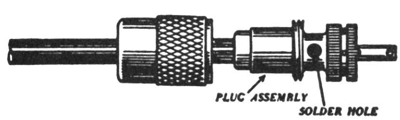
1. — Cut end of cable even. Remove vinyl jacket 3/4" — don't nick braid. Slide coupling ring and adapter on cable.



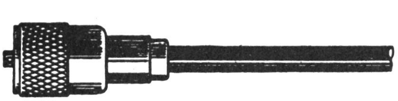
2. — Fan braid slightly and fold back over cable.



3. — Position adapter to dimension shown. Press braid down over body of adapter and trim to 3/8". Bare 5/8" of conductor. Tin exposed center conductor.



4. — Screw the plug assembly on adapter. Solder braid to shell through solder holes. Solder conductor to contact sleeve.

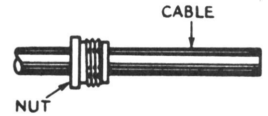


5. — Screw coupling ring on plug assembly.

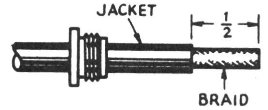
Fig. 5-11 — Details for installing coaxial fittings on RG-58/U type coax. Do not use any more heat than necessary to make solder connections.

Fig. 5-12 — Assembly instructions for BNC type fittings. When using small-diameter cable, care must be taken not to melt the dielectric.

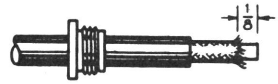
1.—Cut end of cable even.



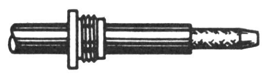
2.—Remove vinyl jacket ½"—*don't nick braid.*



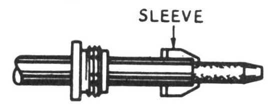
3.—Push braid back and remove ⅛" of insulation and conductor.



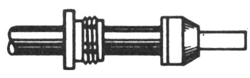
4.—Taper braid.



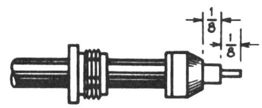
5.—Slide sleeve over tapered braid. Fit inner shoulder or sleeve squarely against end of jacket.



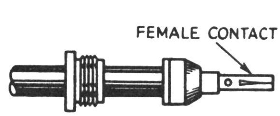
6.—With sleeve in place, comb out braid, fold back smooth as shown, and trim 3/32".



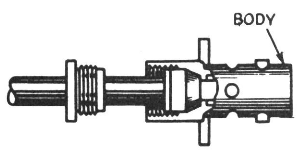
7.—Bare center conductor ⅛"—*don't nick conductor.*



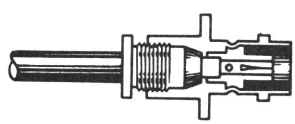
8.—Tin center conductor of cable. Slip female contact in place and solder. Remove excess solder. *Be sure cable dielectric is not heated excessively and swollen so as to prevent dielectric entering body.*



9.—Push into body as far as it will go. Slide nut into body and screw into place, with wrench, until it is moderately tight. Hold cable and shell rigidly and rotate nut.



10.—This assembly procedure applies to BNC jacks. The assembly for plugs is the same except for the use of male contacts and a plug body.



well as make it difficult to load the output stage of the transmitter. This problem is more severe at the higher frequencies. Poorly soldered connections, especially in a moving vehicle, can cause an aggravating noise in the receiver. With some of the solid-state equipment available, an intermittent connection need open for only a small fraction of a second to reflect a mismatch that will destroy the final transistor. Poorly positioned pins and sleeves that do not seat fully can overheat or oxidize and cause noise or loss of power. Any connectors that are exposed to the elements should be sealed with plastic tape and sprayed with a clear protective coating.

PORTABLE EQUIPMENT

Another segment of vhf fm operation that has been aided by the proliferation of repeaters is the use of portable, hand-held equipment. At any sizable gathering of amateurs, voices can be heard emanating from rigs that are carried on shoulder straps or clipped on belts, as the operator checks out the flea-market goodies or attends meetings. There seems to be no limit to the variety of portable equipment available to the amateur. In size, they range from the unit with a large battery pack and 10 to 12 watts output down to the pocket-sized "brick" with its output measurable in milliwatts. Many are units that have been retired from commercial service, and others are adapted from more recently manufactured equipment, designed for marine, police, or commercial use. Some of these units have been described in *QST* in the "Recent Equipment" section.

Trouble shooting and repair of these compact rigs is almost an art unto itself. The components are so small, and the packaging is so dense, that very specialized test equipment is required in order to avoid causing more damage than is repaired. Fortunately, the equipment is among the most reliable that has been available to amateurs. Repairs, when needed, can be done by a properly equipped service shop for a modest fee.

It is perhaps because of this same compactness that not many amateurs have built their own hand-held bricks. The assembly of a portable station by using a Pip-Squeak or Pip-Squawk,[1] and a handful of D cells, would not be particularly difficult. To package the same transmitting and receiving capability in a unit that can fit in a shirt pocket is, for the average amateur, an impossibility. In addition to the impracticality of construction is the cost of the components. Subminiature parts are expensive in small quantities. The prudent amateur will see that the cost of used units, or kits that are available at some suppliers, is far below the tab that would be paid for components alone. We can hope, for the sake of the experimenter, that his situation will improve in the near future.

NICKEL-CADMIUM BATTERIES

Many of the portable units in use by the amateur fm devotee are powered by nickel-cadmium batteries. While this type of power supply can withstand a great number of charge and discharge cycles, certain precautions should be taken for the sake of safety and long battery life.

Gas is generated within the cell during charging and discharging. In normal use, the gas is absorbed by chemicals as fast as it is liberated at the electrodes. If the charging rate is too high, more gas is created than can be absorbed, which causes a pressure build up inside the cell. Some of the larger cells have a vent to release this pressure. However, many of the D and AA size cells are sealed. Any increase in pressure can distort the case, even to the point of causing a short circuit within the cell. Since the gas (hydrogen) is extremely explosive, all that is needed is too much heat or a spark within the cell to create a very destructive – and dangerous – blast. Upon being completely discharged, some cells will reverse their polarity. The next charge cycle often will create the hazardous conditions just described, with the resultant destruction of the cell and nearby components. As with many other aspects of electronics, a small amount of time spent in giving the batteries proper care will result in extended hours of enjoyment of the hobby. Always follow the manufacturers recommendations for the size and style of battery in use.

Use and Care

The rated voltage of the nickel-cadmium cell is considered to be 1.25 under normal load for the

Fig. 5-13 – This is a flexible 1/4-wave whip that can be used with hand-held portables. The antenna shown is a Model HM-4 made by Antenna Specialists.

[1] DeMaw, "An FM Pip-Squeak for 2 Meters," *QST*, March, 1971; "The Pip-Squeak Gets Smaller," *QST* September, 1972. Also see Chapter 4 of this manual; "The 2-Meter FM Pip-Squawk," *QST*, July, 1971; "Pip-Squawk, MK-II FM Receiver," *QST*, August, 1971; "A Single-Conversion 2-Meter FM Receiver," *QST*, August, 1972. Also see Chapter 3 of this manual.

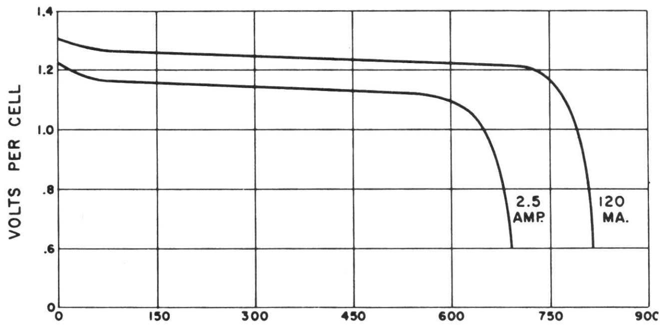


Fig. 5-14 — Voltage vs. milliampere-hour capacity at two discharge rates, 2.5 amp and 120 mA, for a cell rated at 810 milliampere-hours (Sonotone S-102).

particular cell concerned. When placed in use at 1-1/2 times the rated current capability, it will deliver almost the full milliampere-hour rating at voltages between 1.37 and 1.1, after which the voltage drops sharply. A sealed cell in good condition can be recharged on the basis of a ten-hour rate to the full capacity at 1.37 volts. When removed from the charging circuit, there is a tendency for the voltage to increase, in a cell in good condition, to 1.4 (open circuit voltage). When again placed in service the voltage, of course, will drop slightly in accordance with the load or as explained above. Charging time of fourteen to sixteen hours at a slightly higher voltage (1.45) is recommended by most manufacturers to assure satisfactory service. It is always necessary to replace a little more energy than is used. On the basis of a ten-hour rate or less, the cells may be left on charge for longer periods of time without damage and will be ready for use even after months of uninterrupted charging. Similarly they may be left without recharging for long periods if they are not in use. When recharged they will perform as well as ever. As can be seen, the overcharge tolerance is outstanding. Also, it shows some improvement at lower temperatures.

Electrical Characteristics of Nickel-Cadmium Sealed Cells*

Nominal open-circuit potential, volts	1.33
End-of-charge potential, volts	1.60 at 30°F. 1.50 at 80°F. 1.45 at 110°F.
End-of-discharge potential, volts	1.0
Allowable continuous overcharge rate.[1]	$0.1C$

*From "Gulton Hermetically-Sealed Nickel-Cadmium Cells."

[1] C is capacity of cell in ampere-hours.

Fig. 5-15 — Characteristics of Ni-Cad sealed cells.

For many purposes a bank of cells is used, consisting of two or more individual cells of a type determined by load requirements. These are connected in series or series-parallel. Voltages may be derived by multiplication of the above data. Current capabilities must be established from the cell data and the number of parallel circuits.

A simple charger unit may be constructed using a transformer with a secondary voltage of the proper value with a diode of sufficient current rating in series with one of the leads. A variable resistor may be used for adjustment, if the charger is required to take care of several combinations of cell banks. Always connect the positive lead of the charger to the positive contact of the cell bank.

An ac power supply can be designed to operate a device, with a cell bank connected in the circuit to assure fail-safe operation in case of power failure. The power supply should be capable of delivering a constant charge of 20 to 25 percent of the cell-bank charge rate. If the voltage of the device is critical it should not be operated without the cell bank, since voltages will rise without the cell-bank load. This is especially true where solid-state devices, such as transistors, are concerned.

Care of Open Type Cells

Although the information presented has been directed toward hermetically sealed cells it will apply to open-type cells as well. In addition, the open type must be kept dry and free of water from condensation of other sources. Trays or racks, when used, must be clean and dry. A 3-percent solution of boric acid on a rag or cotton waste may be used for cleaning or to neutralize spilled electrolyte. If cells are on intermittent use they should be recharged if the open-circuit voltage is below 1.3 volts. Specific-gravity readings are not entirely dependable because of hydration.

CAUTION

Gas generated during charge or discharge is explosive. Ventilate the area where open-type cells are used.

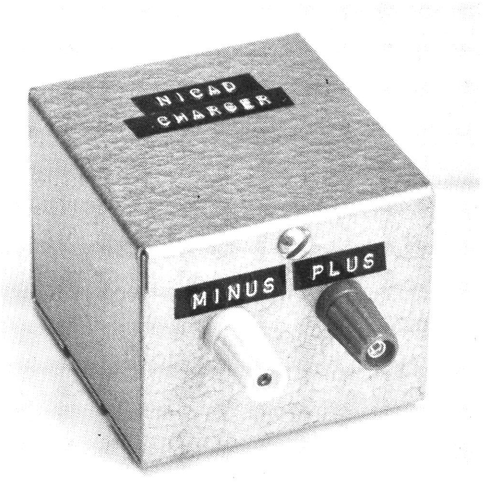


Fig. 5-16 – A compact charger for nickel-cadmium cells such as those in many hand-held portables.

REVITALIZING NICAD BATTERIES

Nickel-cadmium batteries of the kind used in Motorola P-33 hand-carried fm transceivers are prone to becoming relatively lifeless after a few years of charging and discharging. Though the old batteries will take a charge, the capacity of the units is very small. A tired battery will reveal its condition by allowing only a few minutes of transmitting time after being fully charged. However, the receiver will perform fine under the same conditions, mainly because the dc-to-dc converter which supplies operating voltage to the transmitter strip consumes considerable current.

Those wishing to renew battery life can place a pellet of industrial potassium hydroxide (ACS pellets) in each cell bank of the batteries, after removing the plugs. The chemical carries the number FW-56.11, and sells for approximately $1 per pound in most areas of the USA.

A SLOW-RATE CHARGER FOR NICKEL-CADMIUM BATTERIES

Most of the hand-held fm transceivers in use today are powered by Nicad batteries. Since this type battery can be recharged many times it is desirable to have a slow-rate charger available. At least one manufacturer has stated that the 12-volt, 0.5-ampere-hour Nicad pack in their equipment can be recharged between 300 and 400 times before the cells wear out. The rule of thumb for recharging seems to be that the batteries should be slow charged for a period approximately twice the length of the so-called "on" time. That is, if one had his handi-talkie turned on for monitoring and occasional short-time transmitting for, say, 4 hours, the Nicad pack should be slow charged for 8 hours to assure a full charge. The circuit given here will provide a charging rate of roughly 40 mA, and will taper off when the batteries reach a voltage of approximately 13.5.

Building Notes

The circuit is patterned after that used in the E. F. Johnson 540 HT. No transformer is used, nor is the dc filtered. Since very few parts are needed to assemble the circuit, the completed unit can be made quite compact.

A 1-µF blocking capacitor allows some ac voltage to flow from the 117-volt line to the bridge rectifier, in turn providing the required amount of dc voltage to establish a 40-mA charging rate. *The circuit must be isolated from the metal box in which it is built to prevent accidental shock.*

The model shown here is housed in a 2-1/4 x 2-1/8 x 1-3/4 inch Minibox. E. F. Johnson nylon binding posts are used for dc output terminals. Terminal strips are used inside the box for mounting the various components in point-to-point fashion.

This charger has been used to replenish a variety of Nicad batteries whose amp-hour ratings ranged from 0.5 to 4. In all instances good results were obtained. Do not overcharge the Nicads, for shortened battery life will be certain to result if that is done.

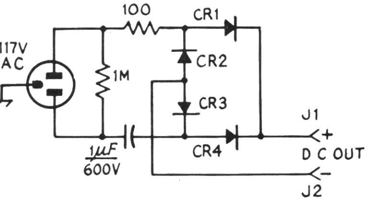


Fig. 5-17 – Schematic diagram of the slow-rate charger. Resistors are 1/2-watt composition and are given in ohms. CR1 through CR4, inclusive, are 600 PRV at 100 mA or greater. Connectors J1 and J2 are nylon binding posts. *Safety first:* Ground the case of the charger to the ground terminal of the ac connector as shown.

Chapter 6

Antennas for Base and Mobile Stations

ANTENNA THEORY for fm and repeater operation is no different than in other modes of amateur radio. Because most repeater operations take place at vhf and uhf, certain precautions must be observed, but the theory is no different than that outlined in *The Radio Amateur's VHF Manual* or in any of the ARRL books that treat antennas.

BASIC CONCEPTS

A very important part of a repeater installation is the antenna. The function of a repeater is to extend the range of communications between mobile stations. To perform this function, the repeater antenna should be installed in the best possible location to provide the desired coverage, and generally this means getting the antenna as high above average terrain as practical. In some instances, it may be desirous to cover only a limited area or direction. In such cases, antenna installation requirements will be completely different with certain limits being set on height, gain and power. Repeater license applications to the FCC require that the applicant must include information on antenna location, height above average terrain, and effective radiated power, all to provide a basis for establishing the intended range of the repeater.

POLARIZATION: HORIZONTAL OR VERTICAL?

Until the upsurge in fm repeater operation, much of the work carried on at vhf was done with antennas using horizontal polarization. However, few, if any, repeater operators or groups use horizontal polarization. There is no purpose served in discussing the pros and cons of the two types of polarization in this manual. The facts show that a majority of repeaters have vertically polarized antennas, and all the antennas described in this chapter are of that type.

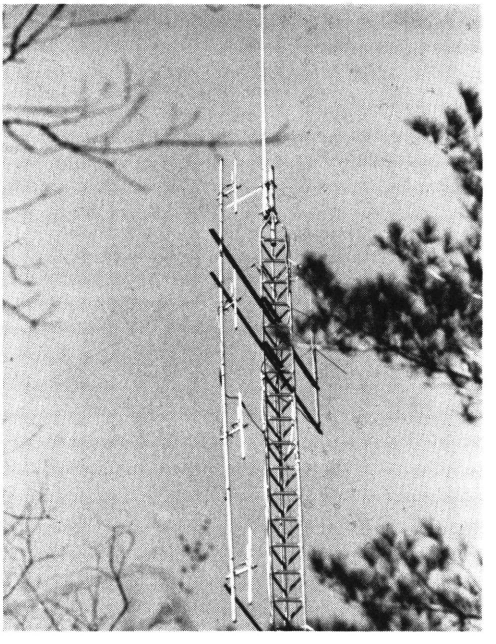
TRANSMISSION LINES

For many amateurs, getting into repeater work may be their first venture into vhf and uhf. The types of transmission lines used at vhf become very important because the losses in a feeder increase as the frequency is raised.

Table I gives the characteristics of the commonly used lines at vhf. Although information is provided for RG58/U and RG59/U it is not recommended that these types be used except for very short feed-line runs, 25 feet or less. These cables are very lossy at vhf and, in addition, unless extreme care is used when installing fittings or making connections, the losses can be appreciably higher.

Also note the differences in loss between the solid polyethylene dielectric types (RG8/U, RG11/U) and those using foam polyethylene (FM8, FM11). If an amateur can afford the difference in cost, he should choose the transmission line that has the least amount of loss.

If it is necessary to bury coaxial cable, it would be best to check with the manufacturer of the coaxial line to get his recommendations. Many of the popular varieties of coaxial cable can not be buried. The dielectric can become contaminated because of moisture and soil chemicals.



Two popular types of antenna are mounted on the tower at this repeater site. The top-mounted antenna is the Station-Master by Communication Products. A set of "side-arm" brackets is used to support a Four-pole antenna by Cush Craft. Partly obscured by the branches is a ground-plane used by a commercial service that shares the tower with the WA1KHK repeater.

Table 1

	Conductor Size	Z_o	Velocity Factor	Attenuation in dB/MHz 50	144	220	420	Power 50	144	220	420
RG58	20	52.5	65.9	3	6	8	15	350	175	125	90
RG59	22	73	65.9	2.3	4.2	5.5	8	500	250	180	125
RG-8/U	7/21	52	65.9	1.5	2.5	3.5	5	1500	800	650	400
RG-11/U	7/26	75	65.9	1.55	2.8	3.7	5	1500	800	650	400
FM8[1]	0.102"	50	80	1.2	2.1	2.5	3.5	6000	3000	2500	1800
FM11[2]	0.64"	75	80	1.0	1.7	2.1	3.2	6000	3000	2500	1800
RG-17/U	0.188"	52	65.9	0.5	1	1.3	2.3	4500	2300	1800	1200
AM5078PJ	0.288"	50	81	0.35	0.65	0.8	1.3	7000	4000	3000	2000

[1,2] Flexifoam [3] Alumifoam

Matching

The figures given in Table I are based on the transmission lines being matched in their characteristic impedances. If there is a mismatch at the end of the line, then the losses increase. Fig. 6-1 shows the additional losses that occur under mismatched conditions.

It should be stressed that the *only way* to reduce the standing-wave ratio on a transmission line is by matching the line *at* the antenna. Pruning a transmission line does not reduce the SWR. The SWR is established by the impedance of the line and the impedance of the antenna, so all matching must be done at the antenna end of the line.

The importance of matching is sometimes overstressed as far as feed-line losses are concerned. Later in this chapter methods will be given for determining the range of a repeater for a given height above average terrain for the power, gain, and feed-line losses. Using this information, the amateur can determine how much SWR and additional losses the system can tolerate. A more important consideration is that some equipment is designed to work into a 50-ohm load. The output circuitry will not tune properly if connected to a mismatched line, resulting in a loss of power or even damage to the final stage.

ANTENNA GAIN

Before getting into the description of antennas used for fm work it is in order to discuss *gain* of antennas. Normally, in measuring hf antenna gain the figures are referenced to those obtained by using a horizontal half-wave dipole. In the fm-communications field, the reference for gain is still a half-wave dipole, but mounted in the *vertical* plane.

Fig. 6-2 is a graph showing the cross-sectional area of the radiation from a vertical half-wave dipole. For comparison, the pattern of a 5/8-wavelength vertical is also shown. The zero points on the graph would be the same as the horizon, if the reader wants to visualize it in that manner. The 5/8-wavelength vertical has a gain of 1.2 dB over the dipole because of a lower angle of radiation.

A common antenna (and the simplest) is a 1/4-wavelength whip perpendicular to a ground plane, called a *ground-plane antenna* by many. By comparison to the half-wave dipole reference, the 1/4-wavelength ground plane shows a loss of 1.8 dB. The 3-dB gain figure so often mentioned for a 5/8-wavelength vertical comes from comparing the antenna to a quarter-wave radiator. All of which indicates that the buyer should determine by what method the antenna manufacturer establishes the gain of his antenna, before making a choice.

Another simple omnidirectional antenna is the 5/8-wavelength vertical. This antenna, as pointed out previously, has a gain of approximately 1.2 dB. There should be three or more radials, each slightly longer than 1/4 wavelength.

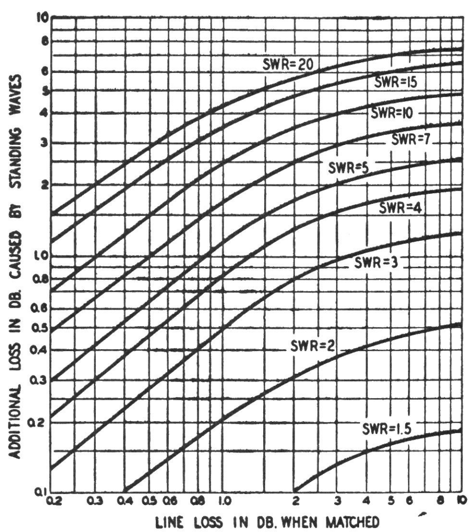


Fig. 6-1 — Increase in line loss because of standing waves (SWR measured at the load). To determine the total loss in decibels in a line having an SWR greater than 1, first determine the loss for the particular type of line, length and frequency, on the assumption that the line is perfectly matched (Table I). Locate this point on the horizontal axis and move up to the curve corresponding to the actual SWR. The corresponding value on the vertical axis gives the additional loss in decibels caused by the standing waves.

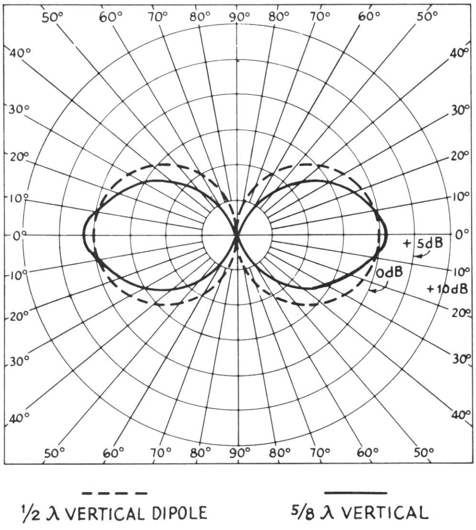


Fig. 6-2 — Vertical radiation pattern of a half-wavelength dipole and a 5/8-wavelength vertical.

Higher omnidirectional gain is usually accomplished by using stacked half-wave dipoles. As an example, four stacked half-wave dipoles on 146 MHz can provide approximately 6 dB of omnidirectional gain. The antenna would be approximately 14 feet in height. Usually, the maximum number of half-wave elements stacked vertically on 146 MHz will be eight, which should provide an omnidirectional gain of about 9 dB. Depending on how the elements are mounted in relation to the supporting mast or tower, the gain can be increased but the pattern will be offset, not omnidirectional (cardioid).

EFFECTIVE RADIATED POWER (ERP)

It will be noted when reading the section on FCC rules and regulations concerning repeater operation that there are certain power limitations for repeater operation. Simply, the amount of power one can use with a repeater is based on the height of the repeater antenna above average terrain. The power ratings are based on **effective radiated power (ERP)** from the repeater antenna. This type of rating has been used for many years in commercial services but seldom in amateur radio.

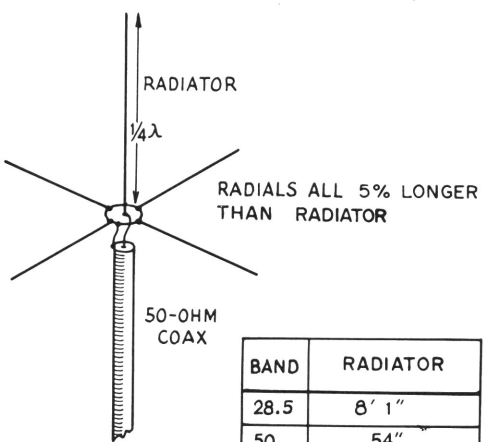
To arrive at the amount of ERP from a given installation is not difficult. First, one must know the exact amount of power *output* from the transmitter. Next, any losses from duplexers, circulators and feed lines are deducted from the power output figure. This leaves the amount of power which is reaching the feed point of the antenna. Finally, this figure combined with the gain of the antenna to arrive at the effective radiated power. The best way to illustrate this procedure is with an example.

Let's assume we have 200 watts output from the transmitter. Also assume that our duplexer and circulator have a total of 3 dB loss, which means we would have 100 watts going into the feed line. Let's also assume that our feed line has an additional 3 dB loss. This means that 50 watts of power will reach the feed point of the antenna. Last, assume our antenna has a gain of 10 dB. With 50 watts reaching the antenna, and 10 dB gain, this means that our effective radiated power would be 500 watts. What this all amounts to is that the power reaching the antenna times the gain of the antenna equals the effective radiated power.

So far as the FCC rules are concerned, antenna gain is based on a half-wave dipole as a reference. This can be important because many antenna manufacturers use an isotropic source as a reference for listing the gain of their antennas. A half-wave dipole has a *gain* of 2.14 dB over an isotropic source. This gain difference must be taken into account in order to meet the FCC regulations. If, for example, an antenna is rated at 9 dB gain over an isotropic radiator, the gain of the antenna by FCC standards is 9 minus 2.14 or 6.86 dB.

THE REPEATER ANTENNA

The choice of the repeater antenna will depend on many factors. Probably the majority of repeater installations are designed for the maximum possible coverage, which will require an antenna with considerable gain. Some repeaters may be designed for coverage in a selected direction, which would mean a directional antenna rather than an omnidirectional one would be needed. Also, it may be desirous to have only limited coverage, in which



BAND	RADIATOR
28.5	8′ 1″
50	54″
146	18½″
220	12″

Fig. 6-3 — The simple 1/4-wavelength ground plane.

case the antenna would not be a high-gain device. It could be as simple as a 1/4-wavelength ground plane.

The first step is to decide how large an area should be covered. Next, using the information given later in this chapter, the repeater group can design their system for the desired coverage.

OMNIDIRECTIONAL GAIN ANTENNAS

The simplest form of omnidirectional antenna used in fm work is the 1/4-wavelength ground plane, shown in Fig. 6-3. This consists of the antenna, a quarter-wave long, mounted over a ground plane which consists of three or four radials, or a ground screen. This type of antenna is widely used in mobile installations with the roof, trunk, or hood serving as the ground screen. The impedance of the antenna is in the vicinity of 30 to 35 ohms, so it provides a reasonable match (SWR of less than 2:1) for 50-ohm feed.

Here is an example of a 450-MHz collinear array made by Cush Craft Corp. This system will provide a theoretical gain of approximately 6 dB omnidirectional or about 9 dB offset.

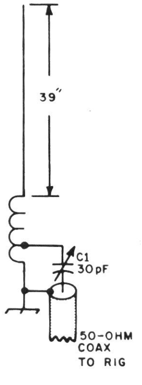


Fig. 6-4 – Circuit of the whip antenna. C1 is a 3 to 30 pF trimmer.

5/8-Wavelength Vertical

Probably the most popular antenna used by the fm group is the 5/8-wavelength vertical. As stated previously, this antenna has some gain when compared to a dipole. The antenna can be used in either a fixed location with radials or in a mobile installation. An inexpensive antenna of this type can be made from a modified CB whip. The antenna shown in Figs. 6-5 and 6-6 is a 5/8-wavelength, 2-meter whip.

The whip that was chosen for this modification is an Archer Model 21-908 (Radio Shack), but there are similar types available. The antenna consists of a clamp-on trunk mount, a base loading coil, and a 39-inch spring-mounted, stainless-steel whip.

The modification consists of removing the loading-coil inductance, winding a new coil, and mounting a 3-30 pF trimmer in the bottom housing. The capacitor is used for obtaining a precise match in conjunction with the base coil tap.

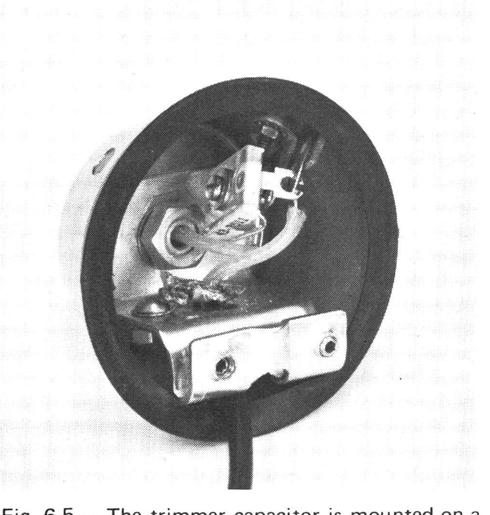
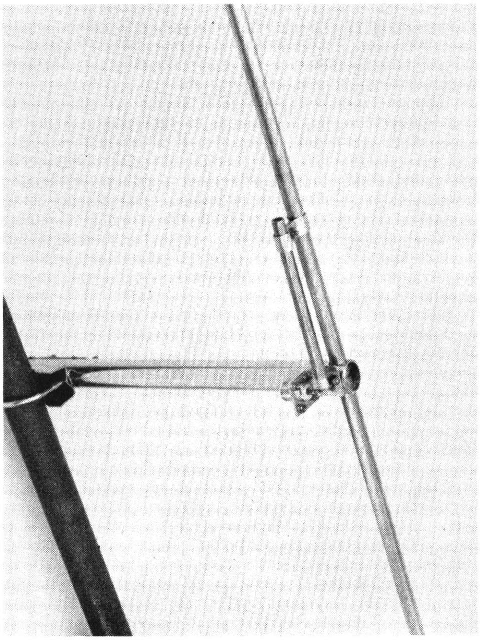


Fig. 6-5 – The trimmer capacitor is mounted on a tie point. Note the hole (lower left) that provides access to the capacitor. The hole should be plugged with a piece of rubber to keep moisture out of the assembly.



The driven element and gamma-matching section of an antenna for 220 MHz. The element is 25 inches long. The gamma section is a 5-inch piece of 3/8-in. OD aluminum tubing. The inner portion of the matching section is the center conductor and foam insulation from FM-8 coaxial cable. Several elements can be stacked and phased to provide gain.

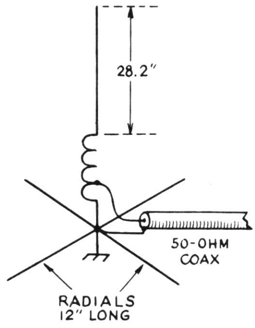


Fig. 6-7 — Diagram of the 220-MHz 5/8-wavelength ground plane.

Modification

The first step is to remove the weather-proof phenolic covering from the coil. Remove the base housing and clamp the whip side of antenna in a vise. Insert a knife blade between the edge of the whip base and the phenolic covering. Gently tap the knife edge with a hammer to force the housing away from the whip section. Proceed carefully, working around the edge of the phenolic covering until it starts to loosen. You'll find that the housing comes off quite easily.

Next, remove the coil turns and wind a new coil using No. 12 wire. The new coil should have nine turns, equally wide spaced. The tap point is two turns up from the base (ground) end on the antenna as modified. The trimmer capacitor is mounted on a terminal strip which is installed in the base housing. A hole must be drilled in the housing to allow access to the capacitor adjustment screw.

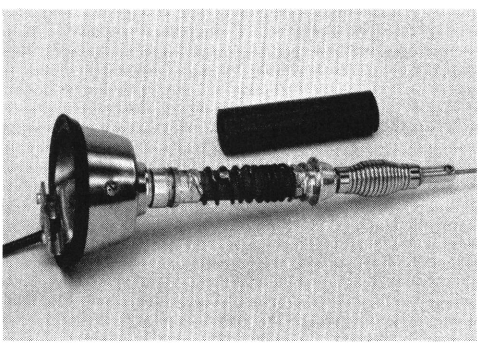


Fig. 6-6 — The new coil is tapped two turns from the base end. It may be necessary to file the coil ends so that the assembly will fit in the phenolic covering.

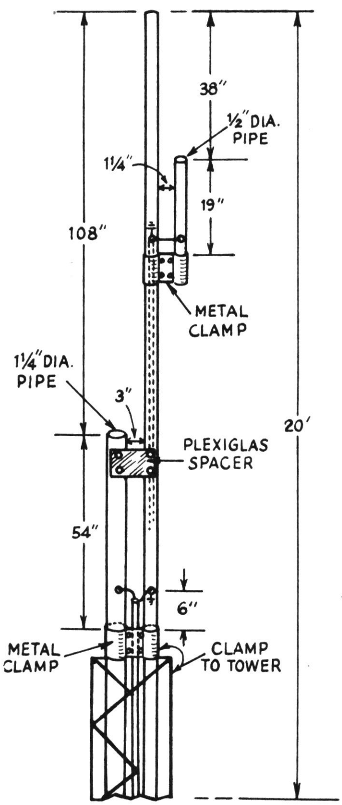


Fig. 6-8 — Constructional details for the 2- and 6-meter J poles.

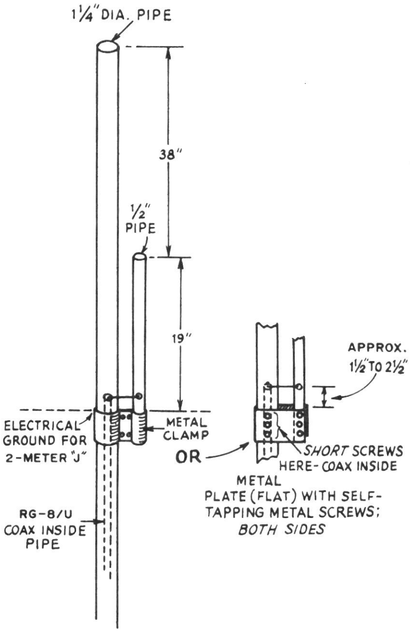


Fig. 6-9 — Details of the 2-meter J pole.

Adjustments

Initially, the tap on the coil was tried at three turns from the bottom. The antenna was mounted on the car, an SWR bridge was inserted in the feed line, and C1 and the whip height were adjusted for a match. A match was obtained, but when the phenolic sleeve was placed over the coil, it was impossible to obtain an adjustment that provided a match with C1 and the whip height. Apparently the dielectric material used in the coil cover has an effect on the coil. After some experimenting it was found that with the tap two turns up from the bottom, and with the cover over the coil, it was possible to get a good match with 50-ohm line. It was interesting to note that mounting the antenna at different points on the car required a readjustment of C1 in order to obtain a match.

This same antenna can be used in a fixed location by adding radials. The radials, three or four, should be slightly longer than 1/4-wave and should be attached to the base mounting section.

220-MHZ 5/8-WAVELENGTH GROUND PLANE

Shown in Fig. 6-7 are the details for a 220-MHz 5/8-wavelength ground plane that can be used either in a fixed location or for mobile work. The vertical radiator is 28.2 inches long and the radials are 12 inches long. The base coil is made from No. 14 enamel-covered wire and consists of 6-1/2 turns with the turns spaced the same as the wire diameter. Polystyrene rod, 1/2-inch diameter, can be used for the coil form and as a support for the vertical portion of the antenna. The coil should be tapped 1-1/2 turns from the bottom end. This tap point should provide a close match for 50-ohm feed.

A COMBINATION 6- AND 2-METER J POLE

Credit for this J Pole system goes to W5WEU who has used these two antennas as omnidirectional radiators with excellent results. The overall antenna is shown in Fig. 6-8. The antenna mast is 1-1/4-inch diameter pipe, 20 feet long. This length can be made up from two 10-foot lengths of TV masting. The first step is to make the 2-meter J pole as shown in Fig. 6-9. Note that the stub dimension of 19 inches is the total length *above* the metal support brackets.

Once the stub is mounted, the antenna can be temporarily supported in a vertical position. Connect an SWR indicator in the feed line, and slide the outer braid of the coax (touching the main mast) and the inner conductor (touching the stub) up and down until you get a low SWR. The point where the SWR is the lowest is where the hole will be drilled in the main mast for the coax. (The coax will be snaked up inside the main mast.) Temporarily ground the braid with a self-tapping screw at the point of lowest SWR. Next, carefully adjust the

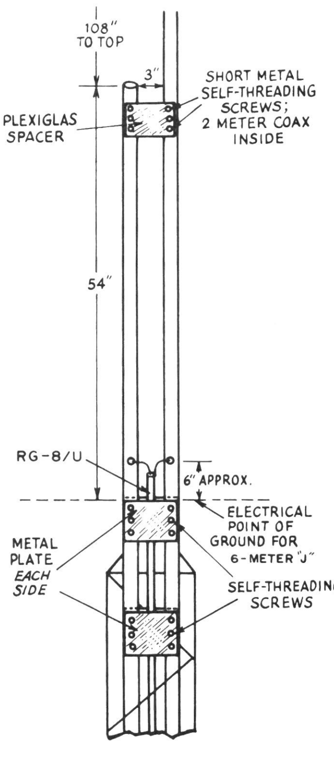


Fig. 6-10 — Details of the 6-meter J pole.

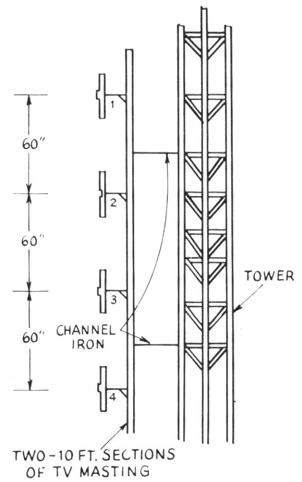


Fig. 6-11 – Spacing and arrangement of the four phased half-wavelength dipoles.

inner conductor up or down the stub until a match is obtained. At the point of matching, drill another hole to take a self-tapping screw for connecting the inner conductor.

The same procedure is used on six meters. However, on this band, the coax is brought up outside the mast in permanent installation. The dimensions shown in Fig. 6-10 will provide a starting point for adjustments. The antennas shown are used on 146.5 and 52.525 MHz.

The completed antenna can be mounted on the top of a tower or mast, providing omnidirectional coverage. Gain of these antennas is the same as that of a vertical half-wave dipole. The coax and feed points should be waterproofed with a good sealing compound.

MULTIELEMENT ARRAYS

Many of the repeater installations in the country use either stacked half-wave dipoles or stacked-coaxial elements. Also, most repeater owners use

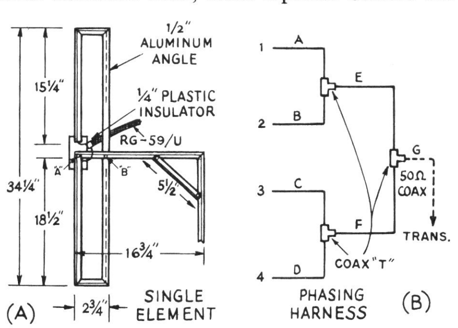


Fig. 6-12 – Constructional details for one of the dipole elements and the phasing harness layout for a four-dipole array. The bottom portion of the dipole is connected to the support arm at two places, "a" and "b."

commercially manufactured antennas. There is no doubt that the antenna manufacturer has an advantage over the home constructor simply because of the tooling and material-procurement advantages. However, the home builder *can* make gain arrays which are as good as or better than manufactured antennas. The antennas described next are practical arrays that are not difficult to make and have been used in the field with excellent results.

A 6-DB GAIN OMNIDIRECTIONAL ARRAY

The antenna shown in Figs. 6-11 and 6-12 was designed by W2EWY and WB2ICP, adapting some of the more attractive features of commercial arrays. This antenna has been in use at the K2AE repeater and excellent results have been obtained.

Basically, the antenna consists of four stacked, grounded, half-wave dipoles, fed off-center, providing a 6-dB gain (omnidirectional) or 9 dB with an offset pattern. One problem in antenna installations is static-type noise. The grounded-dipole configuration has the advantage of reducing this type of noise appreciably.

Fig. 6-12 at A shows the details for one of the elements. The two sides and ends of the elements are made from 1/2-inch aluminum angle stock, available in eight-foot lengths from many hardware dealers. A single eight-foot section will make one element. The element supports are also made from the same type of angle stock.

Fig. 6-12 also shows the details of the phasing harness which is made from RG-59/U. Lengths A,

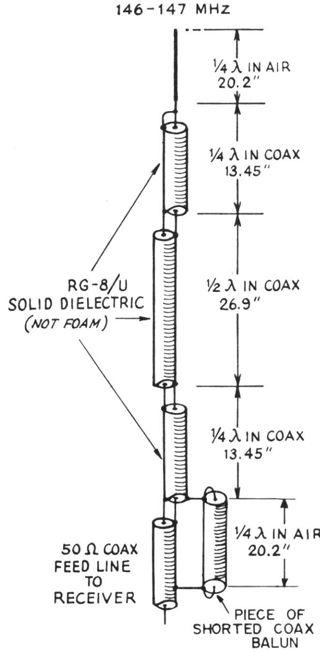


Fig. 6-13 – Basic details of the coaxial-collinear antenna. Only one half-wavelength section is shown.

B, C, and D are each 40.8 inches long from the dipole feed to the center of the T. Lengths E and F are each 63.8 inches long from center of T to center of T.

If the four elements are mounted in line on the TV-mast section, the pattern will be offset with a null in the direction of the supporting mast. The four dipoles can be positioned *around* the mast to provide an omnidirectional pattern. No matching is needed with this antenna. Of several units built from the specifications given, the SWR was below 1.2 to 1.

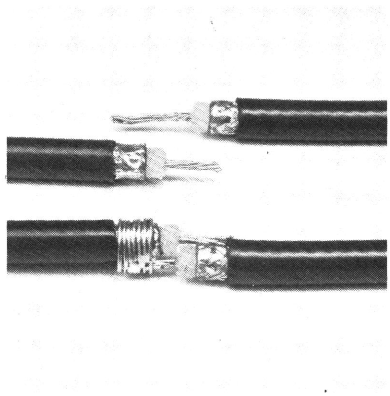
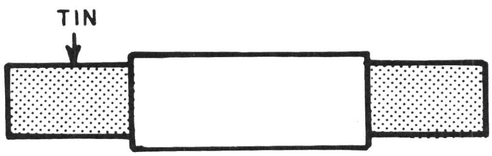


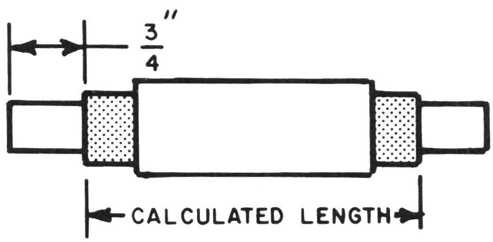
Fig. 6-15 — This shows the prepared end of one of the coax sections and also the method of joining two sections together.

1. Cut to desired length + 2".

2. Cut insulation back 1" on each end. Flux and tin each end, allow to cool.



3. Using tubing cutter, cut shield off 3/4" from first end. Measure off final dimension from shield on cut end to other end, mark, and cut shield with tubing cutter.



4. Using single-edge razor blade, trim insulation leaving 1/16 to 1/8" remaining.

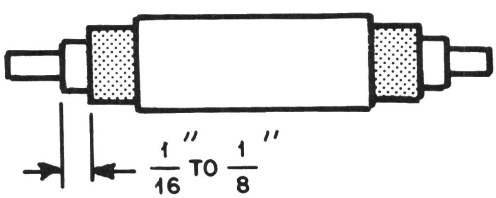


Fig. 6-14 — Method of element preparation.

A COLLINEAR-COAXIAL ARRAY

The antenna shown in Fig. 6-13 is an excellent array for home station or repeater use. The antenna will provide from 6- to 9-dB omnidirectional gain, depending on the number of elements used. This system is one that has been around for years. The refinements shown here were developed by K2CBA, K1DEU, and WA1KJI.

The antenna is a multiple of 1/2-wavelength elements with 1/4-wavelength sections on each end and a 1/4-wave stub at the feed point to reduce feed-line radiation. The dimensions shown are for 146 to 147 MHz, but the antenna can be made for other bands and frequencies.

In order to provide the same amount of gain as would be obtained with stacked dipoles, a larger number of half-wave sections are required. One of the reasons for antenna gain is the spacing between antenna sections. The four stacked dipoles previously described approach optimum spacing for maximum gain. In the coaxial collinear arrangement shown, there is always the problem that as sections are added, the antenna current decreases from one section to the next. In other words, one end of the antenna isn't radiating as much power as the other end. Slightly more than twice the number of elements are required to obtain the same amount of gain as with stacked dipoles. Where four stacked dipoles as described provided slightly less than 6 dB omnidirectional gain, it takes eight half-wave coaxial elements, connected end-to-end, to obtain the same gain figure.

However, the coaxial collinear antenna has certain advantages when installation problems are considered. The completed antenna is encased in either Plexiglas or PVC pipe and can be mounted *above* the supporting tower to get best omnidirectional coverage without the tower interfering with the antenna pattern.

Construction

From the formula 492 divided by the frequency in MHz, calculate a half-wavelength for the desired frequency. This comes out to 3.4 feet, or 40.8 inches for 146 MHz. Next, select the type of coax you plan to use and get the velocity factor (Table I or from the manufacturer.) Generally, the velocity factor for the solid dielectric lines is 0.66 and 0.82 for foam dielectric. The antenna shown in Fig. 6-13 is based on the solid-dielectric coax, 0.66 velocity factor. Using this type of coax provides a shorter overall length for the antenna.

The first step in fabricating the antenna is to make a 3-element version (3 half-waves plus the 1/4-wave top element, the 1/4-wave coax section and the bottom 1/4-wave section.) Fig. 6-14 shows the details for making the coaxial sections. The top section can be made from a piece of copper tubing or No. 12 wire.

When the antenna is completed, suspend it clear of any metallic objects. Using a low-power transmitter and SWR bridge make a check across the band to determine if the antenna is high or low in frequency. The lowest SWR reading will occur at resonance. If this is not within ± 1 MHz of the desired frequency, trim the half-wave elements accordingly. More than likely, this will not be required. Also, don't be concerned about the specific SWR at this time. Look only for the minimum reading.

Depending on whether resonance is too high or too low in frequency, alter another pair of half-wave elements, making them 1/4- to 1/2-inch longer if the antenna is too high in frequency, or a like amount shorter if the antenna is too low in frequency. Continue this operation adding pairs of elements until you reach the desired length. Eight half-wave elements will provide about 6 dB of gain and 16 elements will give approximately 9 dB of gain.

Next, tape each connection with a good grade of electrical tape, applying several layers. This will provide mechanical strength and weatherproofing. With the several arrays that were built using this design, the SWR was always below 1.3 to 1 at the design frequency.

The antenna can be housed inside 1-3/4-inch diameter PVC pipe. Also, a new type of pipe has recently become available from plumbing supply dealers. This is Fiberglas pipe and is available in 25-foot lengths with diameters starting at 2-1/2 inches. The ends of this pipe are tapered so that it can be joined to another section. The Fiberglas pipe is extremely flexible without danger of breaking so it can be supported at one end, such as at the top of a tower, permitting the antenna to be in the clear.

CALCULATING REPEATER COVERAGE

One of the requirements for FCC approval of a repeater license application is the furnishing of information intended to indicate the range of the repeater. The following information may be helpful as background for various calculations which might be involved. It was prepared for Prodelin Corp., Hightstown, New Jersey, by their Chief Engineer, Bob Lewis, W2EBS, and is reproduced by courtesy of Prodelin Corp.

The calculations are based on antenna heights above *average* terrain. The object is to determine range or distance from the repeater that will produce 1 μV of signal across a 50-ohm antenna at a mobile or home station. The antenna that will be used as a standard is a 1/4-wave whip. Fig. 6-16 shows the effective aperture of a 1/4-wave whip at 30, 150, and 450 MHz. To determine what field strength is required to obtain 1 μV across the antenna terminals the following formula is used:

$$F_s = \frac{V}{A_p}$$

where V is the required voltage (1 μV) and A_p is the aperture of the antenna. For example, the required field strength in μV/m to produce 1 μV across the antenna terminals at 150 MHz is *0.32* or 3.3 μV/m. To convert this figure to decibels refer to Fig. 6-17. We find that 3.3 μV/m is a ratio of 3.3 to 1 which is +9.6 dB above 1 μV.

The next step is to determine the field strength at a given distance from the repeater site. Fig. 6-18 indicates the dB level above or below 1 μV/m for transmitter heights of 100 to 500 feet versus the distance in miles. The field strength is based on a mobile or home unit having an effective height of 10 feet above ground and on 1 watt radiated from the repeater antennas. Note that Fig. 6-18 has three frequencies listed, 30, 150, and 450 MHz, which for all practical purposes are close enough to the amateur bands of interest. Fig. 6-19 is a graph for a power correction factor referred to a radiated power of 1 watt.

Let's assume that the repeater antenna is 100 feet high and the transmitter output (not input) is 50 watts. Also, assume that the repeater antenna

Effective Aperture

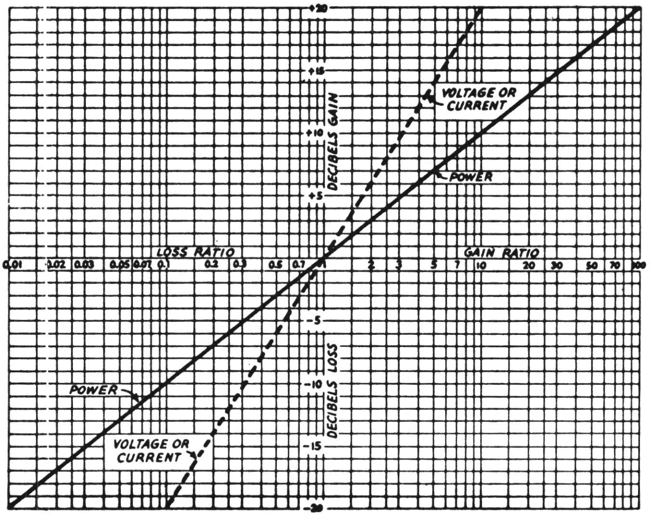
Freq.,MHz	*λ/4 Whip*
30	1.35
150	0.32
450	0.1

$$F_s \frac{V}{A_p}$$

F_s = Field Strength
V = 1 μV
A_p = Effective Aperture

Fig. 6-16 — Effective aperture of a 1/4-wave whip.

Fig. 6-17 — Chart of decibels vs. power or voltage gain or loss. When the voltage curve is used the voltages must be measured across identical impedances. The range of the chart can be extended by adding (or subtracting, if a loss) 10 dB each time the *power* ratio is multiplied or divided by 10, or 20 dB each time the *voltage* is multiplied or divided by 10.



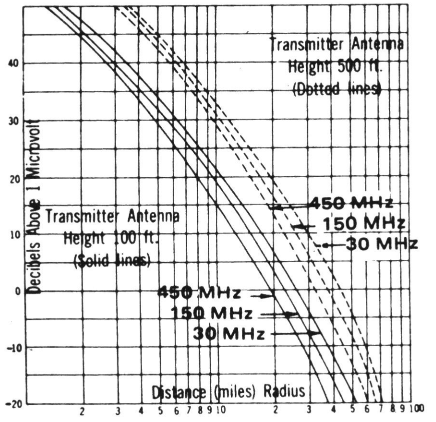


Fig. 6-18 — These curves indicate the dB level above or below 1 μV/m for transmitter heights of 100 ft. and 500 ft. versus distance in miles. The field strength is based on the mobile unit having an effective height of 10 ft. above ground and on 1 watt radiated from the base station antenna.

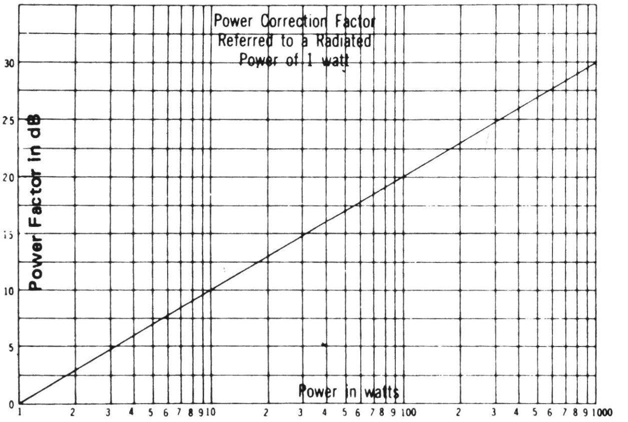


Fig. 6-19 — Power correction factor graph.

has a gain of 6 dB. Since the field strength is based on 1 watt radiated, refer to Fig. 6-19 which gives the power correction factor. The correction factor for 50 watts is 17 dB. Assume the feed line is 100 feet of RG-8/U which has a loss of 2.5 dB at 146 MHz. Taking the power, antenna gain, and feed line loss (17.0 + 6 − 2.5 dB) the total correction is 20.5 dB.

In the case of 1 watt radiated we had determined that +9.6 dB above 1 μV/m was required to produce the 1 μV across the antenna terminals of the 1/4-wave whip. However, because of the repeater transmitter power and antenna gain minus feed line losses, we must consider this a minus figure because we have improved the propagation conditions. Therefore, −20.5 dB +9.6 dB = −10.9 dB below 1 μV/m.

In Fig. 6-18 , 10.9 below 1 μV/m indicates a distance of approximately 35 miles for a 146-MHz signal and a 100-foot-high antenna. Calculations of expected coverage for antenna heights other than those given can be interpolated on the chart in Fig. 6-18.

Chapter 7

Repeaters

A REPEATER IS a device which retransmits received signals in order to provide improved communications range and coverage. This communications enhancement is possible because the repeater can be located at an elevated site which has coverage that is superior to that obtained by most stations. A major improvement is usually found when a repeater is used between vhf mobile stations, which normally are severely limited by their low antenna heights and resulting short communications range. This is especially true where rough terrain exists.

SIMPLE REPEATERS

The simplest repeater consists of a receiver with its audio output directly connected to the audio input of an associated transmitter tuned to a second frequency. In this way, everything received on the first frequency is retransmitted on the second frequency. But, certain additional features are required to produce a workable repeater. These are shown in Fig. 7-1A. The "COR" or carrier-operated relay is a device connected to the receiver squelch circuit which provides a relay contact closure to key the transmitter when an input signal of adequate strength is present. As all amateur transmissions require a licensed operator to control the emissions, a "control" switch is provided in the keying path so that the operator may exercise his duties. This repeater, as shown, is suitable for installation where an operator is present, such as the home of a local amateur with a superior location, and would require no special licensing under existing rules.

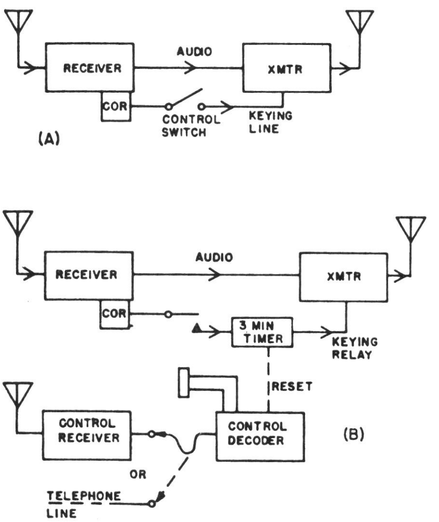


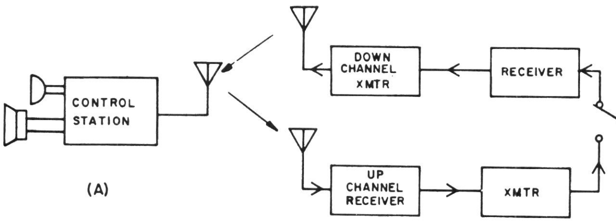
Fig. 7-1 — Simple repeaters. The system at A is for local control. Remote control is shown at B.

In the case of a repeater located where no licensed operator is available, a special license for remote control operation must be obtained and provisions made to control the equipment over a telephone line or a radio circuit on 220 MHz or higher. The licensed operator must then be on hand at an authorized control point. Fig. 7-1B shows the simplest system of this type. The control decoder may be variously designed to respond to simple audio tones, dial pulsed tones, or even "Touch-Tone" signals. If a leased telephone line with dc continuity is used, control voltages may be sent directly, requiring no decoder. A 3-minute timer to disable the repeater transmitter is provided for fail-safe operation. This timer resets during pauses between transmissions and does not interfere with normal communications. The system just outlined is suitable where all operation is to be through the repeater and where the frequencies to be used have no other activity.

Complete System

Fig. 7-2 shows a repeater that combines the best features of the simple repeater and the remote base. Again, necessary control and keying features have not been shown in order to simplify the drawing, and make it easier to follow. This repeater is compatible with simplex operation on the output frequency because the operator in control monitors the output frequency from a receiver at the repeater site between transmissions. The control operator may also operate the system as a remote base. This type of system is almost mandatory for operation on one of the national calling frequencies, such as 146.94 MHz, because it minimizes interference to simplex operation and permits simplex communications through the system with passing mobiles who may not have facilities for the repeater-input frequency.

The audio interface between the repeater receivers and transmitters can, with some equipment, consist of a direct connection bridging the transmitter microphone inputs across the receiver speaker outputs. This is not recommended, however, due to the degradation of the audio quality in the receiver-output stages. A cathode follower connected to each receiver's first squelch-controlled audio amplifier stage provides the best results. A repeater should maintain a flat response across its audio passband to maintain the repeater intelli-



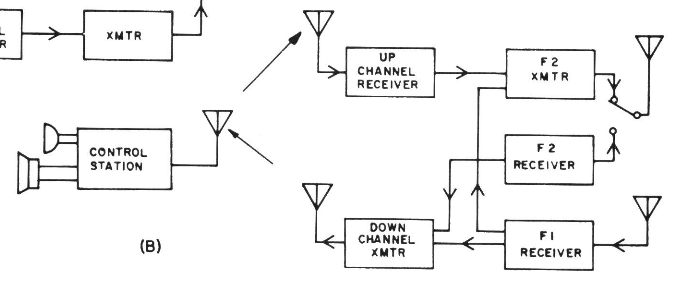


Fig. 7-2 – A remote base is shown at A. A repeater with remote-base operating capability is shown at B. Control and keying circuits are not shown. Telephone-line control may be substituted for the radio-control channels shown.

gibility at the same level as direct transmissions. There should be no noticeable difference between repeated and direct transmissions. The intelligibility of some repeaters suffers because of improper level settings which cause excessive clipping distortion. The clipper in the repeater transmitter should be set for the maximum system deviation, for example, 10 kHz. Then the receiver level driving the transmitter should be set by applying an input signal of known deviation below the maximum, such as 5 kHz, and adjusting the receiver audio gain to produce the same deviation at the repeater output. Signals will then be repeated linearly up to the maximum desired deviation. The only incoming signal that should be clipped in a properly adjusted repeater is an overdeviated signal.

The choice of repeater input and output frequencies must be carefully made. On two meters, 600-kHz spacing between the input and output frequencies is common. Closer spacing makes possible interference problems between the repeater transmitter and receiver more severe. Greater spacing is not recommended if the user's transmitters must be switched between the two frequencies, as happens when the output frequency is also used for simplex operation, either for short-range communications, or to maintain communications when the repeater is not functioning. For operation on 440 MHz, a spacing of 5 MHz is recommended.

Careful consideration of other activity in the area should be made to prevent interference to or from the repeater. Many "open" or general-use repeaters have been installed on one of the national calling frequencies. On two meters, a 146.94-MHz output is usually paired with a 146.34-MHz input, and many travelers have made good use of this combination where it is found. Where 146.94-MHz simplex activity has not permitted a repeater on this frequency, 146.76 MHz has been used as an alternative. On six meters, several choices of input frequencies have been paired with 52.525 MHz. There have been several plans formulated for an orderly usage of the vhf bands. Differences in geography, population, and operating style preclude the use of any one plan on a nationwide basis at this time. Before selecting a band and frequency for a repeater, any local or area plans should be studied thoroughly. More information on frequency coordination and band plans will be found in Chapter 14.

In some cases where there is overlapping geographical coverage of repeaters using the same frequencies, special methods for selecting the desired repeater have been employed. One of the most common techniques requires the user to transmit automatically a 0.5-second burst of a specific audio tone at the start of each transmission. Different tones are used to select different repeaters. Standard tone frequencies are 1800, 1950, 2100, 2250, and 2400 Hz. More detailed information about tone control devices can be found in Chapter 8 of this manual.

PRACTICAL REPEATER CIRCUITS

Because of their proven reliability, commercially made transmitters and receiver decks are generally used in repeater installations. Units designed for repeater or duplex service are preferred because they have the extra shielding and filtering necessary to hold mutual interference to a minimum when both the receiver and transmitter are operated simultaneously.

Wide band noise produced by the transmitter is a major factor in the design of any repeater. The use of high-Q tuned circuits between each stage of the transmitter, plus shielding and filtering throughout the repeater installation, will hold the wideband noise to approximately 80 dB below the output carrier. However, this is not sufficient to prevent *desensitization* – the reduction in sensitivity of the receiver caused by noise or rf overload from the nearby transmitter – if the antennas for the two units are placed physically close together.

Desensitization can easily be checked by monitoring the limiter current of the receiver with the transmitter switched off, then on. If the limiter current increases when the transmitter is turned on, then the problem is present. Only physical isolation of the antennas or the use of high-Q tuned cavities in the transmitter and receiver feeders will improve the situation.

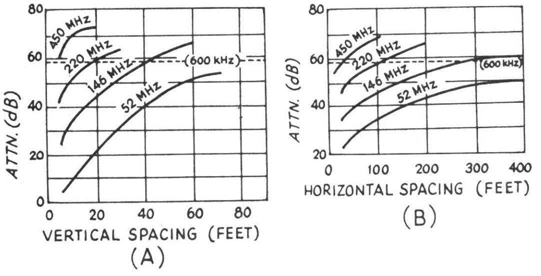


Fig. 7-3 — Charts to calculate the amount of isolation achieved by (A) vertical and (B) horizontal spacing of repeater antennas. If 600-kHz separation between the transmitted and received frequencies is used, approximately 58-dB attenuation (indicated by the dotted line) will be needed.

Antenna Considerations

The ultimate answer to the problem of receiver desensing is to locate the repeater transmitter a mile or more away from the receiver. The two can be interconnected by telephone line or uhf link. Another effective approach is to use a single antenna with a *duplexer*, a device that provides up to 120 dB of isolation between the transmitter and receiver. High-*Q* cavities in the duplexer prevent transmitted signal energy and wideband noise from degrading the sensitivity of the receiver, even though the transmitter and receiver are operating on a single antenna simultaneously. A commercially made duplexer is very expensive, and constructing a unit requires extensive metal-working equipment and test facilities. Duplexers are described in more detail at the end of this chapter.

If two antennas are used at a single site, there will be a minimum spacing of the two antennas required to prevent desensing. Fig. 7-3 indicates the spacing necessary for repeaters operating in the 50-, 144-, 220-, and 420-MHz bands. An examination of the curves will show that vertical spacing is far more effective than is horizontal separation. The chart assumes unity-gain antennas will be used. If some type of gain antenna is employed, the pattern of the antennas will be a modifying factor. A rugged repeater antenna was described in *QST* for January, 1970.

CONTROL

Two connections are needed between the repeater receiver and transmitter, audio and transmitter control. The audio should be fed through an impedance-matching network to insure that the receiver output circuit has a constant load while the transmitter receives the proper input impedance. Filters limiting the audio response to the 300- to 3000-Hz band are desirable, and with some gear an audio-compensation network may be required. A typical COR (carrier-operated relay) circuit is shown in Fig. 7-4A. This unit may be operated by the grid current of a tube limiter or the dc output of the noise detector in a solid-state receiver.

Normally a repeater is given a "tail"; a timer holds the repeater transmitter on for a few seconds after the input signal disappears. This delay prevents the repeater from being keyed on and off by a rapidly fading signal. Other timers keep each transmission to less than three minutes duration (an FCC requirement), turn on identification, and control logging functions. A simple timer circuit is shown in Fig. 7-4B. A unijunction transistor sets the timing cycle while a silicon-controlled rectifier activates the control relay. If desired, an all-solid-state control system can be constructed using a flip-flop IC in place of the relay.

COMMERCIALLY BUILT REPEATER PACKAGES

Club groups wishing to avoid some of the problems common to the interfacing of various brands of surplus fm gear (when building a composite repeater) may want to consider purchasing a new repeater. There are a number of manufacturers involved in the business of selling complete vhf and uhf fm repeaters. In most

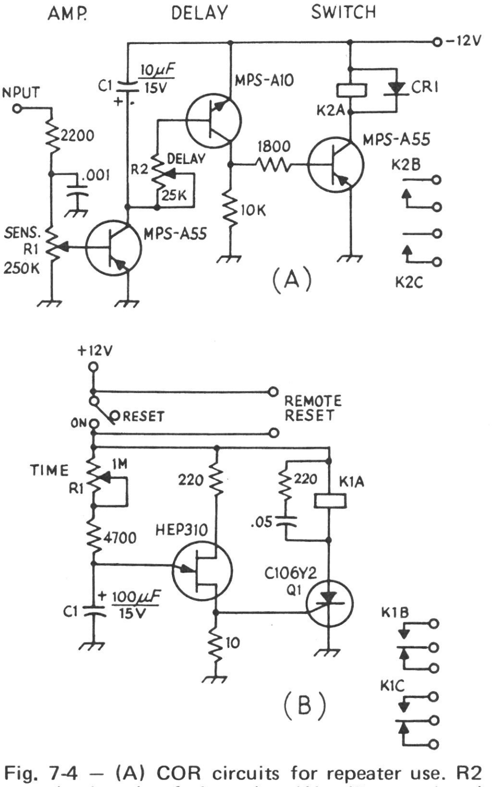


Fig. 7-4 — (A) COR circuits for repeater use. R2 sets the length of time that K1 will stay closed after the input voltage disappears. K1 may be any relay with a 12-volt coil, although the long-life reed type is preferred. CR1 is a silicon diode. (B) Timer circuit. C1 should be a low-leakage capacitor; CR1 is a General Electric silicon-controlled rectifier type C106B. K2 may be any miniature relay with a 12-volt coil. Reset of the timer is accomplished by interrupting the supply voltage momentarily.

instances the equipment can be retuned for use in the 2-meter and 450-MHz amateur bands. These commercial packages come with a relatively large price figure, but offer reliable, efficient operation to those who are willing to spend, say, $1500 to $2500. Some of the companies who specialize in the manufacture of FCC type-accepted repeaters are E. F. Johnson, Motorola, and General Electric.

The striking difference between a modern store-bought repeater and one which consists of myriad pieces of surplus and homemade fm gear is the size. A typical amateur repeater may grow like Topsy, occupying several feet of rack space at the site. Many bundles of interconnecting cable are normally required to marry the various subassemblies. Furthermore, most ham repeaters use tube-type equipment, and this dictates the need for ventilation measures which would not be necessary if solid-state gear was used.

Perhaps the reliability factor deserves the greater emphasis when deciding between homemade and commercial composite repeaters. Some sites, because they are located on mountains that are not accessible the year around (dependent upon weather conditions), need to be equipped with repeaters that are not apt to break down and require frequent servicing. The older surplus fm strips used by many clubs are prone to periodic failure despite the fervent efforts of the technical committee. Well-designed solid-state fm equipment has been proved more reliable than most tube units. Therefore, there may be some wisdom in considering the purchase of a modern solid-state or hybrid machine for use in isolated locales.

Ideally, and in keeping with the true amateur spirit, the repeater operator or club technical committee would build the complete system from scratch. Sometimes, however, this is not practical if time is a determining factor in getting the station on the air. A commercially built system can, in such instances, serve as the nucleus of the repeater station, and the accessory equipment can be built by the club or operator.

The photo in Fig. 7-5 shows a commercial 2-meter repeater capable of delivering 100 watts output. All of the circuitry up to the PA stage is solid-state. An external-anode tube (type 8072) is cooled by a massive heat sink. The latter is connected to a thermostat which turns on a blower when a specific operating temperature is reached. A control panel provides for metering of the important stages in the transmitter and receiver. The equipment comes with a built-in COR and three-minute timer. A front-panel switch can be activated to provide local PTT control or repeat operation. Connections are available for phone-line control of the system.

The decision to buy or build must be considered carefully if a club wants to make the best use of its funds. It is not unlikely that one could spend as much money collecting subassemblies of various brands (and putting them into service) as when investing in a new repeater system of the type just described. The purpose of mentioning this approach is merely to make the reader aware that several companies do manufacture complete repeater packages.

CAVITY RESONATORS

While the problem of desensing of the receiver can be reduced, and often eliminated, by separation of the transmitting and receiving antennas, there is still a need to decrease the amount of

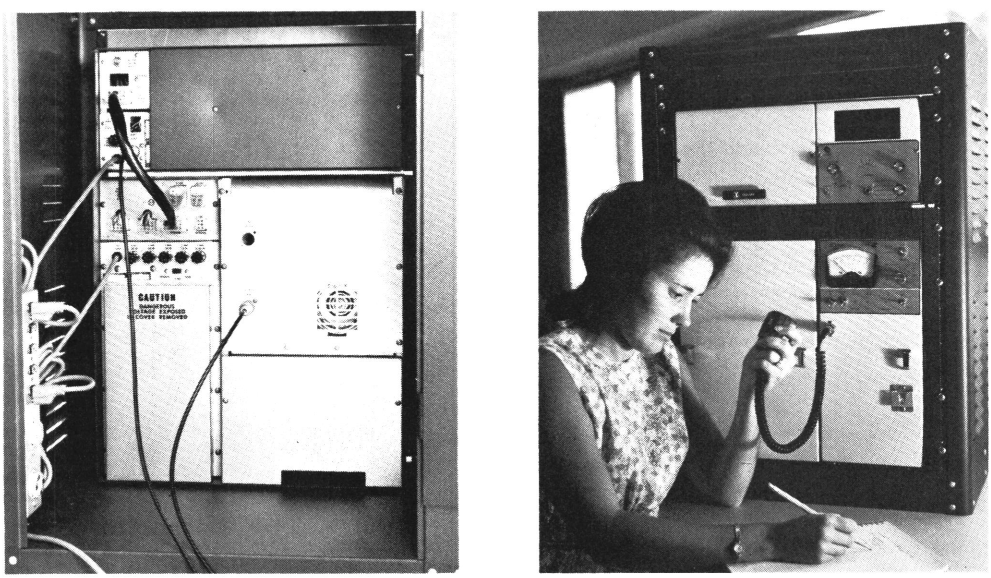
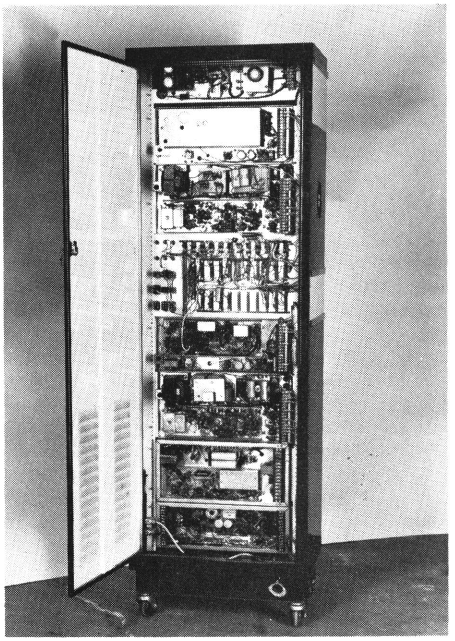


Fig. 7-5 — A complete commercially made 2-meter fm repeater is shown here. All that is needed for amateur operation with this unit is a duplexer, identifier, logging system, and antenna. For unmanned operation, of course, remote-control circuitry would be needed. The equipment shown here is an E. F. Johnson Model 938.



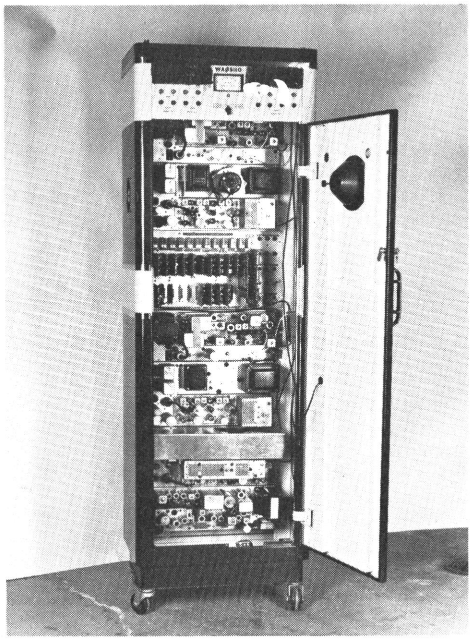


Fig. 7-6 – A desirable feature in a repeater is a redundant system and a means of quick change over in case of failure of the main repeater. Shown here is a well planned 2-meter (with 420-MHz cross-link) repeater. The top panel houses the 6- and 12-volt supply for operation of all relays and a wattmeter that can be switched to either of the three transmitters. Next is the main 2-meter receiver and 60-watt transmitter with power supplies. The complete control system consists of plug-in boards and contains all circuits for the COR, code identifier, audio coupling, and a touch-tone decoding system. Following the control system is the standby receiver and transmitter which is capable of 30 watts on 2 meters. The bottom two items in the equipment rack are a 420-MHz repeater receiver and transmitter. In this outstanding repeater, The Pueblo Amateur Club, WAØSNO, has placed just about everything in one neat package, exclusive of the duplexer and antenna system.

transmitted energy that reaches the receiver input. In addition, nearby transmitters not associated with the repeater can cause overloading and desensitization. A cavity resonator can be effective in solving the problem in either case.

The most common type of cavity resonator is in the form of a large-diameter coaxial line with the length of the center conductor being adjustable to provide a means of tuning the cavity to the desired resonant frequency. An outer conductor length of one-quarter wave is the most often used configuration. This type of resonator has a very high Q. An example of a commercially made resonator is shown in Fig. 7-7. When such a device is placed in series with the transmission line it will act as a band-pass filter, greatly attenuating frequencies other than that to which it is tuned. This mode of operation will require that the resonator have two coupling loops or probes, one for input and one for output.

When such a cavity is connected across, or in parallel with, the transmission line it will act as a band-reject or absorption filter. Energy at the frequency to which the cavity is tuned will be greatly attenuated. Only one coupling probe is needed for this method of filtering. The connecting of a cavity across the transmission line may cause a change in the impedance of the system, which should be

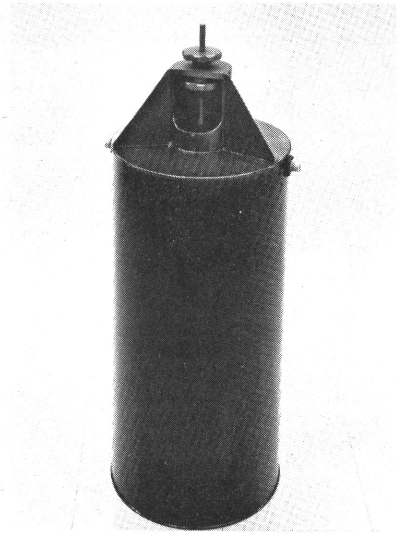


Fig. 7-7 – A tuned cavity of the type used in many repeater systems to overcome desensing problems or for use as part of a duplexer. The unit is of coaxial construction, with the length of the center conductor being adjustable by means of the knobs at the top.

compensated for by the addition of tuning stubs. The graphs in Fig. 7-8 show the attenuation characteristic of a single cavity at (A) and a pair of cavities at (B).

THE HYBRID-RING DUPLEXER

A duplexer is a device that will allow the operating transmitter and receiver to be connected to the same antenna. Energy from the transmitter must not reach the receiver input and cause desensing. Signals from the antenna must reach the receiver without being partially absorbed by the transmitter output circuitry. To accomplish this, two or more cavities similar to that shown in Fig. 7-7 can be combined with proper lengths of coaxial cable to form what is known as a *Hybrid-ring duplexer.*

A hybrid ring is a junction made of sections of transmission line. These line sections are one quarter wavelength or multiples thereof, connected in a ring or circle. Such an arrangement usually has four branches or inputs and a signal connected to one input will appear at only two of the remaining three branches.

Fig. 7-9 illustrates a hybrid ring in which a *reject* cavity is connected at one branch, and an adjustable stub is connected an electrical half-wave away from it. The remaining two branches of the ring can serve as either input or output connections. Two cavities and two hybrid rings are shown in Fig. 7-10, connected to serve as a simple duplexer. Greater isolation between the transmitter

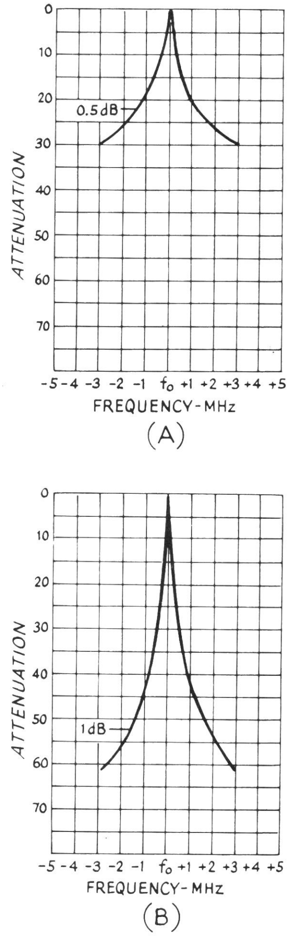


Fig. 7-8 — Frequency response curves for a single cavity (A) and two cavities cascaded (B). These curves are for cavities that have coupling loops exhibiting a loss of 0.5 dB. The selectivity will become greater if lighter coupling can be tolerated.

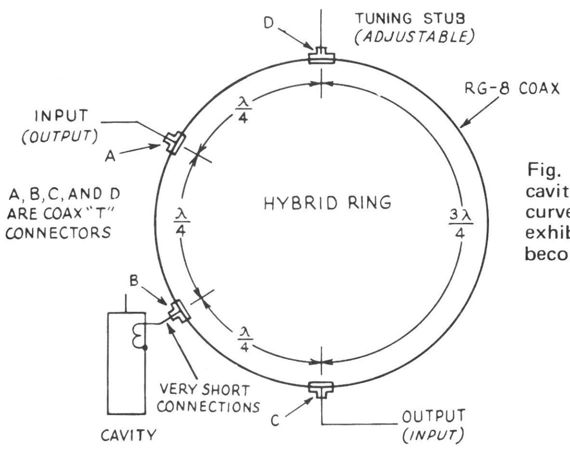


Fig. 7-9 — A hybrid ring with a tuned cavity attached. This type of circuit will pass energy at one frequency while greatly attenuating another. The shorted stub provides a means of "fine tuning" the system.

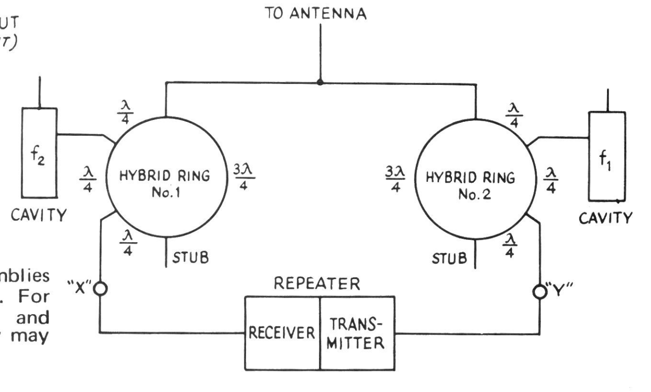


Fig. 7-10 — Two hybrid-ring and cavity assemblies may be combined to serve as a duplexer. For additional isolation between the receiver and transmitter, another ring and cavity assembly may be inserted at points X and Y.

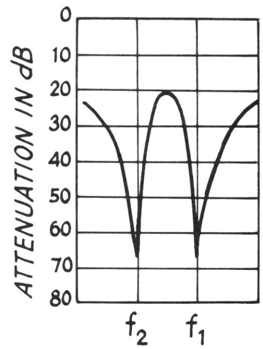


Fig. 7-11 – The isolation that can be expected between the receiver and transmitter when a two-section duplexer is used, such as that shown in Fig. 7-10. Loss between the transmitter or receiver and the antenna feed line should be on the order of 0.5 to 1 dB.

and receiver will require a more complex duplexer using four or more cavities. Fig. 7-11 shows the isolation that can be expected between the receiver and transmitter when the basic two-cavity duplexer is used.

The adjustment of the hybrid ring type of duplexer is quite involved and the details are beyond the scope of this manual. The major manufacturers of such duplexers will provide detailed instructions for tuning their products. The literature supplied usually includes an excellent description of the theory of operation and describes the method used to measure the result of any adjustment. Repeater builders will do well to follow closely the recommendations of the manufacturer.

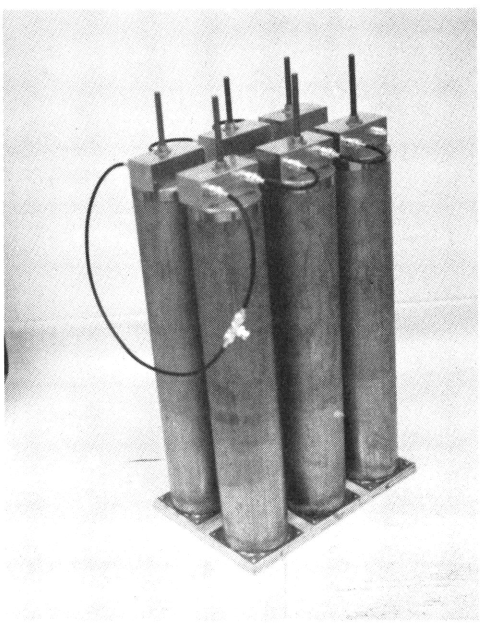


Fig. 7-12 – A six-cavity duplexer for use with a two-meter repeater. The cavities are fastened to a plywood base for mechanical stability. Short lengths of doubled-shielded cable are used for connections between individual cavities. An insertion loss of less than 1.5 dB is possible with this design. This duplexer was described by W1GAN in *QST* for July, 1972.

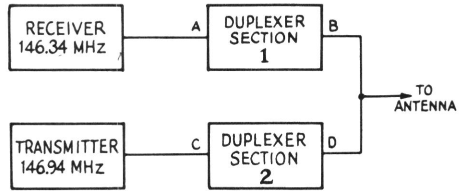


Fig. 7-13 – Duplexers are used to permit using one antenna for both transmitting and receiving. Section 1 prevents transmitter energy from interfering with the receiver, while section 2 keeps the received signal from reaching the transmitter.

A TWO-METER DUPLEXER

One of the major technical problems encountered in putting a repeater on the air is obtaining sufficient signal isolation between the receiver and the transmitter. Many of the solutions to this problem involve a compromise in receiver sensitivity, transmitter power output, and imbalance between receiver and transmitter coverage. When a duplexer is used, the compromise is in the form of insertion loss. Any small insertion loss is more than offset by the use of one antenna for both transmitting and receiving, thereby assuring equal antenna patterns for both.

Duplexers have been in use by many commercially operated repeaters for quite a number of years. Many of these systems use a frequency separation of 2 percent or more between input and output channels. Most amateur repeaters in the 2-meter band have a frequency separation of only 0.4 percent. The problem of providing good isolation becomes more difficult at the frequency separation decreases. The requirements for a duplexer can be summed up as follows: It must attenuate the transmitter carrier so that it does not overload the receiver and thereby reduce its sensitivity. It must also attenuate any noise or spurious energy from the transmitter on or near the receive frequency. In addition, a duplexer must provide a proper impedance match between transmitter, antenna, and receiver. Fig. 7-13 will help the reader to visualize these functions. Transmitter output on 146.94 MHz going from point C to D should not be attenuated. However, the transmitter energy should be greatly attenuated between points B and A. Duplexer section 2 should attenuate any noise or signals that are on or near the receiver input frequency of 146.34 MHz. For good reception, the noise and spurious signal level must be less than –130 dB (0 dBm = 1 milliwatt into 50 ohms). Typical transmitter noise 600 kHz away from the carrier frequency is 80 dB below the transmitter power output. For 60 watts of output (+48 dBm), the noise is –32 dBm. The duplexer must make up

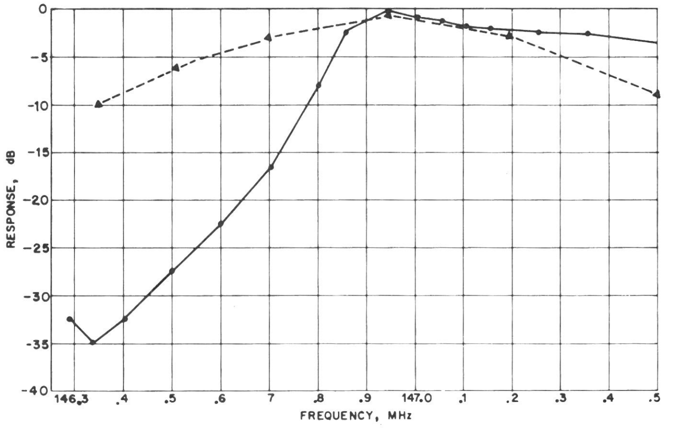


Fig. 7-14 – Typical frequency response of a single cavity of the type used for the duplexer. The dotted line represents one cavity alone, while the solid line is for a cavity with a shunt capacitor connected between input and output. An inductance connected in the same manner will cause the rejection notch to be above the frequency to which the cavity is tuned.

the difference between −32 and −130 dBm or −98 dBm.

The received signal must go from point B to A with a minimum of attenuation. Section 1 of the duplexer also must provide sufficient attenuation of the transmitter energy to prevent receiver overload. For an average receiver, the transmitter signal must be less than −30 dBm to meet this requirement. The difference between the transmitter output of +48 dBm and the receiver overload point of −30 dBm must be accomplished by duplexer section 1.

One thing that many duplexers have in common is the use of high-*Q* coaxial cavities. The loaded *Q* of a cavity is affected by electrical conductivity and dielectric losses. Surface loss can be reduced by silver plating, although clean copper is adequate. Air-dielectric cavities are the most practical for use with amateur duplexers.

The Circuit

A quarter-wavelength resonator was selected for this duplexer design. The length of the center conductor is adjusted by turning a threaded rod, thereby tuning the cavity to frequency. Energy is coupled into and out of the tuned circuit by the coupling loops extending through the top plate. The cavity functions as a series-resonant circuit. When a capacitor or inductor is connected across a series-resonant circuit, an antiresonant notch is produced, and the resonant frequency is shifted. The addition of a capacitor across the cavity causes the notch to occur below the resonant frequency. Addition of an inductance will cause the notch to appear above the resonant frequency. The value of the capacitor or inductor will determine the spacing between the notch and the resonant frequency.

Fig. 7-14 shows the bandpass characteristics of the cavity with shunt elements. With the cavity tuned to 146.94 MHz, and a shunt capacitor connected from input to output, a signal at 146.34 was attenuated 35 dB. With a cavity having an inductance across it, and tuned to 146.34, the attenuation at 146.94 is 35 dB. Insertion loss in both cases is 0.4 dB. Three cavities with a shunt capacitor are tuned to 146.94 and connected together with short lengths of coaxial cable. The attenuation of 146.34 is more than 100 dB, while insertion loss is 1.5 dB. Response curves for a six-cavity duplexer are given in Fig. 7-15. The schematic diagram for the complete duplexer is shown in Fig. 7-16.

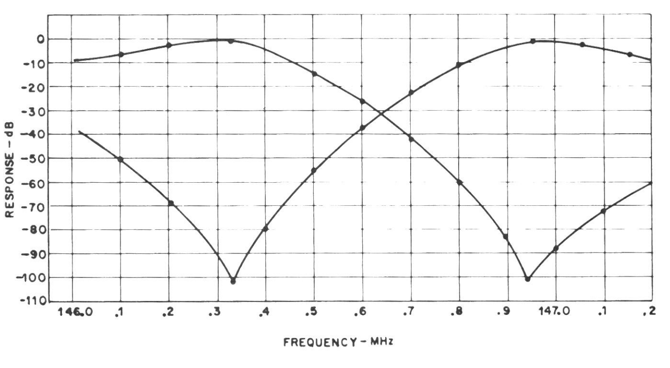


Fig. 7-15 – Frequency response of a six-cavity duplexer tuned for 146.34-MHz reception and 146.94-MHz transmission.

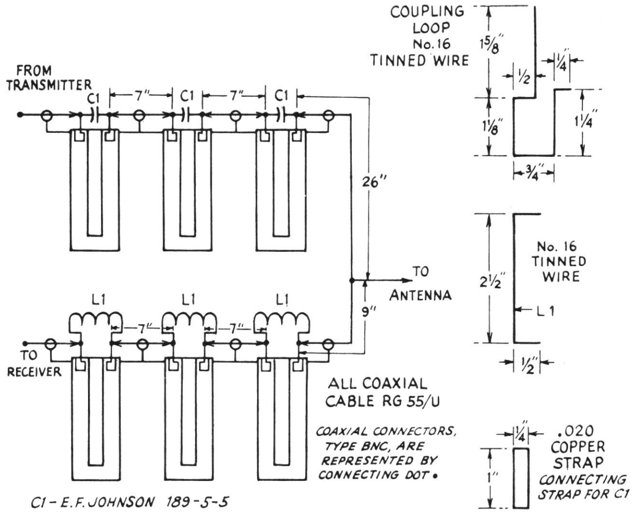


Fig. 7-16 – Diagram of the six-cavity duplexer. Coaxial cable lengths between sections are critical and should be followed closely. Double shielded cable should be used. The size and shape of the coupling loops, L1, and the straps for connecting C1 should be observed. C1 is set at 3/4 closed for initial alignment.

Construction

Three parts for each cavity must be machined; all others can be made with hand tools. A small lathe for metal work will be adequate for the machine work on the brass top-plate, the threaded tuning-plunger bushing, and the Teflon insulator bushing. The dimensions to which these parts must be machined are given in Fig. 7-18.

"DWV" copper tubing is used for the outer conductor of the cavities. The wall thickness is .058 inch, with an outside diameter of 4-1/8 inches. At the time of purchase of the tubing, it would be wise to borrow a tubing cutter large enough to cut this size tubing to the correct length. The wheel of the cutter should be tight and sharp, and the cuts should be made slowly and with care so the ends will be square. The outer conductor is cut to a length of 22-1/2 inches.

The inner conductor is made from type "M" copper tubing having an outside diameter of 1-3/8

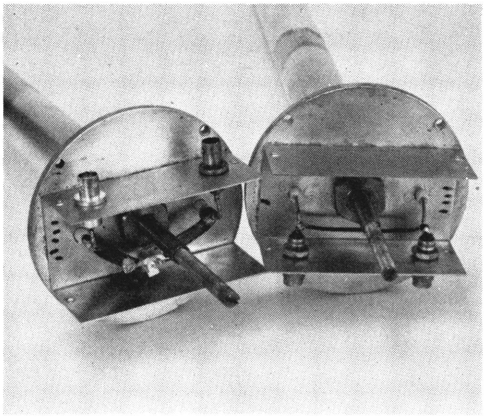


Fig. 7-17 – Two of the center conductor and top plate assemblies. In the unit on the left, C1 can be seen just below the tuning shaft. It is mounted by means of short straps made from sheet copper. The assembly on the right has L1 in place between the BNC connectors. The Miniboxes were fastened to the top plate by a single large nut in these examples. The method described by the author, that of using screws through the Minibox into the top plate, should be used for simplicity.

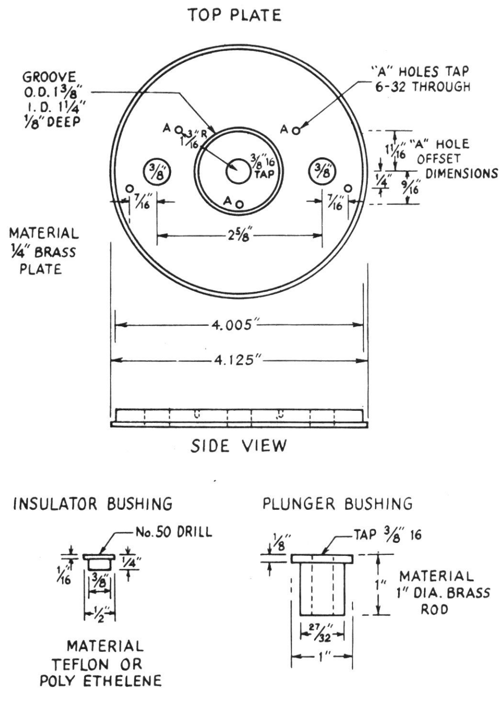


Fig. 7-18 – Dimensions for the three parts that require matching. A small metal working lathe should be used.

inches. A piece of 1-inch OD brass tubing, 6 inches long is used to make the tuning plunger.

Soft solder is used throughout the assembly. Silver solder is not recommended unless the builder has extensive experience with its use. Eutectic type 157 solder with paste or acid flux will provide very good joints. This type has a slightly higher melting temperature than ordinary lead-tin alloy and has considerably greater strength.

The inner conductor should be soldered to the top plate first. Then finger stock can be soldered inside the lower end of the inner conductor, temporarily held in place with a plug made of aluminum or stainless steel. Do not allow the flame from the torch to overheat the finger stock while performing the soldering operation. The plunger bushing is soldered into the tuning plunger and a 20-inch length of threaded rod is soldered into the bushing.

Cut six slots in the top of the outer conductor. They should be 5/8-inch deep and equally spaced around the tubing. The bottom end of the 4-inch tubing is soldered to the square bottom plate. Because the center conductor has no support at one end, the cavities must be mounted vertically.

The size and position of the coupling loops are critical and the dimensions given should be followed closely. Both loops should be 1/8 inch away from the center conductor on opposite sides. A solder lug should be connected to the ground end of the loop and fastened to the top plate with a screw. The free end of the loop is insulated by Teflon bushings where it passes through the top plate to connect to the BNC fittings.

Before final assembly of the parts, they should be cleaned thoroughly. Soap-filled steel wool pads and hot water does a fine job. The finger stock should be checked to see that it makes a firm contact with the tuning plunger. The top plate should fit snugly in the top of the outer conductor. A large hose clamp tightened around the outer conductor will fasten the top plate in place.

Tuning

The antiresonant elements, C1 and L1, should not be installed until the cavities have been checked for band-pass characteristics and insertion loss as shown by the curve in Fig. 7-14. The preferred method of tuning the duplexer requires the use of laboratory test equipment to obtain accurate measurements. A second method to be described uses a low-power transmitter with an rf detector and a VTVM. Fig. 7-19 shows the connections for both methods.

With the test equipment connected as shown in Fig. 7-19A, adjust the signal-generator frequency to the desired repeater input frequency. Connect a calibrated step attenuator between points X and Y. With no attenuation, adjust the HP415 for zero on the 20-dB scale. The calibration of the 415 can be checked by switching in different amounts of attenuation and noting the meter reading. A small error may be noted at either high or very low signal levels.

Remove the step attenuator and replace it with a cavity that has the shunt inductor, L1, in place. Adjust the tuning screw for maximum reading on the 415 meter. Remove the cavity and connect point X to Y. Set the signal generator to the repeater-output frequency and adjust the 415 for a zero reading on the 20-dB scale. Reinsert the cavity between X and Y and adjust the cavity tuning for minimum reading on the 415. The notch should be sharp and have a minimum depth of −35 dB. It is important to maintain this minimum reading on the meter while tightening the locknut on the tuning shaft.

To check the insertion loss of the cavity, the output from the signal generator should be reduced, and the calibration of the 415 meter checked on the 50-dB expanded scale. Use a fixed 1-dB attenuator to assure the error is less than 0.1 dB. Replace the attenuator with the cavity and read the loss. The insertion loss should be 0.5 dB or less. The procedure is the same for tuning all six cavities, with the exception that the frequencies are reversed for those that have the shunt capacitor installed.

Adjustment with Minimum Equipment

A transmitter using tubes is preferred for this method of adjustment to assure a minimum of

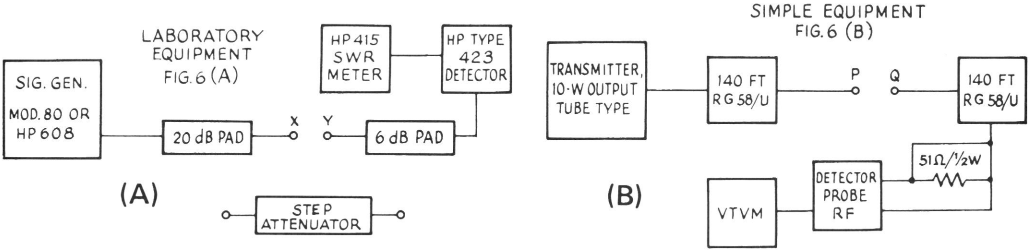


Fig. 7-19 — The duplexer can be tuned by either of the above two methods, although that of A is the more accurate. The signal generator output should be modulated by a 1000-Hz tone. If the simple equipment as in B is used, the transmitter should not be modulated and should have a minimum of noise and spurious signals. The cavities to be aligned are inserted between X and Y in A and between P and Q in B.

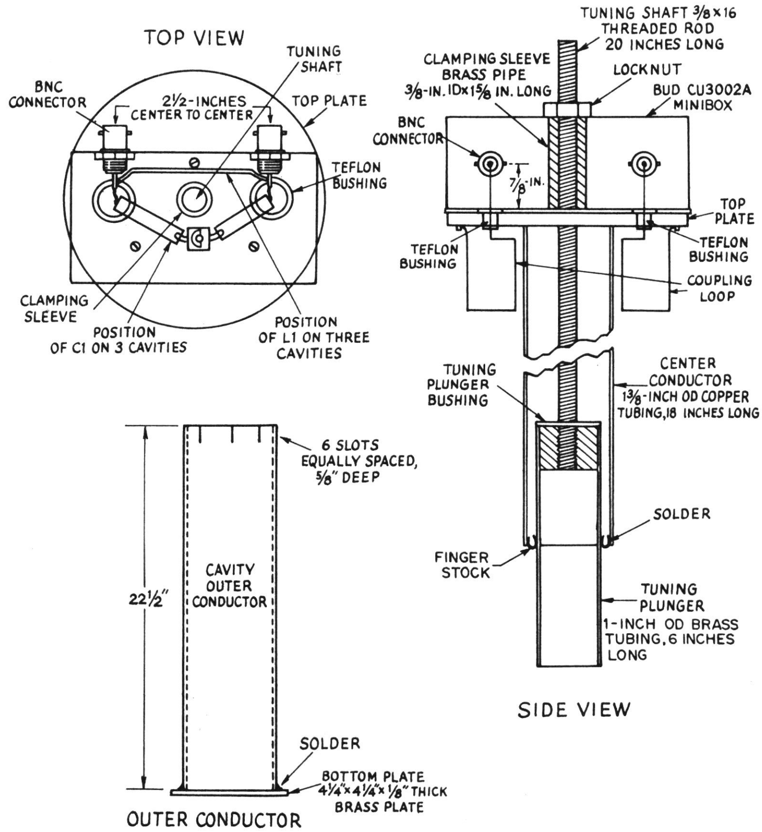


Fig. 7-20 – The assembly of an individual cavity. A Bud Minibox is mounted to the top plate by means of three screws. A clamping sleeve made of brass pipe is used to prevent crushing the box when the locknut is tightened on the tuning shaft. Note that the position of both C1 and L1 is shown, but that three cavities will have C1 installed, and the others will have L1 in place.

spurious signals that would cause false indications. The VTVM should be capable of reading 0.5 volt or less, full scale. The rf probe should be good to 100 MHz or higher. Sections of RG-58/U coaxial cable are used as attenuators, as shown in Fig. 7-19B. The loss in these 140-foot sections is nearly 10 dB and will help isolate the transmitter in case of mismatch during the tuning procedure. The transmitter should be set on the repeater input frequency and P connected to Q. Obtain a reading between 1 and 3 volts on the VTVM. Insert a cavity with shunt capacitors in place between P and Q and adjust the cavity tuning for minimum reading on the VTVM. The reading should be between .01 and .05 volt. Rejection in dB can be calculated by the formula 20 log V1/V2 and should be −35 dB, minimum. Insertion loss can be checked by putting the transmitter on the repeater-output frequency and noting the VTVM reading with the cavity in and out of the circuit. A 0.5-dB attenuator can be made from 7 feet of RG-58/U. This 7-foot section can be used to check the calibration of the detector probe and the VTVM. Cavities using a shunt inductance can be tuned in the same manner but with the frequencies reversed. Transmitter noise can cause the rejection readings to be low (less attenuation) if an attempt is made to tune two or more cavities connected together.

Results

The duplexer is conservatively rated at 150-watts input, but it should be able to withstand up to 300 watts. Silver plating the interior of the cavities is recommended if more than 150-watts input to the duplexer is planned. A duplexer using plated cavities has shown an insertion loss of under 1 dB, and a rejection of more than −100 dB. Unplated cavities should be taken apart every two years and cleaned thoroughly, then retuned.

Miscellaneous Notes

1) Double-shielded cable is a *must* throughout the system.

2) The VSWR from the antenna should not exceed 1.2 to 1 for proper duplexer performance.

3) Good shielding of the transmitter and receiver at the repeater is essential.

4) The antenna should have four or more wavelengths of vertical separation from the repeater.

5) Conductors in the near field of the antenna should be well bonded and grounded to eliminate noise.

6) The feed line should be well bonded and secured to the tower or mast.

7) Feed lines from other antennas in the near field of the repeater antenna should be well bonded and as far from the repeater as possible.

8) Individual cavities can be used to improve the performance of split-antenna or split-site repeaters.

9) Individual cavities can be used to help solve intermodulation problems.

Repeater Controls and Accessories

THERE IS SUCH an endless variety of ways to control a repeater that it is almost impossible to describe more than a few that will be the most useful for a newcomer to the repeater field. As any of those who have installed a repeater will know, there is never a lack of ideas about control circuits and circuits to be controlled. From the basic repeater with its simple COR, systems evolve that encompass unbelievably complex switching functions. Some of these functions involve frequency changes, band changes, turn-on and turn-off of the main repeater or peripheral equipment, and actuating message or time-announcing devices, to name just a few. There seems to be no limit to the imagination of repeater groups. One club has gone so far as to use a TV camera and microwave link for surveillance and control of their remote repeater.

While imagination can run unbridled, a working repeater must be limited by practicality. Each additional control function that is added will also increase the maintenance time needed to ensure a reliable service. Those concerned with the technical aspect of a repeater should consider carefully the amount of expense and time involved to provide more than the basic purpose of the machine; an increase in the range of reliable communication between low-powered or mobile stations should be the overriding factor in all planning.

COR CIRCUITS

The function of turning a repeater transmitter on and off in response to a received signal is performed by a **carrier-operated-relay** (COR). The relay may have other names, such as squelch relay, squelch-operated switch, or signal relay, according to the whim of the builder or manufacturer. Whatever it is called, the function remains the same.

The principle of operation varies only slightly from one type to the next. An early version used a portion of the voltage developed at a limiter grid in the receiver to drive a dc amplifier. The dc amplifier, sometimes called a relay driver, activated the relay, thereby controlling the transmitter. This simple system had some flaws, a major one being that anything which would cause limiter grid current to flow would activate the COR. Noise, off-channel signals, or a change in power-supply voltages often would trigger the repeater. In some systems, the white noise generated by the transmitter would be of sufficient magnitude to keep the machine "locked up."

A more reliable COR is one that is triggered by a voltage derived from the rectification of noise, See Fig. 8-1. This noise is the hissing sound that is heard when the squelch of a receiver is open, but no carrier is being received. The noise is amplified, then applied to diodes to be converted into a dc voltage. Often the rectifiers are used in a voltage doubler configuration to obtain a greater level of dc control. The output from the diode circuit is used to drive a dc amplifier, which in turn operates a control relay in the manner previously discussed. Some systems utilize both the limiter grid-current method and the rectified noise to obtain even greater reliability in the operation of the COR. In many solid-state circuits, a Schmitt trigger is incorporated to provide a rapid switching action.

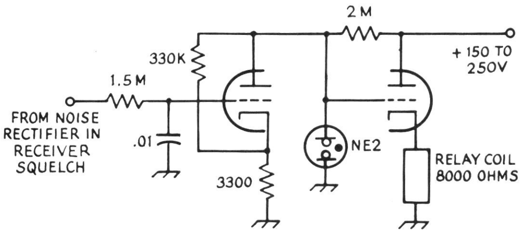
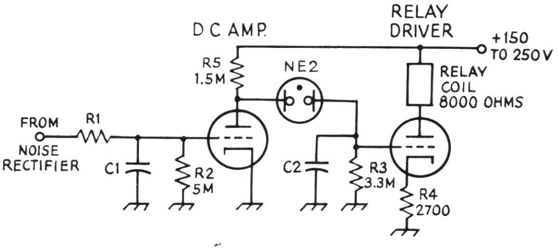


Fig. 8-1 — A COR circuit. The tube can be any of the dual triode family such as 12AX7, 12AU7, or 5963. The neon lamp prevents overdriving the grid of the second stage. For proper operation, the dc input must be slightly positive when no signal is received, and should swing negative to energize the relay.

Fig. 8-2 — Time delay can be incorporated in the opening and closing of the COR by changing the circuit slightly. The neon lamp provides isolation for C2, allowing the charge on C2 to hold the relay closed after the signal has dropped.



VOX Access

Several variations in the basic COR circuitry are possible. The use of tone access to repeaters is covered elsewhere in this book. It is possible to connect a VOX circuit, similar to those commonly used in hf ssb equipment, to the COR control. In order to activate the transmitter, a voice or audio tone, as well as a carrier, must be received. This would prevent the transmitter from being held on for long periods by an unmodulated carrier.

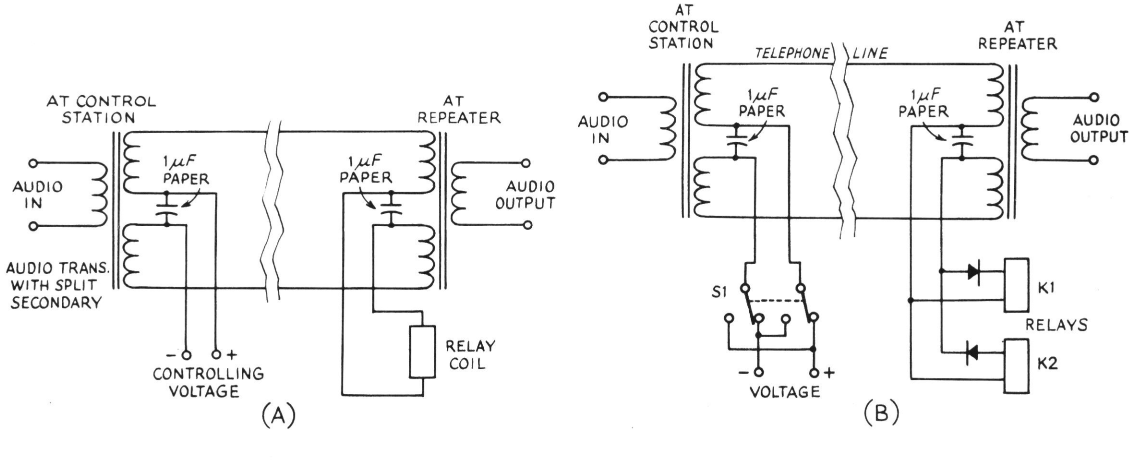
COR Timing

Some flexibility in the relay closing and opening time is possible by changing the circuit slightly. Fig. 8-2 shows a COR with a capacitor connected to the grid of the first stage. The attack and release times of the relay can be changed by using different values for C1, C2, R1 and R3. The same circuit shows coupling to the second stage through a neon lamp. As long as the first stage is biased to cutoff, supply voltage is present at the plate of that tube. The potential is sufficient to ignite the neon lamp, causing a portion of the voltage to appear at the grid of stage two. Stage two is in an "on" condition, keeping the relay closed. When the bias is removed from the grid of the first stage, the tube conducts heavily, causing a voltage drop across R5, and the lamp extinguishes. The lamp provides isolation so that C2 will remain partly charged, holding that stage on. When the voltage in C2 decays sufficiently to allow the tube to be cut off by bias developed across the cathode resistor, R4, the relay will open. The relays specified in these examples are 8000-ohm types, but substitutions can be made. The resistance of the coil should be from 5000 to 10,000 ohms. A relay that will close at a low value of current will work best in this type of circuit.

WIRE CONTROL

One of the basic, and perhaps most foolproof, means of remotely controlling a repeater is called wire control or line control. This system requires that a telephone line connection exist between the control station and the repeater site. If the distances involved are not too great, the expense should not be beyond the means of an average club membership. Any of the tone-control systems explained elsewhere in this chapter may be used, with the phone line providing the means of getting information to the repeater location. Additionally dc control may be used to enhance the number of functions that a tone-control system provides, or as a back-up control in case the tone-decoding circuit should fail. Many telephone companies have their own terminology for a circuit that will pass dc, so those doing the planning should be prepared to explain in detail what they need. Line losses can be great in many areas, and beyond a few miles such a control system may not be practical.

Fig. 8-3 — Direct-line control of a repeater may be accomplished by the application of dc to the split secondary of an audio transformer. A simple system is shown at A, and at B diodes are used to sense the polarity of the applied voltage.



A wire control circuit is shown in Fig. 8-3. At A, the controlling voltage is applied to the center of an audio transformer and is recovered from a similar transformer at the repeater control panel. A variation of this circuit is shown at B, where diodes are used to provide additional functions as the controlling voltage polarity is reversed. When the distance from the control station is not great – perhaps a mile or so – it is possible to use the earth (ground) as one side of the dc path, with the telephone line as the other. However, variations in soil conductivity during wet or dry weather could make this system a poor choice.

TIMING DEVICES

At a repeater site there is usually a necessity for one or more timing devices. These devices are used for various purposes, such as determining the interval between the sending by automatic means of repeater call-letter identification and limiting the duration of transmissions made by individual users of the repeater.

Simple electromechanical timers may be made through the use of small synchronous motors such as those used in electric clocks. A gear train, a cam, and a small cam-actuated switch will complete the installation. Motor and gear-train assemblies are available complete for a number of shaft speeds, such as 1/10, 1/3, 1/2, 1, 2, and other values of revolutions per minute.[1]

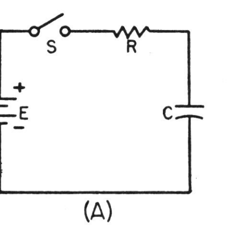
ELECTRONIC TIMING CIRCUITS

Electronic timing circuits offer the advantage over electromechanical timers in that they are essentially maintenance free. A further advantage is that they may be reset easily to restart the timing interval even though the timing sequence is only partially completed, a feat which is nearly impossible to accomplish with electromechanical systems. Some electronic timing circuits, however, are not without a disadvantage – variations in the duration of the timing interval with changes in environmental temperature. These variations occur because of changes in component values of passive devices (resistors and capacitors) and changes in switching thresholds of active devices (usually semiconductors). For use at remote repeater sites, such as hilltops or mountaintops, where the temperatures may range from subzero in the winter to more than 100° in the summer, it will be worth keeping this point in mind when design criteria for timer circuits are being established. Another point worth remembering is that some circuits will exhibit a change in the timing interval with changes in applied voltage – notably those circuits relying on the charge time of a capacitor. These changes are not so much of a problem, however, as simple regulator circuits may be used with an ac-operated power supply to obtain dc voltages which are relatively constant with normal variations in power-line voltage.

There are two basic types of timing circuits. One type relies upon the time required to charge or discharge a storage element, and the other type uses a stable oscillator or other frequency reference in association with frequency-divider networks.

R-C Timing Circuits

The fundamental components of a charge-discharge circuit are usually a resistor and a capacitor, although an inductor may be used in place of the capacitor in some applications where quite short time intervals are being used. Consider the circuit of Fig. 8-4A, where a resistor, a capacitor, a battery, and a switch are all connected in series. When the switch is closed the resistance limits the current flow, and an appreciable length of time is required for the voltage across the capacitor to become equal to that of the battery source, E. The amount of time required for the capacitor to become fully charged is independent



(A)

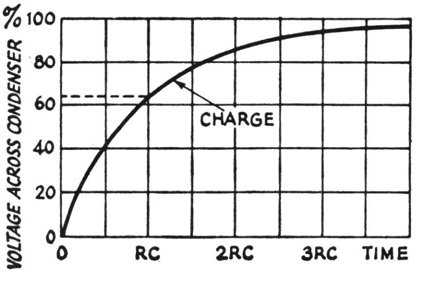


Fig. 8-4 – At A, a circuit illustrating the time constant of an R-C circuit, and at B, a graph showing how the voltage across the capacitor rises with time.

[1]Herbach & Rademan, Inc., 401 E. Erie Ave., Philadelphia, PA 19134.

of the value of emf (E), but *is* dependent upon the time constant of the R-C network. The formula for time constant is

$$T = RC$$

where T = time in seconds
R = resistance in ohms
C = capacitance in farads

Example: The time constant of a 1-megohm resistor (1×10^6 ohms) and a $2\mu F$ capacitor (2×10^{-6} farads) is $1 \times 10^6 \times 2 \times 10^{-6} = 2$ seconds.

If R is in megohms and C in microfarads, the time constant is still obtained in seconds, using the above equation. These units are usually more convenient to use.

Theoretically, the charging process after closure of the switch in Fig. 8-4A is never really finished, but eventually the charge potential across the capacitor is so nearly equal to the applied voltage, E, that the difference is negligible. The time for this condition to be reached is, for practical purposes, equal to 5 times the R-C time constant, or 10 seconds for the values given in the example above. During the period of the first time constant (the first two seconds, in the example), the capacitor will become charged to a potential equal to 63 percent of E; during the second time-constant period the capacitor will acquire 63 percent of the remaining charge it must accept, another 63 percent during the period of the third time constant, and so on. Thus, the charging action takes place at an exponential rate, as shown by the graph of Fig. 8-4B. If the capacitor were allowed to become fully charged and then the battery of Fig. 8-4A were replaced with a short circuit, the capacitor-discharge time after switch closure would also be exponential, with the capacitor discharging 63 percent of its charge potential during the period of the first time constant, and so on. For practical purposes, the capacitor would be completely discharged after five R-C time-constant periods had elapsed.

A circuit based on this technique for obtaining a delay in relay dropout is shown in Fig. 8-5. The switch, shown as S, could, in practice, be the contacts of the carrier-operated relay. Upon closure of S, with no series resistance in the circuit, the capacitor charges quite rapidly to the full potential of E, permitting K1 to be energized. As long as S remains closed, the contacts of K1 will remain closed. However, after S is opened, the charge potential of C is still applied to K1, and K1 will not become de-energized immediately. If a high-impedance type of relay is used (such as a 10,000-ohm plate relay) and a capacitor having a value of several microfarads is selected, the relay may be held in the energized position for as much as several seconds after S is opened. This circuit may be used for the keying of a repeater transmitter when it is not desired that the transmitter be unkeyed at each brief opening of the COR.

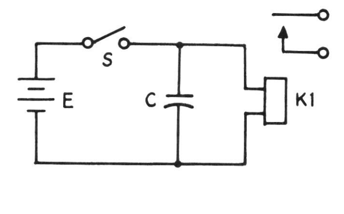


Fig. 8-5 – Relay drop-out delay circuit.

A UJT Timing Circuit

A somewhat simple but effective timing circuit using the R-C charging-discharging principle can be obtained with a unijunction transistor (UJT). By using various values of R and C, the circuit can be made to produce pulses at time intervals ranging from approximately one pulse per minute to thousands of pulses per second. The circuit is shown in Fig. 8-6, and is a form of relaxation oscillator.

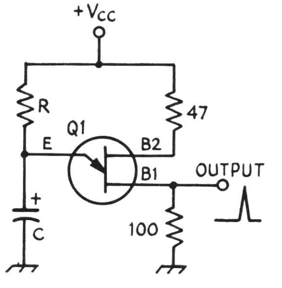


Fig. 8-6 – Unijunction-transistor timing circuit.

With C initially discharged, its charging action takes place through R, toward the voltage applied at +Vcc (usually 15 volts or less). The emitter of the UJT is effectively out of the circuit at this time because a high impedance exists between it and both the base-1 (B1) and base-2 (B2) elements. When the capacitor charge reaches the peak-point (threshold) voltage of the UJT, the UJT 'fires', and its emitter becomes forward biased. C is discharged abruptly through the B1-emitter junction and the 100-ohm resistor, causing a fast-rise-time positive-going pulse to appear at B1. When C is discharged, the emitter is no longer forward biased, and the cycle repeats itself. With 2N2646 UJT in use and a +Vcc value of 3.6 volts, a one-minute timing interval can be obtained with a 68-μF electrolytic capacitor for C and a resistance value in the order of 460,000 ohms for R. The exact value of R should be determined experimentally and may require the connecting of two or more standard-value resistors in series, because of differences in the standoff ratio of the particular UJT in use. Much higher resistance values than 470,000 ohms will not allow the 2N2646 to fire because of leakage through C. The circuit is subject to variations in the timing interval because of temperature and voltage changes.

An IC Timing Circuit

A special-purpose IC is available from Signetics for use in timing circuits. Appropriately enough, the IC bears the name, "timer," although it can be used in other applications. The IC carries the type number 555 and contains two voltage comparators, a flip-flop, and an output stage. Only three external components are required to obtain timing intervals ranging from microseconds to hours. The circuit for use of the IC as a free-running multivibrator is given in Fig. 8-7A.

The external capacitor, C, charges through R1 and R2, and discharges through R2 only. Thus, the duty cycle of the output wave form may be set by the ratio of these two resistors. The capacitor charges and discharges in the range between 1/3 Vcc and 2/3 Vcc. Because a voltage comparator is used rather than the absolute charge on the capacitor to trigger the switching action, the frequency of operation is independent of the supply voltage. Changes in operating frequency arising because of temperature changes are minimized with this circuit, being related primarily to changes in values of the external components. The time duration of the switching cycle in seconds may be determined from the following equation:

$$T = 0.685(R1 + 2R2)C$$

where resistances are in ohms and capacitance is in farads. The graph of Fig. 8-7 may also be used.

Frequency-Dividing Timers

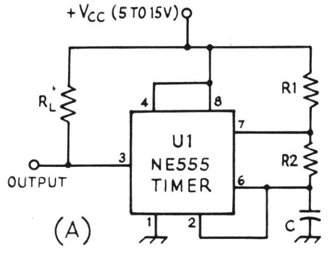
High-precision timers may be made through the use of a stable frequency reference and digital frequency-divider circuits. For the utmost in precision, a crystal-controlled oscillator is used to provide the reference frequency. Where such precision is not required a free-running oscillator may be employed, and the UJT circuit presented earlier will ordinarily be entirely satisfactory. Oscillator frequencies in the subaudio range, 5 to 20 Hz, offer a good compromise between stability of the reference source and the amount of digital circuitry required to obtain the desired time interval, usually a few minutes for repeater applications. A readily available and often-used frequency reference for repeater applications is the 60-Hz powerline frequency.

Basically, frequency division with digital-logic techniques is accomplished with the *J-K* flip-flop, a form of bistable multivibrator. The first pulse of a train applied at its input will "set" the flip-flop, and the second will cause it to "reset" to zero. Thus, two input pulses are required to step the flip-flop through a complete cycle and, as a result, the input frequency has been divided by two in the flip-flop stage. Two flip-flops connected in cascade will cause a division by four, with four input pulses required to step the output of the second stage through a complete cycle. Three flip-flops connected in cascade will divide by 8, four by 16, five by 32, and so on. The progression is a straightforward binary pattern.

Two *J-K* flip-flops connected in cascade can be used to divide by a number lower than four, however, if both are reset to zero at some lower count. Separate inputs are provided on most IC flip-flops for this purpose. If a divide-by-3 circuit is required, two *J-K* flip-flops may be interconnected with appropriate feedback loops to reset the stages to zero at the third input pulse, rather than the fourth. In a similar manner, three cascade-connected flip-flops can be made to divide by 5, 6, or 7, as well as 8.

IC manufacturers, recognizing the need for frequent occasions to divide by higher numbers, produce IC packages which are internally wired to provide division by such numbers as 10 and 12. The divide-by-10 ICs (decade dividers) are usually available as independent divide-by-two and divide-by-five sections in a single package, while the divide-by-12 ICs usually contain independent divide-by-two and divide-by-six sections. Most ICs of this type have only one reset input, however,

Fig. 8-7 — At A, the timer IC is shown connected for use as a free-running multivibrator, and at B, a graph showing the relationships between the values of R1, R2, C, and the timing-interval period.



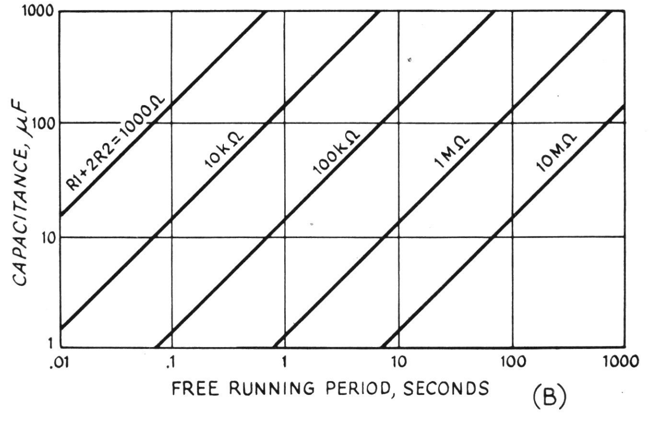
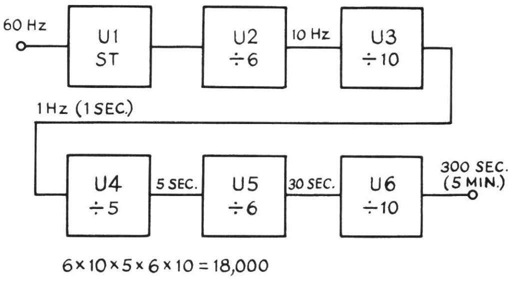


Fig. 8-8 — Block diagram of a 5-minute timer, driven from the 60-Hz power-line frequency. U1 may be a monostable multivibrator such as an N74121A, U2 and U5 may be sections of N7492A divide-by-12 counters, and U3, U4, and U6 may be N7490A decade counters (with only one section of U4 used). All numbers above are those of Signetics. Devices of this nature are used in some of the construction projects shown later in this chapter.



which serves to reset both sections of the IC to zero from a single reset input pulse. Divide-by-16 packages with no internal feedback connections are also available. With ICs such as these, it is not a difficult task to design a frequency-divider network. If, for example, a five-minute timer is to be built and the 60-Hz power-line frequency is to be used as the frequency reference, the divider network must provide a total division of 18,000. (There are a total of 18,000 cycles of a 60-Hz wave form during a five-minute period.) A suitable divider network is shown in block diagram form in Fig. 8-8.

TOUCH-TONE CONTROL

From the inception of automatic dialing, signaling from telephone instruments was accomplished using dc pulses. This signaling method required direct wired connections, as a dc path was needed. For transmission via a radio circuit, the dc pulses had to be converted to a keyed audio tone. In the early 1960s the Bell Telephone Companies introduced a new, faster tone-coded dialing system which was given the registered trade name **Touch-Tone**. Because the tone signals of the Touch-Tone system could be transmitted over any audio, carrier, or radio circuit, many amateurs have adopted the telephone-company system for control of fm remote-base stations and repeaters.

Because two tones are used for each function in the Touch-Tone system, reliability is excellent even when used on radio circuits that are noisy or fading. Another factor that has made Touch-Tone popular with repeater groups is that many use autopatch connections to the public telephone network. By ordering a Touch-Tone line for the repeater autopatch, the same encoders and decoders can be used for the phone patch and repeater control.

ENCODERS

Touch-Tone information is coded in tone pairs, using two of eight possible tones for digits zero through nine and six special functions. The audio frequencies used are given in Fig. 8-9. The tones are divided into the low group, 697, 770, 852, and 941 Hz; and the high group, 1209, 1336, 1447 and 1633 Hz. One tone from each group is used for each function. For residential and business telephones, a 12-button encoder pad consisting of digits zero through nine and symbols pound (#) and star (*) are employed. A typical encoder is shown in Fig. 8-10, and the connections for pads manufactured by Western Electric and Automatic Electric are shown in Fig. 8-11. The telephone pads will work with as little as nine volts or as much as 24 volts dc applied. Either high- or low-impedance output may be employed, as shown in Figs. 8-11C and D.

Low	*High Tone*			
Tone (Hz)	*1209 Hz*	*1336 Hz*	*1477 Hz*	*1633 Hz*
697	1	2	3	Fo
770	4	5	6	F
852	7	8	9	I
941	*	0	#	P

Fig. 8-9 — Frequencies used in the Touch-Tone signaling system.

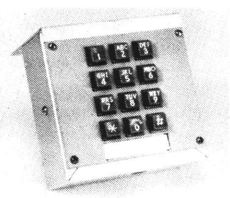


Fig. 8-10 — This Western Electric Touch-Tone encoder has been mounted in a 4 X 4 X 2-inch utility box (Bud AU-1083). Encoders are sold by most telephone supply houses, including Junction Distributors, 164 Cypress Lane, Nashua, NH 03060 (catalog available).

A circuit diagram of the telephone-company pad is given in Fig. 8-12. Individual models will vary slightly, but the basic circuit used in all models is the same. A single transistor produces two tones. Two *LC* circuits are used, one for the high tone group and one for the low tones. Some people are bothered by the use of a single transistor to generate two audio frequencies, so the lower tone can be considered the frequency of oscillation while the high tone is called a parasitic oscillation, for purposes of explanation.

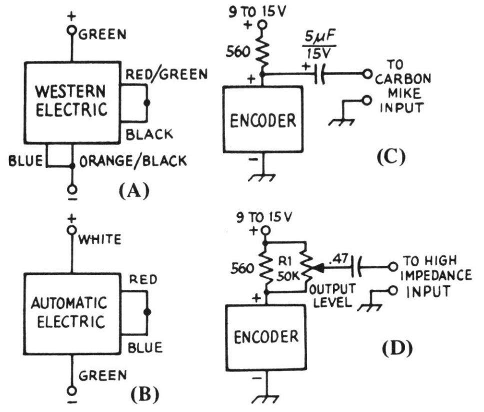


Fig. 8-11 — Typical connections for the encoders manufactured by Western Electric (A) and Automatic Electric (B). If low-impedance output is needed to drive a carbon-microphone input, the circuit at C can be employed for either encoder. Likewise, the circuit at D will provide a high-impedance output. R1 can be any miniature composition control; the types made for mounting on circuit boards are ideal.

A Homemade Touch-Tone Encoder

To generate the Touch-Tone codes, two special integrated-circuit function generators may be used. The ICs are Signetics NE566s, voltage-controlled oscillators that were outgrowths of phase-lock-loop technology. The circuit shown here was developed by Jim Wyland of Signetics. This design, Fig. 8-14, provides 11 number codes. If the additional frequency of the 12-button telephone pad, or the five additional frequencies of the 16-button generator are needed, one can add appropriate timing resistors. The operating frequency of an NE566 is approximately:

$$F_O = \frac{2}{R1C1} \times \frac{V8 - V5}{V8 - V1}$$

where V8, V5, and V1 are the voltages at pins 8, 5, and 1, respectively.

In the practical circuit shown in Fig. 8-14, the value of the timing resistors in each oscillator, R1 and R2, are selected to generate the highest frequency desired. Additional resistors are switched in to lower the frequency of oscillation to the other Touch-Tone frequencies. Both oscillators use a .022μF capacitor for timing. Calibration is needed only at one frequency for each oscillator since the other tones are set by the resistor used.

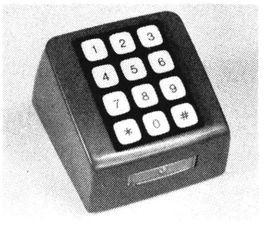


Fig. 8-13 — This homemade Touch-Tone generator is housed in a Western Electric sloping-front plastic box.

The keyboard is a Chromerics EF-20271 which is Touch-Tone encoded. Similar keyboards are available from other vendors. The resistors used in the frequency-determining networks must be one-percent values if the audio produced is to be on the correct frequency. The ICs and the other small components can be mounted on a pc board or electronic pegboard. Sockets are recommended for the ICs.

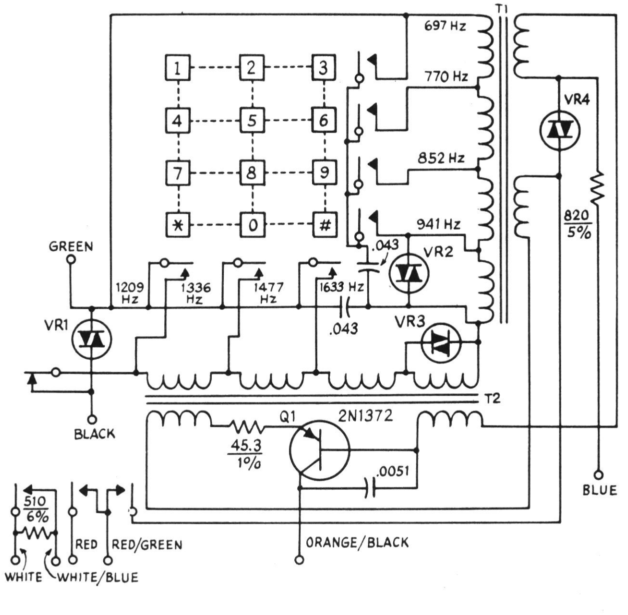


Fig. 8-12 — Diagram of a typical Western Electric Touch-Tone generator. T1 and T2 are special multi-winding transformers manufactured by Sangamo Electric and others. VR1-VR4, incl., are silicon varistors.

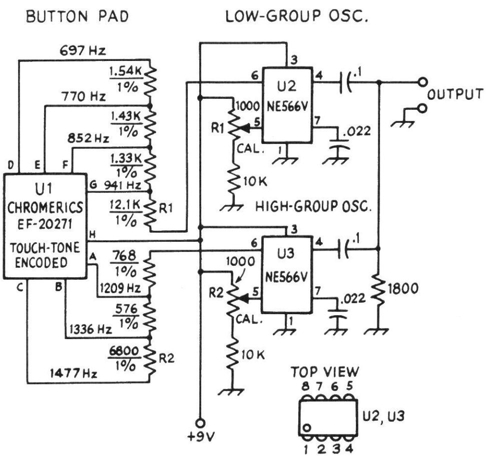


Fig. 8-14 — Schematic diagram of the tone generator. All resistors are 1/2-watt composition. Capacitors are mylar.

BT1 — 9-V miniature battery.
R1, R2 — Linear-taper, 1/2-watt composition control.
U1 — Chromerics EF-20271 keyboard (available from Chromerics, 77 Dragon Court, Woburn, MA 01801.
U2, U3 — Signetics IC (available from Landree Labs., Box 298, Guilford, CT 06347).

Touch-Tone encoded button pad may be employed — the Chromerics EF20271 is used in this design. The small size and low profile of U1 and U2 allow the encoder to be constructed on the side of a hand-held transceiver, such as shown in Fig. 8-16.

For those who require Touch-Tone signals that meet the telephone-company specifications, a simple encoder can be constructed using a hybrid IC. The integrated circuit is manufactured by Microsystems International, a Canadian firm, and has excellent specifications: operating voltage from 4.5 to 45, maximum frequency drift of 1.5 percent, amplitude stability of plus or minus one dB, and total distortion of less than eight percent. Designated the ME8900, the IC is contained in a 1 1/8 × 1 3/8-inch plastic package with 16 leads brought out in dual-in-line fashion.

A typical circuit using the ME8900 is shown in Fig. 8-15. A 9-V transistor radio battery supplies dc potential. If the encoder is to be powered by an automotive electrical system, a 36-V Zener diode should be connected from pin 16 to pin 13 to prevent high-voltage transients from damaging the IC. If a supply voltage of 12 or more is used, the 1-μF connected to pin 1 may be eliminated. Any

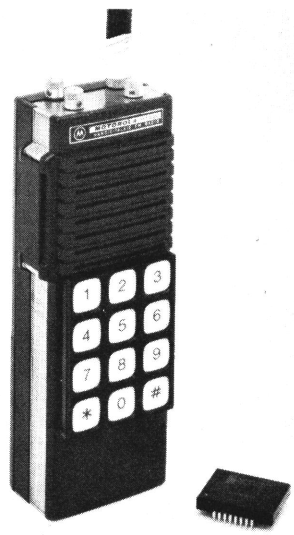


Fig. 8-16 — An encoder has been added to this Motorola HT-220 transceiver. The circuit shown in Fig. 8-15 is used. A complete kit of parts for this Touch-Tone generator is available from Tiny Tone Pad Co., 134 E. Center St., Manchester, CT 06040).

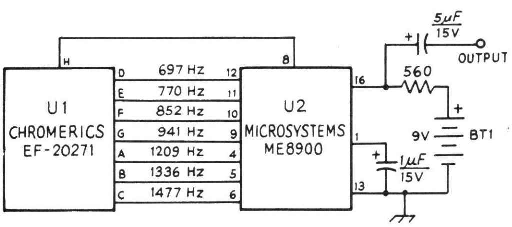


Fig. 8-15 — Circuit for a simple Touch-Tone encoder. The capacitors are electrolytic and the resistor is 1/4-watt composition.

BT1 — Miniature 9-V battery.
U1 — Chromerics EF020271 (See Fig. 8-14 for address).
U2 — Microsystems International ME8900 (Microsystems International, 800 Dorchester Boulvd., Montreal, Quebec.

A Decoder

The Touch-Tone decoders used by the telephone company (Fig. 8-17) consist of input filters which separate the high- and low-tone groups, followed by additional *LC* filters that separate the individual tones. The output control section uses relays. For amateur applications a decoder can be constructed using modern phase-lock loop (PLL) ICs which will allow a decoder to be constructed which is smaller, lighter and less costly than the Western Electric model. The operation of PLL ICs is described in Chapter 3.

The circuit of the IC Touch-Tone decoder is shown in Fig. 8-18. This design was developed by Jim Wyland of Signetics Corp., with a few modifications added by WA5CJG. Seven NE567 ICs are used in the decoder section and four TTL quad gate packages are used in the logic portion. Each IC is tuned to a Touch-Tone frequency by a resistor

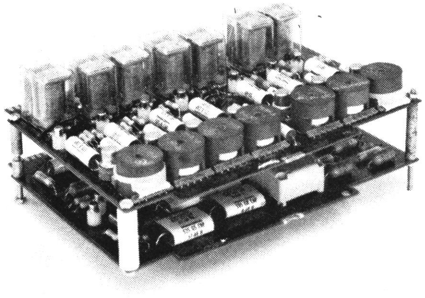
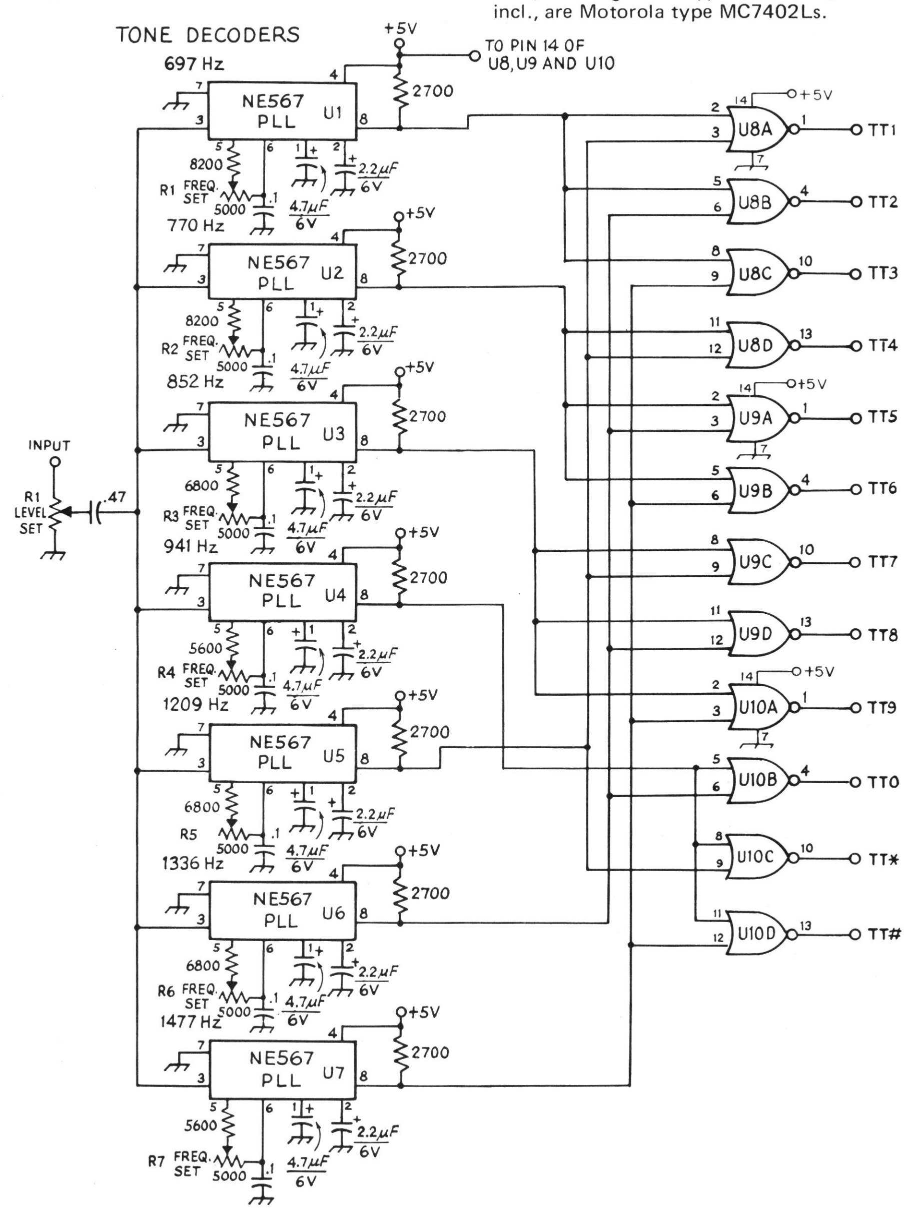


Fig. 8-17 — This Western Electric Touch-Tone decoder uses *LC* filters for tone selection. The low-level transistorized circuits used in the decoder are prone to rf interference, so the unit should be housed in a shielded enclosure if the decoder is located near a transmitter.

Fig. 8-18 — Touch-Tone decoder. Resistors are 1/2-watt composition and capacitors are mylar. R1-R8, incl., are 1/2-watt, pc-mount composition controls. Final adjustment of the frequency of each PLL should be made by adjusting the control as needed to center each phase-locked loop on the telephone-company frequency. A frequency counter facilitates the adjustment procedure. U1-U7, incl., are Signetics type NE-567V, and U8-U10, incl., are Motorola type MC7402Ls.



and a capacitor. The approximate frequency is given by the relationship:

$$f \cong \frac{1}{RC}$$

The bandwidth of the PLL has been set so that a tone no more than four percent high or low in frequency will be demodulated. When a tone is received, the PLL output goes from a logic high to a logic low. When a Touch-Tone encoded pair is present, 697 and 1209 Hz representing the number 1 for example, PLLs U1 and U5 will have logic low outputs. These two lows appear at the input to NOR gate U8A, changing its output to a high. The output of the NOR gate can be used to drive a relay (using a switching transistor) or a function decoder.

A CONTROL-FUNCTION DECODER

The control decoder shown in Fig. 8-20 was designed by W5PCX for the Texas Inter-City Repeater System. The decoder is compatible with any seven-tone system such as the Touch-Tone. The Touch-Tone signals must be decoded to a TTL-compatible output, one output for each tone combination, similar to the decoder shown in Fig. 8-18.

The control decoder allows 32 stations, each having 32 control functions, to work in the same relay system; all stations are capable of independent control.

A control transaction is initiated by the Touch-Tone star (*) button which resets the decoder to a known starting point. The first five Touch-Tone digits are designated as the address field. The station address is predetermined by straps on the control card. The next five Touch-Tone digits (6 through 0) are designated as the control-function field. When the desired address and control digits have been entered, the control transaction is executed by the Touch-Tone pound (#) button. If the entered address agrees with the station address, the control field is then stored and decoded to one of 32 control functions. The control decoder has provisions for an external clear function, and an external control disable function to inhibit any input.

The control decoder consists of two levels of parallel storage, a parallel four-bit comparator, and two binary (four bit) to one-out-of-sixteen decoders. The first level of storage consists of two five-bit universal shift registers to store the address and function entries as they are generated and decoded. The shift registers are used in the parallel mode. The unique features of these storage elements are the individual direct set and the common reset modes of parallel data entry. The Touch-Tone star line is connected to the common reset line and is used to set the ten bits of storage to the zero state. The reset action also erases any logic ones that remain from any previous control transaction. The desired pattern is entered by generating only those Touch-Tone signals that correspond to the required logic ones; the logic zeros are already present because of the reset action. Each Touch-Tone digit provides direct set to the storage-register location assigned to the particular digit; when the digit is pressed, a logic one is stored in that location; if an error is made, the star button must be pushed and the entire sequence repeated.

The station address is assigned by jumpers on the control-decoder pc card. The address is then resident in a particular system and is compared to every Touch-Tone entered address. The address recognition hardware consists of a five-bit register (U1) and a four-bit magnitude comparator (U3) with cascading capability. The address field is five

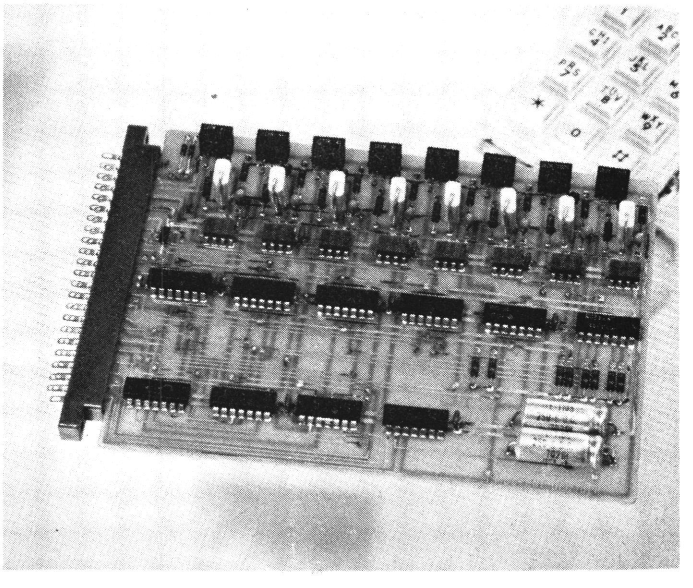


Fig. 8-19 — A commercially manufactured version of the circuit shown in Fig. 8-18. This decoder is available from Lee-Com Associates, P. O. Box 43204, Cleveland, OH 44143.

bits, four bits used as the compare inputs, and one bit used as the cascading input. When the entered address, temporarily stored in U1, compares with the system resident address, a logic one is generated by the magnitude comparator, thus enabling the data field to be permanently stored and decoded when the pound button is pressed. The five-bit address field will allow 2^5 or 32 address combinations. It is advisable that the null set (00000) not be a valid address field; so, there are 31 valid system addresses.

The control-function digits are temporarily stored in the other five-bit register, U2. When the address has been entered, the pound function will cause the control data in U2 to be permanently stored in storage registers U4 and U5.

The five-bit data field allows 2^5 or 32 control functions to be decoded. Only one decoded control function is available at any given time; so, some form of latching relay or other electronic storage element must be provided to implement the control capability available at the decoder output. A decoded output function will appear as a TTL logic low. Typical addresses are shown in Fig. 8-21.

The output-function decoding is accomplished by two binary-to-one-out-of-sixteen decoders, U6 and U9. These binary decoders have two enabling inputs which allow either one or the other decoders to be active at a specific time; this allows the same four bits of control function to be used on both decoders, plus the fifth control function bit used to select which control decoder will be active. In this manner, five encoded (binary) control function bits are decoded to thirty-two output functions. It is advisable to define the null set (00000) control code as the primary system reset code; so, there are only thirty-one valid functions. The null function is decoded in any event, and is there to be used by wiring to the decoded output, if desired.

There are three ways to enter the null set. The first is by Touch-Tone signal. A second null set occurs whenever the system power is turned on. The network of R1, C1, and CR1 with sections of U7 and U8 automatically generate a reset signal to

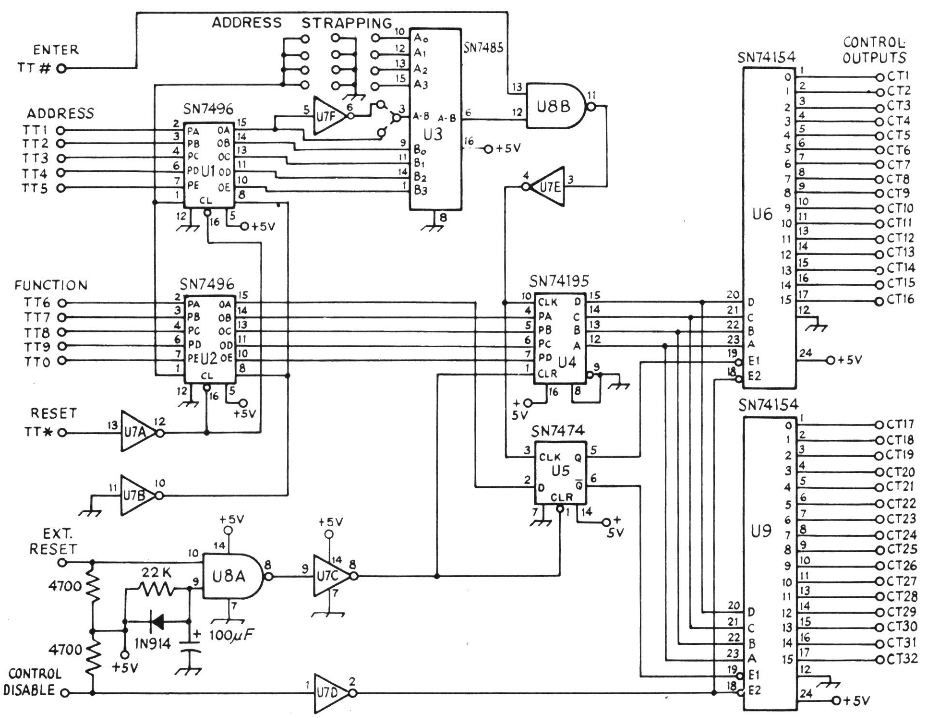


Fig. 8-20 — Circuit of the function and command decoder. Resistors are 1/2-watt composition and the capacitor is electrolytic.

U1, U2 — 5-bit shift register (7496)
U3 — 4-bit comparator (7485)
U4 — 4-bit shift register (74195)
U5 — Dual flip-flop (7474)
U6, U9 — 4-line to 16-line decoder (74154)
U7 — Hex inverter (7404)
U8 - Quad 2-input NAND gate (7400).

SAMPLE CONTROL CODE ASSIGNMENTS

Address	Number	Control Function	Number
Repeater 1	*2*	*CT2 – Cross link on*	*0*
Repeater 2	*3*	*CT3 – Down link on*	*9*
Repeater 3	*2, 3*	*CT4 – Up link on*	*9,0*
Repeater 4	*4*	*CT5 – Autopatch on*	*8*
Repeater 5	*2, 4*	*CT6 – Autopatch off*	*8,0*
Repeater 6	*3, 4*	*CT7 – Timer reset*	*8,9*
Repeater 7	*2, 3, 4*	*CT8 – Antenna 1 on*	*8,9,0*
Repeater 8	*5*	*CT9 – Antenna 2 on*	*7*
		CT10 – Main transmitter on	*7,0*
		CT11 – Backup transmitter on	*7,9*
		CT12 – Direct repeat start	*7,9,0*
		CT13 – Backup receiver on	*7,8*

Fig. 8-21 – An example of some of the remote switching and control operations which can be handled by the control-function decoder. A system such as this can be very useful in emergency situations when it might be necessary to link several repeaters to extend the capability beyond an immediate trouble area.

the secondary storage elements, U4 and U5. When U4 and U5 are reset, the stored data exactly corresponds to the null data field, and is decoded in exactly the same manner. The third way is by use of the external reset function. This input allows external generation of a reset signal for storage registers U4 and U5; the external reset forces a null data pattern to be stored in U4 and U5 and is decoded as that function. A logic 0 on the external reset line (or a contact closure from that connection to ground) will cause the reset signal to be generated.

To provide a local inhibit of any further control functions being decoded, a control-disable function is designed into the decoder logic. A logic low (or a contact closure to ground) will disable all the outputs of U6 and U9; these outputs will remain in the logic high state as long as the disable function is energized. When the disable function is released, the outputs will assume the state of the last encoded function entered in registers U4 and U5. This disable function can be used as an overriding local control of a system via another control link or to lock the system into a particular operational mode. The external-reset and control-disable functions may remain unused by leaving the respective input pins unconnected.

Fig. 8-22 – This dual-tone encoder is built in a surplus housing which was sold with the rotary dial (No. TEL from John Meshna, P.O. Box 62, E. Lynn, MA 01904).

SINGLE- AND DUAL-TONE CONTROL SYSTEMS

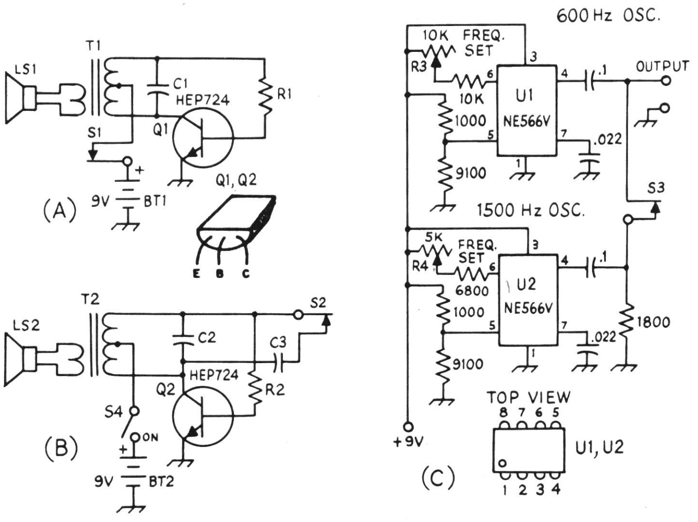


Fig. 8-23 — Diagrams of (A) single-tone and (B & C) dual-tone encoders. Resistors are 1/2-watt composition and capacitors are mylar.

C1-C3, inc. — Value to provide desired frequency. Approx .09 μF for C1 will produce 1500 Hz, while 0.12 μF will allow 1800-Hz oscillation.
BT1, BT2 — Transistor radio battery.
LS1, LS2 — 1-inch dia, 3.2-ohm speaker.
R1, R2 — 50 to 100k ohms.
R3, R4 — 1/2-watt composition control, linear taper.
Q1, Q2 — Motorola transistor.
S1-S3, incl. — Telephone-dial contacts.
S4 — Spst toggle.
T1, T2 — 88-mH telephone loading coil with 16 turns of No. 22 plastic-covered hookup wired added to from a secondary winding. See *QST* ads for sources that sell toroid loading coils.
U1, U2 — Signetics IC (available from Landree Labs., Box 298, Guilford CT 06437)

A single-tone control system is easy to construct. The encoder consists of an audio oscillator which can be keyed on and off. To provide several control functions, a telephone dial is usually employed as the keyer. A typical encoder circuit is shown at Fig. 8-23A. An *LC* oscillator is used, with an inexpensive telephone loading coil providing the required inductance (and coupling to the speaker). The speaker is placed near the telephone handset (if wire-line control is used) or next to the microphone of a radio control-link transmitter. A simple PLL decoder, such as shown in Fig. 8-24, is suitable. The operation of a PLL is described in Chapter 3 and will not be repeated here.

Dual-tone control offers simpler equipment than a Touch-Tone system but better reliability than a single-tone system. A simple frequency-shift encoder is given in Fig. 8-23B. In this circuit the frequency of oscillation is determined by the inductance of T2 and the value of C2. When the telephone-dial contacts are closed, C3 is added in parallel with C2, lowering the frequency of oscillation. To decode the fsk signal two NE567 ICs are used, as shown in Fig. 8-25 with the output circuit of B.

Alternatively, a dual-tone system may be designed where one tone is transmitted continuously while the other tone is pulsed on and off by the

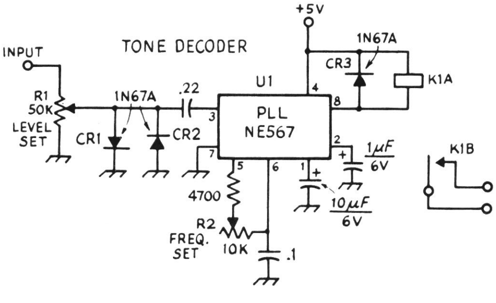


Fig. 8-24 — A simple PLL single-tone decoder. Resistors are 1/2-watt composition and capacitors are mylar, except those with polarity marked, which are electrolytic.

CR1, CR2 — High-speed silicon switching diode.
K1 — 6-volt relay, contact arrangement chosen to fit application.
R1, R2 — 1/2-watt, linear-taper composition control.
U1 — Signetics IC.

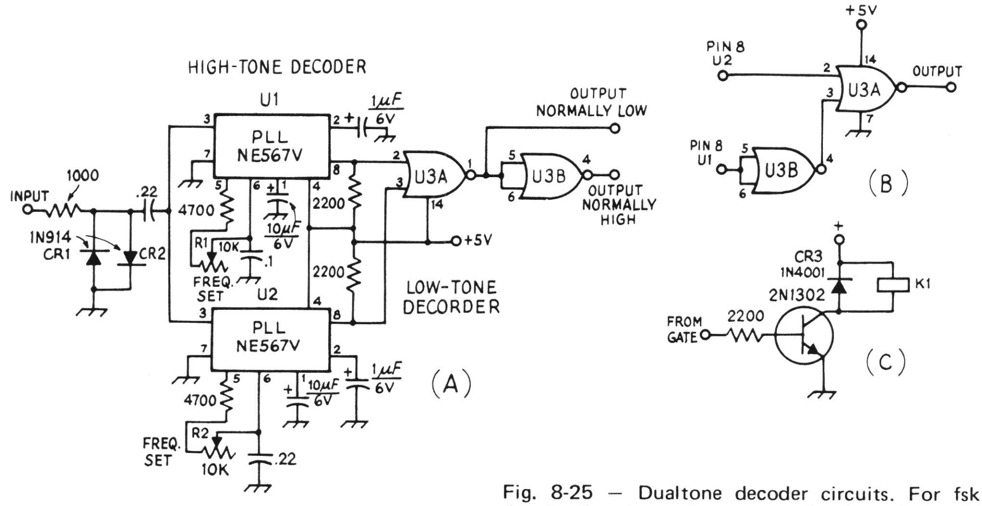


Fig. 8-25 — Dualtone decoder circuits. For fsk signals, the alternative output circuit at B should be used. A relay driver is shown at C. Resistors are 1/2-watt composition and capacitors are mylar, except those with polarity marked, which are electrolytic.

CR2, CR2 — High-speed silicon switching diode.
CR3 — Silicon diode, 100 PRV, 500 mA or more.
K1 — 6-, 12-, or 24-V coil, contact arrangement chosen to fit application.
R1, R2 — Linear-taper, 1/2-watt composition control.
U1, U2 — Signetics PLL IC.
U3 — Quad dual-input gate package (7402).

telephone dial. A typical encoder circuit using two IC audio generators is shown at Fig. 8-23C. For this type of control, the decoder circuit of Fig. 8-25A is needed. When both NE567 ICs have an input signal, their outputs go low, changing the output of U3A to a logic high. A second NOR gate, U3B, is included to provide an inverted output. The decoder can operate relays or telephone stepping switches, using a saturated switching transistor such as shown in Fig. 8-25C.

SOLID-STATE MORSE CODE IDENTIFIERS

Electromechanical systems have often been used to key Morse-code characters for transmitter identification and for other short fixed-format cw messages. But as most users of code-wheel systems and similar methods soon learn, frequent mechanical adjustments are usually required. Not so with a solid-state system having no moving parts! Other advantages of a solid-state digital identifier are that the Morse code is perfectly proportioned, the speed is variable, and, if desired, the message content can usually be changed rather easily.

A DIODE-MATRIX REPEATER IDENTIFIER

The identifier of Figs. 8-26 through 8-34 is simple and economical to build. Of the various types of identifiers, the approach shown in the block diagram of Fig. 8-27 offers considerable flexibility at low cost. The device can be built for about $55, including all components, power supply, and etched circuit boards.

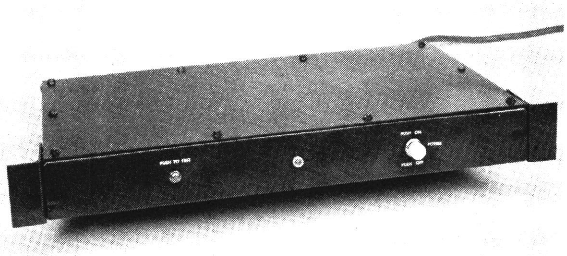


Fig. 8-26 — The Morse-code identifier is built into an aluminum chassis that is 17 inches long, 10 inches wide, and 1-1/2 inches high. Small angle brackets provide a means of mounting the identifier chassis in a standard rack. The cover is held on by self-tapping screws. The basic circuit of this identifier was originally described by K1PLP in *QST* for June, 1970, but the version presented here has been modified to include features especially tailored to repeater operation.

Circuit Operation

A two-transistor oscillator provides a continuous train of clock pulses to the input of a binary counter, Fig. 8-27. The time between successive clock pulses represents the duration of a dot or a space. We'll call this time interval a "bit." A dash occupies the time of three clock pulses, or is three bits long.

When a message is being generated, the binary counter "counts" or "adds up" the number of clock pulses occurring. At any given instant, we can determine exactly how many clock pulses have been generated since the message started, merely by inspecting the counter's output, in 1-2-4-8-16 fashion. A matrix of diodes arranged to form AND and OR gates is used to perform this "inspection" continuously. The matrix converts the various binary output states of the counter into dots, dashes, and spaces, each element occurring at the proper clock time for the message being generated. This output from the matrix operates the keyer.

The end of the message is also detected in the matrix, being determined by the total number of clock pulses required. When this number has been generated, a separate output flips or toggles a control flip-flop, its output resetting and holding the binary counter at zero. Keying stops. To initiate the message again, the state of the control flip-flop is changed by a push-button switch or by an external timing device or circuit. This action permits the binary counter to advance, thereby repeating the entire message cycle. The message is self-completing.

The diode matrix comprises the actual "memory" for a given Morse code message. Each message will have its own particular arrangement of matrix diodes. The number of diodes needed in the matrix depends partially on the length of the message, but primarily on the "rhythm" of the message, in terms of repeated bit patterns at intervals of 2, 4, 8, 16, and so on. For cw identification with most amateur calls, from 60 to 100 diodes will be required.

The maximum permissible length of a message is determined not by the diode matrix, but by the number of clock pulses which may be counted without ambiguity in the binary counter. Using four dual J-K flip-flop integrated circuits in the counter, a count as high as 255 may be registered. That's enough counting capability to send the message DE WR1KHK AVON CT 28/88. Listing the bit duration of each letter and number is helpful for quickly determining the length of a message.

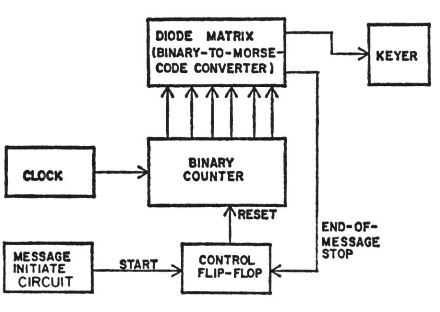


Fig. 8-27 — Block diagram of the basic message generator. The self-completing message may be initiated manually with a push button or from an external timing source.

Circuit Description

Aside from the diode matrix, the generator circuit is the same for all messages, regardless of the message content or length. If the message content is to be changed frequently, it is convenient to build the basic circuit separately from the matrix and to provide a plug-in arrangement for changing the matrix. Otherwise the matrix diodes may be hard wired into the generator. Fig. 8-29 shows the complete schematic diagram of this basic part of the generator. Some sections may be omitted if they are not desired, without affecting the rest of the circuit, and the total cost can be pared accordingly.

The clock circuit is W1WCG's design. The speed-control range is 10 to 50 wpm with the resistor network of R1, R2, and R3. The three resistors may be combined as one fixed value if code-speed changes are not needed.

The binary counter consists of eight J-K flip-flops in cascade, the *Q* output of each toggling the next. Initially all *Q* outputs are low. When a message begins, the first clock pulse will set the *Q* output of U1A high, the *Q* outputs of all other flip-flops remaining low; the second pulse will clear U1A, its output going low and setting the *Q* output of U1B high, all other *Q* outputs being low; the third pulse will set only the U1A output and leave U1B high, and so on. In Fig. 8-29, the *Q* outputs are labeled to show their binary-coded-decimal values, 1-2-4-8, and so on. The status of the counter may be determined at any time, merely by observing the *Q* outputs of all flip-flops, and adding the BCD values for those which are high. These *Q* outputs and their complimentary *not-Q* ($\bar{Q}$) outputs are fed to the diode matrix through J1.

The matrix message signal is available at pin X of J1, going positive or high for the key-up condition and going low for the key-down condition. Q3 functions as a buffer-amplifier, and also inverts the signal.

U6A is connected as an inverter, its filtered output keying the audio oscillator formed by U6C and U6D, which are connected as a multivibrator. Circuit constants were chosen to produce a tone of about 600 Hz, determined after conducting several "listening tests" on various individuals to be the optimum pitch for low-level use in identifying vhf fm repeater transmissions. ("Subaudio" tones in the vicinity of 100 to 250 Hz were found to be difficult to read beneath high-level voice modulation, should an individual be especially interested in knowing whose repeater he was hearing.) The note is very stable. The pitch may be slightly different from one IC to another, and will also depend upon the tolerance of the circuit components. Should you wish to make a change in the pitch, the value of R16 may be altered. A smaller value will yield a higher pitch, and vice versa.

The audio output is available directly at J4. However, this output is not suitable for driving a low-impedance load. Any connections to J4 should be into a high impedance. The value of R26 can be lowered to as little as 10,000 ohms if a higher output level is desired. An emitter follower should be added if it is necessary to drive a low-impedance load.

When no message is being sent, the control flip-flop, U7, is in its set condition, its Q output being high. This high output is applied to the C_D inputs of the counting flip-flops, clearing the entire counter to zero. The counter cannot advance as long as its C_D inputs are held high, as this input overrides all others. To initiate a message, S2 is momentarily pushed (or closure of contacts connected to the MORSE IDENT terminals is made), clearing the control flip-flop and causing its Q output to go low. The low state at the C_D inputs of the counting flip-flops now enables the counter to advance, ticking out the message. Once a message has been initiated, it would cycle through again and again if the state of the control flip-flop were never changed. A message-stop signal, available from the diode matrix at pin Y of J1, is amplified and inverted in Q6. This signal is used to toggle U7, which then clears the counter and prevents the message from repeating immediately.

Q4, K1, and other associated components are used to obtain a transmitter-keying output from the identifier. Being keyed from the control flip-flop, the relay contacts are closed for the duration of the message whenever the identifier is active. These contacts may be wired in parallel with appropriate COR contacts to prevent the transmitter from dropping out in the middle of a code identification, or to key the transmitter if it is desired to identify at periodic intervals when the repeater is active but not in use. R9 limits the relay coil current to the proper value. R10 limits the contact surge current and prevents the relay contacts from sticking when a grid-blocked transmitter is being keyed. Its value should be two ohms for each volt of open-circuit voltage at the keyed terminals.

Power requirements for the generator are meager, being 7 volts at 450 mA, including Zener-diode regulating current to obtain 3.6 V. The current drawn from the 3.6-V portion of the supply is 210 mA. A full-wave rectifier-bridge integrated circuit is shown in Fig. 8-29 but four discrete diodes could just as well be used.

The Matrix

The matrix is nothing more than several diodes and resistors connected to form simple AND and OR gates. With various outputs from the binary counter as inputs to the matrix AND gates, we make use of the fact that the output from each AND gate will be high only when *all* of its inputs are high. Each such gate will contain one resistor and a few diodes, typically from four to seven. The connections are made so that an AND gate output goes high or positive for the message key-up condition. Consider the operation as requiring a positive output to "blank" a continuously keyed signal.

When the generator is in operation, the outputs from the various AND gates will be high at various times and for various intervals, as the binary counter changes the inputs to these gates. Each AND gate contributes its own small part to the overall blanking waveform, and the outputs of all AND gates are combined in one OR gate to form the keying output. The principle is shown in Fig. 8-30. One OR gate diode will be required for each AND gate in use.

Determining how many and what diode connections are needed to produce any message you might desire may be done with a simple, methodical procedure which requires no guesswork or "hocus-pocus." The technique is described briefly in a later section. More detailed information on this procedure is available in booklet form from the ARRL, along with circuit-board etching templates. Custom design service of message matrices is also available.

Construction of Generator

The enclosure shown in the photographs is a standard 8 × 10 × 2-1/2-inch aluminum chassis. An oversize bottom plate, 8 × 13 inches, provides a lip for mounting the identifier on the side panel of a relay rack. Keyhole-shaped slots in this lip provide for easy mounting and removal of the identifier without the need to loosen the mounting bolts which are permanently affixed to the side panel. Other arrangements may be used, but a completely enclosed box is preferred as a precaution against stray rf disrupting operation of the identifier. To avoid the possibility of other problems, the keying leads from the relay should not be routed near the clock circuit or the counter ICs, nor should either of the relay contacts be connected directly to the ground foil of the board. Keyed currents through the ground foil may induce transients into the

A	8	N	8	1	20
B	12	O	14	2	18
C	14	P	14	3	16
D	10	Q	16	4	14
E	4	R	10	5	12
F	12	S	8	6	14
G	12	T	6	7	16
H	10	U	10	8	18
I	6	V	12	9	20
J	16	W	12	Ø	22
K	12	X	14	Slant Bar	16
L	12	Y	16	Word Space	4
M	10	Z	14	Last Character	−3

Fig. 8-28 – International Morse code character duration, bits. The values given include the proper spacing interval following a character. The bit duration of a complete message is, therefore, three bits less than the sum of the bits for its individual characters.

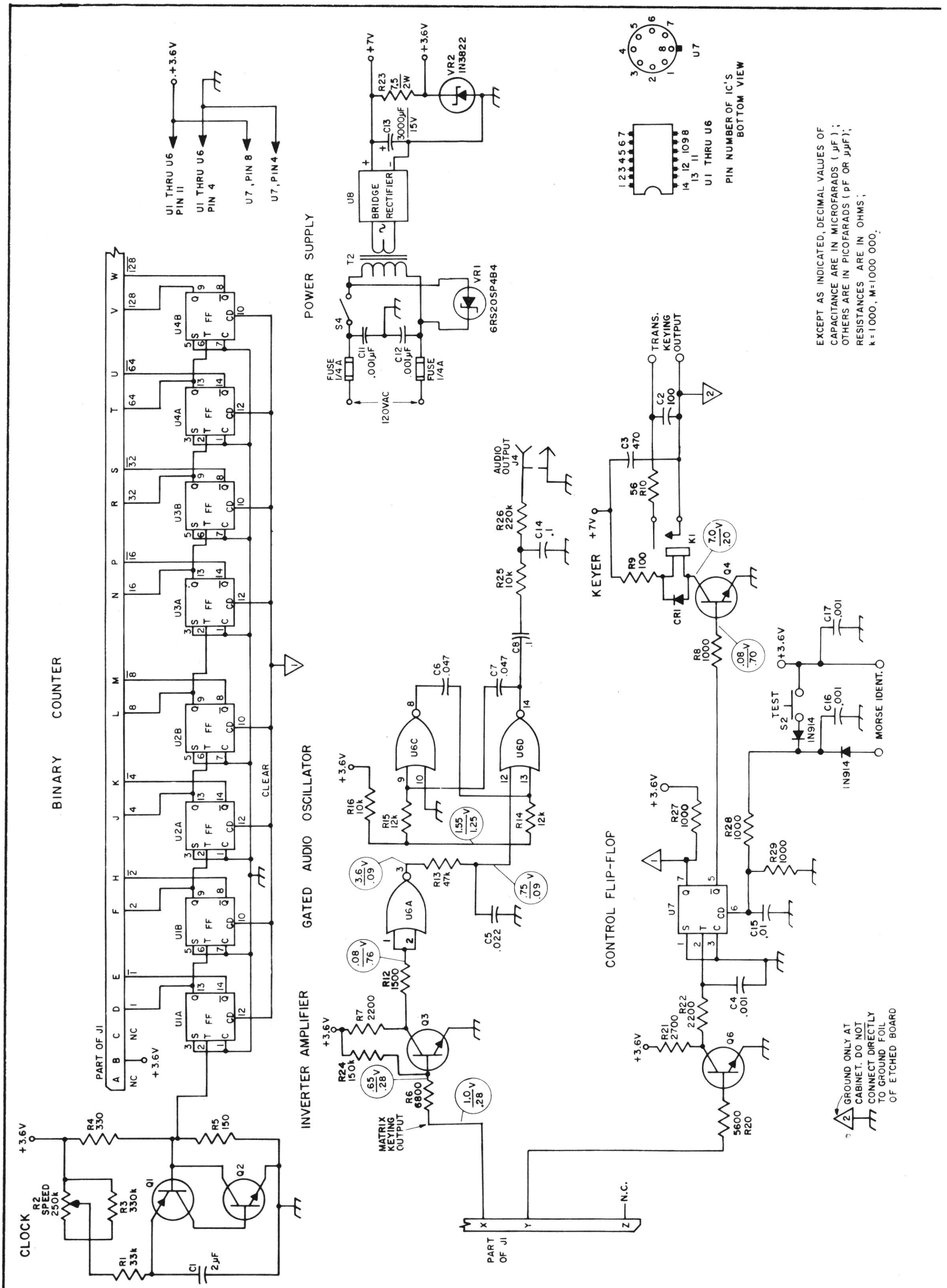

BINARY COUNTER
CLEAR
PART OF J1
POWER SUPPLY
120VAC
BRIDGE RECTIFIER
GATED AUDIO OSCILLATOR
AUDIO OUTPUT
INVERTER AMPLIFIER
MATRIX KEYING OUTPUT
CONTROL FLIP-FLOP
KEYER
TRANS. KEYING OUTPUT
MORSE IDENT.
TEST
CLOCK
SPEED
U1 THRU U6 PIN 11
U1 THRU U6 PIN 4
U7, PIN 8
U7, PIN 4
U1 THRU U6
PIN NUMBER OF IC'S BOTTOM VIEW
EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF); OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS; k=1 000, M=1 000 000.
GROUND ONLY AT CABINET. DO NOT CONNECT DIRECTLY TO GROUND FOIL OF ETCHED BOARD

Fig. 8-29 — Basic circuit of the message generator. All fixed resistors are 1/4- or 1/2-W, 10% tolerance. Components not listed in the parts list below are for text reference and circuit-board identification. Connections to the diode matrix are made through J1. As a troubleshooting aid, dc operating voltages are encircled in the amplifier, keyer, and oscillator sections. All voltages are positive measured with respect to chassis ground with a VTVM or 20,000-ohms-per-volt meter. Voltages may vary around the values given as the binary counter changes states. Except in the keyer section, values above the lines represent voltages for the key-up condition at the generator's audio output, while values below the lines are for the key-down condition. In the keyer section, the value above the line represents the voltage during standby, and below the line the voltage during the time a message is being sent. Some component designations used in the original version do not appear in this diagram.

C1 — 2-µF, Mylar or metallized paper, 100 V.
C2 — 100 pF, disk, 1000 V. Mount directly as J2.
C4 — .001 µF disk, 1000 V. Mount as closely as possible to pin 2 of U7.
C13 — Electrolytic.
CR1 — Any small-signal silicon diode.
J1 — Printed-circuit connector, 22 contacts, 2 unused (Amphenol 143-022-01 or equiv.). If there is no requirement for changing the message content frequently, J1 may be omitted and direct connections made to the matrix instead.
J4 — Phono jack.
K1 — Spst reed relay (Magnecraft W102MX-1 or equiv.).
Q1 — Silicon npn rf or high-speed switching transistor (2N4126, Motorola HEP 52 or equiv.).
Q2 — Silicon npn rf or high-speed switching transistor (2N4123, Motorola HEP 50, or equiv.).
Q1-Q4, incl., Q6 — Silicon npn audio transistor. Q3 must have Ω = 50 or greater (Motorola MPS 3394 or equiv.).
R2 — 250,000 ohms, reverse or right-hand logarithmic taper (Mallory U45 or equiv.). Connect for zero resistance when fully clockwise.
R10 — See text regarding value.
R23 — 7.5-ohm, 2-watt; made by paralleling two 15-ohm 1-watt 10% resistors.
S2 — Spst, momentary push.
S4 — Spst. toggle.
T2 — Filament, 6.3-V, 1.2-A (Stancor P6134 or Triad F14X or equiv.).
U1 - U4, incl. — Dual J-K flip-flop (Motorola MC790P, HEP 572, or equiv.).
U6 — Quad 2-input gate, one section unused (Motorola MC724P, HEP 570, or equiv.).
U7 - *J-K* flip-flop (Motorola MC882G, HEP 583, or equiv.).
U8 - Full-wave rectifier bridge, 1-A 50-V (Motorola MDA 920-2, HEP 175, or equiv.). Four silicon diodes of the same rating may be used instead, if connected in the full-wave bridge configuration.
VR1 — G.E. Thyrector, 120 V.
VR2 — Zener diode, 3.6-V, 1-W (1N4729, 1N3822, or Motorola HEP 102 or equiv.).

remaining circuitry. The leads from the relay contacts should be run as a twisted pair to the keying terminals, or small-diameter coaxial cable may be used.

After the basic generator has been assembled, the current should be metered at two points. First connect a milliammeter between the anode of the Zener diode, VR2, and ground. Then with all the ICs plugged into their sockets (if used), apply power and measure the Zener current. It should be in the neighborhood of 150 to 200 mA. If not, the value of R23 may be changed to obtain the proper Zener current.

Next, meter the current through the coil of K1, in the collector lead of Q4. If this current is not within ten or fifteen percent of the proper amount for the relay being used, the value of R9 may be changed for the correct current. The W102MX-1 relay coil is rated for a current of 40 mA, and with a 7- or 7.5-volt output from the power supply, 100 ohms should be the correct value for R9.

Testing the Generator

The following tests will check every circuit in the generator. These tests should be performed with no matrix connected at J1. The MC790P flip-flops are quite rugged as far as taking abuse from wrong external connections goes, but to play it safe you may wish to connect the jumpers for the following tests only while the power is removed.

This first test will check the clock and the first binary counter flip-flop, as well as the keying circuit. Connect a jumper lead between pins D and X of J1. With the generator energized, a steady string of keyed dots should be emitted. If nothing happens, press the MESSAGE INITIATE button to release the counter. The speed of the dots should be variable by moving the speed control.

Next, remove the jumper and connect it between pins W and X. Set the speed control at the maximum speed. Now you should have keyed dashes, about three seconds long and with a spacing of about three seconds. If all is okay here, the complete chain of flip-flops in the binary counter is working properly.

Now we'll test the message stop circuitry. Connect a jumper between pins E and X of J1, and another jumper between pins L and Y. With the generator energized, you should hear nothing other than perhaps a few dots just after turn-on. Now press the MESSAGE INITIATE button. You should get a perfect letter H, and nothing more. (You'll have to get your finger off the button quickly at high code speeds, or you'll get several Hs run together.) Each press of the button should give an H. There should be a corresponding closure of K1 for each H, followed by an opening of the contacts upon completion of the H.

Designing the Matrix

To understand how the identification message can be keyed on a sequential basis, consider an

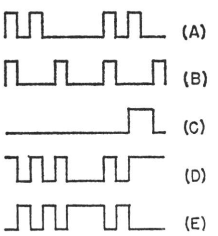


Fig. 8-30 — Formation of a code character in the generator. The wave forms at A, B, and C represent outputs of three separate matrix AND gates, each waveform derived from binary counter inputs to the gates. Each AND gate output is high during some part of the character's key-up time. The waveform at D is the OR-gate output resulting from combining the three AND gate signals. This is the keying or "blanking" output signal from the matrix. At E, the keying waveform is shown after inversion in Q3, and is now recognized as the letter F. This same letter, however, can and often will, be formed by other combinations of AND-gate waveforms.

AND gate wired to decode only the number 5. Following the initiation of a message, the output of this gate will be low after the first, second, third, and fourth clock pulses have been registered in the binary counter. The gate's output will become high as the fifth clock pulse is registered, and remain high until the sixth clock-pulse transition occurs. In this identifier the time interval between clock pulses is equivalent to the duration of a dot or an element space in Morse code. With our gate wired to produce a positive output on the fifth clock pulse, we have seen that we would have to wait for the time interval of the first four bits of the message to occur before we would see a change in this output. Following the sixth clock pulse, no combination of counter flip-flop states will make the output of this gate high until the counter stages reset to 0 (at a total count of 256) and again reach a count of 5.

The first step in the design of the matrix is to lay out the code message on a bit-by-bit basis, to establish a time base for the message in terms of when to begin and end marks and spaces. This is done as shown in Fig. 8-32 where the bits are numbered sequentially for the message DE W1AW. Use one bit for a dot or a space between elements of a letter; use three successive bits for a dash or a space between letters, and use seven successive bits for a space between words or code groups. The key-down condition *must begin after 0*, because the counter state is 0 when "at rest." The exact starting point for the message, in terms of clock pulses, will affect the design of the matrix and, to some degree, the number of diodes required. To conserve diodes, it is suggested that the message always be started on the second clock pulse.

Each of the bit numbers of Fig. 8-30 is uniquely associated with a combination of the binary outputs from the flip-flops of the counter; that is, there is a unique combination of 1s and 0s for each decimal number from 0 to 255. Each of these various combinations is given in Table 8-1 for numbers from 0 to 127. We make use of these combinations in choosing the numbers (and consequently the times) for which marks and spaces of the identification message are to be initiated. The customary way of writing binary numbers is to place the least significant digit at the right, just as in writing decimal numbers. However, for our purposes it is more convenient to start with the least significant digit at the left, and the numbers of Table 8-1 are given in this way. Thus, the digits from left to right correspond to the states of the counting flip-flops from left to right, beginning with U1A of Fig. 8-29 for a particular binary number.

In our DE W1AW message, the necessary key-up conditions occur during bit numbers 0, 1, 5, 7, 9, 10, 11, and so on – those numbers which have not been shaded out in Fig. 8-32. We must construct the AND gates of our message matrix to produce a high output at each of these counter states, but at no others. The desired matrix output wave form is obtained by connecting the matrix diodes so that at least *one* AND-gate output is positive or high for each key-up bit. By combining the outputs of all AND gates in one OR gate, each AND gate is able to contribute, as required, to some portion of the overall keying wave form, as shown in Fig. 8-30 for the letter F.

To key the DE W1AW message without bothering to give the matrix much design consideration, we could just individually decode each of the 32 numbers for which a positive output is needed (numbers beyond the end of the message, marked STOP in Fig. 8-32 may be ignored for the moment). This would be done by using information from Table 8-1. The necessary counter connections for each decimal number are indicated by the binary number in the body of the table. The left-most number represents the connection to the 1 stage, the next to the 2 stage, the third to the 4 stage, and so on, with the eighth number representing the connection to the 128 stage. A 1 means to connect to the Q output, and a 0 means to connect to the $\overline{Q}$ output. Thus, to decode the number 5, 10100000 in binary form, we would make connections to the $1, \overline{2}, 4, \overline{8}, \overline{16}, \overline{32}, \overline{64}$, *and* $\overline{128}$ counter outputs for an AND gate. This approach, however, would require a total of 32 × 8 = 256 diodes for the AND gates, plus 32 diodes for the OR gate, or a total of 288 diodes (and 32 resistors) for the complete keying matrix. However, we can reduce this number significantly (to 34 diodes and 7 resistors in the complete keying matrix) by using *groups* of numbers at the counter's output, rather than by using individual numbers with which to assemble our keying wave form. One AND gate is required for each group, and members of the group will be numbers separated by 1, 2, 4, 8, and so on, or any combination of these. The more numbers that may be included in a single group, the smaller will be the quantity of diodes needed for that AND gate – and the fewer the numbers remaining to be selected in other groups. It does no harm to decode the same number in two or more different groups, and often many diodes can be saved by making redundant selections.

Matrix Design with a Karnaugh Map

The secret to designing a matrix successfully lies in finding the most efficient groupings of the numbers for decoding in terms of the quantity of diodes required. A simple way of doing this is to use a mechanical aid known as a Karnaugh map. Such a map allows us to determine graphically the best of several possible ways to group the numbers for decoding. This type of map is often used by logic-design engineers, and is not confined to use for matrices in the code generator

A portion of a map evolved especially for use in designing message matrices for this generator is shown in Fig. 8-33. This map contains the same information as does Table 8-1, but in different form. The map shows at a glance the exact states of the first seven counting flip-flops for each decimal number within their counting capability, 0 through 127. Above and to the left of the squares, the possible states of the flip-flops are shown directly. Because we are interested only in the high or positive outputs from the counting flip-flops for developing our AND gates, only these are shown. For example, a $\bar{2}$ at the head of a column of squares indicates that for all decimal numbers in that column, the $\bar{Q}$ output of the second counting flip-flop will be high. A 4 at the left of a row of squares indicates that for all decimal numbers in that row the Q output of the third counting flip-flop will be high. A glance at the binary-coded decimal numbers heading the column and row for a particular decimal number in a square will show which counter outputs are to be used as AND-gate inputs for decoding that number alone.

To see how this ties in with our earlier example using the number 5, observe that this number appears in the second column and second row of squares of the upper left block. By glancing at the top of the column and to the left of the row we see that the required flip-flop connections for driving

Table 8-I

BINARY COUNTING TABLE

DECIMAL	LSD MSD	DECIMAL	LSD MSD	DECIMAL	LSD MSD	DECIMAL	LSD MSD
0	00000000	32	00000100	64	00000010	96	00000110
1	10000000	33	10000100	65	10000010	97	10000110
2	01000000	34	01000100	66	01000010	98	01000110
3	11000000	35	11000100	67	11000010	99	11000110
4	00100000	36	00100100	68	00100010	100	00100110
5	10100000	37	10100100	69	10100010	101	10100110
6	01100000	38	01100100	70	01100010	102	01100110
7	11100000	39	11100100	71	11100010	103	11100110
8	00010000	40	00010100	72	00010010	104	00010110
9	10010000	41	10010100	73	10010010	105	10010110
10	01010000	42	01010100	74	01010010	106	01010110
11	11010000	43	11010100	75	11010010	107	11010110
12	00110000	44	00110100	76	00110010	108	00110110
13	10110000	45	10110100	77	10110010	109	10110110
14	01110000	46	01110100	78	01110010	110	01110110
15	11110000	47	11110100	79	11110010	111	11110110
16	00001000	48	00001100	80	00001010	112	00001110
17	10001000	49	10001100	81	10001010	113	10001110
18	01001000	50	01001100	82	01001010	114	01001110
19	11001000	51	11001100	83	11001010	115	11001110
20	00101000	52	00101100	84	00101010	116	00101110
21	10101000	53	10101100	85	10101010	117	10101110
22	01101000	54	01101100	86	01101010	118	01101110
23	11101000	55	11101100	87	11101010	119	11101110
24	00011000	56	00011100	88	00011010	120	00011110
25	10011000	57	10011100	89	10011010	121	10011110
26	01011000	58	01011100	90	01011010	122	01011110
27	11011000	59	11011100	91	11011010	123	11011110
28	00111000	60	00111100	92	00111010	124	00111110
29	10111000	61	10111100	93	10111010	125	10111110
30	01111000	62	01111100	94	01111010	126	01111110
31	11111000	63	11111100	95	11111010	127	11111110

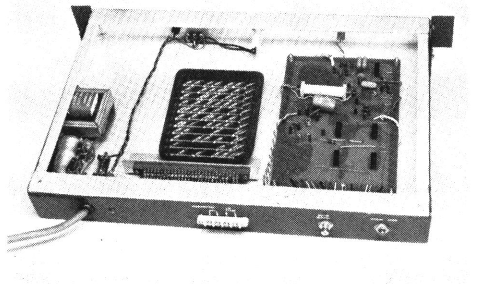


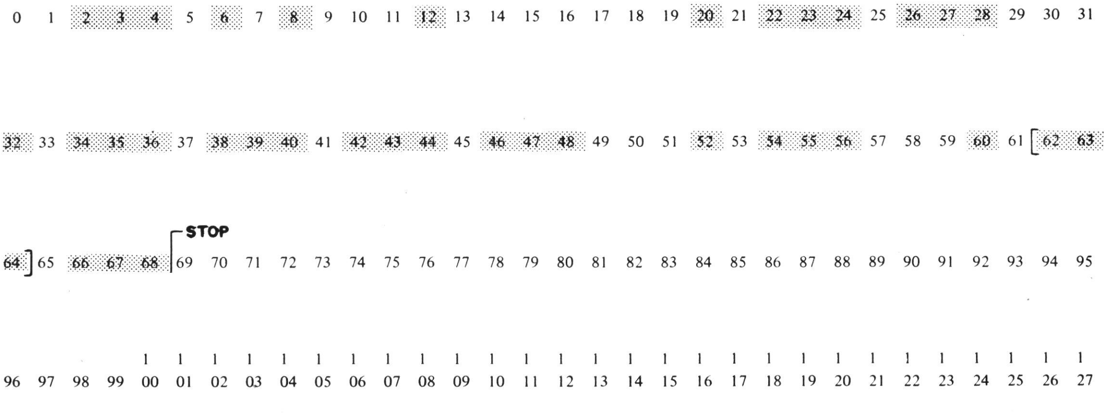
Fig. 8-31 – In this photograph, the cover has been removed to show the interior layout. The power supply is at the left. The main circuit board is in the right half of the chassis, with the diode matrix near the center. A junk-box variety of connector was used for the matrix board, which explains the unused pins. The connector has a block installed to prevent the board from being improperly positioned.

the AND gate are 1, $\overline{2}$, 4, $\overline{8}$, $\overline{16}$, $\overline{32}$, $\overline{64}$, and $\overline{128}$, corresponding to the 10100000 of Table 8-1.

For now, let's just suppose our message requires that we decode both the number 4 and the number 5. If we were to decode each of these numbers individually, our diode connections to counter outputs for decoding the 4, as shown in Fig. 8-33, would be $\overline{1}$, $\overline{2}$, 4, $\overline{8}$, $\overline{16}$, $\overline{32}$, $\overline{64}$, $\overline{128}$, plus one resistor and one OR-gate diode. For the 5, we would connect diodes to 1, $\overline{2}$, 4, $\overline{8}$, $\overline{16}$, $\overline{32}$, $\overline{64}$, $\overline{128}$, and use a second resistor and second OR-gate diode. Altogether to decode the 4 and the 5, we've used 18 diodes and 2 resistors. But look closely at those counter connections for the two numbers. In either case the $\overline{2}$, 4, $\overline{8}$, $\overline{16}$, $\overline{32}$, $\overline{64}$, and $\overline{128}$ connections are the same. The only difference between the two gates is that in one case we made a connection to the $\overline{1}$, and in the other to the 1. In effect, we're giving the matrix output two instructions which override each other by wiring the gates in this manner – go positive when the 1 is high (for the 5), and also go positive when the 1 is low ($\overline{1}$ is high, for the 4). Wouldn't it be simpler to have the matrix disregard the counter's 1 output completely, and only tell it to go positive when the $\overline{2}$, 4, $\overline{8}$, $\overline{16}$, $\overline{32}$, $\overline{64}$, and $\overline{128}$ are high? It certainly would be, and we do this merely by making no connection at all to the counter's 1 flip-flop. By making a single gate instead of the two above, with diodes now wired to the 2, 4, 8, 16, 32, 64, 128, plus one OR-gate diode and one resistor, we will decode both the 4 and 5. And it may be seen that we've reduced the component requirements from 18 diodes and 2 resistors to 8 diodes and 1 resistor. The message would be keyed the same way in either case, but the difference in component count is significant.

We were able to combine the 4 and the 5 into a single group of numbers because the binary representations for the two numbers differ in only one counter stage – 00100000 for the 4, and 10100000 for the 5. The difference appears in the least significant digit at the left. We could not combine just the 3 and the 5 in this simple manner for decoding, as their binary representations, 11000000 and 10100000 respectively, differ in *more than one* position; in this case there is a difference in both the second and third positions from the left. The Karnaugh map is arranged so that numbers which may be combined in this manner are easily located – such numbers lie in squares which are horizontally or vertically adjacent to each other. In Fig. 8-33 the 4 and 5 lie in adjacent squares. Using the map to determine the counter connections for decoding these two numbers as a pair, we just ignore the counter states shown at the top or the left for a particular stage which are different for the two numbers. As may be seen in this case, the 1 and the $\overline{1}$ connections differ for the 4 and 5, so we make no connection at all to the 1 flip-flop but use only the connections which are the same for the two numbers. As another example, the decimal numbers 5 and 7 are in adjacent squares. However the 3 and 5 may not be decoded as a 2-number group, as we saw earlier, and these numbers do not lie in squares which are vertically or horizontally adjacent to each other on the map.

Fig. 8-32 – The code layout for the message DE W1AW, with bit numbers indicated as they occur throughout the message. The transition from one bit to the next occurs as clock pulses are registered in the binary counter.



The map is arranged so that numbers which are on *opposite edges* of a block may also be treated as if they were adjacent. In Fig. 8-33 the counter states for 1 and 9 are shown to be identical except for the 8 and $\overline{8}$, and therefore these numbers may also be decoded as a 2-number group. Additional 2-number groups like this are 4 and 6, 0 and 2, 0 and 8, or 2 and 10. There are still others.

By ignoring or making no connections to more than one counter stage for a particular gate, we can increase the size of the group of numbers being decoded by that gate. For every additional counter stage which is "ignored" the quantity of numbers in the group will double. On the map, members of such a group are mutually adjacent to each other. By using the same reasoning that was given earlier for the overriding instructions to decode the 4 and 5 individually, it may be seen that two 2-number groups such as the 5-7 and the 13-15 may be combined into a pair of pairs or a single 4-number group. In either group alone there is already no connection made to the counter's 8 stage. Other 4-number groups in the upper left block are 1-3-5-7, 0-1-3-2, 3-7-15-11, or even 0-2-8-10 (opposite edges again), and more.

With three diodes or three counter connections omitted, 8-number groups are formed for decoding, by combining pairs of fours. Such groups are 0-1-4-5-12-13-8-9, 4-5-7-6-12-13-15-14, or 0-2-4-6-12-14-8-10.

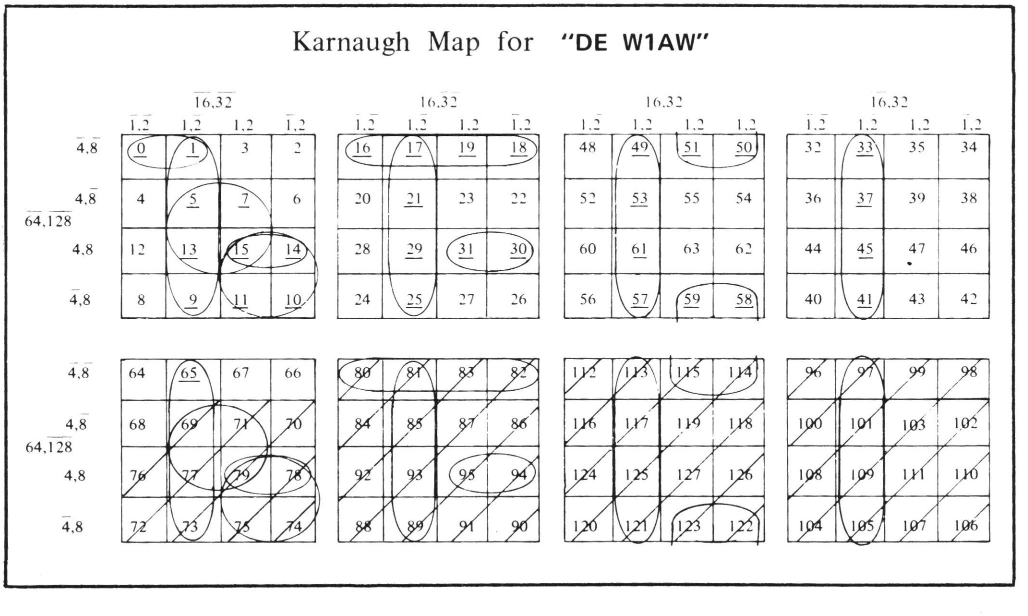
The quantity of numbers decoded in a group will always be a power of two, i.e., 1, 2, 4, 8, 16 members, and so on. It is not possible to decode the 0-1-4 group, for example, without also accepting the 5, or the 1-5-13-9-3 without also accepting the 7-15-11. Considering a large group as being formed by pyramiding smaller groups of numbers will aid in locating a complete group on the map.

The remaining seven blocks of Fig. 8-33 contain numbers above 15. The positions of the blocks relate them to the states of the last four flip-flops, as given by the binary-coded decimal numbers at the far top and far left of the map. The method of using the blocks is identical to the way we used the columns and rows of squares earlier. For example, if we take the block in the second row and second column (decimal numbers 80 through 95), the Q output of the fifth flip-flop (16), the Q output of the sixth flip-flop (32), the Q output of the seventh flip-flop (64), and the Q output of the eighth flip-flop (128) are all high for every number contained inside that block. Information for the states of the first four flip-flops, the 1, 2, 4 and 8 stages, is related to the positions of the squares inside the block and is determined from the binary-coded decimal numbers which are located at the near top and near left of the map. Numbers in the same relative positions of adjacent blocks or blocks at opposite edges of the map, such as 5 and 21, 5 and 37, or 5 and 69, may be paired as a 2-number group.

To use the map for determining the necessary diode connections, first underline in the appropriate squares all the numbers of the message which are to be decoded. This has been done in Fig. 8-33 for the message DE W1AW. Once the numbers are underlined, a methodical inspection of the relative positions of these numbers in the map

Fig. 8-33 -- Portion of Karnaugh map used in designing matrices. The numbers underlined and circled represent bit numbers required to decode the message DE W1AW, while those numbers ruled out with diagonal lines represent counter states beyond the end of the message. It makes no difference whether or not these numbers are included in circled number groups for decoding.

▼



with respect to each other is made, selecting, circling, and making separate note of the largest groups possible for decoding. More than one "pass" through the map will be required – usually two, sometimes three. On the first pass, only those groups of numbers are selected that require no decision. (Many numbers can be decoded only in small, select groups). On the later passes it will be found that several numbers formerly open to decision, as far as group placement is concerned, have already been selected for decoding, leaving not much decision for selection of remaining numbers. A simple cross-check at the end of the work with the map will reveal any over-redundancy. With a little practice, a complete 80- or 90-bit message matrix design can be obtained in an hour or so.

The map of Fig. 8-33 is shown as it appears upon completion of designing the matrix for the message DE W1AW, with number groupings circled to show the optimum use of matrix diodes. Table 8-2 shows these groupings, the diode quantities, and necessary counter connections in tabular form. For numbers greater than 68, the last message bit, it makes no difference whether or not they are selected for decoding, as the counter is reset to zero immediately upon completion of the message and these counter states are never reached. Utilization of these numbers in the number groupings, however, results in the requirement for fewer diodes.

In addition to determining the diode connections for the keying output, it is also necessary to find the diode arrangement needed to form the stop signal at the end of the message. We do this simply by decoding only the wanted number, disregarding any connections to NOT functions. For the DE W1AW message the stop pulse is required at a counter state of 69. We may connect diodes to the 1, 4, and 64 counter outputs only, as all "unwanted" numbers will occur *after* 69, at states which the counter will never reach for this message. The stop gate is an AND gate like all the others in the matrix, but its output is fed separately to the stop-signal input of the generator. This gate is also tabulated in Table 8-II, and is identified as group S1. Because a single AND gate provides the stop-pulse output, no OR-gate diode is required for this output.

The complete schematic diagram of a diode matrix for a simpler message, a repetitive *CQ* is shown in Fig. 8-34.

Construction of the Matrix

Germanium diodes should be used in the construction, because they exhibit only one-fourth the forward voltage drop that silicon diodes do; the "leakage" currents are about the same for either type in the voltage range at which they are used here.

"Bargain" and "junk-box" diodes may certainly be used in construction of the matrix, if they meet the requirements of a test which can be performed simply. A VTVM and a microammeter, preferably 50-μA full scale, are required. In addition, a variable voltage source up to about 3 volts is required. This may be nothing more than a pair of flashlight cells and a potentiometer. Connect the test circuit as shown in Fig. 8-35. The 47-K-ohm resistor is included mainly for protection of the microammeter in case of accidental short, and its value is not critical. First connect the diode for forward conduction, adjust E for a current reading of 50 μA, and read the voltage drop on the VTVM. Select only those diodes which read 0.2 volt or less. For most germanium diodes the reading will be between 0.1 and 0.15 volt. If the voltage reads between 0.4 and 0.6 volt, the diode is probably silicon, and should not be used in the matrix. Next,

Table 8 - II

Tabulation of design information from Karnaugh map for the message DE W1AW.

Group	*Diodes*	*Group Members*	*Counter Connections**
S1	3	Stop at 69	1, 4, 64
A	6	0-1-16-17	$\overline{2}, \overline{4}, \overline{8}, \overline{32}, \overline{64}$
B	5	5-7-13-15 (69-71-77-79)	$1, 4, \overline{16}, \overline{32}$
C	5	10-11-14-15 (74-75-78-79)	$2, 8, \overline{16}, \overline{32}$
D	3	1-5-9-13-17-21-25-29-33-37-41-45-49-53-57-61-65 (69-73-77-81-85-89-93-97-101-105-109-113-117-121-125	$1, \overline{2}$
E	5	14-15-30-31 (78-79-94-95)	$2, 4, 8, \overline{32}$
F	5	50-51-58-59 (114-115-122-123)	$2, \overline{4}, 16, 32$
G	5	16-17-18-19 (80-81-82-83)	$\overline{4}, \overline{8}, \overline{16}, \overline{32}$

*Except for the stop gate, an additional diode is required for each number grouping for the *OR* gate.

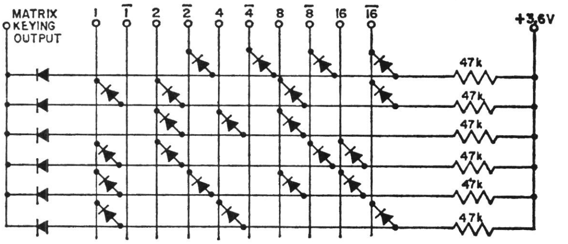


Fig. 8-34 — A matrix for sending the message CQ. With no stop signal provided in this matrix, the message will repeat continuously.

reverse the diode and adjust E for a reading of 2 volts on the VTVM. Read the reverse leakage current on the microammeter. Select only diodes which read less than about 3 μA – the lower the better. If a large number of diodes is to be used in the matrix, 150 or more, you should be a bit more stringent on the reverse leakage test, rejecting those diodes that read greater than 2 μA.

By using care to connect and to orient the diodes properly, the completed message matrix should work the first time. If faulty operation occurs, it can probably be traced to a single AND gate. Often troubles may be found quickly by slowing the message down considerably and determining approximately what counter states are producing the wrong outputs, by listening to the message. Then from the matrix design information, see which gates contribute to bits around those counter states. A VTVM or 20,000-ohms-per-volt meter connected to the output of the AND gate will flick positive during the times the gate is decoding. While listening to the message and watching the meter, a bad gate can be isolated by noting improper "flicking" action, either at the wrong time or not at some desired time. The usual problems which are encountered in a newly constructed matrix which does not key satisfactorily are open or shorted diodes (caused by the use of excessive heat during soldering), missing or misplaced diodes, and diodes wired in backwards. Resistance checks can be made to pinpoint troubles localized by "meter flicking" tests. With the ohmmeter on its R×100 scale, the forward resistance of any diode in the matrix should read approximately 250 ohms. The back resistance of the diodes in the circuit will vary greatly because a completed matrix has a maze of parallel paths across each diode; typical readings range between 5000 and 10,000 ohms. The back resistance should be greater than 50,000 ohms with one lead of the diode unsoldered from the matrix for critical checks, still using the meter on the R×100 scale.

References

1) Hall, "A Digital Morse-Code Message Generator," *QST*, June, 1970.

2) Van Cleef, "ICKEY – An Integrated-Circuit Electronic Keyer with Dot and Dash Memories," *QST*, November, 1968.

3) A package of information is available which presents a 256-bit Karnaugh map developed especially for use in designing message matrices for this generator. The map permits a graphical solution of the design problem to be reached. A working copy of the map, detailed instructions, sample problems, and circuit-board templates with parts layout are included. Send $1.00 to ARRL, 225 Main St., Newington, CT 06111. Templates alone are available for 25 cents and a stamped return business-size envelope.

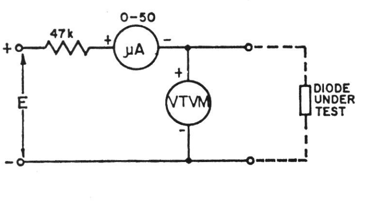
4) As a service to those who wish to avail themselves, custom design of matrices is offered by Matrix Design Consultants, 181 Brimfield Rd., Wethersfield, CT 06109. A fee of $5.00 is charged for a repeater "ID" matrix design in the form DE WR1XXX.

5) Tinned glass-epoxy circuit boards are available from Spectrum Research Laboratory, Inc., P.O. Box 5824, Tucson, AZ 85703. The main circuit board is drilled; the matrix board must be drilled by the user for the individual message. At the time of publication, the main circuit board is $5.30 and the matrix board is $5.65 postpaid in the U.S.

6) For further information about Karnaugh mapping and minimization techniques, the reader may refer to one of several books which are available, such as Hoernes and Heilweil, *Introduction to Boolean Algebra and Logic Design*, McGraw-Hill, 1964, or Maley, *Manual of Logic Circuits*, Prentice-Hall, 1970. Recent editions of the GE *Transistor Manual* also include a brief description of Karnaugh maps in the section on logic.

7) Poly Paks, P.O. Box 942, So. Lynnfield, MA 01949, offers germanium diodes in bags of 50 for $1.00 (stock number 13L642), or 100 for $1.59 (stock number 10L716). Using the test described, usually about 60% or more of the diodes obtained are suitable for matrix use.

Fig. 8-35 — Circuit for testing diodes.



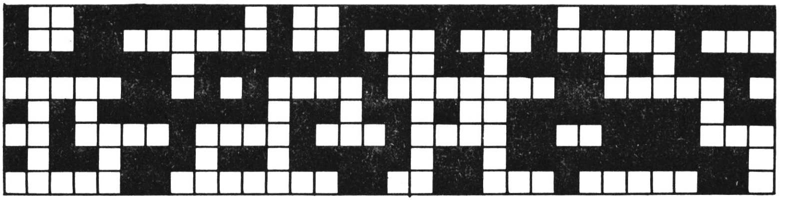


Fig. 8-36 – Memory organization of the 8223 IC. The identification message from the memory represented here is DE WR1KHK AVON CT 28/88.

A READ-ONLY-MEMORY IDENTIFIER

The identifier just described is elementary in nature, requiring few parts (other than the number of diodes in the matrix). It does, however, have the disadvantage of requiring that a rather complex matrix be designed and constructed for each message which is to be sent. Field-programmable read-only memory (ROM) ICs are available, and although they are relatively expensive, a single one of these ICs can be used in much the same manner as a complete matrix for the identifier described earlier. An IC of this type is Signetics' 8223, a 256-bit bipolar field-programmable ROM. The memory portion of the 8223 is organized as 256 diodes in an 8 × 32 array. Connections to the diodes are not available directly at the pins of the IC, however. The memory is organized as 32 words with 8 bits per word. The words are selected by five binary address lines, and full word decoding is incorporated on the chip. Programming of the IC is performed by fusing (or burning out) unwanted diodes in the array.

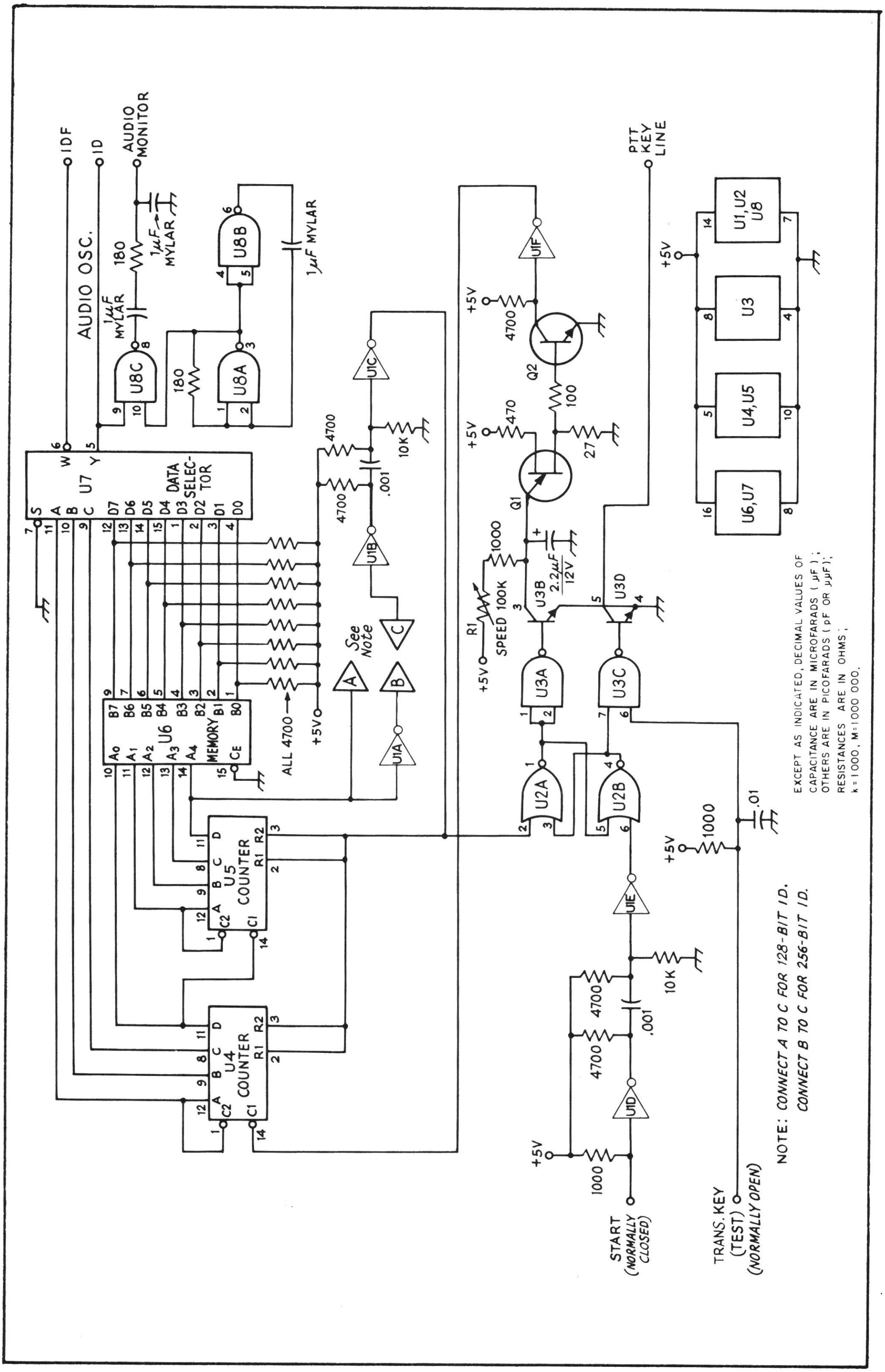
Fig. 8-36 gives an example of the memory organization. Each square represents one bit, a dot if filled or a space if empty. Three adjacent filled squares represent a dash. In effect, the memory is scanned bit by bit, beginning at the upper right corner and progressing to the left and down. Address lines connected to the IC select one of the 32 words, and the 8 bits of the word are available simultaneously at eight mutually independent outputs of the memory. An 8-bit multiplexer IC, which might be called an electronic commutator, connected to the output of the ROM scans the word bit by bit to produce the keying wave form from an ROM which is properly programmed. Fig. 8-37 is the schematic diagram of an identifier using this type of memory.

The 8223 may be obtained custom programmed from the manufacturer, or commercially available programming devices may be used to program the memory in the field. Such programmers are Curtis Electro Devices PR23 series and Spectrum Dynamics 300 and 400 series. The 8223 may also be successfully programmed in the field with a battery or dc supply and a switch, if care is used in the process. The manufacturer's instructions for such programming are given below.

The standard 8223 is shipped with all outputs at logical "0." To write a logical "1" proceed as follows:

1) Remove Vcc.
2) Remove any load from the outputs.
3) Ground the *Chip Enable*.
4) Address the desired location by applying ground for a "0" and 5.0 ±0.25 V for a "1" at the address input lines.
5) Apply +12.5 V to the output to be programmed through a 390-ohm 10-percent- tolerance resistor. Program one output at a time.
6) Apply +12.5 V to Vcc (pin 16) for 50 ms (1.0 sec. max.). Do not exceed a 25-percent duty cycle. Limit the Vcc overshoot to 1.0 volt max. with a "clamping" or "crowbar" circuit. Vcc current requirement is 400 mA max. at 12.5 volts.
7) Remove Vcc.
8) Open the output.
9) Proceed to the next output and repeat, or change address and repeat procedure.
10) Continue until the entire bit pattern is programmed.

Fig. 8-37 – Solid-state identifier with read-only memory. (Circuit courtesy of W5PCX.) All resistors may be 1/4 watt. Power requirement is 5 V at 185 mA nominal.
Q1 – 2N4852
Q2 – 2N2222
R1 – Linear-taper control.
U1 – TTL hex inverter IC, 7404.
U2 – TTL quad 2-input positive NOR gate IC, 7402 (2 sections unused).
U3 – Multifunction IC, TI 75451A or equiv.
U4, U5 – TTL 4-bit binary counter IC, 7493.
U6 – Fieldprogrammable ROM, Signetics 8223 or equiv.
U7 – TTL 8-line to 1-line data selector/multiplexer IC, 74151.
U8 – TTL quad 2-input positive NAND gate IC 7400 (1 section unused).


IDF
ID
AUDIO MONITOR
AUDIO OSC.
PTT KEY LINE
U7 DATA SELECTOR
U6 MEMORY
U5 COUNTER
U4 COUNTER
ALL 4700
See Note
SPEED 100K
START (NORMALLY CLOSED)
TRANS. KEY (TEST) (NORMALLY OPEN)
EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF); OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS; k = 1000, M = 1000 000.
NOTE: CONNECT A TO C FOR 128-BIT I.D.
CONNECT B TO C FOR 256-BIT I.D.

COMMERCIALLY MANUFACTURED REPEATER IDENTIFIERS

Identifiers for use at repeater sites are available in manufactured form, with custom programming of the memory done according to the user's requirements. One such identifier is offered by Curtis Electro Devices, Box 4090, Mountain View, CA 94040, their model ID-401. Pictured in Fig. 8-38, this identifier has a memory capacity of 127 bits and uses a programmable ROM IC. The ID-401 contains its own monitor and code-speed controls, and operates from 12 to 28 volts dc in temperature extremes between -40 and +60°C. This identifier provides both audio-tone and keying-relay outputs. When in operation with an fm repeater the instrument transmits the station call letters in mcw on initial activation and every three minutes thereafter, as long as the repeater is being used. A final identification is sent after activity has ceased.

HAL Communications Corp., Box 365, Urbana, IL 61801, offers an identifier, their model ID-1A, which is programmed in a somewhat different manner than the techniques described earlier. With no programming applied to the ID-1A, it will emit a message consisting of a string of 39 dots. Programming is accomplished with a simple diode matrix on a bit-by-bit basis. A dot at any position in the string can be programmed to become either a dash or a space with a diode at the proper position in the matrix array. Thus, the total memory capacity is 39 dots, dashes, and spaces, and only a small number of diodes is required for the programming. Programming is done by the manufacturer for the initial purchaser, but the message may be changed without difficulty and at low cost. The ID-1A is pictured in Figs. 8-39 and 8-40.

This identifier has several other features which make it desirable. The interval between identification periods may be timed by the power-line frequency, and is selectable at nominal intervals of 3, 6, 12, or 24 minutes. The identifier contains controls for code speed, audio pitch and volume. It may be operated from 117 V ac or from a 12-V 300-mA dc source.

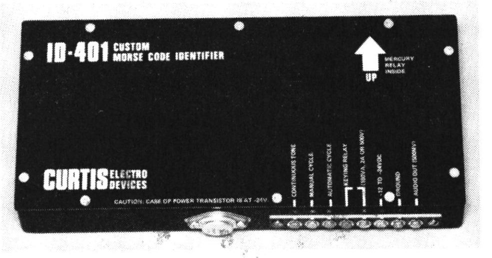


Fig. 8-38 – The Curtis ID-401 custom Morse-code identifier. Measuring 11-1/4 X 5-3/8 X 1-5/8 inches, the identifier is made for mounting on a vertical panel. The audio sine wave output is adjustable in pitch and amplitude.

Fig. 8-39 – The HAL ID-1 repeater identifier as supplied for mounting in a 19-inch relay rack.

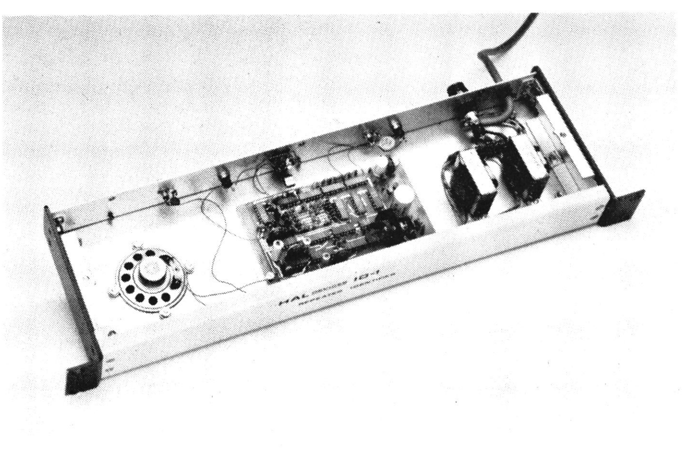


Fig. 8-40 – An inside view of the HAL ID-1 identifier. The complete diode matrix for programming the message is contained in an area measuring approximately 1 X 2 inches. This area is visible inside a perimeter of ICs, just behind and to the left of the center of the circuit board. Power transformers and the monitor speaker are located at the sides of the circuit board.

When the repeater is keyed up, a switch closure to ground actuates the ID-1A, and the station call is sent immediately. If the repeater is used again within the next three-minute interval, the call sign will be retransmitted three minutes after the initial identification. Although the repeater may be off the air at the moment, the identifier keys it up to transmit the call. As long as the repeater is used at least once during each succeeding three-minute period, the call will be transmitted at the desired intervals. If, however, the initial key up was caused by a noise burst or a short call to which there was no response and if the repeater then remains inactive for the next three minutes, the call sign will not be sent again. To protect against noise triggering, the identifier will ignore any key ups occurring within five seconds after the initial identification has been completed.

A MORSE-CODE TIME IDENTIFIER

Often, in addition to call-letter identification of a repeater, it may be desired to transmit the time of day in Morse code. The schematic diagrams of a device for this purpose are given in Figs. 8-41 and 8-43.

Circuit Description

Basically, the circuit counts 60 Hz from the power line and registers this count in an integrated-circuit divider chain. Upon request, the hours and minutes, which are stored in binary form, are converted to a serial output, translated into Morse code, and used to turn on and off an integrated-circuit 3000-Hz audio oscillator.

The 60-Hz frequency is very slow moving for IC counters which are designed to run at 10 MHz. This allows the gates to remain in their active region far too long. In this region they act as high-gain amplifiers, rather than gates, and can be expected to oscillate. The 74121 monostable multivibrator, U9, is designed to accept a slow-moving wave form on its Schmidt-trigger input and provide a square wave output. Since it is not retriggerable it will not accept an input during its pulse time and thus serves to guard against noise during this portion of the input cycle. U2A divides the 60 Hz by two. U1A divides by two again so that the basic timing frequency applied to U23 is 15 Hz. The 30 Hz from pin 12 of U2A is divided by five in U2B and comes out at 6 Hz on pin 11. Division continues through U1B, U3B, and U4, so that one pulse per minute is applied to pin 1 of U26A. The three gates of U26 are used to lock the time in the next five dividers so that it cannot be changed during an output keying cycle.

Dividers U5, U6, U7, U3A, and U8A register minute units, minute tens, hour units, and hour tens respectively. Gates U28A and B convert from a forty-hour to a twenty-four-hour clock. Because of the reset lead into U8A, pins 2 and 3, there will always be a time identification of 0000 sent at midnight.

U10 and U11 are each dual 4-line-to-1-line data selectors/multiplexers. They are used to select the binary number that is to be converted into Morse code. U12 converts that binary number into a decimal number. Gates U13 through U17 are wired to program a Morse-code dash at code-element positions one through five respectively. For example, if pin 3 of U12 is at zero or a low logic level, all other decimal outputs will be high and the number two is to be encoded. A two in Morse code has a dash in element positions 3, 4 and 5; therefore, zeros are sent to U15, U16, and U17. If the number had been an eight instead of a two, then a zero would have been sent to U13, U14, and U15.

The basic clock frequency, 15 Hz, is fed into pin 14 of U19 from U23A. U19 is a binary counter which is used to sequence through gates U13 through U17. U20, U29, U27, and U26C sequentially enable leads from gates U13 through U17 into gate U18. When U18 detects a dash its output goes from zero to one and starts monostable multivibrator U22. U22 fills in the space between two Morse-code dots, thus making a single dash. It does this by stopping the clock pulses going through gate U23A.

When U19 has counted to twelve it is cleared by U23B and U29F, and counter U8B advances. This causes data selectors U10 and U11 to advance to the next time digit. When U8B has advanced through all four time digits and U19 has reached a count of eleven, all of the inputs to U24 are in the one state. Its output goes to zero and additional timing pulses are inhibited at U23A. Through *Q1* this also releases the relay and through U30A enables U26 so that the minutes and hours counters can continue to count.

U26B and D are wired as a flip-flop memory, with U26A being used as an inverter. When the time is being sent, the memory is latched so that if a one-minte pulse arrives from U4 it will not reach U5 immediately. Instead, it is "stored" in U26B and D. When the time message is completed the memory is unlatched, and the time will then be advanced by a pulse from the memory.

The dots and dashes are formed in gate U21. When its output goes to the one state, gates U28B and D are enabled. The first of these gates is held in its active state by the 220-ohm resistor and the audio frequency is controlled by the 0.5-μF capacitor. The output tone is a 3000-Hz square wave fed out through an isolating resistor.

Construction

There are many ways of mounting and interconnecting these integrated circuits. A simple method has been nick-named the "dead bug" technique. The ICs are laid on their tops with their pins sticking up in the air and are glued to a brass

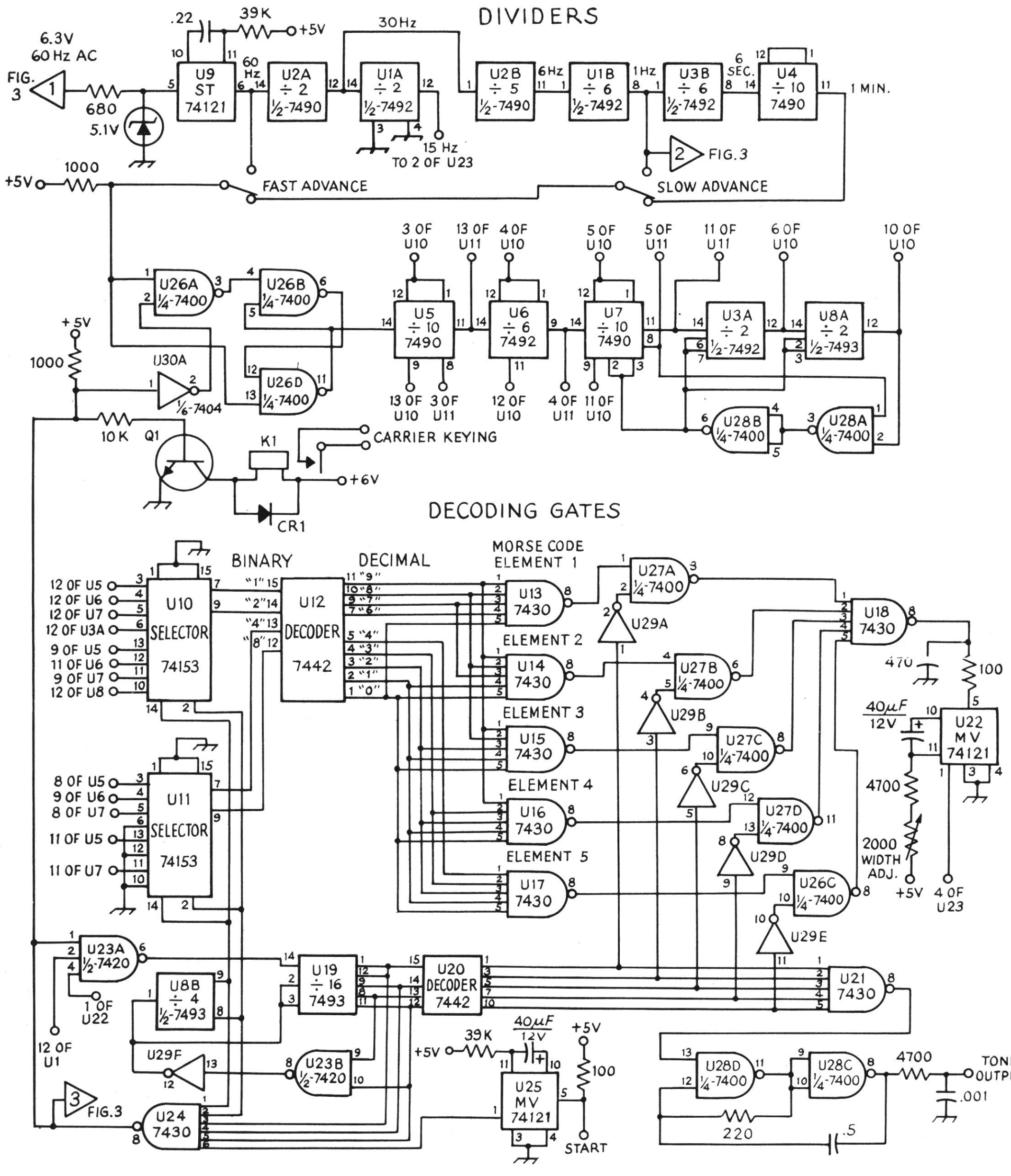
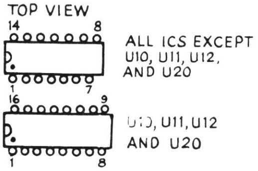


Fig. 8-41 — Schematic diagram of the cw clock. All ICs are dual-in-line package; pin numbers may not be compatible with other package types. No connections are made to IC pins which are not shown.

CR1 — Any small-signal silicon diode.
K1 — Low-voltage relay (Magnecraft W102MX-1 suitable).
Q1 — See text.
U1, U3, U6 — TTL divide-by-12 counter IC, 7492.
U2, U4, U5, U7 — TTL decade counter IC, 7490.
U8, U19 — TTL 4-bit binary counter IC, 7493.
U9, U22, U25 — TTL monostable multivibrator IC, 74121.
U10, U11 — TTL dual 4-line-to-1-line data selector/multiplexer IC, 74153.
U12, U20 — TTL BCD-to-decimal decoder IC, 7442.
U13-U18, inc., U21, U24 — TTL 8-input positive NAND gate IC, 7430.
U23 — TTL dual 4-input positive NAND gate IC, 7420.
U26, U27, U28 — TTL quad 2-input positive NAND gate IC, 7400.
U29, U30 — TTL hex inverter IC, 7404 (5 sections of U30 unused.).



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF) ; OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS; k =1000, M=1 000 000

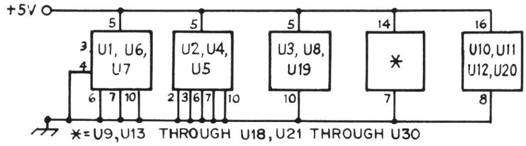


plate. The plate serves as both ground and a heat sink. The ICs are interconnected with No. 30 solid hookup wire. *Warning!* Don't use heavy-gauge wire. Soldering to these tiny things is difficult enough when a small-diameter wire is used. With anything else it would be impossible to avoid solder bridges and wrong connections. Use a very small, relatively hot soldering iron. A reasonable amount of heat will not damage integrated circuits.

First connect the ground leads, next the signal leads, then the +V leads, and finally the 0.1-μF disk capacitors. To minimize the possibility of interference from nearby transmitters, each IC has its own ground lug and its own +V bypass capacitor. Don't just string the +V feed lead from one IC to the next. Instead start with the center IC and let the +V feed spread out like a spider web. This will minimize the +V difference between ICs.

The plate on which the ICs are mounted can be used as the bottom plate of a 7 × 9-inch chassis. The sides of the chassis may be used for power supply, rf bypass capacitors, fuse mounting, and other parts. The time-setting switches and pilot lamp were mounted on top of the chassis. This permits mounting everything within the box and only shielded, bypassed, leads enter the box. By completely shielding it this way no trouble should be experienced with rf interference.

Q1 and the other transistors shown can be anything with a gain of 20 or more and sufficient current-handling capability. Don't eliminate the 12-ohm resistor in series with the number 47 pilot lamp of Fig. 3. This limits the cold inrush current and also lowers the lamp voltage to prolong its life.

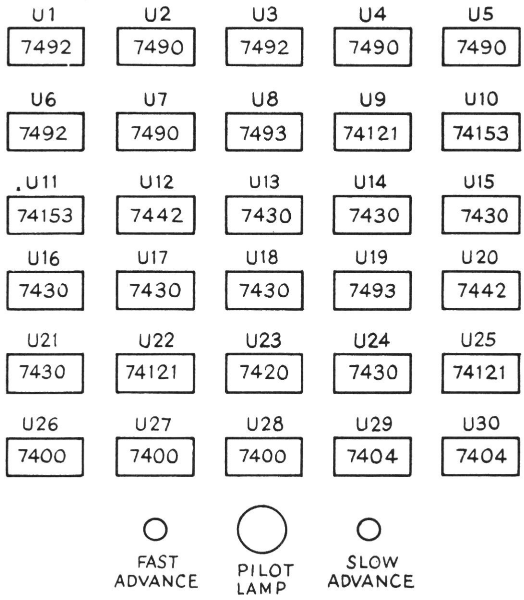


Fig. 8-42 — Physical layout used by the author for the ICs. See text regarding wiring technique. Originally described by W8BEB in *QST* for November 1972.

Time Settings

One of the more difficult jobs is resetting the clock to the correct time after a power failure. The switches marked FAST ADVANCE and SLOW ADVANCE are normally in a position such that pin 11 of U4 is connected to pin 1 of U26A. When set this way the clock will count normally and the pilot lamp will blink at a one-second rate.

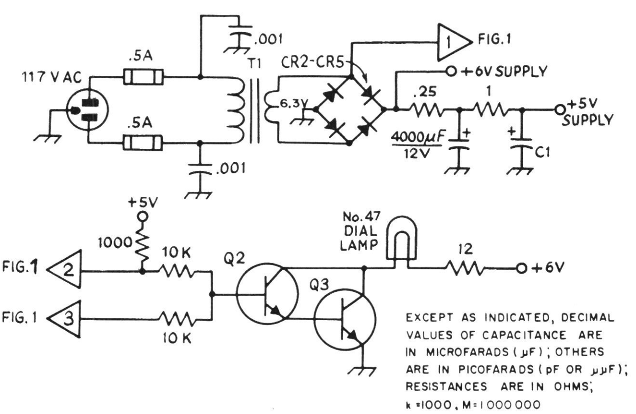
Fig. 8-43 — Power supply and dial-lamp circuit

C1 — A 0.1-μF disk ceramic at each IC and several 100-μF capacitors in parallel.

CR2-CR5, incl. — Silicon rectifier, 2.5 A, 50 V.

Q2, Q3 — See text.

T1 — 120-V primary, 6.3-V 1.5-A secondary.



To advance the clock forward in time, operate the **FAST ADVANCE** switch. The clock will advance one hour for each blink of the pilot lamp. Operating the **SLOW ADVANCE** switch will advance the clock one minute for each blink of the pilot lamp. Because of contact bounce in the switches, they can be operated or released only when the clock is sending out cw. The procedure then is:

1) Briefly ground the start lead.
2) While the time is being sent, turn on **FAST ADVANCE**.
3) Count the lamp blinks.
4) When desired count is reached, again briefly ground start lead.
5) Turn off **FAST ADVANCE**.

If one wishes to set seconds as well as minutes and hours, the clock can be stopped by switching pin 5 of U9 to ground. Opening or grounding leads at other points will not work because contact bounce in the switch will cause incorrect readings.

Operations

Operation is initiated by grounding the **START** input momentarily, pin 5 of U25. This ground need be present for only a few microseconds to start a message, but may be of longer duration. The presence of a continuous ground at the **START** input will activate a time message only once, at the initial grounding of the input. It is not feasible to include here the control circuits that may be used for initiating a time message, as each repeater will probably have its own individual requirements.

A SOLID-STATE CONTROL CIRCUIT

A very important consideration when planning a repeater is reliability in the control circuitry. Relays have been doing an admirable job for a long time, but even the best relay will fail sooner or later. It is almost a truism that the more remote the location, the greater the inclination for a relay to fail. Added to the need for maintenance of relays is that of tube replacement.

The tube problem has been solved by the availability of solid-state transmitters. Applying the same technique to the control circuit should result in a repeater installation that requires little in the way of maintenance. This theory has been proven by the operators of the WR2ABB repeater on Mt. Beacon, N.Y. The filtering of supply and control leads for their solid-state equipment has been covered elsewhere. The control circuit, by WA2-DHA, is shown in Fig. 8-44. It eliminates all relays in the system, save one. A "panic-relay" is connected in the main power feed to the repeater so that if all else fails, the system can be shut down by means of wire line control – a desirable safety feature.

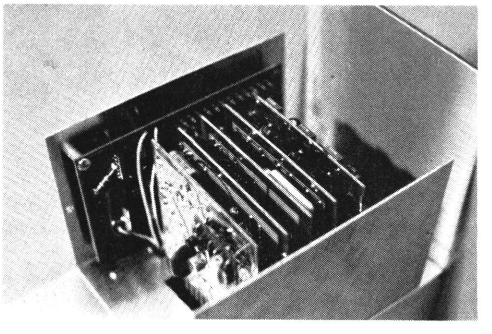


Fig. 8-44 – A solid-state control system constructed by the WR2ABB repeater technical committee. Each card has edge connectors that plug into matching connectors on the main chassis. A Minibox provides shielding from noise and rf energy. Reliability is enhanced by eliminating relays in the transmitter- and receiver-switching circuits.

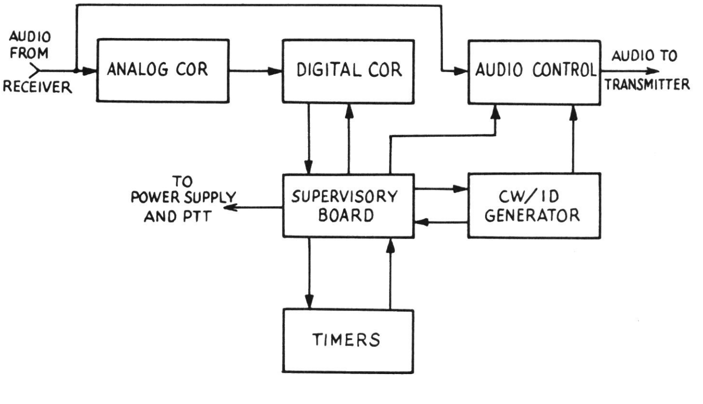


Fig. 8-45 – Block diagram of the repeater control system. Many of the currently available Morse code generators can be used for identification, although the one selected by the WR2ABB committee was designed by the Seattle repeater group and described by W7PUG in *73* for September, 1970.

The block diagram, Fig. 8-45, shows the many functions that are built into the control circuit. It provides the necessary actions of a COR, time-out timer, identification start, and audio control. Many of the operations are controlled by RTL circuits, but those well versed in digital techniques will be able to convert to the more popular TTL. Transmitter switching is accomplished by triggering an SCR, thereby controlling the supply voltage to the equipment.

Analog COR

The purpose of the analog COR is to activate the remaining controls when there is a carrier present at the receiver output, and to deactivate them when the carrier drops. Audio from the discriminator in the receiver (through an emitter follower for isolation) is applied to the input of the analog COR and the audio control sections simultaneously. The first transistor in the analog COR, Fig. 8-46, is a noise amplifier with the bandpass determined by the inductance across the output. The second transistor acts as a detector or noise rectifier. The dc from the rectifier is filtered by an *RC* network. The variable resistor in this network, R2, provides a means of shaping the time constant of the filter. This dc is applied to one half of a dual op amp, connected as a Schmitt trigger. The hysteresis of the circuit is adjustable by means of R4 in the supply lead. R3 is used to set the trigger point. All four controls interact to some extent so that considerable experimenting is necessary to find the correct operating point for the receiver in use. On and off action should be fast and firm, with a minimum of chopping from a signal that is marginal.

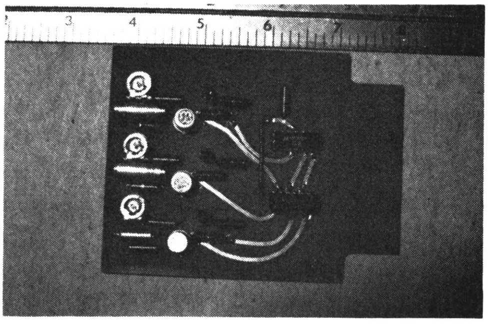


Fig. 8-47 — Double-sided pc board is used in constructing the plug-in cards for the control system. In this view of the digital COR board, controls for adjusting the delay are on the left. The UJT timers and switching transistors are between the controls and the two ICs. Those who are adept at pc board layout could use single-sided material.

Digital COR

The digital COR, Fig. 8-48, translates the on-off information from the analog circuit into drive signals to activate the transmitter, start the timer circuits, or provide some timing functions related to the length of time a carrier is received. The normal output (pin 7) has a complementary output (pin 11). There are some unused output connections that could be wired to perform functions not incorporated in the system described.

When a carrier is being received, the input to U2A is high. This condition is inverted at the

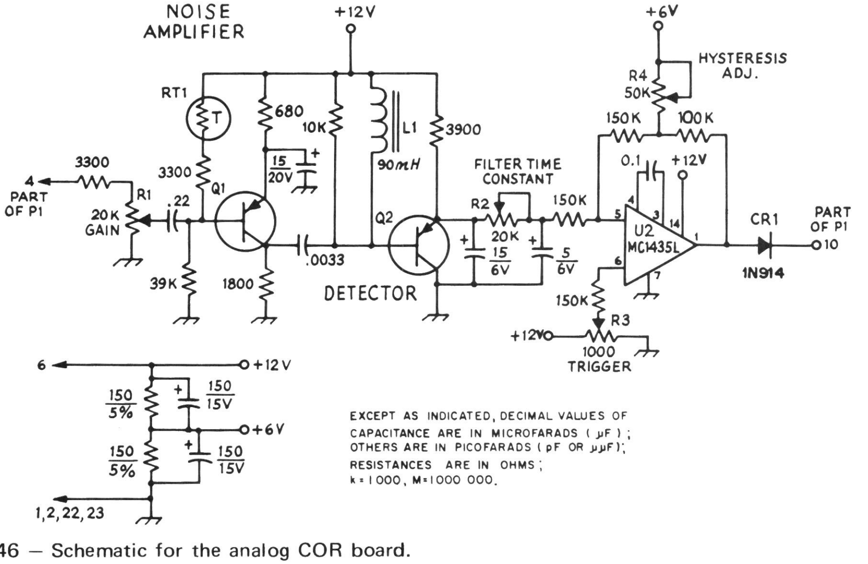


Fig. 8-46 — Schematic for the analog COR board.

L1 — 90-mH audio choke (Motorola 25B8-2788CO1) or 88-mH toroid.

P1 — Edge connectors etched as part of pc board pattern.

Q1, Q2 — Pnp audio transistor (Motorola M9130 or equiv.).

R1-R4 incl. — Miniature composition control, pc mount.

RT1 — Thermistor, 1000 ohms at 25°C. (Motorola 6B858402 or equiv.).

U1 — Dual op amp IC, one half not used (Motorola MC1435L or equiv.).

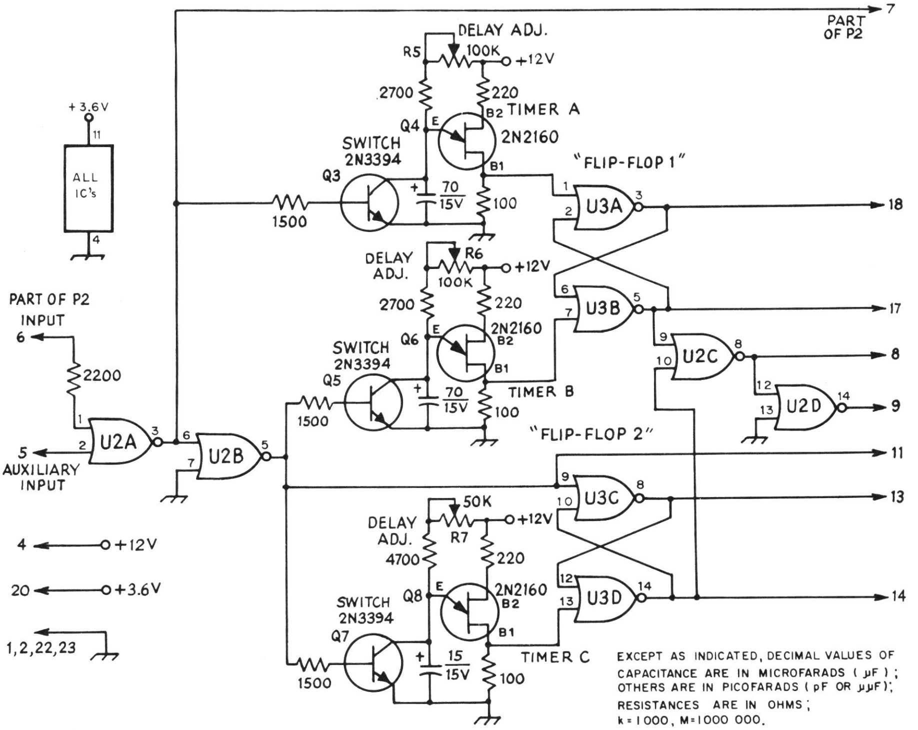
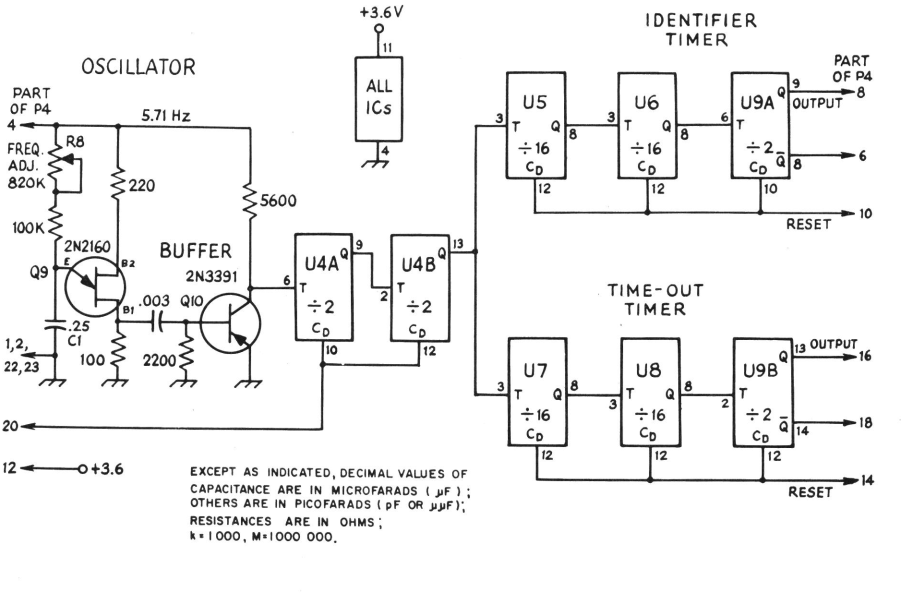


Fig. 8-48 – The digital COR schematic.
P2 – Edge connectors, part of pc board pattern.
R5, R6, R7 – Miniature composition controls, pc mount.
U2, U3 – RTL quad two-input gate IC (Motorola MC724P or equiv.).

Fig. 8-49 – Schematic diagram of the timer circuit.
C1 – 0.25-μF capacitor. Must be high quality such as polystyrene or Mylar 30.
U4 – RTL dual *J-K* flip-flop IC (Motorola MC790P or equiv.)
P4 – Edge connector. Part of pc board pattern.
U5-U9, inc. – RTL binary up counter IC (Motorola MC877P or equiv.).



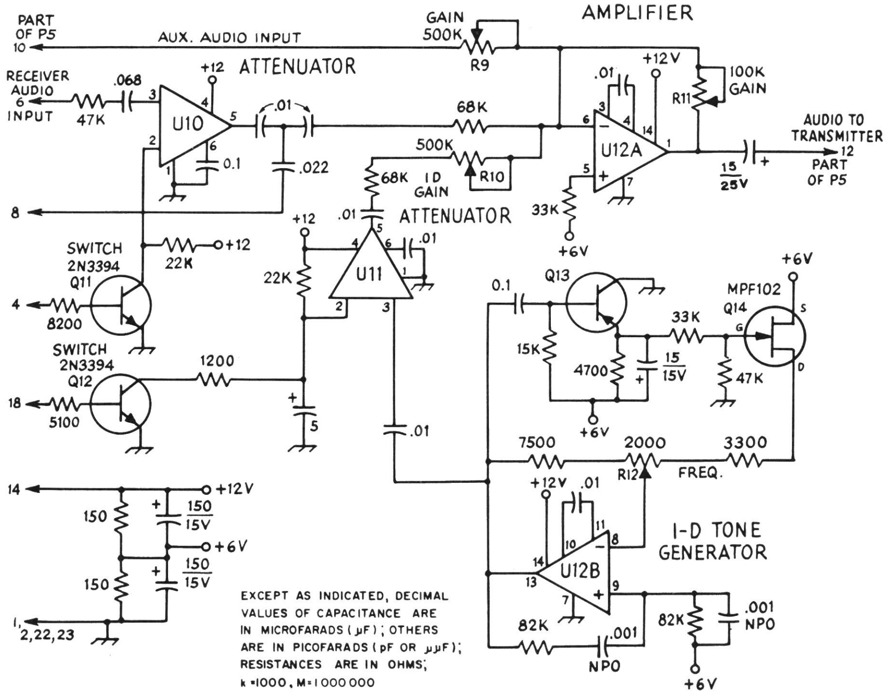


Fig. 8-50 — The audio control diagram.

P5 — Edge connector. Part of pc board pattern.

R9-R12 incl. — Miniature composition control, pc mount.

U10, U11 — Electronic attenuator IC (Motorola MFC6040 or equiv.).

U12 — Dual op amp IC (Motorola MC1435L or equiv.).

output of U2A, and applied to U2B, timer A, and to the supervisory board.

There are three timers on the digital COR board, each consisting of a UJT oscillator and a switching transistor. The switching transistors are controlled by the high or low output from U2A or U2B. In each case, a high, or on, condition at the base of the transistor causes it to conduct, preventing the large capacitor in the UJT oscillator from charging up. Since the output from U2A is low when a carrier is received, timer A will start immediately after action by the analog COR. Timers B and C are counting when no carrier is incoming, and are shut off by U2B upon COR action.

Thus timer A provides a pulse at some definite time (adjustable by means of R5) after *receiving* a carrier, and timers B and C provide pulses after *loss* of carrier. The pulses from the timers are applied to *R-S* flip-flop circuits (U3A, B, C, D) to cause them to change state after a time delay. This delayed information is fed to the supervisory board for further processing.

Pin 5 on the digital COR board is an auxilliary input to U2A. A pedestal from the cw i-d generator is applied to this input, through the supervisory board, to hold the transmitter on until after the i-d sequence has been completed.

Timer Board

The time base for the counters on the timer board, Fig. 8-49, is a 5.71-Hz signal from a UJT oscillator. By having a frequency source that is independent of the 60-Hz power-line, the system can be operated from battery power if necessary. The oscillator and buffer circuits are followed by frequency dividers to derive the long-term timing needed for activation of the i-d generator and the time-out control.

The i-d Timer is always counting, except for an instant rest during the i-d sequence or during a "time-out sequence." At the end of three minutes, it provides a pulse to the supervisory circuit to initiate the identification.

The time-out timer starts counting when a carrier is received. If the carrier is dropped before three minutes, the timer is reset. If the incoming carrier is held longer than three minutes, the timer sends a pulse to the supervisory circuit, which, in turn, shuts off the audio from the receiver, activates the i-d, and stops all timing action by means of the C_d input to U4A and B. After the i-d is complete, the transmitter is shut off and will not return until the incoming carrier is dropped. When the transmitter returns to the air, an i-d is given immediately, thereby notifying the offending party that he has "timed-out" the repeater.

Audio Control

The audio control circuit, as the name implies, performs the function of controlling the audio to the transmitter. U10 and U11 are attenuators that have a remote control feature. In this case, the device is switched from on to off, causing them to

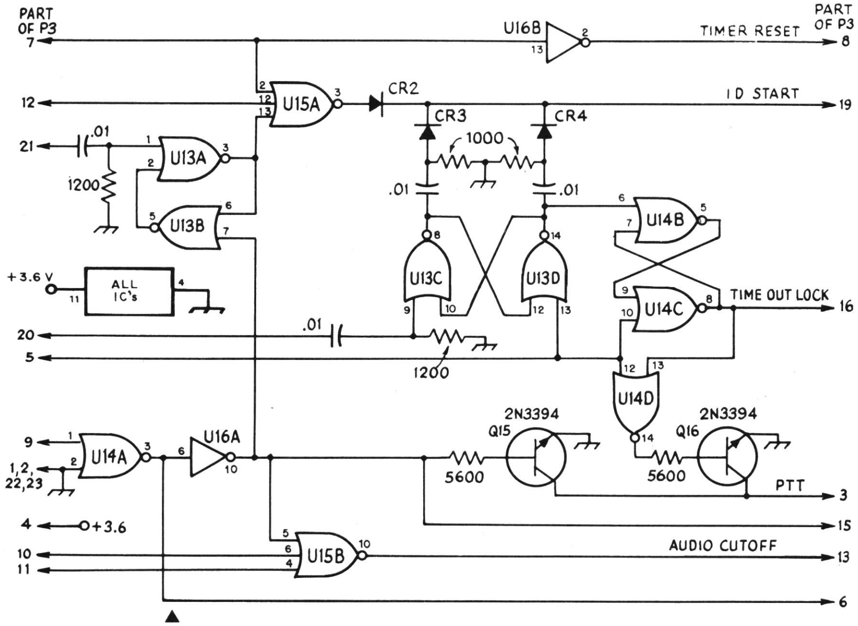


Fig. 8-51 — Diagram for the supervisory circuit.

CR2, CR3, CR4 — General-purpose germanium diode. 1N435, 1N770 or HEP134 suitable.

U13, U14 — RTL quad two-input gate IC (Motorola MC724P or equiv.).

U15 — RTL dual three-input gate IC (Motorola MC715P or equiv.).

U16 — RTL dual buffer IC (Motorola MC799P or equiv.).

Fig. 8-52 — Schematic of the control unit power supply. Input and output connections are made via a barrier-strip connector.

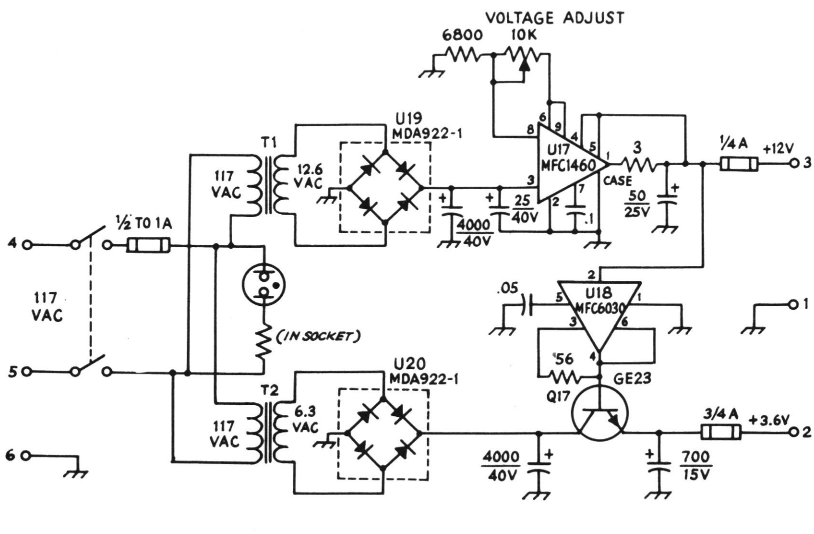
T1 — 117-volt primary; secondary 12.6 volts at 1 A (Stancor P8384 or equiv.).

T2 — 117-volt primary; secondary 6.3 volts at 1.2 A (Stancor P6134 or equiv.).

U17 — Voltage regulator IC (Motorola MFC1460R or equiv.).

U18 — Voltage regulator IC (Motorola MFC6030P or equiv.).

U19, U20 — Full-wave bridge rectifier, 25 PRV 1.8 A (Motorola MDA922-1 or equiv.).



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF) ; OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS ; k = 1 000, M = 1000 000.

act as attenuators controlled by an output from the supervisory board. Audio from the receiver is controlled by U10 through the action of Q11. U11 is keyed on and off by the train of pulses from the i-d generator. Since the audio oscillator, U12B, is running all the time, the keying of U11 produces code for identification purposes. U12 is used as an audio amplifier to feed either received audio or i-d tone to the transmitter. Q13 and Q14 help to stabilize U12B so that it is less sensitive to temperature changes.

The Supervisory Circuit

The supervisory circuit is, in some ways, the crossroad of the signal paths for controlling the repeater. It receives pulses and level-change information from timers and COR circuits and uses these instructions to control other parts of the circuit.

A "high" output at Pin 8, Fig. 8-51, is used to reset the time-out timer or to hold it in a noncounting state when no carrier is received. A pulse on pin 19 will start the i-d generator. Pin 16, when high, holds the timers off during the time-out period as described before. Pin 3 connects to the PTT circuit in the transmitter. At pin 15 is the pulse to reset the 3-minute timer and also to hold the transmitter on during the i-d sequence via the auxiliary input to the digital COR. Pin 13 is connected to the audio control circuit to cut off received audio during the i-d sequence or during the time-out period.

Power Supply

The power supply for the control system embodies two complete circuits, each with a separate transformer, rectifier, and regulator, Fig. 8-52. One supply provides 12 volts for the larger number of circuits. The other output is 3.6 volts as needed for the frequency dividers on the timer board. Some of the ICs require dual voltages, which are provided by voltage-dividing resistors and filter capacitors on the individual boards.

Assembly

There are many ways in which to construct a control unit such as this. As shown in the photographs, each basic part of the circuit is assembled on an individual board that plugs into a main frame or chassis. This method allows considerable flexibility in new design, since a board can be wired in the comfort of the workshop and then taken to the repeater site to be plugged in. Reliability has been good enough that spare boards have not been necessary, but it is worth considering for extremely remote repeater locations.

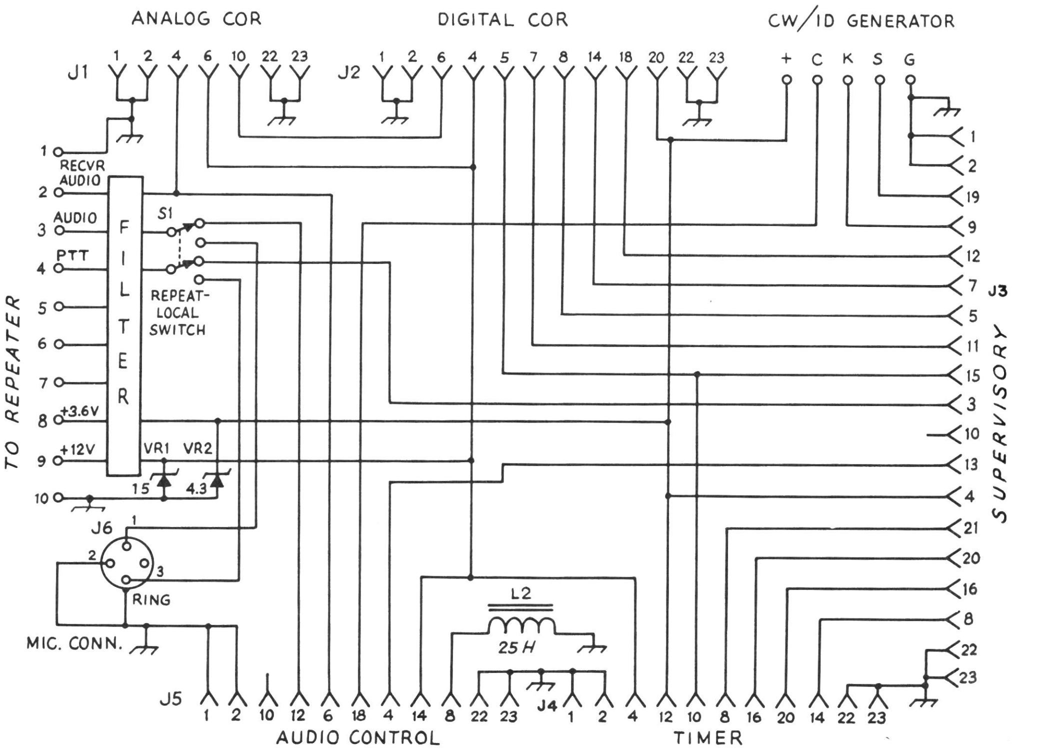
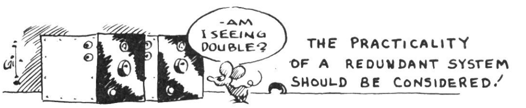


Fig. 8-53 — Internal connections for the control unit. J1 through J5 are pc connectors to match the etched pattern on the circuit boards. The filter is identical to that used in the transmitter and is described and pictured in Chapter 9. L2 is part of the bandpass network at the output of U10 on the audio control board. The choke is mounted on the main chassis because of space considerations. VR1 and VR2 are Zener diodes to eliminate spikes or transients on the dc from the power supply.

Repeater Technical Problems and Cures

ANY GROUP contemplating the operation of a repeater should give serious consideration to the matters of longevity, trouble-free operation, and minimum maintenance requirements. Since most repeaters must be relied upon to provide round-the-clock service, they should be considered in the same light as is a commercial installation. The foregoing is particularly significant because most repeaters used by amateurs are unattended. Furthermore, reliable service in time of emergency can assure the usefulness of the system to the community. It follows, therefore, that reasonably good equipment be used at the repeater site, and that certain guidelines must be established when planning the installation.



Such factors as the natural environment at the repeater location, the kind of vault or enclosure the equipment is housed in, and how accessible the apparatus is to unauthorized persons, must be carefully pondered before the system is placed in operation. One should also give consideration to the practicality of having a redundant system which can be controlled from some remote point, thus allowing the operator to switch in a standby receiver or transmitter (or other necessary equipment) in the event of a failure. The more complex the installation becomes, of course, the greater will have to be the planning and financial outlay. Such reliability measures can only be inspired by the goals and means of the repeater club or technical committee, but should be given serious thought while the station is in the planning stages.

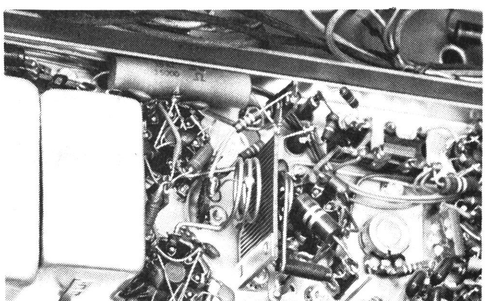
This chapter will treat some of the methods for establishing a reliable repeater station, and the techniques outlined are similar to those followed in the commercial services.

DESENSITIZATION

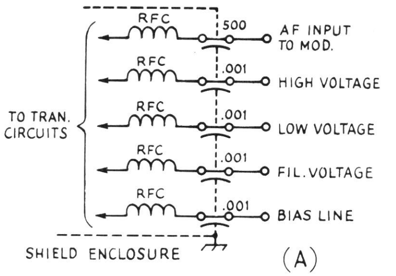
One of the most frequent and serious problems encountered by inexperienced repeater operators is known as desensitization or "desensing." This is a condition brought about by unwanted energy reaching the repeater receiver input port – usually in the form of broadband "white noise" generated in the repeater transmitter. However, severe line noise or energy from some adjacent-channel service (usually nearby the repeater site) can cause the problem.

One of the first preventive measures to be taken is that of cleaning up the repeater transmitter. Some commercial two-way radio transmitters are designed for use in duplex systems (GE MTS models for one), and are very acceptable for use in repeaters. Such transmitters are well shielded, their power supplies and signal leads are carefully filtered, and the tuned circuits are designed for narrow-band applications (high *Q*) to further reduce broadband noise output. The use of a Faraday shield between the driver and PA stage tuned circuits is also beneficial in reducing white noise. A discussion of methods suitable for reducing white-noise output in transmitters not designed for duplex or repeater service was published in *QST* and is a worthwhile reference.[1]

Many repeater operators employ GE Progress-Line transmitters and receivers. Others utilize some models of Motorola equipment. All such equipment is capable of providing satisfactory service in amateur applications if attention is paid to the shielding and filtering of the individual equipment decks. One of the first steps in checking out and preparing the transmitter for repeater service is to



A Faraday shield is used between the stages of a General Electric MTS transmitter. This is a very effective method of preventing coupling of harmonic energy from one stage to another. Similar shields, made of copper-clad board material, can be used to "clean up" many of the transmitters available.



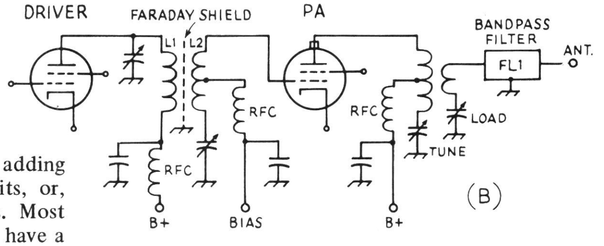


Fig. 9-1 – At A, suggested manner for filtering the leads leaving and entering the repeater transmitter. The value of RFC will depend upon the band of operation. The circuit at B shows a Faraday shield, used to reduce spectrum noise.

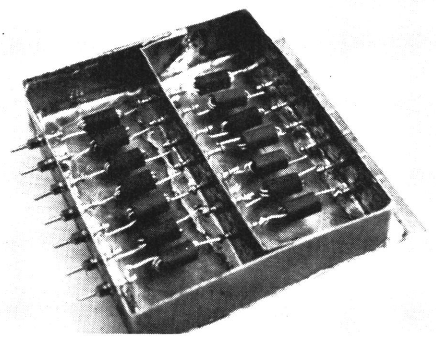
"narrow band" the tuned circuits by adding capacitance across the various tank circuits, or, increasing the *C*-to-*L* ratio of the circuits. Most two-way radio transmitters are designed to have a fairly wide power-bandwidth without retuning the transmitter to 500 kHz in many instances. In order for this to be possible it is necessary to reduce the tuned circuit *Q*, which contributes to the passage of spectrum noise.

The next significant step in reducing white noise is to filter the power and audio leads leaving and entering the transmitter. An effective method is to install a feed through capacitor of 500 pF or .001-μF (of suitable voltage rating) in each lead at the transmitter shield material. When space permits, a vhf rf choke should be included inside the transmitter at each feed through capacitor terminal. The foregoing measures will prevent unwanted radiation of energy via the power and audio leads, Fig. 9-1.

Thorough shielding of the transmitter chassis is mandatory if desensing is to be minimized. The same techniques that are used in reducing TVI are applicable here. The more rf-tight the shielding, the better. Two shields of poor design can often be more effective than one good one. The primary objective is, of course, to confine the rf output to its intended path – the output terminal of the final stage of the transmitter.

Some form of bandpass filter is recommended at the transmitter output, especially in systems that do not employ a duplexer. A high-*Q* strip-line filter or resonant cavity is useful in reducing both white noise and energy above and below the carrier frequency.[2] Fig. 9-2 illustrates typical filters that can be used for the application.

The transmitter should be installed (whenever practical) in a metal cabinet separate from that

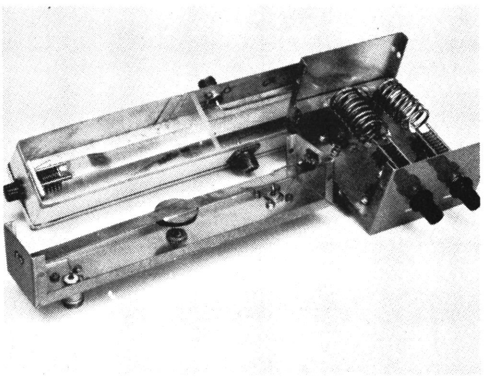


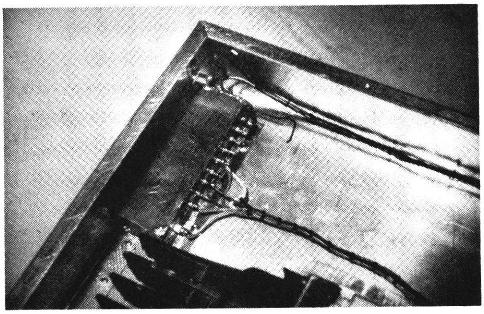
▲

A two-section filter constructed for use at the WA2CVT repeater. Each rf choke consists of a few turns of wire through a ferrite bead. Solder-in feed through capacitors are used in the center partition as well as in the outside walls of the enclosure. After assembly, a cover should be soldered on to complete the shielding. If the filter is used in conjuction with a tube-type repeater, the capacitors must have an adequate voltage rating to avoid breakdown.

Some examples of tuned filters that can be installed at the output of a transmitter or the input of a receiver to reduce noise and spurious signals. A 50-MHz unit is on the right, with a half-wave filter for 440 MHz beside it. The unit in the back is a quarter-wave filter for 144 MHz.

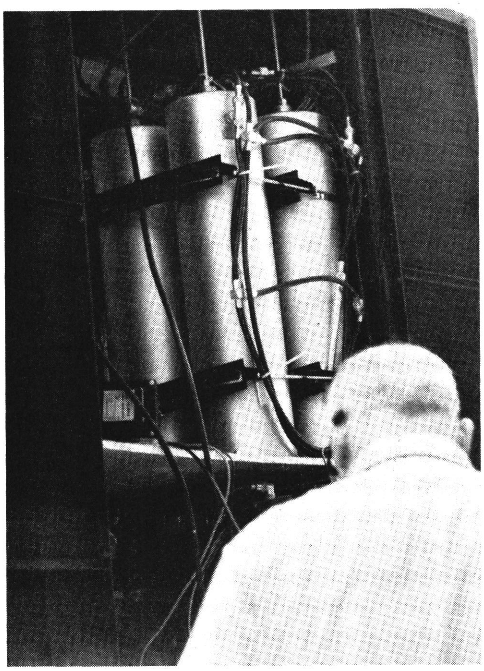
▼





In order to reduce desensitization and noise problems, the WA2CVT repeater has a filter installed on each dc supply, audio, and control lead that enters the enclosure. The transmitter is a Motorola Motrac unit that has been mounted in an aluminum chassis. Screened openings allow air to be circulated through the cooling fins by a small fan. In use, a cover plate is fastened to the chassis to make an rf-tight box.

which houses the receiving equipment. Many repeaters have the transmitting gear and the duplexer (if used) in one metal cabinet, and the remainder of the station equipment in another metal enclosure. The feed lines between the duplexer and transmitter, and between the transmitter and filter, should be doubly shielded coaxial cable (RG-9B/M or equivalent) to prevent line-leakage radiation.



A Sinclair duplexer mounted in an outdoor cabinet at a repeater site. While the cavities are high-Q circuits, excellent mechanical construction of these and similar duplexers assures that they are almost insensitive to temperature changes.

Similarly, doubly shielded cable should be installed between the duplexer and the receiver. Aluminum-jacketed coaxial transmission line, sometimes called "hard line," is recommended for connecting the equipment or duplexer to the antenna. This type of line is excellent with regard to rf leakage as opposed to that which uses shielded braid as an outer conductor.

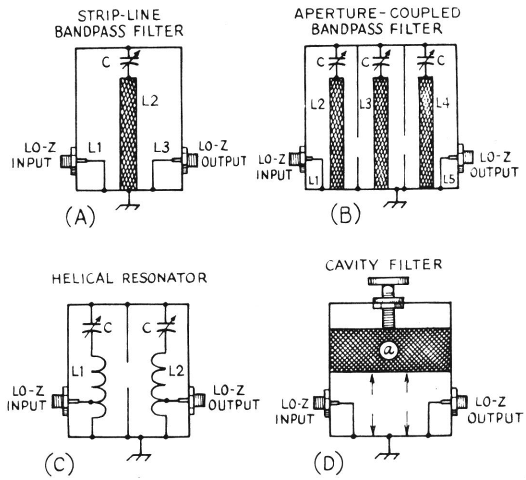


Fig. 9-2 – Examples of bandpass filters suitable for use at the output of a repeater transmitter, or at the input of the repeater receiver. *The Radio Amateur's Vhf Manual* gives information on the construction of similar filters.

OPERATION WITHOUT A DUPLEXER

Since a duplexer is a device which permits simultaneous operation of a receiver and transmitter with a common antenna and feed line, the device must exhibit very high Q. Depending upon the number of sections used in a hybrid-ring duplexer (two or four, typically), the isolation between transmitter and receiver at 600-kHz channel spacing (i.e., 146.34/146.94 MHz) should be between 45 and 90 dB. Some insertion loss results from the use of a duplexer – 0.8 to 1.8 dB, dependent upon the number of sections used. The latter is determined by the duplexer design, how it is tuned, and how low the SWR on the antenna feed line is. The sacrifice in efficiency is a price worth paying when one considers the reduction in desensitization afforded by a duplexer. Furthermore, the device enables the operator to use a single, well-elevated antenna for both transmitting and receiving . . . an aid to reciprocity of signal range.

Some repeater operators are not able to build or purchase a duplexer. Therefore, they must employ separate antennas for transmitting and receiving. When this method is used the desensing problem can become formidable. This practice makes it necessary to use the greatest possible physical separation between antennas to reduce receiver overloading and attendant desensitization. The net result is often one where the transmitting antenna is near ground level and the receiving antenna is atop the supporting structure. The lower antenna is usually side-mounted, thereby radiating somewhat directionally. The upper antenna is omnidirectional (if above the tower). The two antennas are, therefore, quite incompatible if close matching of the repeater's receiving and transmitting coverage is desired.

Some amateurs report success in improving the effective antenna separation by using two ground-plane verticals, one above the other, but with the bottom one inverted. The lower antenna is experimentally moved up or down the tower until the best null is found (minimum desensing point). The antenna is then secured to the structure at that spot. Horizontal separation of the two antennas is far less effective than is vertical separation. Where a 50-foot vertical separation is frequently acceptable, several hundred feet of horizontal separation would be required to achieve a similar effect. Alternatively, some repeater groups locate the receiver a mile or more away from the transmitter, then cross link the two units by means of a 450-MHz transmitter (at the receiver site) and a 450-MHz receiver at the repeater transmitter site.

NOISE REDUCTION

There are many kinds of man-made and random noises which can degrade the performance of the repeater receiver. Noise of this variety is most noticeable when the incoming signal is relatively weak, normally on the order of 0.2 to 1 μV in level. Stronger signals appear to mask the noise as the inherent limiting action of the fm receiver clips these amplitude variations.

The noise must be identified and its source located before corrective steps can be taken. In this regard the power line is suspect and should be checked. An oscilloscope is useful in determining the level of noise on the 117- or 230-volt ac line. Because many repeaters are located on mountains, hills, or buildings where commercial transmitters are installed, transients can be developed in the power supplies and switching circuits of those nearby transmitters. Therefore, it is not uncommon to find spikes of several hundred volts pk-pk on the primary service of the repeater. Pulses of this kind can harm the repeater equipment as well as cause interference.

An effective grounding system should be installed at the repeater. All chassis and cabinets should be securely bonded to the earth-ground terminal. Next, a brute-force ac line filter should be installed between the service entrance and the line feeding the repeater equipment. The ground connection of the filter should be bonded to the earth-ground connector with large-conductor wire, shield braid, or copper strap. Fig. 9-3 illustrates recommended techniques for treating pulse interference which appears on the primary line. Though an outdoor installation is shown at A, the same grounding principles apply to indoor arrangements. The ground rod should be soldered to a number of buried radial wires to effect a proper ground system. Both the tower and the cabinet should be strapped to the ground post to reduce interference and to protect the equipment from lightning damage. A brute-force line filter should be mounted inside the cabinet where the ac line enters. The ground terminal of the filter must be connected to the cabinet in a secure manner.

A typical line filter is shown in Fig. 9-3B. The inductors, L1 and L2, must be able to carry the current taken by the entire system without causing a significant voltage drop.[3] Various high-current inductors are available from commercial sources, and these can be used in the circuit shown.[4] The inductance of L1 and L2 should be on the order of 100 to 600 μH. The associated capacitors are usually between 0.1 and 2 μF in value. If separate cabinets are used to house the receiving and transmitting gear, each cabinet should employ its own line filter.

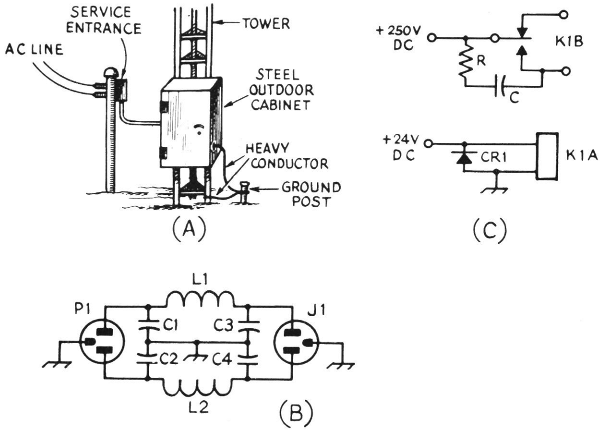


Fig. 9-3 — Grounding techniques for outdoor equipment cabinets are shown at A. The circuit at B illustrates a brute-force line filter for use at the service entrance to the shack. Capacitors C1 through C4 should be between 0.1 and 2 μF in value. Inductors L1 and L2 are discussed in the text. Suitable types are manufactured by J. W. Miller Co. of Compton, Calif. R and C, in illustration C, comprise a damping network used to prevent sparking of the relay contacts. CR1 is used across the relay coil to prevent transients.

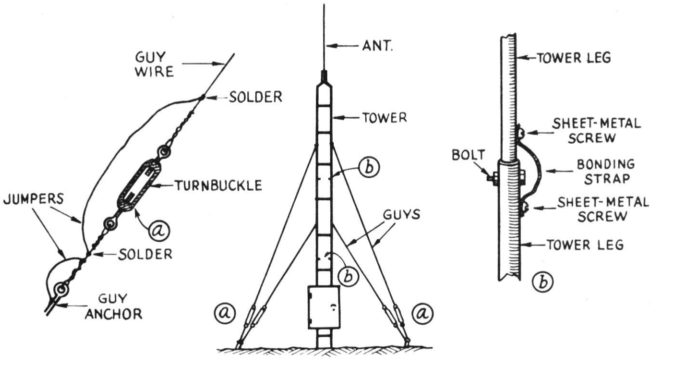


Fig. 9-4 — Suggested methods for assuring proper grounding and electrical continuity of tower guys and sections. At A, jumpering of the turnbuckles is shown. Example B shows bonding of the tower-leg joints.

Internal Noise

It is common to experience noise problems brought about by components within the repeater system. Each noise source requires individual treatment. The cures are generally simple to effect.

Cooling-fan motors will frequently generate hash which can interfere with reception. Such noise will sometimes enter the transmitter and appear on the carrier. It should be standard practice to install small filters near the fan-motor housing to prevent motor noise from being fed into the ac or dc control lines.

Relay contacts can produce spikes in circuits which use relays to break operating voltages. Damping networks are effective when bridged across the relay contacts. The value of *C* and *R* used will depend upon the current and voltage involved and can be determined experimentally. A diode used in parallel with the relay field coil will help prevent inductive-kick transients from being transmitted to other parts of the system via the control lines. An example of a damping network is given in Fig. 3C.

Random Noise

One of the more challenging noise sources is that of chafing metal sections and poor connections in the antenna and tower structure. Noise from these sources is most likely to become manifest during periods of moderate to high wind. The condition can become so severe that even strong signals are difficult to copy through the repeater. Poor bonding of this variety can also cause problems with stray rectification, leading to intermodulation problems and TVI.

To minimize interference from random noise and stray rectification it is important to assure that continuity exists between related metal parts in the antenna structure. Guy wires should be arranged to make it impossible for them to rub against one another. Turnbuckles should have wire bridged across them and soldered to the respective wires on either side (Fig. 9-4).

Bonding should be used across each joint where tower sections are joined. Antenna connectors should be inspected regularly for corrosion or for poor connections. Once determined to be in proper condition they should be weatherproofed with outdoor tape or Silastic sealer. If aluminum-jacketed hard line is used for a feeder it should be secured to the tower (electrically) every few feet to prevent chafing under stress. Some operators prefer vinyl-covered hard line so that the possibility of metal-to-metal contact between the tower and the feed line can be avoided. It is desirable to use a single run of feed line between the equipment and the antenna to avoid the chance for intermittent of resistive contacts which could occur between sections of line if more than one were employed. Good engineering practice dictates that the guy wires be grounded separately where they join the dead men or anchors. Noise caused by the foregoing conditions usually appears as a loud popping sound with no particular repetition rate. It can vary from a popping to scratching sound and may be heard occasionally or at an almost constant rate, depending on the wind level and the number of trouble points in the system.

TRANSIENT PROTECTION

Transients were discussed earlier in this chapter to indicate they can be present on the 117-volt ac line. Though a brute-force line filter can help to alleviate the problem of transients, additional measures should be taken to protect the equipment.

It is not unusual to encounter momentary line surges brought about by changes in load somewhere along the power service, or by switching functions at a substation. The brute-force filter is of little value in protecting the station equipment during voltage surges. Therefore, it becomes necessary to take additional steps to ensure against damage. Perhaps the most inexpensive device that can be used is the Thyrector clipper, a component manufactured for the purpose by GE. The assembly consists of back-to-back diodes which clip peaks in line voltage above 120. The Thyrector is bridged across the primary circuit of a power supply as shown in Fig. 9-5A. Similar units are available for other primary voltages, and should be chosen for the nominal line voltage at the repeater site. Zener diodes can be used in the same manner as the Thyrector. If protection of this kind is not

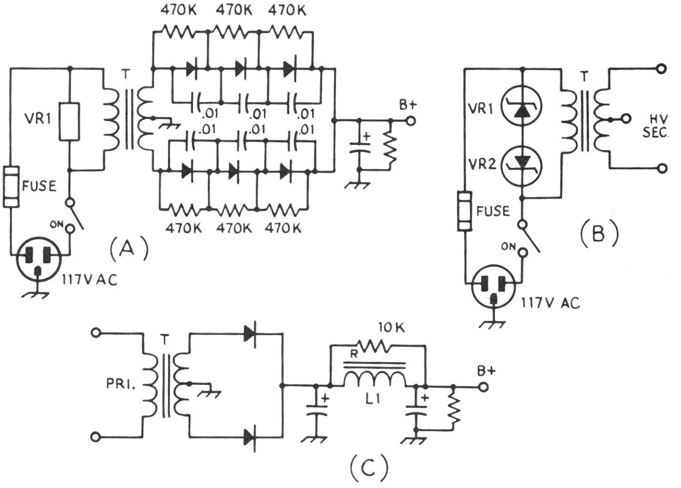


Fig. 9-5 – VR1 (at A) is a GE Thyrector used to clip voltage peaks in excess of the normal value. VR1 and VR2, at B, are Zener diodes, and can be used for the same purpose. The circuit at C shows a damping resistor (R) across choke L1 to prevent inductive kick-back which could damage the rectifier diodes.

included in the system, line surges can easily destroy the silicon rectifiers or capacitors in the power supply, in turn requiring maintenance that would not otherwise be needed.

When power supplies are used that employ filter chokes and silicon rectifier diodes it is wise to damp the filter choke with a resistance to swamp inductively caused transients when the supply is turned on and off. This condition can damage the rectifier diodes if they are not rated well beyond the surge level which could occur. Fig. 5C shows a simple method for adding this protection in the filter circuit.

DERATING FOR LONGEVITY

This chapter has stressed equipment reliability, and minimum maintenance. We do not wish to continually equate the amateur service to that of commercial operation, but in the case of repeaters the concept is justified. Reliability can be better assured if the various pieces of electronics equipment in the system are designed and operated with a margin of reserve. Thus, do not push the components to their safe limits in order to extract that last fraction of a dB of performance. The safe approach here is a philosophical one perhaps, but the results have been proven worthwhile time and again.

TUBE LIFE

A typical repeater might utilize, say, a commercial high-band transmitter strip to drive a homemade power amplifier. The exciter (high-band strip) might have a 6146A or a pair of 2E26s in its last stage. However, the power required to excite the amplifier – a 4CX250 or similar – is around 5 to 8 watts. The usual temptation is to place the TUNE-OPERATE switch of the exciter in the TUNE position and operate in that fashion. Most commercial transmitter strips will deliver approximately five to ten watts output when used that way. However, the tube life of the exciter may be no greater than if the unit were operated at full power. This is because most commercial strips are set up so that the screen voltage to the PA stage is lowered in the TUNE position. This being the case, all tubes except those in the PA are running at full power. Heat is still being generated at the near-normal level, and drive to the PA stage remains high. A better way to get the job done, if tube life is to be extended, is to apply fixed negative bias to the PA, the driver, and the stage ahead of the driver (usually a low-power pentode or tetrode). Then, install a drive control in the screen-grid circuit of the stage preceeding the driver (see Fig. 9-6). Lowering the screen voltage to that stage will reduce its plate and screen current as well as that of the following stages. Alternatively, the plate and screen voltages of all three stages can be reduced until the desired power-output level is attained.

A similar philosophy is recommended for operating an outboard power amplifier. Many repeaters use an amplifier which contains a single-ended or push-pull 4X150A or 4CX250 setup. Though one can obtain 250 watts output on 146 MHz with a single tube of either kind, the maximum ratings are being utilized. For longevity, it is wiser to operate the amplifier at 150 to 180 watts output (assuming normal Class C efficiency), thus allowing the tube to loaf along. If two tubes are used, settle for less than 500 watts output, say, 300 watts. The service will be much more reliable in the long run. Needless to say, the screen-grid and control-grid voltage and current ratings should be well within their maximum safe limits too.

Forced-air cooling of the exciter and the amplifier is a matter that requires serious attention. Make certain that the manufacturer's specifications on tube temperatures are observed. If the tube requires 100 cfm of forced air, install a fan that can deliver much more than is needed. The

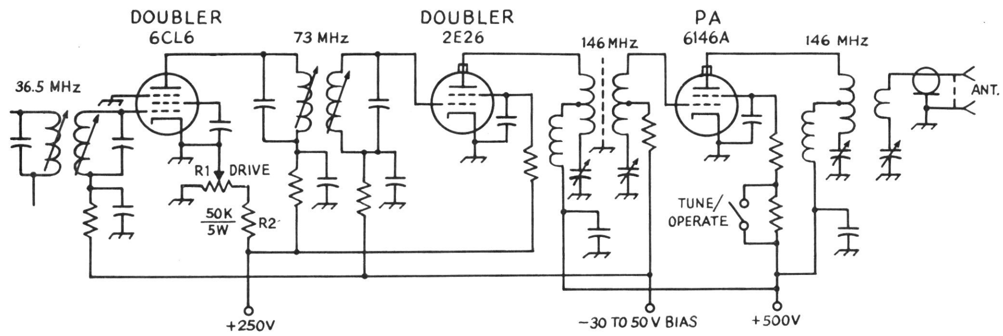


Fig. 9-6 – Typical circuit showing the last three stages of a high-band fm transmitter strip. Fixed-value negative bias has been added to the circuit, and R1 is included to vary the driving power to the last two stages. R2 should be the normal screen resistor used in the strip.

difference in price for a larger blower is not great. There is no such thing as too much air – the more the better! Install a blower on the exciter deck too, directing the air stream toward the PA and driver stage tube envelopes and seals.

Power Supply Components

Solid-state rectifier-diode strings should be able to handle considerably more current and voltage than the supply and its load can impose. A good rule of thumb to follow is one of allowing 20-percent additional leeway for safety over what is normally required of the diodes in a given circuit. *The ARRL Radio Amateur's Handbook* gives complete design information for selecting diodes. (See the chapter on power-supply design.)

Filter capacitors should be chosen carefully if reliability is to be expected. Though it may seem a bit old fashioned to suggest it, give thought to using oil-filled capacitors wherever practical. If the supply voltage maximum is, for example, 600 volts, use 1000-volt capacitors. Though computer-grade capacitors are popular these days (and compact), they are not as rugged under extremes of temperature as are oil-filled types. The dielectric material is thin and can puncture easily.

Power transformers should have considerable current reserve to prevent excessive heating. Remember, repeaters operate under CCS conditions more than under ICAS specifications. If the equipment draws 300 mA (bleeder current included) don't hesitate to install a transformer whose current rating is 400 or 500 mA. The more rugged component may use more space, and cost a bit more, but the reward will be fewer trips to the site for maintenance purposes! Filter chokes, when used, should be selected with the same safety factor in mind.

MOISTURE AND TEMPERATURE CONSIDERATIONS

Foı greatest reliability the repeater electronics equipment would be installed in a controlled environment to assure constant temperature (cool) and minimum humidity. Some repeater operators can afford such a luxury, and use a well-insulated vault which is equipped with an air conditioner that operates "round the clock". However, many groups must struggle with outdoor installations (weatherproof racks mounted to the tower base) or with shacks that are mediocre at best. Those who must house their gear in enclosures that aren't heated or humidity-controlled can minimize equipment failures by observing a few simple rules. (1) In cold climates seal the cabinets used in outdoor installations against wind, rain, and snow. Install rubber gaskets on the cabinet doors, and insulate the interior of the cabinets with suitable material of the type used for houses. (2) Install a large light bulb inside the cabinet and let it burn continually to maintain a fairly moderate cabinet temperature. (3) In warm or hot climate areas install a *large* exhaust fan in each cabinet and provide an intake port near the *lower level* of the cabinet. Use screening over the air-system holes to prevent insects from entering the cabinets. (4) Where humidity levels are high take extra care in assuring adequate insulation in the high-voltage circuits of the repeater. Hermetically-sealed transformers, chokes, and relays should be employed whenever possible to prevent failures brought about by excessive moisture.

These same general hints are applicable when housing the station apparatus in small buildings (or vaults). In areas where all of the aforementioned weather extremes prevail, provision should be made to alternately use the foregoing techniques as the seasons change.

INTERMODULATION PRODUCTS

Intermodulation distortion products – commonly called "intermod" or "IMD" – can create serious problems for the fm repeater operator. This condition can affect the receiver if the latter has poor front-end selectivity, especially if the rf amplifier and mixer stages can be made to overload easily. Bipolar-transistor front ends are quite prone to IMD problems, and some tube and FET front ends can be afflicted too, if poor design is involved. Nonlinear operation of the rf and/or mixer stages leads to intermod problems when strong signals enter the receiver (more than one incoming signal that can be passed by the tuned circuits). These signals mix in the rf or mixer stages and produce sum-and-difference frequencies, giving rise to reception of unwanted signals and spurious responses across the band.

Of greater significance to the repeater operator is the matter of IMD in the last stage of the *transmitter*. This is a common condition which has plagued most repeater groups. Here the mixing takes place in the transmitter output stage, and the spurious or IMD products are sent up the feed line to the antenna to be radiated. Single-ended Class C amplifiers are the most prone to IMD, though all classes and styles of amplifier can produce intermod products.

Since repeaters are generally located in high places to achieve maximum coverage of a given area, nearby amateur repeaters or commercial transmitters can get into the act. The strong signal of a nearby transmitter travels down the feed line from the repeater antenna, enters the PA stage, and there mixes with the output frequency of the repeater, or with its second or third harmonics. In this instance the PA tube functions as a high-level mixer, producing a relatively strong IMD product. Example: The offending repeater transmitter produces normal output at 146.880 MHz. On a nearby hill we have a second repeater. Its output frequency is 146.790 MHz. There is a third amateur repeater nearby, operating at 146.970 MHz output. When the *first two* repeaters are operating at the same time, interference is heard up to several miles away on the output frequency of the 146.970 system. Why? Here's how. The 146.880-MHz offender has second-harmonic energy present within the PA tube (293.760 MHz). The energy from the 146.790-MHz repeater comes down the feed line of the 146.880 "machine" and mixes within the PA, beating against the 293.760-MHz harmonic energy to produce a difference frequency of *146.970 MHz*. This IMD product is sent back up the feeder to be radiated by the antenna:

$$f_1 \text{ (146.880 MHz)} \times 2 - f_2 \text{ (146.790 MHz)} = f_3, \text{ or } 146.970 \text{ MHz.}$$

Other products can also be produced at the same time (e.g., 146.880 MHz can mix with 147.790 MHz to produce the sum frequency of 293.760 MHz). This type of IMD is seldom serious in that the PA tank, duplexer, and antenna will attenuate the IMD product because they are resonant in the 2-meter band. There is little attenuation, however, of the 146.970-MHz product in the first example given, hence it can be heard a long way from the repeater site.

CORRECTIVE MEASURES

It is the legal and moral obligation of each repeater licensee to transmit a clean signal, and to assure that minimum spurious energy is present at the transmitter output. Therefore, certain precautions should be observed when installing a repeater system.

The use of a push-pull amplifier will help to reduce the possibility of in-band products of the kind cited in Example 1 of the foregoing. This type of amplifier tends to cancel even harmonics, thus reducing the level of the most common product in the IMD dilemma – the second-harmonic current. If the amplifier is operating Class C, use the minimum amount of grid current (grid 1) consistent with efficient operation. Excessive grid drive contributes to envelope distortion, and therefore increases the harmonic-current level in the stage. Linear amplifiers are less prone to IMD problems, so it would be prudent to consider operating the power amplifier in Class AB1. Make certain that the various stages of the transmitter are without parasitic oscillation. Neutralization, where applicable, should be effected. Low-pass filters and bandpass filters are of little help in reducing in-band IMD products because the bandpass characteristics of such filters can not be made sharp enough at vhf or uhf to attenuate the offending signal without causing high insertion loss at the transmitter output frequency.

Using Circulators

Some commercial firms manufacture and sell what is known as a ferrite isolator, or terminated circulator.[5] The device is a very precisely engineered ferrite component which functions like a loss less transmission pad. It can be considered as a one-way-path device in that very little transmitter energy is lost through the circulator as rf travels to the antenna, but a considerable loss is imposed on any energy coming down the feed line to the transmitter. The circulator, therefore, can be used effectively in reducing IMD products. A secondary advantage in using a circulator is that it provides a matched load at the transmitter output regardless of what the SWR might be in the antenna system.

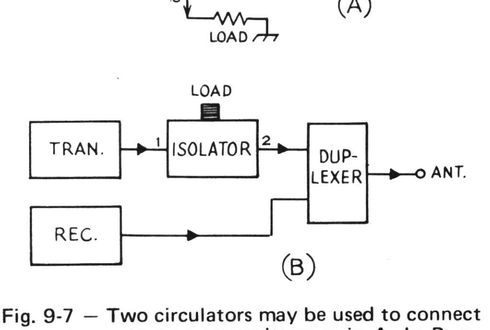
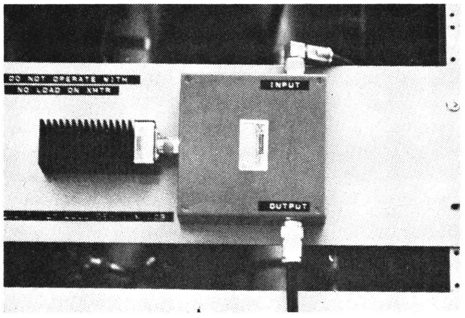
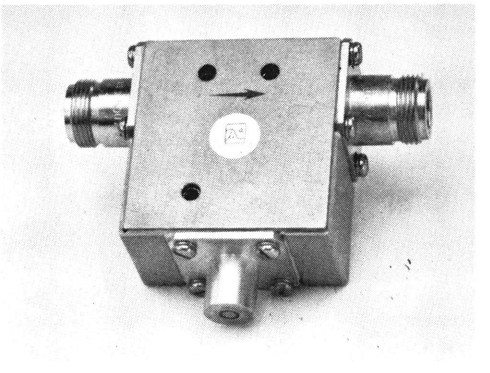


Fig. 9-7 – Two circulators may be used to connect one antenna to two transmitters as in A. In B, an isolator is placed between the transmitter and the duplexer to reduce intermodulation products.



The WR1ABM repeater uses a circulator at the output of the 146-MHz transmitter. The unit is fastened to a panel of aluminum to prevent distortion of the magnetic field within the circulator. A load capable of dissipating considerable power is connected to the third port.



A circulator for use with 440-MHz repeaters. This model can be tuned to the exact frequency that is used. Similar units are available for 144 MHz. The small projection at the bottom is a built-in load connected to port three. The load will dissipate any reflected power or other energy coming down the feedline from the antenna.

Two devices are suitable for use in reducing intermod – the *circulator* and the *isolator*. The circulators are three-port units which can be used to combine two or more transmitters for operation on one antenna, Fig. 9-7A. While serving as combiners they also eliminate IMD problems. The isolator is a two-port device for reducing IMD products, but has a built-in termination, or load. (See Fig. 9-7B.)

The two items under discussion can be purchased for use in the 148-MHz and 450-MHz bands. They are available for power levels up to a few hundred watts. Typical bandwidth for a 150-MHz unit is 3 MHz. Insertion loss is roughly 0.5 dB, and rejection of the unwanted energy coming down the feeder is typically 20 to 28 dB. The 450-MHz types have greater bandwidth – roughly 20 MHz, but exhibit otherwise similar characteristics to the 150-MHz versions. Though isolators and circulators are fairly expensive, they should be included as part of any amateur vhf or uhf repeater if IMD is to be handled effectively.

Footnote References

[1] "A Trap-Filter Duplexer for 2-Meter Repeaters," *QST*, for March 1970, page 42. Also, O'Brien, "Improving the Fm Repeater Transmitter for Amateur Use," *Ham Radio* for October 1969, page 24.

[2] Design information is given in *The ARRL Handbook*.

[3] The dc resistance of the wire used in the inductor causes *IR* losses. The smaller the wire size, the greater the voltage drop for a given load current.

[4] Commercially made heavy-duty line filters and line-filter components are available from J. W. Miller Company, Compton, CA 90224. Write for catalog.

[5] Ferranti Electric, Inc., E. Bethpage Rd., Plainview, NY 11803; Microwave Associates, Inc., 999 Arques Ave., Sunnyvale, CA 94086; Narda Microwave Corp., Engrs. Hill, Commercial St., Plainview, NY 11803; Sinclair Radio Labs, Inc., Box 23, Tonawanda, NY 14150; Western Microwave Labs, Inc., 16845 Hicks Rd., Los Gatos, CA 95030.

Testing FM Gear

ANYONE NOT ACCUSTOMED to finding and curing trouble in sophisticated equipment might have a sense of helplessness – or perhaps even despair – the first time his new fm rig goes silent. This feeling is not lessened any as he watches the serviceman to whom he has taken the equipment plug in a few pieces of test gear, replete with meters and bright lights, and locate the trouble in short order. The procedure seems to have an aura of guarded knowledge held by a select few in the trade. The effect is heightened by the newness – to many – of fm communications technique and equipment. Many amateurs simply have not had the time to keep up with the rapidly advancing technology that has caused the trunk-filling rig of yesterday to mutate into the compact solid-state unit hanging under the dashboard today.

These seemingly magical test boxes, upon closer scrutiny, really contain rudimentary circuits. They were packaged in a manner designed to aid the professional in doing his job in the least amount of time. The box with several meters is really a means of monitoring several circuits at once, instead of making use of one meter and a selector switch. The interesting – and expensive-appearing – box with an oscilloscope, frequency readout, and assorted dials is actually a receiver, signal generator, oscilloscope, and frequency counter all put together in one complete package. To the professional, time is one of the most expensive items to contend with; anything that will help to save time is a boon to his operation.

The amateur, however, need not worry about the time involved in servicing his rig; the knowledge gained is of far greater value. Except for the most compact equipment, he should be able to find and fix most troubles with the aid of ordinary test equipment. Many of the tools needed are those that *should* be available in any hamshack worthy of the name. Other pieces of test gear can be borrowed or improvised. As an example, a signal generator to help align the low i-f in many receivers can be devised from a cast-off bc receiver. The local oscillator can be made to work at 455 kHz by increasing the capacitance across the coil. Alternatively, a test oscillator may be built using an old i-f transformer (or an inexpensive new one) as described later.

Two pieces of test equipment that will be found to be most useful are the VOM (or VTVM) and a signal generator. Neither of these need be expensive, precision instruments. The signal generator should cover the range of most low i-f systems, such as 455, 915 and 1700 kHz. Many of the solid-state rigs have an i-f at 10.7 MHz, so a signal generator for that frequency will be of great help. To work on solid-state equipment, the VOM should have one or two ranges that will read low voltages; full-scale readings of 3 and 15 volts will be good.

A grid-dip oscillator is a *very* useful tool. It is almost essential as an aid to converting a rig from a commercial frequency to an amateur band. Although many of them are not too stable, a grid-dip meter can serve as a signal source for alignment of rf and i-f stages.

Clubs should not overlook the possibility of forming a technical services group. Classes about basic theory and troubleshooting techniques might be of interest to many of the members. Frequency checking or "netting" sessions before or after regular meetings have proven quite popular in many clubs. Servicable test equipment can be found at surplus outlets, advertised in Ham-Ads, or perhaps on a dusty shelf at the local service shop. The nearby serviceman might be prevailed upon to give a talk or demonstration as part of a meeting.

RECEIVER SERVICING

To anyone taking a first look at an fm receiver that needs repair, it might appear to be hopelessly complex. However, a receiver is made up of several basic circuits which can be isolated and treated individually in most instances. These circuits should be familiar as a result of their appearance in many other types of receiver. A block diagram, as in Chapter 3, will show an audio amplifier, detector, i-f amplifier, oscillator, mixer and rf amplifier. Many receivers have a squelch system that can be considered part of the audio circuit. These parts of a receiver have been listed from back-to-front, since that is the logical order in which to troubleshoot. (This assumes, of course, that the power supply has been checked and is working properly.)

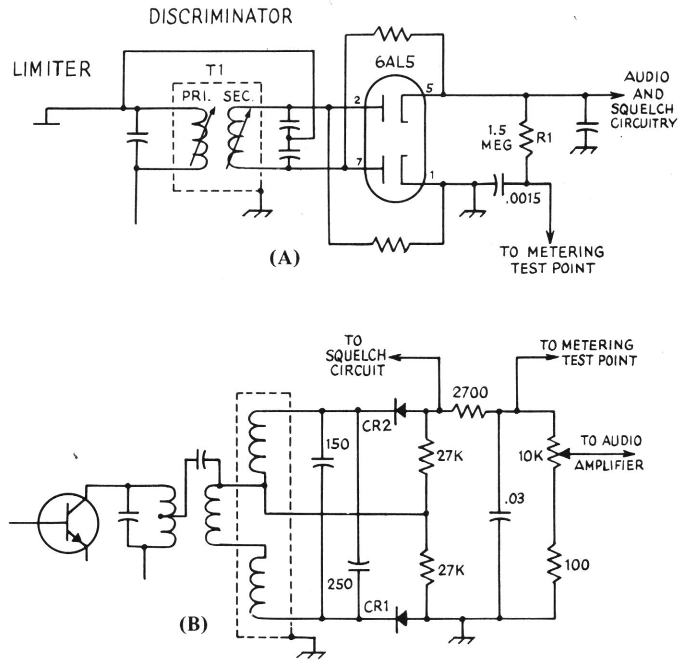


Fig. 10-1 – Discriminator circuits of the type that may be found in many fm communications receivers. (A) is representative of a circuit using a tube such as a 6AL5. (B) is the solid-state version. The diodes are typically Germanium.

An old but frequently ignored adage in servicing is to check the obvious things first. Are the tubes lighted, cracked, or loose? Is the fuse blown? Is the speaker lead disconnected or broken? Has the power plug fallen out of the socket? An inspection should reveal any overheated resistors, electrolytic capacitors that are swollen or have been leaking fluid. If a discolored resistor is found, the cause of the excess current should be found and cured. The speaker can be tested with an ohmmeter; a noise should be heard when the probes are connected to the speaker leads. The audio output transformer can be checked in the same manner.

Audio amplifier stages can be tested by applying a signal to the input of each one. A test signal can be obtained from an audio oscillator, another receiver, or from the secondary of a filament transformer. A potentiometer should be connected across the transformer secondary to provide a source of low-level audio.

The purpose of a squelch circuit is to keep the audio section turned off when there is no signal being received, and to turn the audio on when a signal is present. Some circuits use a dc voltage derived from the diode action of the limiter grids; others use a voltage obtained from rectified noise. A few squelch systems use a combination of both dc sources. Since the biasing networks in these circuits can be quite involved, it is best to obtain a schematic which, hopefully, will indicate the voltages to be found during squelched or non-squelched conditions. If this information is not available, comparison with another receiver of the same type can be helpful.

Detector Circuit

In an fm receiver, the detector is called a discriminator, ratio detector, or quadrature detector. There are also other types, as discussed in Chapter 3, but the three just mentioned are the most common. The discriminator circuit, if reduced to a basic form, can be thought of as two a-m detectors connected to a common load. A typical circuit is shown in Fig. 10-1. One half of the transformer secondary is resonant above the center frequency, and the other half is resonant an equal amount below center frequency. When a signal is applied to the input of the transformer at the design center frequency, voltage at the metering point should be zero. As the signal frequency is varied to either side of center, the meter should indicate a positive or a negative voltage. There is considerable interaction between the primary and secondary of the transformer. When the transformer is properly adjusted, equal movement of the signal above and below center frequency will be indicated by equal positive and negative readings on the meter. *The importance of maintaining a zero, or center frequency, reading at the discriminator output cannot be overstressed.* The performance of the receiver depends on the alignment of all rf and i-f stages to the correct frequencies. An on-frequency indication at the discriminator is a reliable check that the signal has not drifted.

I-F Amplifiers

The i-f amplifiers and limiters should be checked to see that each stage has gain and is aligned to the correct frequency. A limiter is simply an

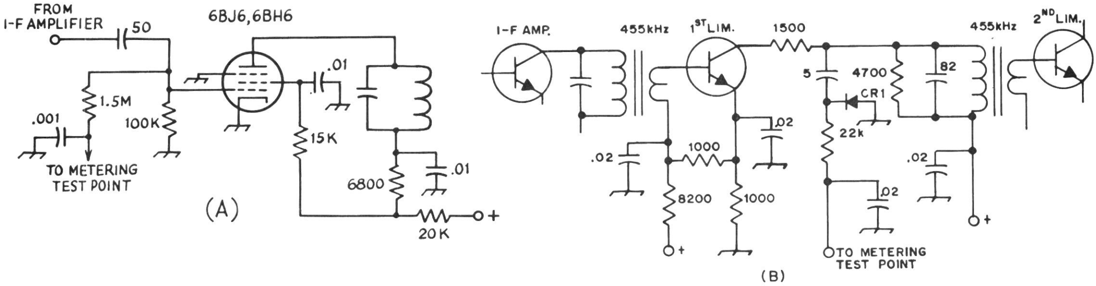


Fig. 10-2 — Limiter circuits using a tube in (A) and transistor in (B).

amplifier that easily can be saturated by the incoming signal. This saturation is indicated by rectification of the input signal, producing what is referred to as **limiter grid current.** Such grid current is a good indication of amplitude changes in the signal level through the preceding stages. A meter can be connected to monitor the signal level (grid current) in the manner of an S meter found in receivers for the hf bands. Fig. 10-2 shows some typical metering connections to limiter stages. All adjustments to the rf and i-f stages can be made while watching the indication on the limiter-grid meter for signal strength and also while checking for a center-frequency reading at the discriminator. For this type of testing and alignment, it is helpful to have two meters so that both quantities can be monitored at the same time.

The actual amount of gain in each stage is not particularly important. A stage that shows no gain or a loss can be considered defective and should be inspected for bad components or wrong voltages. A signal applied to the input of an amplifier should produce a larger limiter-current reading that it did when applied to the output of that stage. The signal level must, however, be reduced at each stage so that it will not drive the limiter so far into saturation that the grid will no longer respond to changes in level. Most receivers have a provision for monitoring either the first or second limiter stage grid current, as needed.

The Oscillator

Some fm receivers are single-conversion, requiring one oscillator to provide injection voltage to the mixer. Many receivers have two oscillators; one is used for vhf mixing and the second beats with the mid or high i-f signal to produce a signal at the low i-f. A few receivers utilize one oscillator and multiplier string to provide both the vhf and hf injection voltages. See Fig. 10-3 for a typical circuit. The operation of the oscillator can be checked by the use of a grid-dip meter or by a detector probe connected to a VOM. Frequency-multiplying stages also can be tuned to the correct harmonic with the help of the grid-dip.

SOLID-STATE EQUIPMENT

Some of the low priced, solid-state equipment that is now available does not have convenient test points in the different stages. A very useful tool in such cases is the oscilloscope. Many 'scopes can display a 455-kHz signal, and some will work at 10.7 MHz as well. The i-f and rf stages can be tuned while watching the display on the CRT. It is not necessary to see a sine wave on the 'scope; a pattern that appears as an unmodulated carrier will

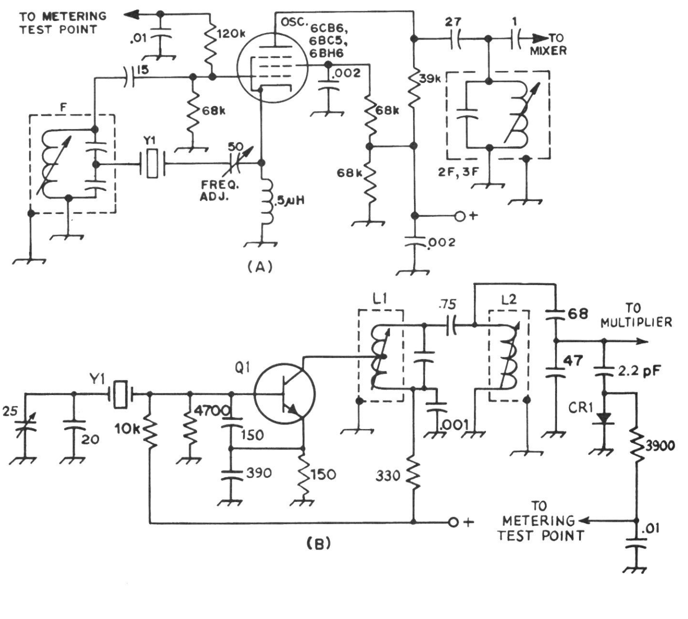


Fig. 10-3 — Local oscillators vary greatly in design. A typical one using a tube is shown at (A) and a transistor at (B). Frequency stability is the prime consideration.

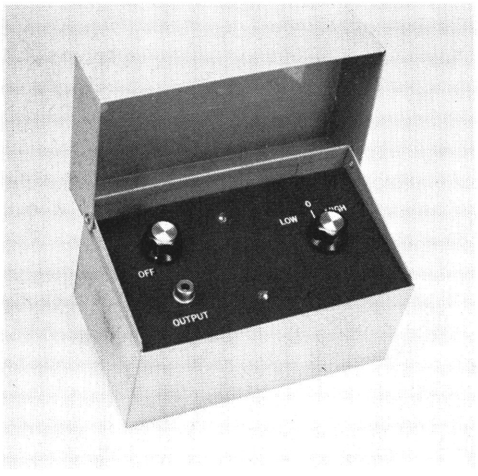


Fig. 10-4 – The signal source to aid in aligning 455-kHz i-f amplifiers is housed in an inexpensive file card box. The three-position switch, on the right, selects a center frequency or one that is preset above or below center. A self-contained battery provides power for the unit.

do. The level of the input to the receiver should be kept below the point at which any stage starts to saturate and limit the amplitude of the signal. Frequent checks should be made to assure that the energy is in the center of the bandpass of any filter in the i-f system.

Another precaution in working on transistorized gear is to be very sure where ground is, and to what reference any measurements are made. Connections for signal path, dc returns, and chassis ground are not always the same. The leads or probes from the meter or 'scope must be insulated sufficiently that they will not short to a nearby component; transistors seldom forgive such a slip.

AN I-F SIGNAL GENERATOR

The signal generator shown in Fig. 10-4 will provide an output to aid in aligning 455-kHz i-f amplifiers. The circuit uses a J. W. Miller BFO transformer in a transistorized oscillator. One switch position selects a trimmer that can be adjusted to set the output at 455 kHz. Two other positions select components for an output of 450 or 460 kHz, or 5 kHz low and 5 kHz high. Thus the oscillator can be used to align the i-f at the center frequency and to check that the discriminator response is linear above and below center. A greater spread between the low and high frequencies is possible by adjusting the trimmers.

The unit is housed in an inexpensive file-card box. Power consumption is low enough that a small 9-volt battery will provide many hours of operation.

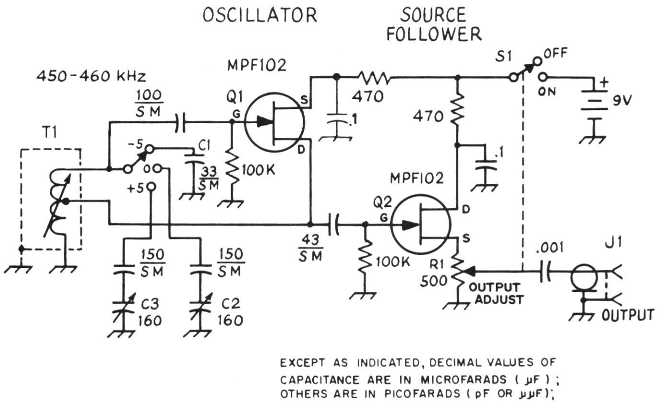
Calibration

Good construction techniques should be followed to assure that the oscillator is stable with regard to vibration. In the unit shown, drift was a matter of a few hertz per day at room temperature. The second harmonic can be checked against an a-m broadcast station at 900, 910, and 920 kHz. Broadcasting stations must maintain excellent frequency stability and thus are good standards for such calibration.

The oscillator should be adjusted first at the lower frequency of operation. With the switch (S1, Fig. 10-5) in the -5 kHz position, the slug in T1 should be turned until the frequency is 450 kHz. If the particular transformer used will not tune to the low setting, a different value of C1 should be tried.

The switch can be placed in the zero (center frequency) position, and C2 adjusted for an output of 455 kHz. The same procedure is used to obtain 460 kHz, with the switch in the +5 kHz position and the frequency set by C3.

To use the i-f signal generator to align a receiver, a 2- or 3-foot length of small diameter coax can be connected to J1. The free end of the cable can have the braid removed for approximately 2 inches, leaving the center conductor protected by the dielectric. For most purposes, simply placing the insulated end of the wire near the input of the stage to be aligned will provide enough signal to obtain a reading. For the more stubborn cases, a small capacitor can be connected between the end of the center conductor and the



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF); OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS; k = 1 000, M = 1 000 000.

Fig. 10-5 – Schematic for the i-f signal generator.

C1 – For text reference
C2, C3 – 10 to 160 pF mica compression padder (J. W. Miller 160-D or equiv.).
J1 – Coaxial connector. RCA phono type, BNC, or SO-239 suitable.
Q1, Q2 – Motorola JFET.
R1 – 500 ohm linear taper compostion control with switch.
S1 – Spst switch. Mounted on R1.
T1 – 455-kHz BFO transformer (J. W. Miller 1727 or equiv.).

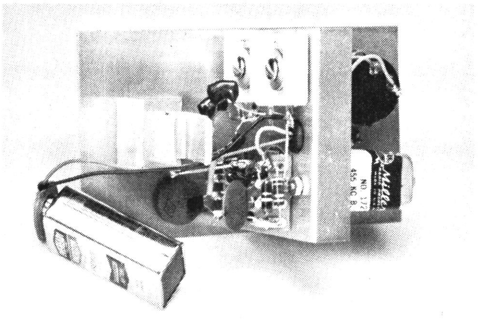


Fig. 10-6 — The transistors are mounted by fastening their leads to tie-point strips. The BFO transformer and two padder capacitors, C2 and C3, are mounted on the vertical partition. A small C-shaped bracket is used to fasten the battery clip over the frequency selector switch.

circuit to be adjusted. The output from the oscillator can be reduced, by adjusting R1, to prevent overloading of the i-f stages.

A VHF OSCILLATOR FOR RECEIVER TESTING

To locate and cure some of the more serious problems that occur in fm receivers, it is necessary to take the unit to the test bench or workshop. However, there are times when a minor touch up of the alignment can be performed with the rig in the car. In such cases, it is handy to have a portable signal source to apply to the receiver input, thus eliminating the need for extension cords, carrying of heavy equipment, and the like.

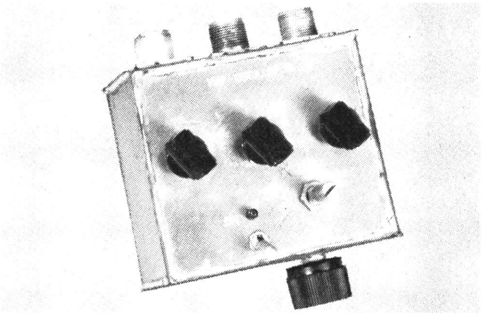
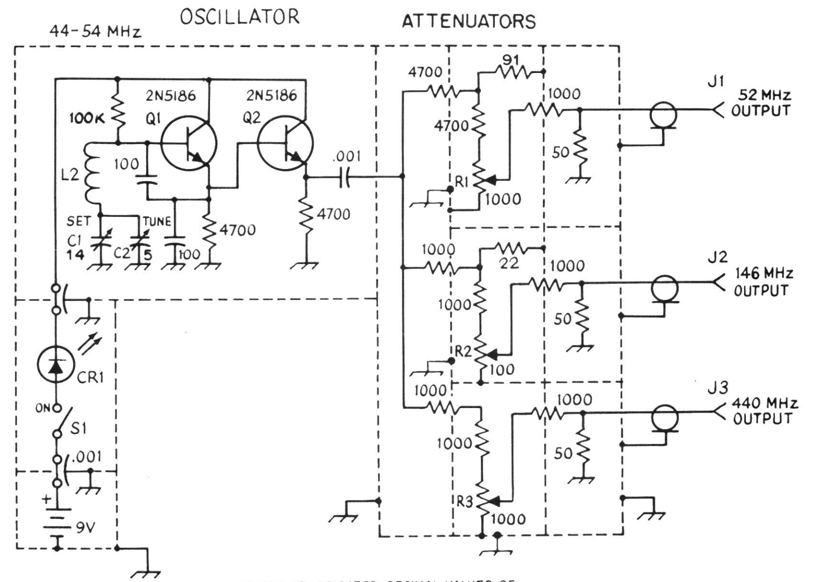


Fig. 10-7 — A portable rf signal generator that can be helpful in receiver alignment and sensitivity checks. The enclosure is fabricated from pc board material, soldered together to make a light but rugged assembly. Three knobs are output attenuator adjustments, one for each band. The slotted shaft is a coarse frequency adjustment. A single knob on the side is a fine adjustment of frequency. An internal 9-volt battery powers the unit.

Such an aid to alignment is shown in Fig. 10-7. It was built by K2CBA as a rugged and functional piece of test equipment. Two transistors are used, one as an oscillator, the other as an emitter follower. The frequency of oscillation is 44 to 54 MHz. Thus the output may be used directly on 6 meters, and harmonics of the oscillator will be useful on the higher frequencies.

The Circuit

In the oscillator, Fig. 10-8, C1 is used to set the frequency to the receiver input. C2 is a fine-tuning adjustment to aid in tuning the frequency to a



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF) ; OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS ; k = 1 000, M = 1 000 000.

Fig. 10-8 — Schematic for the rf signal generator. Fixed capacitors in the oscillator section should be silver-mica units for good stability. L1 can be wound on a plastic rod and cemented to the compartment wall to prevent trouble from vibration.

C1 — 2.3 to 14.2 pF miniature variable (E. F. Johnson 160-07 or equiv.).
C2 — 1.5 to 5 pF miniature variable (E. F. Johnson 160-102 or equiv.).
CR1 — Small LED.
L1 — 16 turns No. 24 enam., 1/4 inch ID X 1/2 inch long.
R1 — 1,000-ohm linear-taper composition control.
R2, R3 — 100 ohm, linear-taper composition control.

precise channel, as indicated by a meter at the output of the discriminator in the receiver.

An emitter follower provides isolation between the oscillator and the output attenuators. R1, R2, and R3 provide attenuation of the signal to the output connectors, one for each band. The 440-MHz output may be used for 220 MHz as well. Separate output connections are more desirable than a single attenuator and connector since it is difficult to obtain uniform output levels over a wide range of frequencies with one common circuit. The values associated with the individual output channel were selected to obtain nearly equal performance when connected to a receiver. The range of adjustment will provide a weak signal for sensitivity tests, as well as a stronger one for alignment purposes. A 9-volt transistor radio battery is the source of power for the unit. The current required is quite low, allowing the use of an LED in series with the supply voltage to provide a visual indication that the oscillator is turned on.

Construction

Double-sided pc board is used to make a housing for the oscillator. Each part of the circuit is enclosed in a compartment for isolation and ruggedness. After assembly and testing, small squares of board material are soldered in the back of each compartment, providing a complete enclosure that effectively shields the oscillator and the attenuators. Leads from the battery and the LED are filtered by feedthrough capacitors at each compartment wall. Small holes through the partitions allow other components to be connected to the circuit within. Insulating sleeve material should be used where there is danger of a lead shorting to the foil.

Performance

Since the circuit is essentially a VFO, there will be some drift with temperature change. The unit is not particularly sensitive to vibration since the method of construction provides a rugged mechanical assembly. Stability is quite adequate for the short-term needs of receiver alignment. Frequent checks can be made, with a discriminator meter, to ensure that the signal is "on channel."

A TEST PANEL FOR RECEIVERS AND TRANSMITTERS

When several members of a club show an inclination or desire to maintain their own rigs, it can be to the advantage of the club to have test equipment available. In such instances, a concerted effort by the membership can provide better test facilities than an individual is likely to afford or take the time to build.

An example of a worthwhile project of this type was contributed by K1GZU, of the Insurance City Repeater Club. The test panel, shown in Fig. 10-9, was patterned after the Motorola TEK-5C, but using a smaller housing. The reduction in size was possible because of some surplus meters that were on sale at a very low price.

While the unit shown is wired for use with Motorola equipment, it should be pointed out that the wiring of the cable and plug can be arranged to fit whatever equipment is predominate in a club or area. Adapters can be wired to make the test panel useful with any of the more common rigs that have a metering socket. It should be emphasized, however, that the actual wiring *must* be checked to assure that it is compatible with the equipment being tested, both transmitters and receivers.

Using the Panel

While the use of seven meters on a single test instrument may seem extravagant at first, it will take only a few alignment sessions with the panel to see the great advantage of such an arrangement. When the action in all the stages can be monitored simultaneously, one very quickly "gets the feel" of what is happening in a receiver or transmitter. The consequences of an adjustment can be noted two or three stages away from the actual point of making that adjustment.

Each type of equipment has a particular arrangement for metering, and the operator should become familiar with what meter is providing an indication for a given part of the circuit. As an example, in some receivers the first and second limiter stages have provision for metering grid current. In others, the last i-f stage has this provision as well as the limiters. Therefore, a set by manufacturer A might require the use of M1, M2,

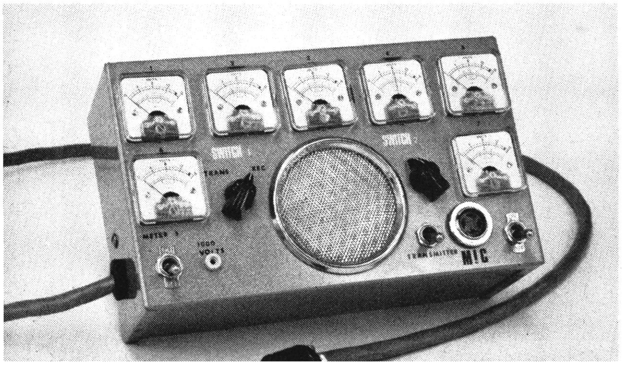


Fig. 10-9 — A transmitter/receiver test set constructed by K1GZU, patterned after a Motorola metering panel. The meters are surplus 0 to 50 μA units. The cable connector has been wired to work with Motorola equipment, but adapters can be made to permit the use of the test set with other makes of equipment. Switch 1 selects metering of either transmitter or receiver voltages. Switch 2 connects the audio output to either an internal speaker or to a load resistor.

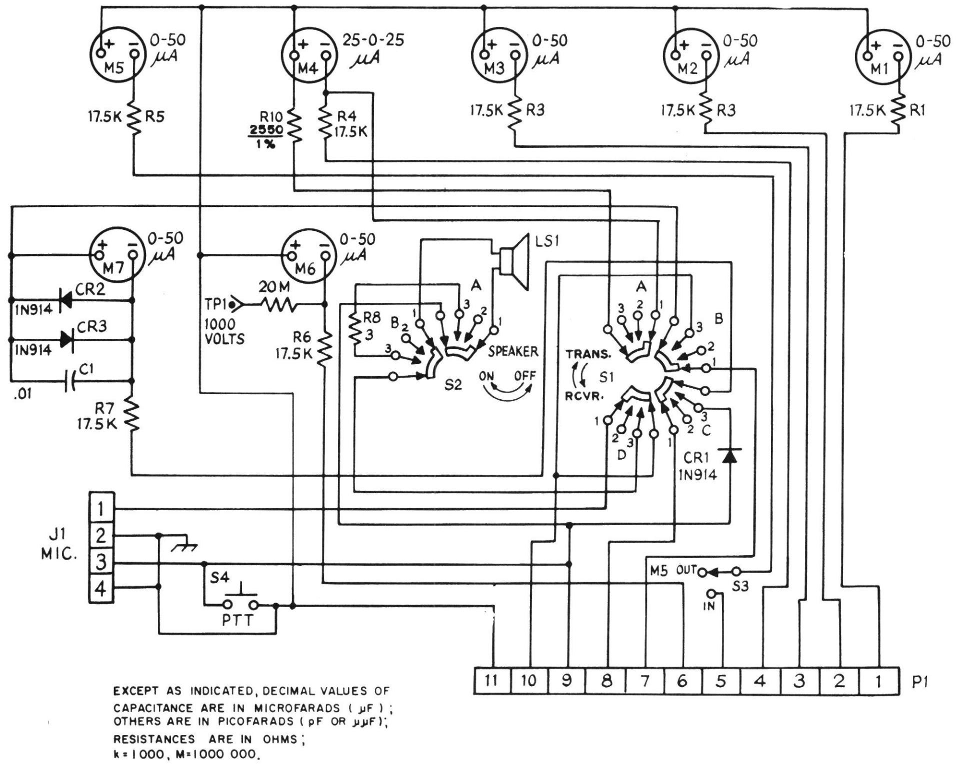


Fig. 10-10 — Circuit of the test panel. The meters are all 0-50 μA units. M4 has been modified to provide a zero-center indication. A conventional 25-0-25 μA meter may be used however.

P1 — 11-pin cable connector, male. See text.

S1 — 4-pole, 3-position rotary switch.
S2 — 2-pole, 3-position rotary switch.
S3 — Spdt toggle switch.
S4 — Spst push-button switch, normally open (or spring-return toggle switch).

and M3 for sensitivity adjustment, while that of manufacturer B would need only M2 and M3 for the same test. This can be determined by inspection of the wiring diagram of the equipment in question.

Generally speaking, M1 should provide an indication from either the last i-f stage or the first limiter. M2 should be connected to the first limiter if M1 is not used for this function. M3 will usually read second-limiter grid current. M4, the zero-center meter, is connected to the discriminator circuit. M5 is used in some sets to indicate alignment of the primary of the discriminator transformer. A switch is provided in the wiring to M5 for the purpose of disabling it, since the meter does upset the balance of the circuit to some extent. For this reason, S3 should be open whenever the discriminator secondary is being adjusted. M6 is used, in some instances, to provide an indication that the local oscillator is working. M7 is connected to the audio output of the receiver, and can be used to measure the degree of quieting that a weak signal will provide.

With S2 in the transmit position, the meters are connected for correct indication if the cable is inserted in the test socket of a transmitter. In this position, M1 will usually indicate relative output in those rigs equipped with the proper detector, as shown in Fig. 10-25.

The other meters, M2 through M7, are connected to stages such as the oscillator, doublers, triplers, and PA. Exactly which meters are used will have to be determined from the instruction manual for the equipment being tested.

A speaker is built into the test panel so that the output from the receiver may be monitored. S1 is used to connect the audio to either the speaker or a load resistor.

A microphone jack is provided, so that the operator may use the normal PTT function while adjusting the deviation of a transmitter. An auxiliary push button or toggle switch will allow the transmitter to be keyed without a microphone. An insulated tip jack is connected through a 20-megohm resistor to one of the meters, allowing it to be used as a voltmeter for measurement of B+.

SWEEP GENERATORS

Sweep generators have been neglected as a class of test equipment for servicing fm communications equipment. There was a time when the sweep generator occupied a prominent spot in the service shop, especially for use with entertainment-bandwidth receivers.

Perhaps because of the lack of familiarity with the method of using such equipment, many very good generators can be found stored away in a shop. Often they are offered for sale at bargain prices in swap sheets or Ham Ads.

The need for rapid servicing of two-way equipment has caused other means of aligning receivers to be developed, and these are in almost universal use today. However, anyone who is interested in learning just what goes on inside the receiver will do well to obtain a sweep generator and a manual that describes the technique of using it. One small drawback to the sweep method of alignment is that an oscilloscope is required to see the results. Nevertheless, an amateur who likes to roll his own will find that the sweep generator and oscilloscope can speed things up greatly. One picture of the response characteristics in an i-f system is worth several hours of cut-and-try time.

Those fortunate enough to possess such test equipment should dust it off and practice the technique of using it. If a sweep generator cannot be found, the one to be described on the following pages should not be difficult to construct and use.

A SIMPLE SWEEP GENERATOR FOR RECEIVER ALIGNMENT

In the past a sweep generator was such an expensive piece of test equipment that it was rarely found in amateurs' workshops. Today, however, because of a new low-cost integrated-circuit function generator, anyone willing to spend an evening building a simple project can enjoy the advantages of a sweep oscillator. Such a generator is useful for aligning fm receiver i-f strips, for checking home-made i-f amplifiers and filters, plus for determining the response characteristics of band-pass tuned circuits.

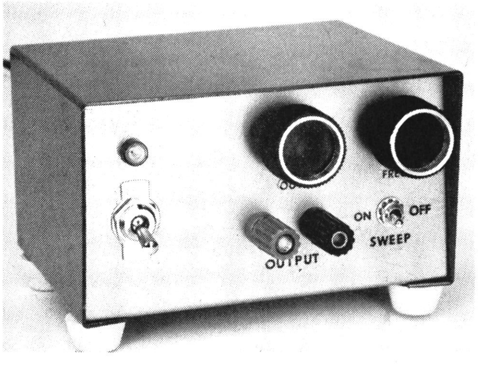


Fig. 10-11 — This sweep generator for receiver alignment was built by WA6JLJ, and appeared in *QST* for January, 1972.

TABLE 10-I

C1 (or C2) in µF	*Frequency Range*
10	1.2-12 Hz
1	12-120 Hz
.1	120-1200 Hz
.01	1.2-12 kHz
.001	12-120 kHz
.0001	120-1000 kHz

The heart of the sweep generator is a Signetics NE566 integrated-circuit voltage-controlled oscillator. The '566 produces square- and triangular-wave outputs simultaneously. The frequency of oscillation is determined by an external resistor, a capacitor, and the voltage applied to the control terminal. The device can be made to shift frequency over a ten-to-one range with exceptional linearity. The upper frequency limit of the NE566 is approximately 1 MHz.

Circuit Information

A schematic diagram of the sweep generator is shown in Fig. 10-12. Integrated circuit U2 functions as the main oscillator whose frequency can be varied from 100 kHz to 1 MHz. Control R2 provides the means of frequency adjustment. The output level from the oscillator may be varied by adjustment of R3. When S1 is closed, a sawtooth wave is applied to the control terminal of U2, sweeping the output frequency. The sweep frequency is determined by the setting of R1. The triangular-wave output from U1 is modified to a sawtooth wave using Q1 and Q2. Square-wave output from pin 3 of U1 is applied to Q2 via Q1, which is connected to function as a Zener diode. When the voltage reaches sufficient level to turn Q2 on, the timing capacitor, C1, is immediately discharged. This discharge occurs just as the triangular wave form reaches its peak voltage, preventing the down-slope side of the wave form from appearing at the output.

Either the sweep timing or the frequency range of the generator may be modified by changing the value of the timing capacitor, C1 for U1 and C2 for U2. Table 10-I shows approximate values for frequency ranges from 1.2 Hz to 1 MHz.

Power for the generator is provided by a 6.3-volt filament transformer. A voltage doubler and an N5723 integrated-circuit regulator are employed to deliver 12 volts to the NE556s. Approximately 40 mA of current is needed.

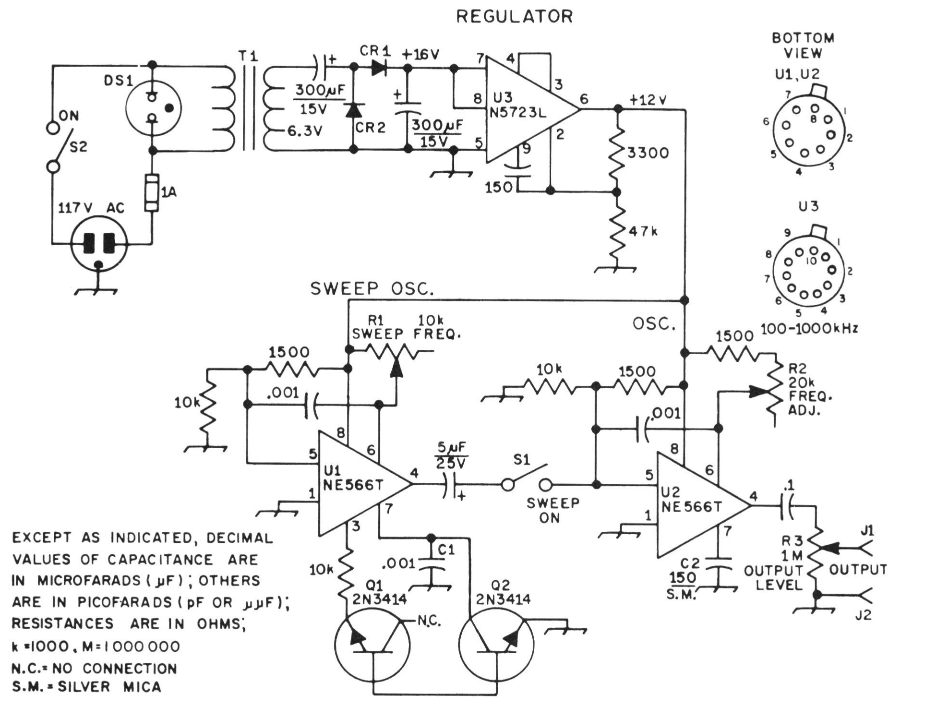


Fig. 10-12 — Circuit diagram of the sweep generator. Resistors are 1/2-watt composition and capacitors are disk ceramic (except those with polarity marked, which are electrolytic) unless otherwise noted.

C1, C2 — See Table 1.
CR1, CR2 — Silicon diode, 100 PRV, 500 mA.
DS1 — Neon indicator, panel mount, for 117 V ac.
J1, J2 — 5-way binding post.
Q1, Q2 — GE bipolar transistor; most low-power npn amplifier or switching types with medium beta should be suitable.
R1 — Linear taper, pc mount.
R2, R3 — Linear taper, panel mount.
S1, S2 — Spst toggle.
T1 — Filament type, 117-V primary, secondary 6.3 V at 300 mA.
U1-U3, incl. — Signetics integrated circuit (available from Landree Labs, P.O. Box 298, Guilford, CT 06437).

Construction

The sweep generator is assembled on electronic pegboard. A pc board can be employed, if desired, although making a circuit board would probably double the amount of time needed to complete the project. A small 3 × 5 × 4-inch cowl-type Minibox is used as an enclosure.

After checking the completed unit for wiring errors, apply line voltage and measure the dc voltage at pin 6 of U3. The reading should be approximately 12 volts. With S1 open, the output from the oscillator can be checked by monitoring the second harmonic with a bc radio. A short piece of hookup wire connected to J1 will serve as an antenna. With S1 closed, R1 should be set to produce the desired sweep frequency.

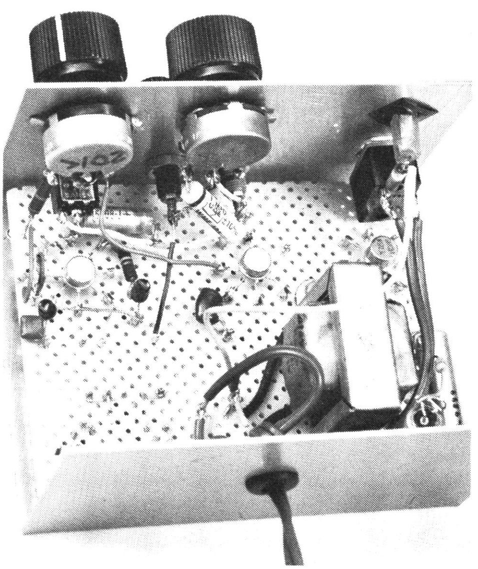


Fig. 10-13 — Inside view of the sweep generator. Small components are mounted on Vector T2.8 terminals which have been inserted in a piece of electronic pegboard. The voltage-regulator IC is located to the far right, just above the power transformer. The small pc-mount control to the far left is used to set the sweep frequency.

FREQUENCY STANDARDS

Many amateurs are undoubtedly familiar with the method of calibrating a receiver or transmitter in the hf spectrum by means of a spotting or marking signal. In most cases, a basic frequency is provided by a crystal-controlled oscillator, and a multivibrator or a divider circuit is used to obtain markers at 100-, 10-, or even 1-kHz intervals. The same system will work at vhf, with a slight variation. To be compatible with the spacing currently in use on the 2-meter band, markers should occur at 300 kHz and 30 kHz. The unit to be described here will meet this requirement. It is part of an article by W1KLK, and appeared in *QST* for April, 1972.

A STANDARD FOR FMERS

The fm operator needs to spot vhf-band frequencies with accuracy. Most fm transceivers are crystal-controlled, although some tunable receivers and an occasional VFO-controlled transmitter are in use for fm on the 6- and 2-meter bands. The crystal-controlled standard shown in Fig. 10-14 is intended as an aid to setting vhf gear "on channel." A high-speed gate package is used as the oscillator and an "on-card" regulator is employed in the power supply. The use of high-speed gates assures that oscillation at 3 MHz can be achieved and that fast rise-time pulses (rich in harmonics) are provided. A Schottky TTL IC (SN74S00) might be a better choice, especially if harmonics into the 220- and 420-MHz bands are desired.

Only two outputs, 300 kHz and 30 kHz, have been provided from the 3-MHz standard. The 300-kHz markers are useful as "sign posts" among the 30-kHz markers. For example, when the 300-kHz output is selected, markers will be heard at 147.00, 146.70, and 146.40 MHz. If reception of 146.94 is desired, once the 147.00-MHz marker signal has been located, the standard is switched for 30-kHz output. Then, the receiver should be tuned lower in frequency past the marker on 146.97 to the signal at 146.94 MHz. If 60-kHz markers are needed, an additional output signal can be obtained from point C Fig. 10-16.

National Semiconductor, followed by Fairchild, has recently introduced 5-V IC regulators in TO-3 or TO-22 housings. These devices have only three connection leads (input, output and ground) and require a single external bypass capacitor to perform their function. Current output up to 1 A is

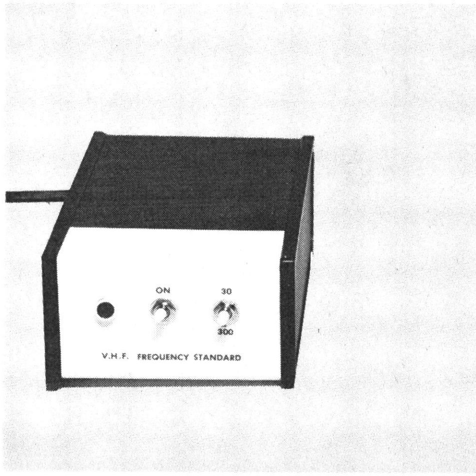


Fig. 10-14 – A frequency standard that will provide markers at 300- and30-kHz spacing through the vhf spectrum.

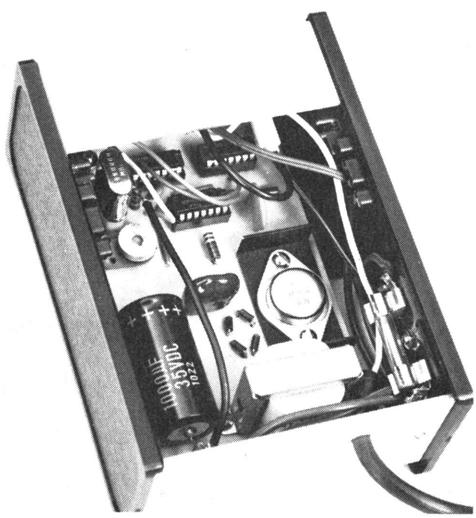


Fig. 10-15 – All components in the 3-MHz standard, except the switches and the fuse, are mounted on an etched circuit board. The trimmer capacitor is used to align the frequency of the crystal oscillator. A Ten-Tec JW-4 enclosure is used for this version. The IC regulator is mounted on a small aluminum heat sink which has been painted to improve its ability to radiate heat.

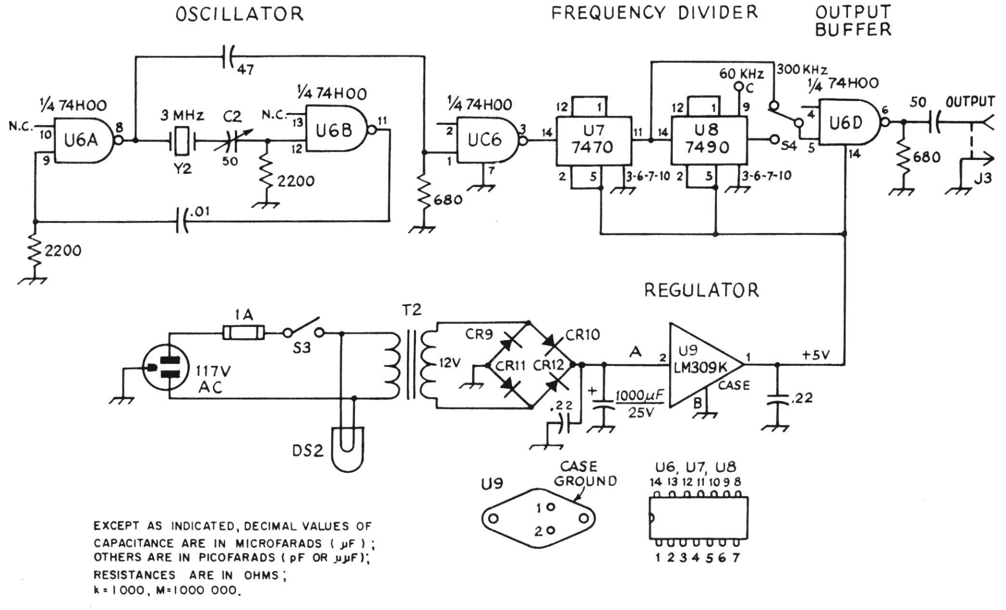


Fig. 10-16 — Circuit of the 3-MHz standard. Unless otherwise marked, resistors are 1/2-watt composition and capacitors are disk ceramic, except those with polarity marked, which are electrolytic.

C2 — 8- to 50-pF ceramic trimmer (Centralab 822-AN or equiv.).
CR9-CR12 — Silicon diode, 200 PRV or more, 500 mA or more (Motorola HEP156 or equiv.).
DS2 — Neon panel-mount indicator, 117 V. (Allied/ Radio Shack 272-1501 or Leecraft 36N2311).
J3 — Panel-mount jack, phono type (Swtichcraft 3505F or 3501FR, or equiv.).
S3 — Spst subminiature toggle (Allied/Radio Shack 275-325 or Calectro E2-116).
S4 — Dpdt subminiature toggle (Allied/Radio Shack 275-326 or Calectro E2-118).
T2 — Filament transformer, 12 V, 0.3 A, pc mount (Allied/Radio Shack 273-1385).
U6 — Quad high-speed TTL NAND gate (Signetics N74H00A, Fairchild SN74H00 or equiv.).
U7, U8 — TTL decade counter (Signetics N7490A, Motorola HEPC3800P, or equiv.).
U9 — On-card regulator, 5 V (National Semiconductor LM309K, Fairchild LM309 or UGH 7805393.
Y1 — International Crystal, type EX.

available, if an appropriate heat sink is used. These ICs were originally designed so that a separate regulator could be included on each logic card in a computer to reduce noise and common-impedance problems engendered when a single high-current supply is used. Hence the name "on-card" regulator!

If battery operation is desired, 12 V dc may be applied to points A and B of Fig. 10-16. Mobile operators may wish to include a switch to allow a quick changeover from ac to battery power.

Parts Talk

The first task of any construction project is to collect the parts. Appendix A lists suppliers for the crystal, ICs, cabinet and pc board used in this project. Most of the components needed will be available at local dealers or by mail order from "catalog" houses. A check in the Hartford area showed that everything except the cabinet and the pc board could be purchased "over the counter." Kits were available for those who wanted to make their own circuit boards, also. One dealer indicated he could order the Ten-Tec case. Parts procurement shouldn't be much of a problem for this project.

The circuit-board foil pattern and parts-layout diagram are shown in Fig. 10-17. Alternatively, a commercially made pc board may be purchased for the project (see Appendix A). The foil pattern of the board is arranged to use the on-card regulator and the pc-mount power transformer.

Alignment

Once a standard has been constructed and all connections have been rechecked for errors, plug in the power cord and turn on the power switch. Use a voltmeter to check the output of the power-supply regulator, which should be 5 volts. Monitor 15 MHz on an hf receiver. A marker signal should be heard very close to 15.000 MHz. When band conditions are suitable, listen to WWV or WWVH on 15 MHz and adjust trimmer C2 (of Fig. 10-16) so that the output of the standard is zero beat with the NBS transmission.

Correct alignment of the standard is vital if accurate markers are to be obtained. The receiver tuned to 15 MHz should have wide-band audio response so that low-frequency beat notes can be heard. As the oscillator trimmer is adjusted so that the output from the standard is close to zero beat,

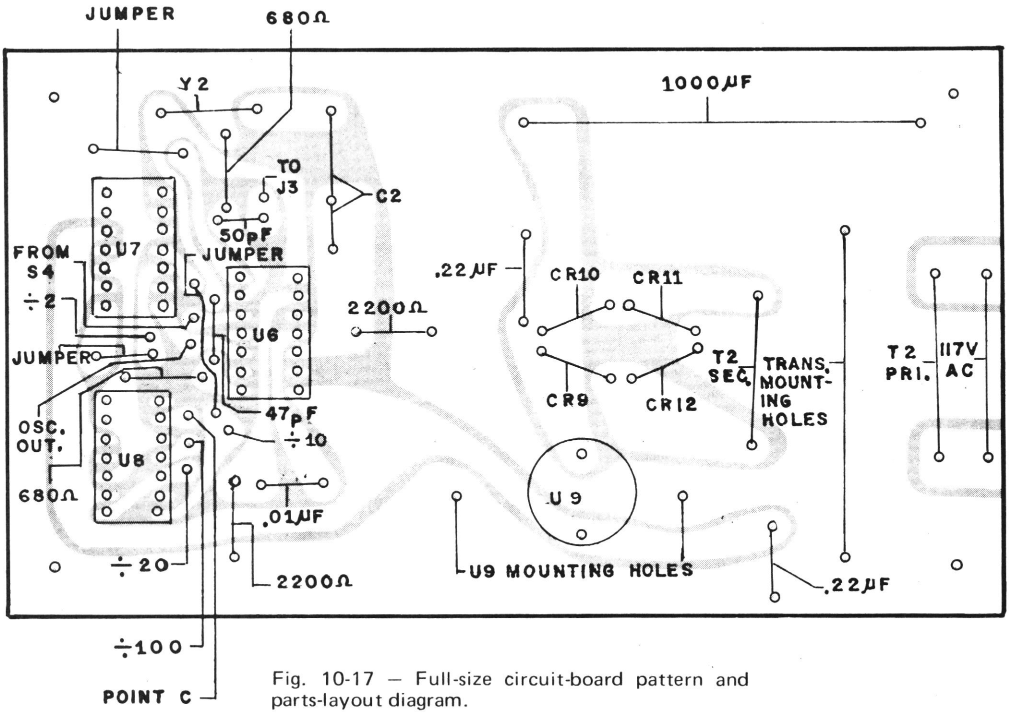


Fig. 10-17 — Full-size circuit-board pattern and parts-layout diagram.

pulsations will be heard. The difference in frequency between WWV (or WWVH) and the standard will be the number of pulses per second. Thus, C2 should be carefully set for the minimum number of pulsations per second.

Most crystals age slightly in the first few weeks of use. The standard should be rechecked for correct alignment once a week, or so, during the first month of use. However, a check against WWV is a good idea whenever the standard will be needed to make accurate measurements.

Using a Frequency Standard

Use of the 3-MHz standard to find a channel on a 2-meter tunable receiver has been described above. The procedure for a crystal- or VFO-controlled transmitter is similar. Once the correct harmonic from the standard has been located on the receiver, the transmitter frequency is zero beat against the marker. For a crystal-controlled transmitter, the crystal trimmer provides the means of frequency adjustment.

If a crystal-controlled receiver is to be set "on channel," monitor the discriminator output voltage with a voltmeter or microammeter. Consult the manufacturer's instruction manual for the proper test point. Turn on the standard and adjust the crystal trimmer for a zero-voltage indication on the meter. Some receivers use an oscillator where the tuning of the tank circuit affects the crystal frequency. Thus, the tuned circuit should be set for maximum drive to the following multiplier stage before the crystal trimmer is adjusted.

Appendix A

Listed below are sources for the major components needed to build the frequency standard. The list contains the sources actually used; many other vendors can supply suitable parts.

Cabinet: From Ten-Tec dealers or direct from Ten-Tec, Inc., Highway 411 East, Sevierville, TN 37862.

Circuit board: A pc board similar to that shown in Fig. 10-17 is available from Spectrum Research Laboratory, P.O. Box 5824, Tucson, AZ 85703. Price: $3.50.

Crystals: International Crystal Mfg. Co., 10 N. Lee, Oklahoma City, OK 73102. (Note: Other crystals are suitable if ground for a 32-pF load capacitance and mounted in an HC-6/U holder.)

Integrated circuits: Fairchild and Motorola components are available from Allied Electronics, 2400 W. Washington Blvd., Chicago, IL 60612 (free catalog available). Motorola HEP devices can be obtained by mail order from Lafayette Radio Electronics, 111 Jericho Turnpike, Syosset, NY 11791 (free catalog available). A list of local HEP dealers is available from Jack L. Jacques, Motorola Semiconductor Products, 8201 East McDowell Road, Scottsdale, AZ 85251. National Semiconductor components can be purchased from Cameradio, 2801 Liberty Ave., Pittsburgh, PA 15222, and Signetics components are available from Landree Labs, P.O. Box 298, Guilford, CT 06437.

TESTING AN FM TRANSMITTER

Accurate checking of the operation of an fm or pm transmitter requires different methods than the corresponding checks on an a-m or ssb set. The common forms of measuring devices either indicate amplitude variations only (a milliammeter, for example), or their indications are most easily interpreted in terms of amplitude.

The quantities to be checked in an fm transmitter are the linearity and frequency deviation and the output frequency, if the unit uses crystal control. The methods of checking differ in detail.

Frequency Checking

The crystal-controlled, channelized operation that is now popular with amateur fm users requires that a transmitter be held close to the desired channel, at least within a few hundred hertz, even in a wide-band system. Having the transmitter on the proper frequency is particularly important when operating through a repeater. The rigors of mobile and portable operation make a frequency check of a channelized transceiver at regular intervals a recommended procedure.

Frequency meters generally fall into two categories: the heterodyne type and the digital counter. For amateur use, the vhf/uhf counterparts of the popular BC-221 frequency meter, the TS-174 and TS-175, will provide sufficient accuracy. Frequency counters that will work directly up to 500 MHz and higher are available, but their cost is high. The less expensive low-frequency counters can be employed using a scaler, a device which divides an input frequency by a preset ratio, usually 10 or 100. The Heathkit IB-102 scaler may be used up to 175 MHz, using a counter with a 2-MHz (or more) upper frequency limit. If the counting system does not have a sufficient upper frequency limit to measure the output of an fm transmitter directly, one of the frequency-multiplier stages can be sampled to provide a signal in the range of the measurement device. Alternatively, a crystal-controlled converter feeding an hf receiver which has accurate frequency readout can be employed, if a secondary standard is available to calibrate the receiving system.

Deviation and Deviation Linearity

A simple deviation meter can be assembled following the diagram of Fig. 10-19A. This circuit was designed by K6VKZ. The output of a wide-band receiver discriminator (before any de-emphasis) is fed to two amplifier transistors. The output of the amplifier section is transformer coupled to a pair of rectifier diodes to develop a dc voltage for the meter, M1. There will be an indication on the meter with no signal input because of detected noise, so the accuracy of the instrument will be poor on weak signals.

To calibrate the unit, signals of known deviation will be required. If the meter is to be set to read 0-15 kHz, then a 7.5-kHz deviation test signal should be employed. R1 is then adjusted until M1 reads half scale, 50 μA. To check the peak deviation of an incoming signal, close both S1 and S2. Then, read the meter. Opening first one switch and then the other will indicate the amount of positive and negative deviation of the signal, a check of deviation linearity.

Measurement of Deviation Using Bessel Functions

Using a math relationship known as the Bessel function it is possible to predict the points at which, with certain audio-input frequencies and predetermined deviation settings, the carrier output of an fm transmitter will disappear completely. Thus, by monitoring the carrier frequency with a receiver, it will be possible by ear to identify the deviation at which the carrier is nulled. A heterodyne signal at either the input or receiver i-f is required so that the carrier will produce a beat note which can easily be identified. Other tones will be produced in the modulation process, so some concentration is required by the operator when making the test. With an audio tone selected from the chart (Fig. 10-19B), advance the deviation control slowly until the first null is heard. If a higher order null is desired, continue advancing the control further until the second, and then the third, null is heard. Using a carrier null beyond the third is generally not practical.

For example, if a 905.8-Hz tone is used, the transmitter will be set for 5-kHz deviation when the second null is reached. The second null

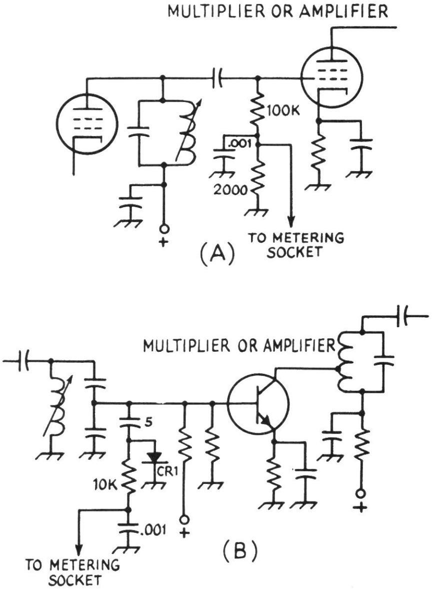
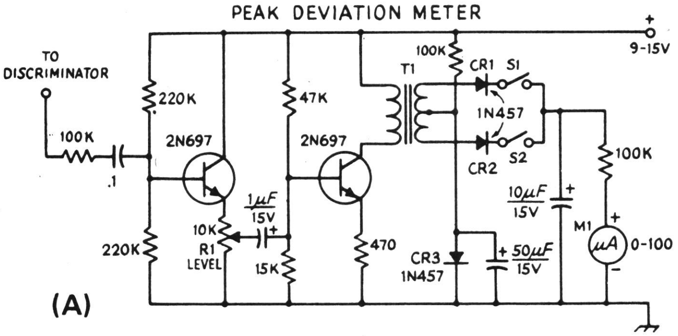


Fig. 10-18 – Connections used to monitor drive to frequency multiplier or amplifier stages. (A) for tube type equipment, and (B) for transistors.



(B)

Audio Frequency	Deviation Produced 1st Null	2nd Null	3rd Null
905.8 Hz	±2.18 kHz	± 5.00 kHz	± 7.84 kHz
1000.0 Hz	±2.40 kHz	± 5.52 kHz	± 8.65 kHz
1500.0 Hz	±3.61 kHz	± 8.28 kHz	±12.98 kHz
1811.0 Hz	±4.35 kHz	±10.00 kHz	±15.67 kHz
2000.0 Hz	±4.81 kHz	±11.04 kHz	±17.31 kHz
2079.2 Hz	±5.00 kHz	±11.48 kHz	±17.99 kHz
2805.0 Hz	±6.75 kHz	±15.48 kHz	±24.27 kHz

Fig. 10-19 — (A) Schematic diagram of the deviation meter. Resistors are 1/2-watt composition and capacitors are ceramic, except those with polarity marked, which are el-electrolytic. CR1-CR3,incl.,are high-speed silicon siwtching di-odes. R1 is a linear-taper com-position control, and S1, S2 are spst toggle switches. T1 is a miniature audio transformer with 10,000-ohm primary and 20,000-ohm center-tapped secondary (Triad A31X). (B) Chart of audio frequencies which will produce a carrier null when the deviation of an fm transmitter is set for the values given.

achieved with a 2805-Hz audio input will set the transmitter deviation at 15.48 kHz. The Bessel-function approach can be used to calibrate a deviation meter, such as the unit shown in Fig. 10-19A.

Reactance-Modulator FM Calibration

It is possible to calibrate a reactance modulator by applying an adjustable dc voltage to the modulator input and noting the change in oscillator frequency as the voltage is varied. A suitable circuit for applying the adjustable voltage is shown in Fig. 10-20A. The battery voltage is 3 to 6 volts (two or more dry cells in series). The arrows indicate clip connections so that the battery polarity can be reversed.

The oscillator frequency deviation should be measured by using a receiver in conjunction with an accurately calibrated frequency meter, or by any means that will permit accurate measurement of frequency differences of a few hundred hertz. One simple method is to tune in the oscillator on the receiver (disconnecting the receiving antenna, if necessary, to keep the signal strength well below the overload point) and then set the receiver BFO to zero beat. Then increase the dc voltage applied to the modulator input from zero in steps of about 1/2 volt and note the beat frequency at each change. Then reverse the battery terminals and repeat. The frequency of the beat note may be measured by comparison with a calibrated audio-frequency oscialltor. Note that with the battery polarity positive with respect to ground the radio frequency will move in one direction when the voltage is increased, and in the other direction when the polarity is reversed. When several readings have been taken, a curve may be plotted to show the relationship between input voltage and frequency deviation.

A sample curve is shown in Fig. 10-20B. The usable portion of the curve is the center part which is essentially a straight line. The bending at the ends indicates that the modulator is no longer linear; this departure from linearity will cause harmonic distortion and will broaden the channel occupied by the signal. In the example, the characteristic is linear 1.5 kHz on either side of the center or carrier frequency.

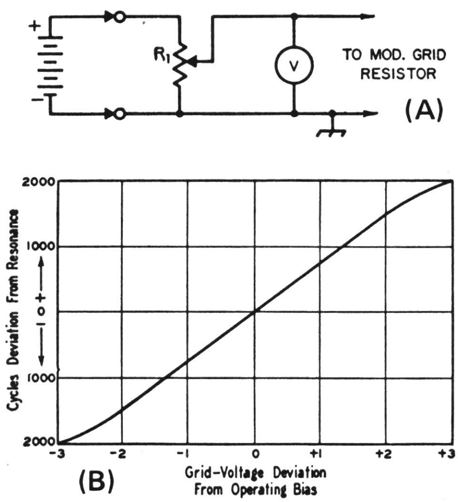


Fig. 10-20 — (A) Dc method of checking frequency deviation. R1 is 500 to 1000 ohms. (B) A typical curve of frequency deviation versus gate voltage for an fm modulator.

A HETERODYNE DEVIATION METER

The instrument described here can be used to check the audio deviation of an fm transmitter, or to determine how far off frequency the transmitter carrier may be. It can also be used as a signal source to aid in setting a receiver on frequency, if a crystal of known accuracy is plugged into the oscillator.

The Circuit

As shown in Fig. 10-22, a transistor oscillator is used to feed energy to a mixer diode, CR1. A small pick-up antenna is connected to the diode also, thereby coupling a signal from a transmitter to the mixer. The output from the diode, in the audio range, is amplified by U1, half of a 2747 operational amplifier. The 2747 amplifies and clips the audio, providing a square wave of nearly constant amplitude at the output. This square wave is applied to a rectifier circuit through variable coupling capacitors and a selector switch. A meter is connected to the rectifier circuit to read the average current. Since the amplitude of the input to the diodes is constant, a change in frequency will produce a change of average current. Three ranges are selected by S1, with individual trimmers being placed in the circuit for calibration purposes.

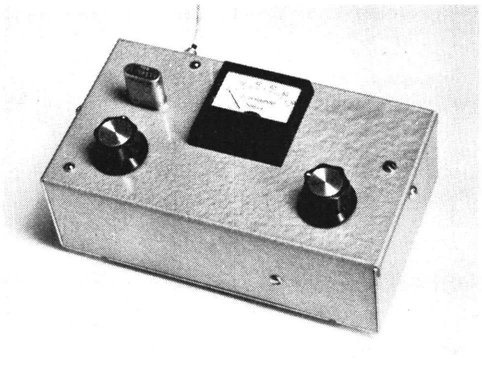


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Fig. 10-21 — The deviation meter is constructed in a Calectro aluninum box. A four-position switch is at the lower right. The crystal plugs in on the left with the frequency adjusting trimmer just below. A short whip or pick-up wire can be plugged into the phono connector that is mounted on the back wall of the box.

Fig. 10-22 — Circuit of the deviation meter.

C1 — 360 to 1000 pF mica trimmer (J.W. Miller 160-A or equiv.).
C2, C3 — 3 to 40 pF mica trimmer (J.W. Miller 86 MA 2 or equiv.).
C4 — 50 pF miniature air variable (Hammarlund MAPC 50 or equiv.).
CR1 — Germanium diode, 1N34, 1N58, or 1N82 suitable.
CR2, CR3 — Silicon diode, 1N914 or equiv.
J1 — Coax connector, BNC or phono type suitable.
M1 — Microammeter, 0 to 100 μA (Simpson Model Wide-Vue or equiv.).
Q1 — Motorola transistor.
R1 — 10,000 ohm miniature control, pc mount.
S1 — 2 pole, 4-position rotary switch, non shorting.
U1 — Operational amplifier IC μA741, MC1741, or equiv.
Y1 — Crystal to produce harmonic on desired transmitter or receiver frequency. Fundamental range 6 to 20 MHz

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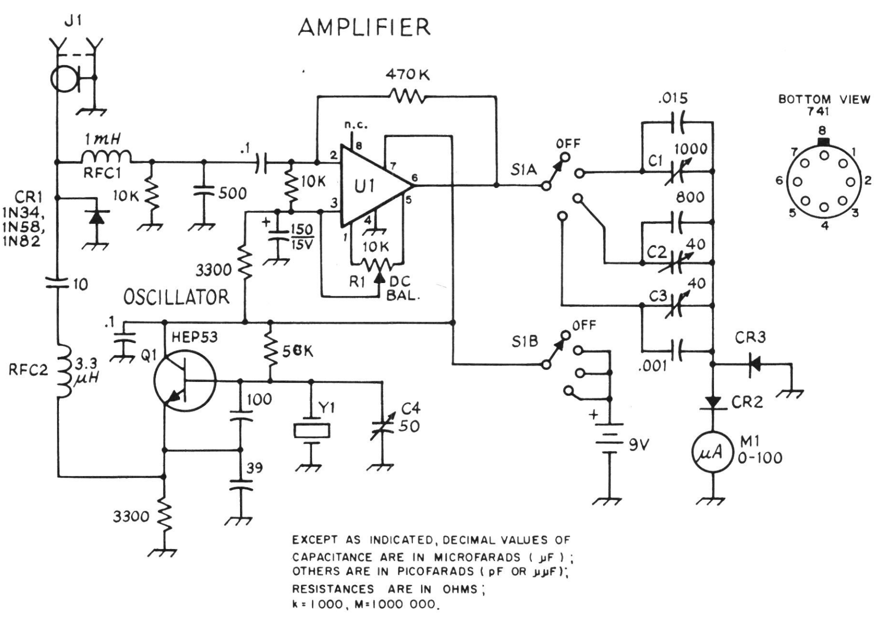


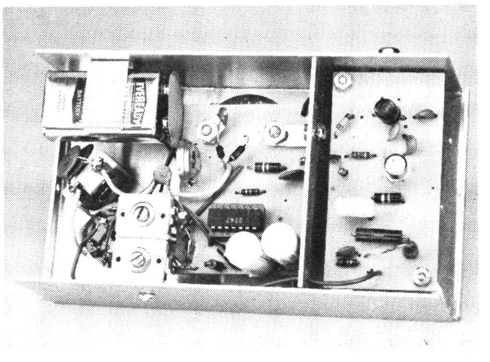


Fig. 10-23 — The dual op amp is located just below the center. Meter terminals are used as a convenient support for the amplifier pc board. The oscillator board is at the right, held in place by means of metal spacers.

Construction

An aluminum box is used for an enclosure, 6-1/2 × 3-1/2 × 2 inches. A meter, switch, variable capacitor, and crystal socket are all mounted on the top panel. A small pc board is fastened to the meter terminals as a convenient support. This board contains the IC and associated circuit components, as well as the rectifier diodes.

The oscillator is constructed on a separate pc board which mounts behind the crystal socket and variable capacitor. Metal spacers and 4-40 screws and nuts are used to hold the oscillator board in place. A shield made of pc board is placed between the oscillator and the amplifier to provide isolation. Power for the instrument is furnished by a 9-volt transistor radio battery that is held by a clip inside the box.

Testing and Use

Before calibrating the deviation meter, the dc balance of the op amp should be adjusted. A voltmeter should be connected to the output of U1 (pin 12), then R1 should be adjusted until the potential at this pin is one half of the supply voltage.

A low-level audio signal can be used to test the amplifier and meter circuit. As little as 10 mV, applied to pin 1 of U1, will produce a square wave at the output of the amplifier. Three ranges are provided is this meter; 0-1000, 0-10k, and 0-20 kHz. Each position can be calibrated by adjustment of the associated trimmer capacitor. The amount of capacitance needed may vary with different diodes, so fixed ceramic capacitors may be placed in parallel with the trimmers to bring the adjustment within range. As the frequency of the input to U1 is varied, the meter reading should correspond with that frequency over most of its range. On the upper meter range, 0-20 kHz, a multiplication factor must be applied to the reading obtained.

In use, a short whip or piece of wire is connected to J1, and the meter placed near a transmitter. A crystal that will produce a harmonic on the correct frequency is plugged into the socket. The selector switch should be in the first (0-1000 Hz) position. When the transmitter is turned on, the meter will indicate the difference in frequency between the transmitter and the harmonic from the oscillator. The trimmer, C4, should be adjusted for a minimum reading. Any hum, noise, or power-supply whine will cause a residual reading that could mask true zero beat. Modulation can be applied to the transmitter and the deviation control adjusted for the amount desired as indicated on the meter. Note that there is a difference between the indications obtained from a sine wave and those from voice. Readings will be lower with voice, the amount being dependent upon the meter that is used and upon the individual voice.

Several transmitters can be "netted" to a system by setting the crystal in the meter to the correct frequency at first, then adjust the oscillator in each transmitter for an indication of zero beat.

Since there is some energy from the oscillator present at the input, J1, the unit will provide a signal to align receivers to the correct frequency. When the deviation meter is being used as a signal source for checking alignment or sensitivity, care should be taken not to overload the receiver. The energy received can be decreased by placing the oscillator some distance away, or by enclosing it in a metal container that provides partial shielding.

POWER OUTPUT MEASUREMENT

The last step in any construction or testing of a transmitter should be a measurement of the output power. An absolute measurement may not be necessary unless the efficiency of the equipment needs to be determined or if some part of the output circuitry is suspect. For such measurements a calibrated output meter is a necessity to assure consistent and reliable readings.

For most mobile installations a field strength measurement will suffice as an indication that the last stage of the transmitter is loaded properly. On the lower frequencies, such as 28 and 50 MHz, a quick and simple indicator can be made by connecting an rf diode between the probes of a VOM and placing the diode in the field of the antenna. To tune the transmitter for maximum output, set the meter to read micro- or milliamperes.

Many of the absorption type of instruments can be adapted to make field strength readings. A small whip made of stiff wire can be connected to the tuned circuit to pick up energy near the antenna. Such a circuit is shown in Fig. 10-24.

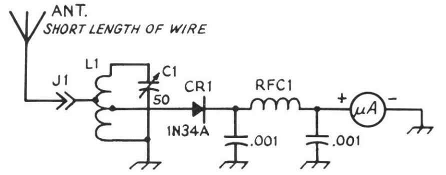


Fig. 10-24 — A simple field-strength meter to check transmitter loading and antenna performance.

L1 — 30 to 90 MHz, 4 turns no. 20 enam., 1 inch dia., 1 inch long. Tap 1-1/2 and 2 turns from ground. 95 to 300 MHz, Hairpin loop of no. 14 tinned wire, 1/2-inch spacing, 2-inches long. Tap at 1 and 1-1/2 inches from ground.

M1 — Microammeter, 0 to 100 or 0 to 500 suitable.

Many of the commercially manufactured fm transmitters have a metering point connected to a built-in detector. This type of circuit, seen in Fig. 10-25, is very useful in making relative output measurements. It should be remembered that a poor load can cause reflected power to appear at the pick-off point. Under these conditions the actual meter reading might be higher at one time than another. The value of the coupling capacitor, C1, can be varied to change the sensitivity of the detector or to prevent overloading the diode. In some cases, such as a transmitter with 100 or more watts out, a small length of insulated hook-up wire placed near the output circuitry would be sufficient. The resistances in the circuit can be changed to suit the range of the meter used.

A SENSITIVE FIELD-STRENGTH METER

Accurate instruments for checking antenna performance can be rather expensive devices. When checking radiation characteristics of an antenna, most amateurs resort to a simple wavemeter for making tests. It is true that a receiver with an S meter can be used for many tests but this method has several drawbacks. If one has ever tried to make tests outdoors, it becomes quite a problem with long extension cords in order to power the receiver.

The instrument described here goes a little beyond the simple wavemeter. In order to check any antenna patterns or gain, tests should be made with the test instrument several wavelengths away from the antenna. The simple wavemeter usually is lacking in sensitivity to meet these requirements. Also, such a device has a serious drawback in that the linearity of instrument can leave much to be desired.

This field-strength meter takes care of these problems. It is small, measuring only 4 × 5 × 8 inches. The device has its own power supply built in (batteries). Sensitivity can be set up for practically any degree desired. However, from a practical standpoint, the meter should not be too sensitive otherwise it would respond to undesired signals. Also, this unit has excellent linearity. The frequency range includes the 80- through 2-meter bands, with bandswitched circuits, thus avoiding the use of plug-in inductors. All in all, it is a very useful instrument to anyone interested in comparing antenna gain, front-to-back measurements, or field patterns.

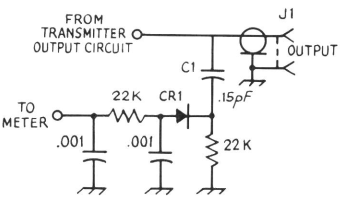


Fig. 10-25 — A circuit for metering the relative output from a transmitter. The circuit shown is suitable for output to approximately 50 watts. For higher power, the value of C1 should be decreased or a resistor connected in series, between C1 and the rf circuit, to prevent diode burnout.

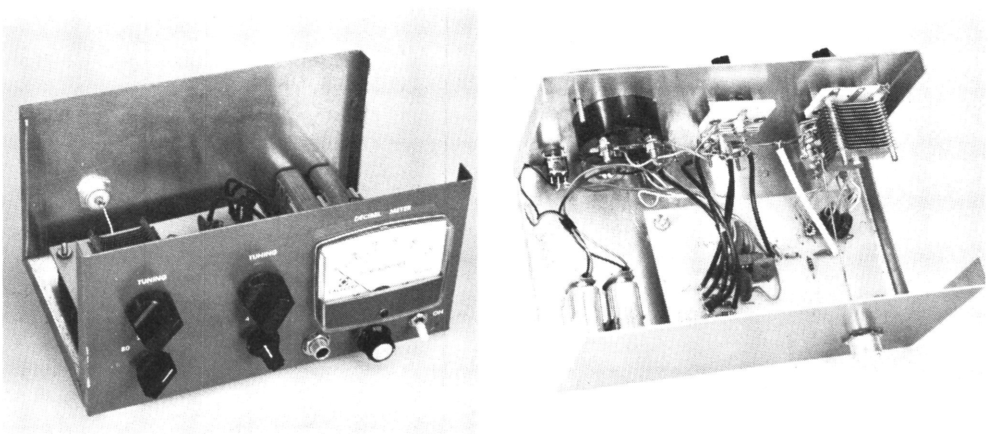


Fig. 10-26 — Front and rear views of the meter. Controls near the end of the front panel are the bandswitch and C1. A sensitivity-selector switch and C2 are located beside the meter.

Ratio	*.0*	*.1*	*.2*	*.3*	*.4*	*.5*	*.6*	*.7*	*.8*	*.9*
1	0.00	0.83	1.58	2.28	2.92	3.52	4.08	4.61	5.11	5.58
2	6.02	6.44	6.85	7.23	7.60	7.96	8.30	8.63	8.94	9.25
3	9.54	9.83	10.10	10.37	10.63	10.88	11.13	11.36	11.60	11.82
4	12.04	12.27	12.46	12.67	12.87	13.06	13.26	13.44	13.62	13.80
5	13.98	14.15	14.32	14.49	14.65	14.81	14.96	15.12	15.27	15.42
6	15.56	15.71	15.85	15.99	16.12	16.26	16.39	16.52	16.65	16.78
7	16.90	17.03	17.15	17.27	17.38	17.50	17.62	17.73	17.84	17.95
8	18.06	18.17	18.28	18.38	18.49	18.59	18.69	18.79	18.89	18.99
9	19.08	19.18	19.28	19.37	19.46	19.55	19.65	19.75	19.82	19.91
10	20.00	20.09	20.17	20.26	20.34	20.42	20.51	20.59	20.67	20.75
× 10	+ 20									
×100	+ 40									
× 1000	+ 60									
× 10,000	+ 80									
× 100,000	+ 100									

TABLE 10 - II

VOLTAGE RADIO TO DECIBEL CONVERSION

Decibels	*.0*	*.1*	*.2*	*.3*	*.4*	*.5*	*.6*	*.7*	*.8*	*.9*
0	1.00	1.01	1.02	1.04	1.05	1.06	1.07	1.08	1.10	1.11
1	1.12	1.14	1.15	1.16	1.18	1.19	1.20	1.22	1.23	1.24
2	1.26	1.27	1.29	1.30	1.32	1.33	1.35	1.36	1.38	1.40
3	1.41	1.43	1.45	1.46	1.48	1.50	1.51	1.53	1.55	1.57
4	1.59	1.60	1.62	1.64	1.66	1.68	1.69	1.72	1.74	1.76
5	1.78	1.80	1.82	1.84	1.86	1.88	1.91	1.93	1.95	1.97
6	2.00	2.02	2.04	2.07	2.09	2.11	2.14	2.16	2.19	2.21
7	2.24	2.26	2.29	2.32	2.34	2.37	2.40	2.43	2.46	2.48
8	2.51	2.54	2.57	2.60	2.63	2.66	2.69	2.72	2.76	2.78
9	2.82	2.85	2.88	2.92	2.95	2.99	3.02	3.06	3.09	3.13
10	3.16	3.20	3.24	3.27	3.31	3.35	3.39	3.43	3.47	3.51
11	3.55	3.59	3.63	3.67	3.72	3.76	3.80	3.85	3.89	3.94
12	3.98	4.03	4.07	4.12	4.17	4.22	4.27	4.32	4 37	4.42
13	4.47	4.52	4.57	4.62	4.68	4.73	4.79	4.84	4.90	4.95
14	5.01	5.07	5.13	5.19	5.25	5.31	5.37	5.43	5.50	5.56
15	5.62	5.69	5.76	5.82	5.89	5.96	6.03	6.10	6.17	6.24
16	6.31	6.38	6.46	6.53	6.61	6.68	6.76	6.84	6.92	7.00
17	7.08	7.16	7.24	7.33	7.41	7.50	7.59	7.67	7.76	7.85
18	7.94	8.04	8.13	8.22	8.32	8.41	8.51	8.61	8.71	8.81
19	8.91	9.02	9.12	9.23	9.33	9.44	9.55	9.66	9.77	9.89
+ 20	× 10									
+ 40	× 100									
+ 60	× 1000									
+ 80	× 10,000									
+ 100	× 100,000									

DECIBEL TO VOLTAGE RATIO CONVERSION

Circuit Details

Fig. 10-27 shows the circuit of the unit. The heart of the instrument is a μA741 integrated circuit. This is an operational amplifier that can provide signal gains on the order of 60 dB. The entire circuit is quite simple. A pick-up antenna is connected to J1 and a signal is coupled (from the antenna under test) to a tuned circuit. Energy from the tuned circuit is rectified by CR1 and CR2 and fed into the op amp. The rectified and amplified output from the '741 is then read on M1. Sensitivity of the op amp is controlled by inserting resistors R3 through R6 in the circuit.

With the circuit shown in its most sensitive setting, M1 will respond to a signal from the pick-up antenna on the order of 100 μV. Linearity is poor for approximately the first 1/5th range of M1 but then is almost straight line from there to full scale deflection. The reason for the poor linearity at the start of the readings is because of the nonlinearity of diodes at low signal levels. However, this is of no real importance because any accurate gain measurements can be made in the linear portion of the meter readings.

The '741 requires both a positive and a negative voltage source. This is obtained by connecting two 9-volt batteries in series, with the center connection grounded. One other feature of the instrument is that it can be used remotely by connecting an external meter to J2. This is handy if one wants to adjust an antenna and observe the results without having to leave the antenna site.

L1 is the 80/40-meter coil and is tuned with C1. The coil is wound on a toroid form. When going to 20, 15, or 10 meters, L2 is switched in parallel with L1 providing the correct amount of inductance to cover the three bands. L5 and C2 cover approximately 40 to 60 MHz, and L7 and C2 from 130 MHz to about 180 MHz. The two vhf coils are also wound on toroid forms.

Construction Notes

The majority of the components are mounted on an etched circuit board. No special problems are involved in wiring with the possible exception of using shielded leads between pin 4 of the '741 and S2, and the same for the leads from R3 through R6 to the switch. This precaution was observed because in the breadboard version the '741 had a nasty habit of "taking off." With the amount of gain in μA741, some 60 dB, good shielding and bypassing techniques are required.

In order for the unit to tune to the 2-meter band, L6 and L7 should be mounted directly across the appropriate terminals of S1. When first tried, the circuit would not cover 144 MHz when the coil was mounted on the circuit board because of the inductance in the relatively long lead lengths to the switch. Also, it isn't really necessary to use toroid forms for the 6- and 2-meter coils. They happened to be available for the test model, but air-wound coils of the appropriate inductance could be used.

Calibration

The field-strength meter can be used "as is" for a relative reading device. However, it is much more useful if the instrument is calibrated in decibels. If one has access to a calibrated signal generator, it can be connected to the field-strength meter and a calibration chart made up. To make it easy for the builder, Table I is a chart of voltage ratio to decibel conversion. Keep in mind that this device is reading rectified voltage, not power.

As an example, if a change from 100 to 200 μV at the input causes the meter reading to increase from 1 to 5, than a voltage ratio of 2 to 1 is indicated by 4 divisions on M1 (assuming, of course, that the scale of M1 is divided evenly from 1 to 10).

Table II shows that a voltage ratio of 2 equals 6.02 dB which in turn means that there is a range of 6.02 dB between 1 and 5 on M1. M1 can be calibrated more closely between 1 and 5 by adjusting the generator and figuring the ratio. For example, a ratio of 100 to 140 μV is 1.4 and Table II shows this as 2.92 dB. Using this method, all of the settings of S2 can be calibrated. In the instrument shown here, the most sensitive setting of S2 with R3, 1 megohm, the range was approximately 6 dB for M1. Each setting of S1 must be calibrated as well as each band.

Another approach to calibrating the instrument is using a transmitter where the output power is measured with a Bird Thru-Line wattmeter or similar device. In this case we are dealing with power ratios, not voltage, so Table III should be used. With most transmitters, the power output can be varied so the calibration of the test instrument is rather easy. Attach a pick-up antenna to the field-strength meter, just a short wire a foot or so long will do, and position the device in the transmitter antenna field. Let's assume we set the transmitter output for 10 watts and get a reading on M1. We note the reading and then increase the output to 20 watts, or a power ratio of 2. Note the reading on M1 and then refer to Table III. A ratio of 2 in power is 3.01 dB. Using this method the instrument can be calibrated on all bands and ranges.

With the tuned circuits and coupling links specified in Fig. 10-27, this instrument had an "average" range of 6 dB for the two most sensitive positions of S2, and 15 dB and 30 dB for the next two successive ranges. The last scale is handy for making front-to-back measurements without having to switch S2.

TABLE 10-III

POWER RATIO TO DECIBEL CONVERSION

Ratio	*.0*	*.1*	*.2*	*.3*	*.4*	*.5*	*.6*	*.7*	*.8*	*.9*
1	0.00	0.41	0.79	1.14	1.46	1.76	2.04	2.30	2.55	2.79
2	3.01	3.22	3.42	3.62	3.80	3.98	4.15	4.31	4.47	4.62
3	4.77	4.91	5.05	5.19	5.32	5.44	5.56	5.68	5.80	5.91
4	6.02	6.13	6.23	6.34	6.44	6.53	6.63	6.72	6.81	6.90
5	6.99	7.08	7.16	7.24	7.32	7.40	7.48	7.56	7.63	7.71
6	7.78	7.85	7.92	7.99	8.06	8.13	8.19	8.26	8.33	8.39
7	8.45	8.51	8.57	8.63	8.69	8.75	8.81	8.87	8.92	8.98
8	9.03	9.09	9.14	9.19	9.24	9.29	9.35	9.40	9.45	9.49
9	9.54	9.59	9.64	9.69	9.73	9.78	9.82	9.87	9.91	9.96
10	10.00	10.04	10.09	10.13	10.17	10.21	10.25	10.29	10.33	10.37
× 10	+ 10									
× 100	+ 20									
× 1000	+ 30									
× 10,000	+ 40									
× 100,000	+ 50									

DECIBEL TO POWER RATIO CONVERSION

Decibels	*.0*	*.1*	*.2*	*.3*	*.4*	*.5*	*.6*	*.7*	*.8*	*.9*
0	1.00	1.02	1.05	1.07	1.10	1.12	1.15	1.18	1.20	1.23
1	1.26	1.29	1.32	1.35	1.38	1.41	1.45	1.48	1.51	1.55
2	1.59	1.62	1.66	1.69	1.74	1.78	1.82	1.86	1.91	1.95
3	2.00	2.04	2.09	2.14	2.19	2.24	2.29	2.34	2.40	2.46
4	2.51	2.57	2.63	2.69	2.76	2.82	2.88	2.95	3.02	3.09
5	3.16	3.24	3.31	3.39	3.47	3.55	3.63	3.72	3.80	3.89
6	3.98	4.07	4.17	4.27	4.37	4.47	4.57	4.68	4.79	4.90
7	5.01	5.13	5.25	5.37	5.50	5.62	5.76	5.89	6.03	6.17
8	6.31	6.46	6.61	6.76	6.92	7.08	7.24	7.41	7.59	7.76
9	7.94	8.13	8.32	8.51	8.71	8.91	9.12	9.33	9.55	9.77
+ 10	× 10									
+ 20	× 100									
+ 30	× 1000									
+ 40	× 10,000									
+ 50	× 100,000									

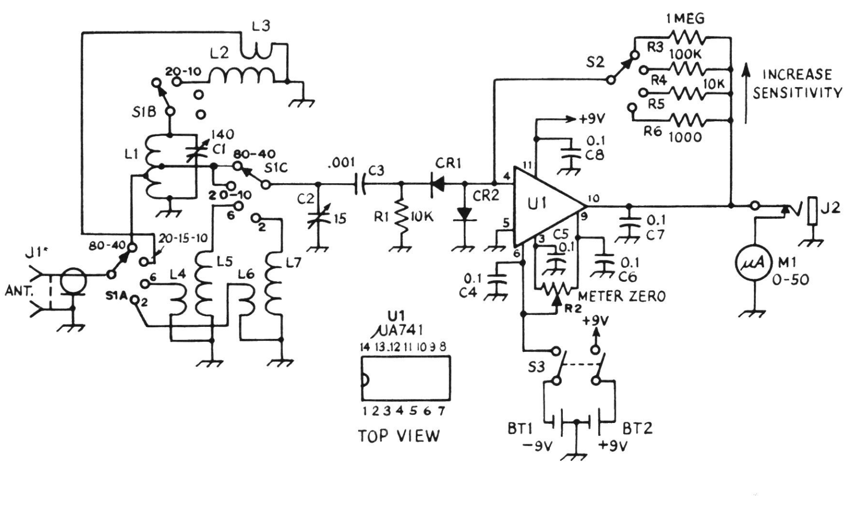


Fig. 10-27 — Circuit diagram of the linear field-strength meter. All resistors are 1/2 or 1/4 watt.

C1 — 140 pF variable.
C2 — 15 pF variable.
CR1, CR2 — 1N914 or equiv.
L1 — 34 turns No. 25 enam. wound on an Amidon*T-68-2 core, tap 4 turns from ground end.
L2 — 12 turns No. 24 enam. wound on T-68-2 core, L3 two turns No. 24 wound at ground end of L2.
L5 — 12 turns No. 26 enam. wound on T-25-12 core, L4 one turn No. 26 enam. wound at ground end of L5.
L7 — 1 turn No. 18 enam. wound on T-25-12 core, L6 one turn No. 26 enam.
M1 — 50- or 100-μA dc.
R2 — 10,000-ohm, linear taper control.
S1 — Rotary switch, 3 poles, 5 positions, 3 sections.
S2 — Rotary switch, 1 pole, 4 positions.
S3 — Dpst toggle.

AN INEXPENSIVE DIRECTIONAL COUPLER

Precision in-line metering devices that are capable of reading forward and reflected power over a wide range of frequencies are very useful in amateur vhf and uhf work, but their rather high cost puts them out of the reach of many vhf enthusiasts. This device is an inexpensive adaptation of their basic principles. It can be made for the cost of a meter, a few small parts, and bits of copper pipe and fittings that can be found in the plumbing stocks at many hardware stores.

Such an instrument is known by several names: directional coupler, in-line wattmeter, SWR indicator, and so on. This one is called a "line sampler." It can be left in the antenna line at all times, without consuming appreciable power or affecting reception. Commercially available units are also simple. It is the precision workmanship and reliable calibration over wide frequency ranges that make them costly to buy, though a joy to own.

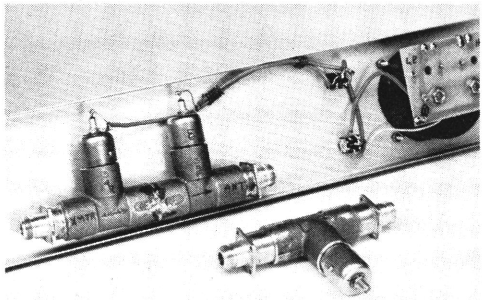


Fig. 10-28 – Two versions of the line sampler. The single unit described in detail herewith is in the foreground. Two sections in a single assembly, made by W1NTH, provide for monitoring forward and reflected power without probe reversal.

Construction

The sampler consists of a short section of hand-made coaxial line, in this instance of 50 ohms impedance, with a reversible probe coupled to it. A small pickup loop built into the probe is terminated with a resistor at one end and a diode at the other. The resistor matches the impedance of the loop, not the impedance of the line section. Energy picked up by the loop is rectified by the diode, and the resultant current is fed to a meter equipped with a calibration control.

The principal metal parts of the device are a brass plumbing T, a pipe cap, short pieces of 3/4-inch ID and 5/16-inch OD copper pipe, and two coaxial fittings. Other available tubing combinations for 50-ohm line may be usable. The ratio of outer-conductor ID to inner-conductor OD should be 2.4/1. The photographs and Figs. 10-28 and 10-29 just about tell the rest of the story.

Soldering of the large parts can be done with a 300-watt iron or a small torch. A neat job can be done if the inside of the T and the outside of the pipe are tinned before assembling. When the pieces are reheated and pushed together, a good mechanical and electrical bond will result. If a torch is used, go easy with the heat, as an over-heated and discolored fitting will not accept solder well.

The inside of the line section must be smooth and without gaps or burrs. Any protrusions into the line must be removed with a file or reamer. If a tubing cutter is used, apply minimum pressure, or large burrs will be formed and will be hard to remove.

Coaxial connectors with Teflon or other heat-resistant insulation are recommended. Type N, with split-ring retainers for the center conductors, are preferred. Pry the split-ring washers out with a knife point or small screwdriver. Don't lose them, as they'll be needed in the final assembly.

The inner conductor is prepared by making eight radial cuts in one end, using a coping saw with a fine-toothed blade, to a depth of 1/2 inch. The fingers so made are then bent together, forming a tapered end, as seen in Fig. 10-29. Solder the center pin of a coaxial fitting into this, again being careful not to overheat the work.

In preparation for soldering the body of the coax connector to the copper pipe, it is convenient to use a similar fitting clamped into a vise as a holding fixture, with the T assembly resting on top, held in place by its own weight. Use the partially prepared center conductor to insure that the coax connector is concentric with the outer conductor. After being sure that the ends of the pipe are cut exactly perpendicular to the axis, apply heat to the coax fitting, using just enough so that a smooth fillet of solder can be formed where the flange and pipe meet.

Before completing the center conductor, check its length. It should clear the inner surface of the connector by the thickness of the split ring on the center pin. File to length, if necessary, slot as with the other end, and solder the center pin in place. The fitting can now be soldered onto the pipe, to complete the 50-ohm line section.

The probe assembly is made from a 1-1/2-inch length of the copper pipe, with a pipe cap on the top to support the upper feedthrough capacitor, C2. The coupling loop is mounted by means of small Teflon standoffs on a copper disk, cut to fit inside the pipe. The disk has four small tabs around the edge for soldering inside the pipe. The diode, CR1, is connected between one end of the loop and a 500-pF feedthrough capacitor, C1, soldered into the disk. The terminating resistor, R1, is connected between the other end of the loop and ground, as directly as possible.

When the disk assembly is completed, insert it into the pipe, apply heat to the outside, and solder the tabs in place by melting solder into the assembly at the tabs. The position of the loop with respect to the end of the pipe will determine the sensitivity of a given probe. For power levels up to 200 watts the loop should extend beyond the face of the pipe about 5/32 inch. For use at higher power levels the loop should protrude only 3/32 inch. For operation with very low power levels the probe position can be determined by experiment.

The decoupling resistor, R2, and feedthrough capacitor, C2, can be connected, and the pipe cap put in place. The threaded portion of the capacitor extends through the cap. Put a solder lug over it before tightening its nut in place. Fasten the cap with two small screws that go into threaded holes in the pipe.

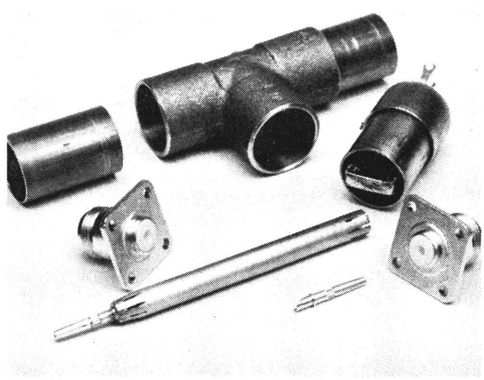


Fig. 10-29 — Major components of the line sampler. The brass T and two end sections are at the back of the picture. A completed probe assembly is at the right. The N connectors have their center pins removed. The pins are shown with one inserted in the left end of the inner conductor and the other lying in the right foreground.

Calibration

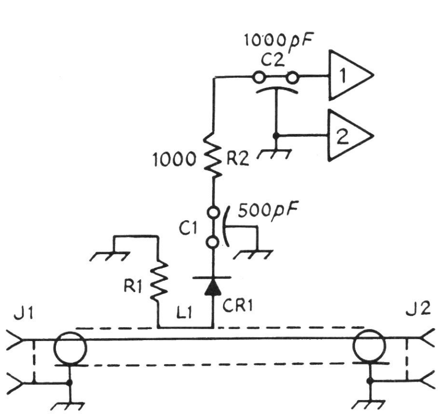
The sampler is very useful for many jobs, even if it is not accurately calibrated, though it is desirable to calibrate it against a wattmeter of known accuracy. A good 50-ohm dummy load is a must.

The first step is to adjust the inductance of the loop or the value of the terminating resistor, for lowest reflected-power reading. The loop is the easier to change. Filing it to reduce its width will increase its impedance. Increasing the cross-section of the loop will lower it, and this can be done by coating it with solder. When the reflected-power reading is reduced as far as possible, reverse the probe and calibrate for forward power, by increasing the transmitter power output in steps and making a graph of the meter readings obtained. Use the calibration control, R3, to set the maximum reading.

Variations

Rather than use one sampler for monitoring both forward and reflected power by repeatedly reversing the probe, it is better to make two assemblies by mounting two T fittings end-to-end, using one for forward and one for reflected power. The meter can be switched between the probes, or two meters can be used.

The sampler described was calibrated at 146 MHz, as it was intended for 2-meter repeater use. On higher bands the meter reading will be higher for a given power level, and it will be lower for lower-frequency bands. Calibration for two or three adjacent bands can be achieved by making the probe depth adjustable, with stops or marks to aid in resetting for a given band. And, of course, more probes can be made, with each calibrated for a given band, as is done in some of the commercially available units.



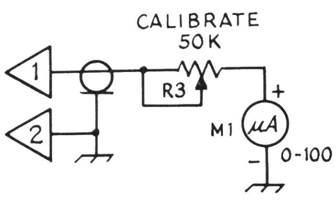


Fig. 10-30 — Circuit diagram for the line sampler.

C1 — 500-pF feedthrough capacitor, solder-in type.

C2 — 1000-pF feedthrough capacitor, threaded type.

CR1 — Germanium diode 1N34, 1N60, 1N270, 1N295, or similar.

J1, J2 — Coaxial connector, type N (UG-58 A/U).

L1 — Pickup loop, copper strap 1 inch long X 3/16 inch wide. Bend into "C" shape with flat portion 5/8-inch long.

M1 — 0-100 μA meter.

R1 — Composition resistor, 82 to 100 ohms. See text.

R3 — 50,000-ohm composition control, linear taper.

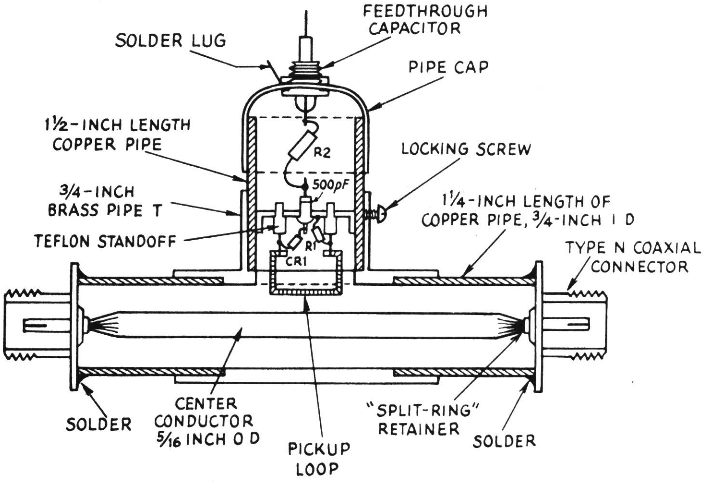


Fig. 10-31 – Cross-section view of the line sampler. The pickup loop is supported by two Teflon standoff insulators. The probe body is secured in place with one or more locking screws through holes in the brass T.

Other sizes of pipe and fittings can be used, by making use of information given in *The Radio Amateur's Handbook* and the *VHF Manual* to select conductor sizes required for the desired impedances. (Since it is occasionally possible to pick up good bargains in 72-ohm line, you might like to make up a sampler for this impedance.)

Type N fittings were used because of their constant impedance, and their ease of assembly. Most have the split-ring retainer, which is simple to use in this application. Some have a crimping method, as do apparently all BNC connectors. If a fitting must be used that cannot be taken apart, drill a hole large enough to clear a soldering iron tip in the copper-pipe outer conductor. A hole of up to 3/8-inch diameter will have very little effect on the operation of the sampler.

Using Surplus FM Equipment

THE UPSWING in amateur fm activity which started in the early 1960s was fueled by large amounts of surplus gear that was made available to hams. Changes in FCC standards which made the older rigs obsolete for commercial service, normal replacement of rigs that had been in service for many years, plus the changeover from tube rigs to solid-state transceivers combined to create a surplus market where the prices for sophisticated fm gear were only a fraction of the original cost.

SHOPPING FOR SURPLUS

Motorola and General Electric have long been preeminent in selling fm gear to commercial users, so it is not surprising that much of the surplus equipment available today was manufactured by these two firms. Because conversion information and spare parts are widely available, the cost of used GE and Motorola units are generally higher when sold used than those of other suppliers. Rigs made by RCA, Karr, Bendix, Link, and others can be very inexpensive, and thus are good buys for those technically competent to fabricate a missing part or to work without the aid of an instruction book.

The lowest prices on fm gear are usually found at amateur flea markets and auctions. *QST* Ham Ads contain many offerings of fm gear. A list of the major dealers whose primary business is selling surplus fm gear is given in Fig. 11-2. These firms have catalogs available, and they often have sales which feature reductions of the catalog prices. One advantage of purchasing equipment from a dealer is that you can get a unit tested and tuned to a desired frequency for an additional charge. Also, a dealer often has instruction manuals and schematic diagrams available for the equipment he sells.

There are no set rules that an amateur can follow when purchasing surplus gear. Often the unit that appears to be in "mint" condition will not work, while a unit covered with several year's collection of dirt will work the first time it is turned on. When rigs are sold "as is" or labeled "technicians's specials," they often have only minor problems, but in other units whole sections may be burned out or missing. The prospective purchaser is advised to be sure of what is being offered before placing his order. Accessories (cables, speaker, microphone, control head) are usually included in the price of a rig. But, some dealers charge extra for accessories – read the ad or catalog carefully.

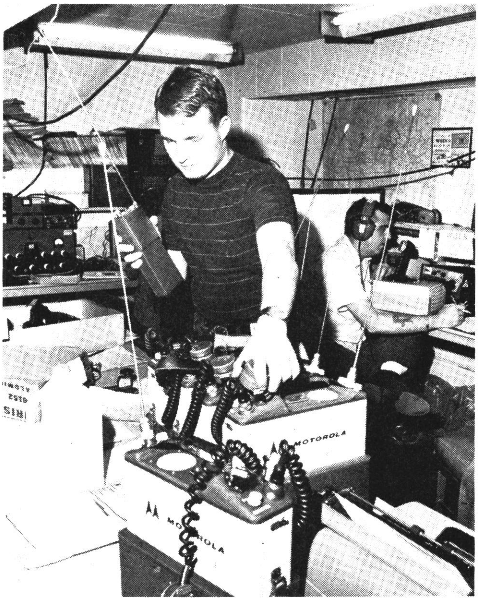


Fig. 11-1 – One advantage of the fm mode is the large amount of surplus equipment which can be converted for amateur use. AREC and civil-defense groups increasingly are using vhf fm for local communications networks because of the low cost and high reliability of surplus commercial gear. Here WA6ECK checks Motorola Handi-Talkies, which have been modified for 6-meter operation, at the San Fernando Emergency Operating Center during an earthquake emergency.

If a surplus transceiver needs repair, an instruction book can be an invaluable aid. Fig. 11-3 lists sources for manuals and schematic diagrams. If a manual isn't available from the manufacturer, often a *QST* Ham Ad will aid in locating the information needed. Most two-way radio service

Fig. 11-2 – FM SURPLUS DEALERS

Gregory Electronics Corp. 246 Route 46 Saddle Brook, NJ 07662	Mann Communications 18669 Ventura Blvd. Tarzana, CA 91356
Newsome Electronics 19675 Allen Road Trenton, MI 48183	Spectronics 1009 Garfield Ave. Oak Park, IL 60304

Fig. 11-3 – SOURCES FOR INSTRUCTION MANUALS AND DIAGRAMS

GE – General Electric Co., Marketing Communications Production, Box 4197, Lynchburg, VA 24502. (Two booklets available with schematic diagrams of the popular Pre-Progress Line rigs.)

Motorola – Motorola Communications and Electronics, Inc., 1301 E. Algonquin Road, Schaumburg, IL 60172. Two-Way Radio Engineers, 1100 Tremont Street, Boston, MA 02120, sells a booklet of schematic diagrams covering Motorola equipment up to the early Motrac models.

RCA – RCA Corporation, Customer Technical Information Service, Meadow Lands, PA 15347. Information available on RCA transceivers manufactured from 1946 on.

shops perform maintenance on many types of rigs, so they keep extensive files of instruction manuals. A check of the telephone directory will reveal the names and addresses of area service shops.

The age and condition of a surplus rig will determine how much work will be needed to put the unit into amateur service. The best procedure is to get the unit working to the manufacturer's specifications before adding whatever modifications are needed to bring performance up to current standards. Additional operating channels, an extra limiter stage, or a preamplifier may be desirable; suitable circuits are given later in this chapter. If the unit will be used in a home station, the details given later about tunable oscillators and an ac-operated power supply will be of interest. The designs and data presented in this chapter apply to specific pieces of surplus equipment, but the circuits shown are examples which can be adapted easily for use with most older commercial equipment.

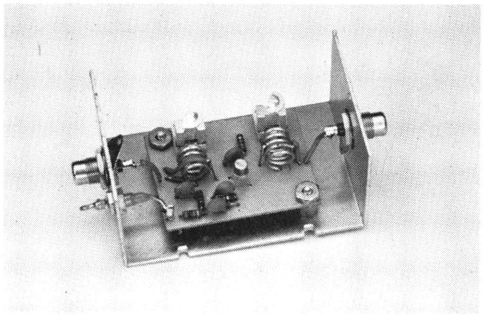


Fig. 11-4 – The 2-meter preamp may be mounted in a small Minibox or connected directly inside an fm receiver.

CRYSTALS

A few words about the selection of crystals may help the fm beginner to avoid costly mistakes. The various manufacturers of fm equipment use different oscillator circuits, thus, the capacitance loading on the crystal also varies. Often a crystal that is "on channel" in one rig can be quite far off frequency in another. The crystal manufacturers can grind a crystal for any of the commercial fm rigs – if you supply the necessary information:

1) Make, model and chassis number of the rig.
2) Operating frequency desired.
3) Frequency of the crystal.
4) Whether or not the crystal will be used in an oven.
5) Whether or not an afc-controlled oscillator will be used.

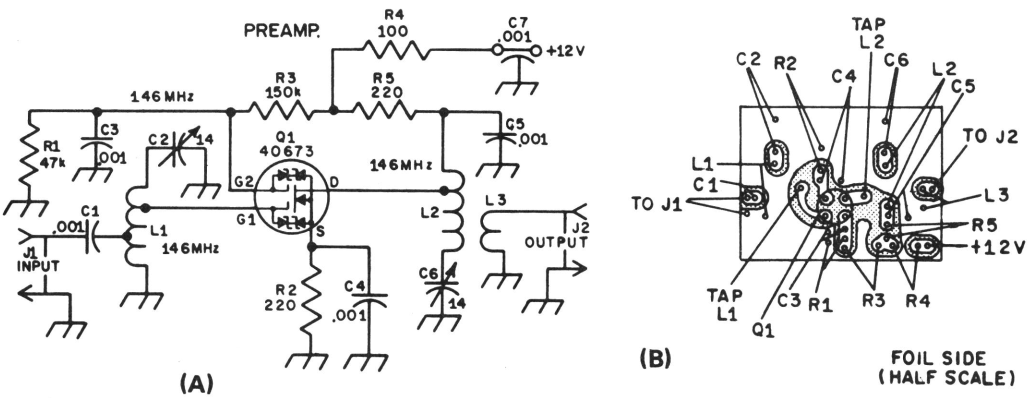


Fig. 11-5 – Circuit diagram (A) and pc-board layout (B) for the 2-meter preamplifier. Resistors are 1/4-watt composition and capacitors are disk ceramic unless otherwise noted. Components not listed below are given designators for circuit-board location purposes.

C2, C6 – Air variable (Johnson 189-506-5).
J1, J2 – Phono type, panel mount.
L1 – 5 turns, No. 16, 5/16-inch dia, 1/2 inch long. Tapped at 2 turns for the antenna connection, and 4 turns for G1.
L2 – 4 turns, No. 16, 5/16-inch dia, 3/8-inch long. Tapped at 2 turns.
L3 – 1 turn, plastic-covered hookup wire, 5/16 inch dia, placed between two turns of L2.

6) Order the crystal ground to "Commercial Standard" unless a tighter tolerance is needed.
The major crystal suppliers keep records of the crystal specifications for each make and model of fm transceiver. If you supply the correct information, they can produce a crystal that will be "on channel."

IMPROVING FM RECEIVER PERFORMANCE

Many older fm receivers, and some new models, do not have sufficient sensitivity or limiting capability. Suitable accessory units can be constructed easily to improve the performance of a rig deficient in any of these areas.

A simple preamplifier, such as shown in Fig. 11-4 for 146 MHz and in Fig. 11-6 for 440 MHz, may be added to a receiver to increase its sensitivity and to improve limiting (as the overall gain before the limiter will be increased by 10-15 dB). The 2-meter version uses a dual-gate MOSFET while the 440-MHz unit employs two JFETs in a grounded-gate circuit. Both amplifiers are adjusted by peaking all tuned circuits for maximum limiter current while receiving a weak signal.

A receiver will have poor limiting characteristics if the gain before the limiter circuit is insufficient, or if the limiter itself is of poor design. The circuit of Fig. 11-8 can be added to a receiver to replace an existing limiter stage. The new limiter uses an RCA CA3012 integrated circuit. Care must be used in the installation and layout of this high-gain IC to insure stability. The CA3012 will provide a "hard" limiting characteristic with about 100 mV of signal input.

A SELECTIVE 2-METER PREAMPLIFIER

The preamplifier used ahead of a surplus receiver as part of a repeater must be based on something more than casual design if good performance is to be realized. Special attention must be paid to selectivity, and the noise figure should be low enough to assure the kind of sensitivity desired by most repeater operators – 0.2 μV or less for 20 dB of quieting. Transient and rf-burnout protection represent the remainder of the criteria for successful use at the repeater site.

While some groups have had success with solid-state preamplifiers, others have decried the reliability of transistorized preamps, mainly because of overloading, IMD, and susceptibility to device damage from static discharges and line transients. Certainly tube-type equipment is less subject to catastrophic failure from the foregoing causes, but a properly designed solid-state preamplifier can hold its own when competing against a vacuum-tube equivalent. The unit treated here meets the design specifications of most amateur repeaters. Precautions have been taken to prevent the usual problems inherent in homemade preamps.

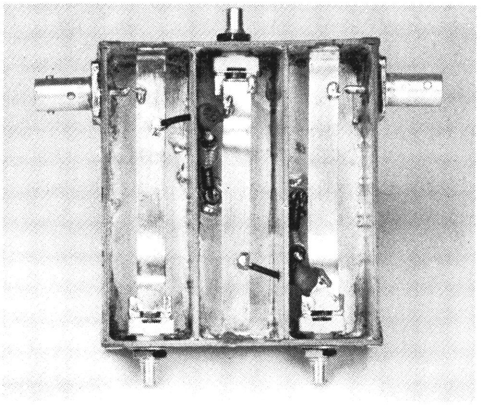


Fig. 11-6 – The 440-MHz preamplifier is constructed in a 3 × 3-1/2 × 1-inch box made of double-sided circuit board. All abutting edges are soldered to complete the enclosure. Two 3 X 15/16-inch shields separate the tuned lines.

Design

JFETs were chosen for use in the preamp over gate-protected MOSFETs because the former can sustain up to 80 volts pk-pk, gate to source, before being damaged. Protected MOSFETs are rated at 20 volts maximum. Furthermore, the employment of JFETs eliminated four resistors and two capacitors, all of which would have been required in the gate-2 biasing circuits of the MOSFETs.

In the interest of eliminating the need for those sometimes-tricky neutralization circuits, the common-gate configuration was chosen. Common-gate amplifiers provide somewhat less gain than do the common-source types – approximately 10 dB less gain per stage, but by using two stages in common-gate the gain of the preamplifier is more than adequate for most applications. The circuit of Fig. 11-9 should exhibit a gain of between 15 and 20 dB, depending upon the transconductances of the two FETs picked from the supplier's shelf.

Motorola 2N5484s (MPF106) are used at Q1 and Q2. Alternatively, 2N4416 or 2N4417s can be used if one is willing to pay a bit more money. MPF102s would probably do a good job in the circuit of Fig. 11-9. Since the 2N5484s are designed for use into the 400-MHz region, they seemed like wise choices for low-noise operation. The noise figure of this preamplifier is somewhat less than 2 dB.

To assure good selectivity, and thereby offer reasonable immunity to nearby out-of-band commercial signals, high-*Q* tuned circuits were employed. The section between Q1 and Q2 is a bandpass type, lightly coupled by means of a 2-pF silver-mica capacitor. Lighter coupling will provide greater selectivity, but with an attendant loss in gain. Aperture coupling can be used in place of the method shown. If so, the aperture size must be adjusted to establish the gain and selectivity desired by the user.

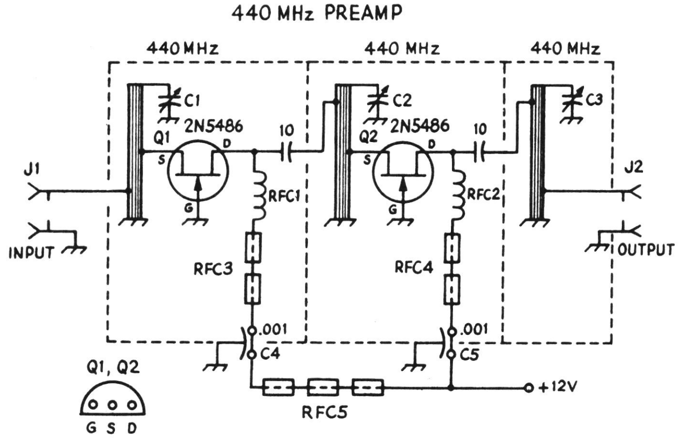


Fig. 11-7 — Schematic diagram of the uhf preamplifier. Capacitors are disk ceramic unless otherwise noted.

C1-C3, incl. — 1.4 to 9.2-pF miniature variable (Johnson 189-0563-001).
C4, C5 — Feedthrough type.
J1, J2 — BNC type, chassis mount.
L1-L3, incl. — 2-5/8 X 1/4-inch strip of brass, soldered to the enclosure on one end and to the capacitor at the other. Input and output taps (on L1 and L3) are 1/2-inch up from the ground end. Drain taps for Q1 and Q2 on L2 and L3, respectively, are made just below C2 and C3.
RFC1, RFC2 — 420-MHz choke (Miller 4584).
RFC3, RFC4 — Two ferrite beads on a short piece of No. 20 hookup wire. (Beads are available from Amidon Associates, 12033 Otsego St., N. Hollywood, CA 91607).
Q1, Q2 — Motorola JFET.

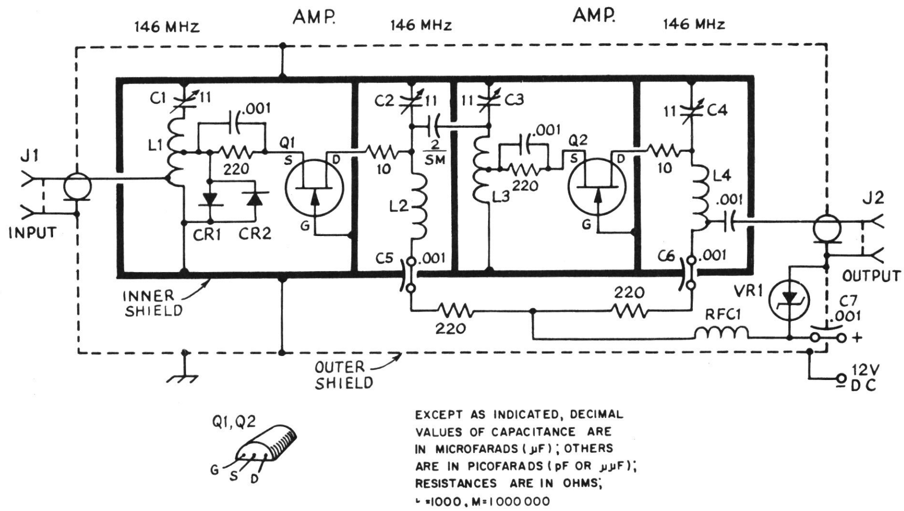


Fig. 11-9 — Circuit diagram of the preamplifier. Heavy lines indicate the pc-board shield box and dividers. The outer shield box is shown in dashed lines. Fixed-value capacitors are disk ceramic unless otherwise noted. S.M. indicates silver mica. Resistors are 1/2 watt carbon.

C1-C4, incl. — 11-pF subminiature air variable (E. F. Johnson 189-564). Piston trimmers or Johnson 160-0104-001 suitable also.
C5-C7, incl. — Feedthrough capacitor.
CR1, CR2 — High-speed silicon switching diode, 1N914 or equivalent.
J1, J2 — Coaxial connector of builder's choice. (Type BNC used in this model.)
L1, L3 — 3-1/2 turns No. 14 tinned bus wire, 1/2 inch ID X 3/4 inch long. Tap source at 1-3/4 turns from trimmer end. Tap L1 also at 1/2 turn from ground.
L2, L4 — 3-1/3 turns No. 14 tinned bus wire, 1/2 inch ID X 3/4 inch long. Tap L4 1/2 turn above C6.
Q1, Q2 — Vhf or uhf JFET (see text). Keep gate lead as short as possible, 1/8 inch or less.
RFC1 — 144-MHz rf choke, approximately 2.7 μH. (James Millen 34300-2.7 or equivalent.) Alternatively, wind 20 inches of No. 30 enam. wire on the body of a 2700-ohm, 1-watt carbon resistor. Use pigtails as anchor points for ends of winding.
VR1 — 15-volt, 1-watt Zener diode.

Source bias is used in each stage to prevent the amplifiers from saturating in the presence of strong signals. The sources are tapped down on their respective tuned circuits to prevent loading and to provide impedance matching.

As an aid to stability each stage has a 10-ohm resistor between its drain and the related tuned circuit. The photo shows the drains being tapped down on the tuned circuits – an earlier method used to achieve stability. However, the gain of the preamplifier was somewhat less when using that arrangement. Better results can be had by using the 10-ohm resistors and connecting them to the stators of C2 and C4.

Decoupling networks are used between the stages (220-ohm resistors and .001-μF bypass capacitors) to prevent interstage coupling along the 12-volt supply line. Filtering at rf is provided by using RFC1 and another .001-μF feedthrough capacitor, thus helping to prevent unwanted rf from entering the preamplifier on the dc supply line.

Rf burnout protection is offered by two 1N914 diodes connected from the source tap on L1 to ground. The diodes are located at an impedance point which is higher than that of the 50-ohm antenna tap. This means that the diodes will conduct sooner at the source tap because the rf-voltage level from static discharge or abnormally strong signals will always be greater at the tap point than at the 50-ohm terminal. No change in amplifier performance could be noted after adding the diodes.

Protection from any abrupt increase in supply voltage, brought about by ac-line transients, is afforded by the use of a 15-volt, 1-watt Zener diode (VR1) which is connected between the 12-volt supply line and chassis ground.

Construction Information

Examination of the photograph will show that two boxes are used in the construction of the preamp. The inner box is made from double-sided copper-clad pc board. It measures 4-1/2 × 1-7/8 × 1-1/4 inches. The box walls and the partitions are soldered in place by using a 100-watt soldering iron with a small-diameter tip. The metal surfaces of the pc-board sections are silver-plated, though

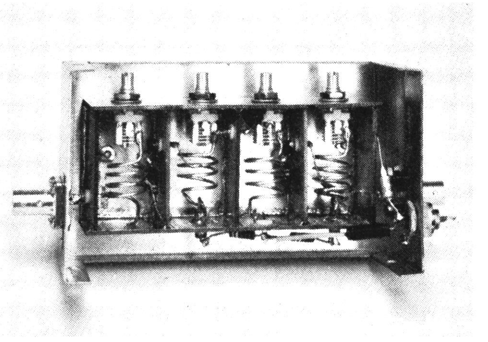


Fig. 11-10 – The inner compartment is fashioned from double-clad pc board sections (see text). The four coils are centered in their compartments. Q1 and Q2 are mounted by their leads, keeping the latter as short as possible. *Do not use pc-board sockets for mounting the JFETS.* The decoupling-circuit components are located outside the pc-board enclosure. Holes are drilled in the Minibox cover opposite each trimmer-capacitor shaft to permit adjustment when the box is closed.

the plating is not necessary as far as circuit performance is concerned. The plating does, however, retard tarnishing and make soldering somewhat easier.

The input and output rf connections, and those between the compartments, are made by means of small Teflon push-in feedthrough terminals which were obtained as surplus. The source-bias resistors and bypass capacitors are attached to Teflon standoff posts. Satisfactory substitutes for the feedthrough bushings can be fashioned from short lengths of RG-59/U coax with the vinyl jacket and shield braid removed. Epoxy cement can be used to hold the homemade bushings in place.

Once the circuit is assembled in its pc-board enclosure the subassembly can be installed in a Minibox which measures 5-1/4 × 3 × 2-1/8 inches.

Adjustment and Use

Connect the preamplifier ahead of the fm receiver with which it is to be used. Apply 12 volts dc to the preamp, then supply a low-level signal to Q1 via J1. Peak each tuned circuit for maximum response by observing the 1st-limiter-current reading of the fm receiver. The unit should then be ready to use.

This preamplifier was used ahead of a Motorola 5-pipe Sensicon receiver during all tests. The "barefoot" fm receiver provided 20 dB of quieting with a 0.4-μV input signal. With the preamp installed it was possible to obtain 20 dB of quieting with somewhat less than 0.1 μV of input signal.

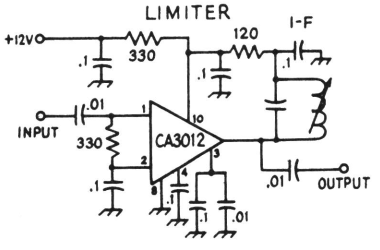


Fig. 11-8 – Diagram of a limiter which may be added between the last i-f stage and the detector of a receiver.

ADDING ADDITIONAL CHANNELS

Many fm units currently available from surplus sources are single-channel models. Others provide 2-channel operation by switching between two first-oscillator crystals with a spdt relay. In some, a dpdt relay is employed, so that the unused crystal

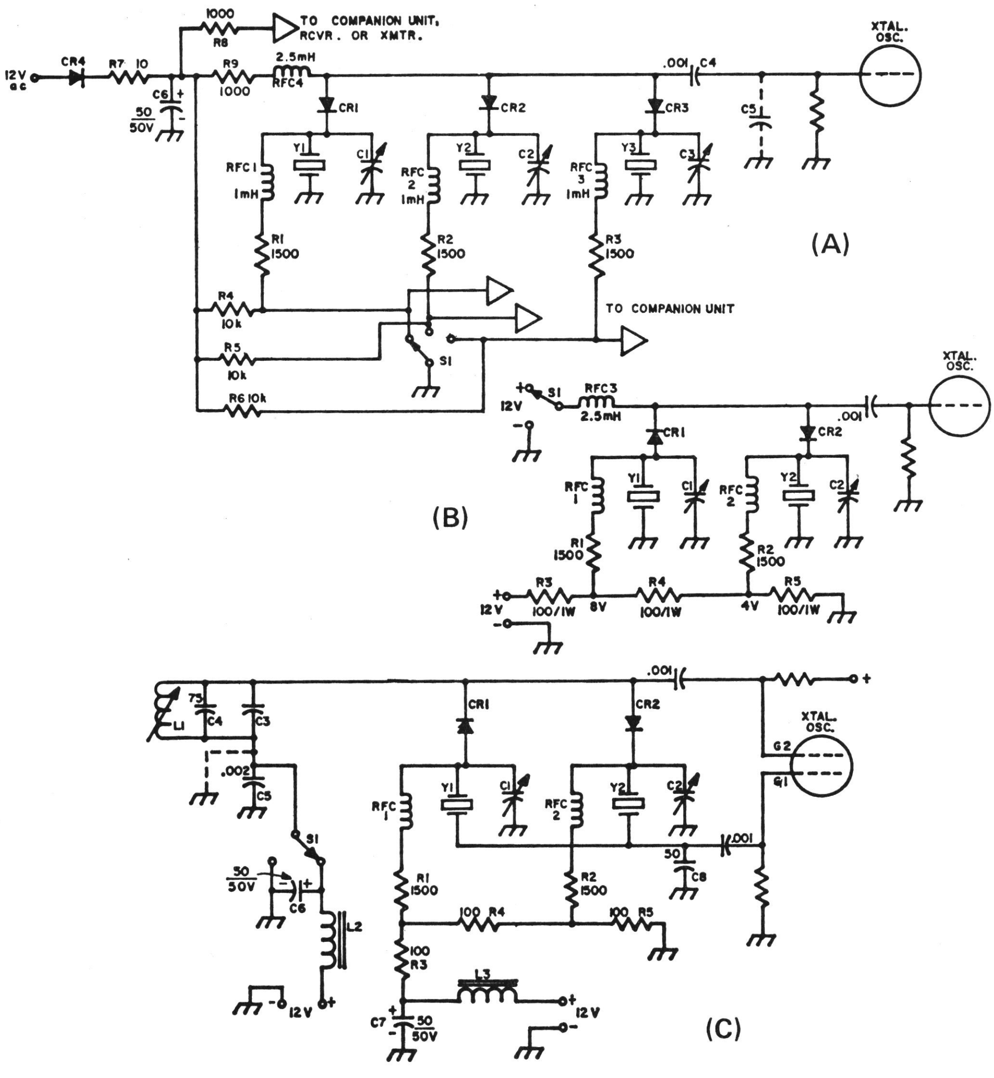


Fig. 11-11 — (A) Diode-switching of crystals having paralleled "netting" capacitors, in circuits where one side of the crystal is grounded. Three positions are shown, but up to four have been used. The dc source and the switching circuit can be used for the crystals in the companion unit of a transceiver. Power is shown here taken from the 12-volt ac line in one of the units, though an external dc source can be used. (B) Switching circuit for oscillators in which the crystal is above ground on both sides. Filtering in the 12-volt leads may be dispensed with if the voltage source is free of hum or other objectionable modulation. (C) Crystal switching of two positions with a single control wire. Values of the rf chokes RFC1 and RFC2 can be set up by experiment, though 2.5 mH is satisfactory.

and its netting capacitor are grounded. Most often, separate oscillators are used for each channel, selection being made by grounding the cathode of the appropriate oscillator stage.

A convenient solution to the crystal-switching problem lies in the use of diodes, changing the bias on the diode in the desired channel so that it goes from an open-circuit to a conducting condition. This is particularly convenient for remote control of the channel selection in a mobile installation, as up to four crystals can be used, and the system works quietly and with very low current drain. It is most readily applied to equipment in which one side of the crystal is grounded.

A circuit for crystal switching, for use in any equipment where one side of the crystal is grounded, is given in Fig. 11-11A. An example is the Marconi DT45. Three crystals are shown, but up to four have been used. The dc is shown here being obtained from the 12-volt ac line in the receiver, with CR4, R7, and C6 comprising the rectifier-filter circuit. The isolation capacitor, C4, should be added if one is not already in the circuit. The grid-to-ground capacitor, C5, usually about 10 pF, should be removed if there is a capacitor of this type in the circuit.

The 12 to 14 volts dc from the supply is fed through R9 and RFC4 to the anodes of CR1, CR2, and CR3. One diode, in this instance CR1, will conduct, its circuit to ground being completed through S1, R1, and RFC1. Its current, approximately 5 mA, and the resultant voltage drop across R9, brings the potential on the diode cathodes to 8 to 9 volts positive. The full supply voltage is used to reverse-bias the diodes not selected. (There will be no voltage drop across R5-R2 and R6-R3, as the only current flow in these essentially open circuits is the minute leakage current through CR2 and CR3.) The diodes being reverse-biased, their junction capacitances are quite low. The switch does two things: it grounds R4, removing the supply voltage from the cathode of CR1, and it completes the forward-bias circuit from R9 through RFC4, CR1, RFC1, and R1 to ground.

The same power source and switching may be used for both transmitter and receiver if it is desired to switch both simultaneously. Only separate 1000-ohm isolating resistors, R8 and R9 in Fig. 11-11A, are required.

The arrangements discussed thus far require one control wire between the operating position and the equipment for each channel to be switched. A two-channel system using but one control wire is shown in Fig. 11-11B. It requires that 12 volts dc be available at the control position, as well as in the equipment itself. A voltage divider, R3-R4-R5 is tapped at 4 and 8 volts. The remote control switch S1 connects the switching matrix to either +12 volts or ground. In the position shown, the dc voltage is applied through RFC3 to the diodes. Note that it is applied to the cathode of CR1 and the anode of CR2. The anode of CR1 has 8 volts on it, from the voltage divider, so it is reverse-biased. The cathode of CR2 has 4 volts on it, so it is forward-biased, connecting crystal Y2 into the circuit. The situation reverses when S1 is in the other position, CR1 being forward-biased and CR2 reverse-biased.

The rf chokes, RFC1 and RFC2, affect the operation. It is easiest to get working if 2.5-mH chokes are used, but smaller ones, or TV peaking coils, may work. Oscillator output level can be checked by measuring bias developed at the first multiplier grid (or grid current), and chokes selected for best results.

This modification is easily used with Motorola or Marconi transmitters, but may be more difficult with GE Progress-Line transmitters and receivers. The GE units have their crystals working into a lower capacitance (10 pF) than the other two, and the modification introduces some stray capacitance, which tends to lower the frequency of oscillation. Motorola crystals, for 24-times frequency multiplication, may be used in the Progress-Line transmitters, to get around this problem. It may also be necessary to increase the value of the screen-to-cathode capacitor in these units.

Diode switching can be used in circuits where both sides of the crystal are above ground, but providing for individual frequency adjustment may be difficult. A modification for the Motorola 5V transmitter is shown in Fig. 11-11C. The tuned circuit L1-C4 is as in the original, with C3 added to tune down into the 2-meter band. The extra

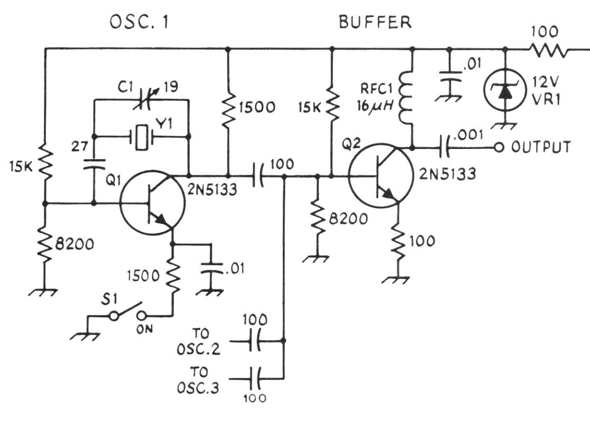


Fig. 11-12 — Circuit of the adapter which provides additional channels for an fm receiver. The oscillator circuit, Q1, is duplicated for each channel. Resistors are 1/2-watt composition and capacitors are disk ceramic, except for C1. A 7-channel wired-and-tested adapter board is available from Ham Circuits, 122 Greendale Cr., Kitchener, Ontario, Canada. Price is $16.

C1 — Air or mica-insulated trimmer.
RFC1 — Miniature rf choke.
S1 — Single-pole, multiposition switch, one position needed for each oscillator.
VR1 — Zener, 12 V, 1W (required only if supply voltage changes or is above 14 V).
Y1 — Crystal made to the specifications for GE's Progress Line transceivers.

capacitance required is 30 to 40 pF. The netting capacitors C1 and C2 are added for individual crystal-frequency adjustment. The chokes and electrolytic capacitors, L2-C6 and L3-C7 are to be used only if necessary to remove hum or other modulation from the dc leads. Otherwise, the circuit is similar to that of Fig. 11-11B.

There is a practical limit to the number of crystals that can be switched using diodes, because each diode, even when biased off, adds capacitance to the circuit. With six or more crystals, total capacitance becomes high enough to cause trouble. For 6 to 20 channels, a practical approach is to use a separate oscillator stage for each crystal. All switching is done at dc potential so the length of the leads from the oscillators to the switch is not an important consideration. Such a circuit, developed by Ham Circuits, is shown in Fig. 11-12. The oscillator portion is duplicated as many times as needed. All oscillators are capacitively coupled to an output buffer, Q2. The circuit shown is suitable for use with transmitters or receivers in the GE Progress-Line series and Motorola's FMTR gear. The oscillator has been designed to use crystals ground to Progress-Line specifications.

USING FM SURPLUS IN THE HOME STATION

An fm station for home use can be constructed easily and inexpensively from surplus transmitter and receiver strips. Usually, the individual strips cost less than a complete unit because they have little resale value to commercial users. Two-meter transmitter and receiver strips which have been removed from mobile rigs are now priced at about $30 each, while the 6-meter and 450-MHz models are $8 to $12. To make a home station (often called a base station by fm-ers) requires an ac-operated power supply, a control relay, and a few panel controls.

AN INEXPENSIVE VHF FM RECEIVER

For whatever amateur fm frequency you may have in mind, a 10-meter commercial fm receiver is a "best buy." A review of the advertisements and flyers from fm dealers in used equipment will show that 30- to 40-MHz crystal-controlled receiver strips are priced far below those models that are designed for 50- or 146-MHz operation. The reason for the lower cost is twofold: much more 30- to 40-MHz equipment is available, and there is less demand for the older low-band gear. A receiver strip that can be converted to 10-meter operation should cost $5 to $20, depending on condition, age, and model.

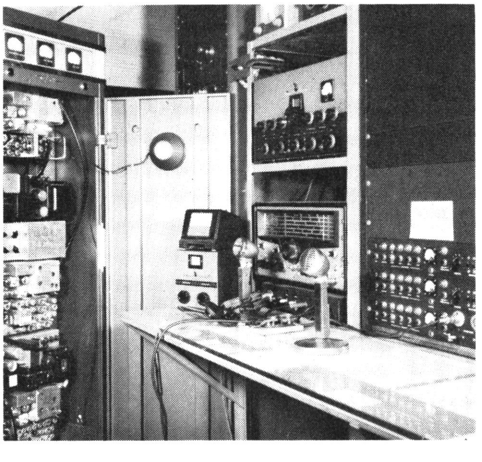


Fig. 11-13 – The rack on the left in this picture of the main operating position at W9BGX contains three complete transmitters and receivers. At the top is a 60-watt-output unit, and the two 30-watt units below it have been modified for 4-frequency operation. The pushbutton control panel at the far right provides for power and frequency control to all units, as well as switching various microphones.

For monitor service, a wide-band (36-kHz-wide i-f) receiver may be preferable to a narrow-band (13-kHz bandwidth) model, as amateurs currently use both wide and narrow fm deviation. A wide-band receiver can copy signals of either deviation while a narrow-band receiver is suited only for narrow-band transmissions. The 30- to 40-MHz receiver, once set on 29.6 MHz can be used to monitor that channel, or, using a converter, to receive either 6- or 2-meter fm signals.

The scheme to use a 10-meter receiver for vhf fm reception is shown in Fig. 11-15. Any of the popular converter designs may be adopted – any of the converters described in this book would be an excellent choice. Instead of using the specified conversion-oscillator crystal, however, one is chosen that will heterodyne the desired channel – 149.94 MHz for example, down to 29.6 MHz. Using a 28-MHz-i-f converter, a 58.57-MHz crystal will be required.

A trial conversion was made on a somewhat dilapidated GE 4ER7A2 receiver. With a receiver in hand, the next job was to find out what crystal would be required for reception on 29.6 MHz. To obtain details on receivers made for the land mobile service, one can purchase an instruction book (see Fig. 11-3) or can consult with a local amateur who works for a "two-way" radio service company (such firms usually keep files on all popular models).

Crystals

The GE receiver required a 23.6-MHz "rock." For a 10-meter receiver, where the crystal frequency is not multiplied, and no oven is used, you can order a general-purpose crystal and save a few dollars – if you're a gambler. One of International Crystal's inexpensive EX crystals was tried with the

4ER7A2, and it "hit" frequency. Anyone taking this approach does so at his own risk, though.

Alignment

With crystal in hand, the next step is to get the receiver going. Though fm receiver alignment can be a complicated procedure, only a few simple adjustments are required to set up most fm receivers. Test jacks are found on most receivers, and these points can be used to check operation of the various stages. The oscillator should be adjusted for a point just below maximum output. Then the discriminator must be checked for a zero-voltage output with no signal input to the receiver. Then, injecting a signal from a crystal calibrator, the trimmer across the crystal in the hf oscillator should be adjusted so that the calibrator harmonic on 29.6 MHz also produces a zero voltage reading at the discriminator output. Metering the grid voltage developed at the second limiter, any rf-stage adjustments should be peaked for maximum voltage at the limiter.

If a variable-frequency signal generator is available, it can be used to further check the discriminator. Again metering the discriminator output, check to see that a cw signal 15 kHz on either side of 29.6 MHz produces the same absolute voltage reading. (Note that the voltages read will have different polarities.) If one side or the other is off a bit, adjusting the input trimmer on the discriminator transformer will usually correct the situation.

As can be seen from alignment procedure outlined above, voltages measured at the limiter and discriminator stages tell quite a bit about how a receiver is working. Constant metering of these stages will make the receiver more useful in giving reports to other stations. The first meter, Fig. 11-16, indicates the relative strength of incoming signals. One peculiarity of the fm mode is that, once a signal produces full quieting of the receiver noise, further increases in signal strength will not be detectable by ear. This limiter grid-current meter serves as an S-meter, allowing an operator to observe changes in strength of incoming signals.

A second meter, connected to the discriminator, indicates if a station being received is "on channel." Because of the temperature changes and vibration encountered in mobile operation, and because of the crystal problems mentioned earlier, many stations can get off frequency. (On loud signals, off-frequency operation is also difficult to detect by ear.) Once the receiver is properly aligned with a crystal calibrator, the plus-or-minus voltage indication on the discriminator meter will indicate to which side, and relatively how far off, a particular station may be. Of course to remain accurate, the receiver must be checked against a frequency standard on a regular basis.

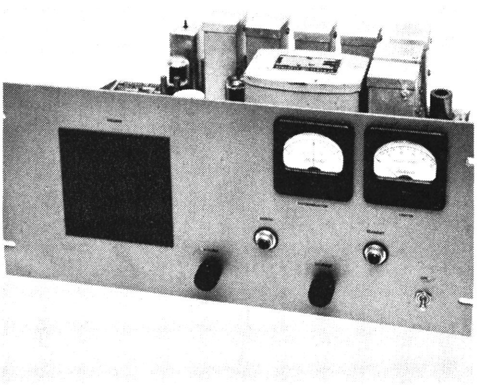


Fig. 11-14 — Front view of the modified Pre-Progress GE receiver. The volume and squelch controls have been brought out to the front panel. The panel has been refinished, and a new speaker grill, cut from perforated aluminum stock, has been added.

CONVERTING GE MTS "PROGS"

General Electric Progress-Line transceivers have long been popular in commercial and amateur services. The excellent reputation that the "Progs" enjoy has kept the price of used units high, usually between 100 and 300 dollars. Recently, telephone companies have been releasing quantities of 5-channel, narrow-band MTS (Mobile-telephone service) Progress-Line rigs, which have a number of features that make this unit an excellent choice for conversion to amateur service.

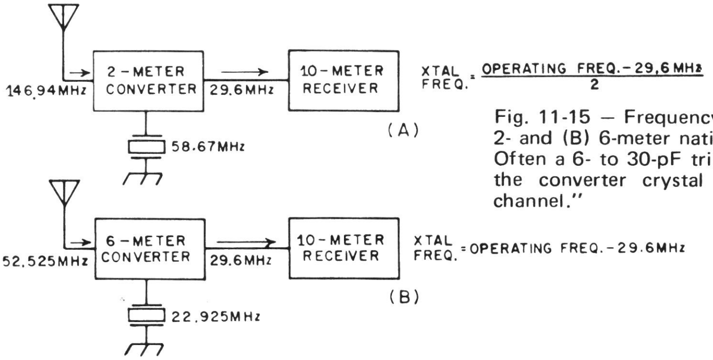


Fig. 11-15 — Frequency scheme to receive the (A) 2- and (B) 6-meter national fm calling frequencies. Often a 6- to 30-pF trimmer must be added across the converter crystal to "pull" it exactly "on channel."

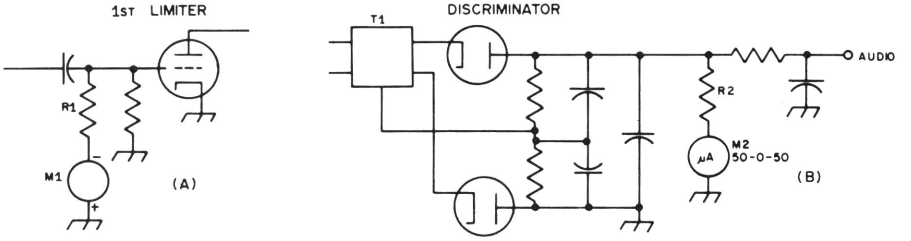


Fig. 11-16 – Connections to meter (A) limiter grid voltage and (B) discriminator output voltage. M1 may be a 0-50, 0-200 or 0-500 microammeter or 0-1 milliammeter, with R1 chosen to provide a half-scale reading with a signal input of 50 microvolts. M2 is a zero-center (50-0-50-μA) meter with an appropriate multiplier resistor (usually 0.22 to 0.47 megohms). T1 is the discriminator transformer.

Telephone companies should not be overlooked as a source of well-maintained vhf gear. The changeover to 11-channel direct-dial mobile telephone service has rendered the 4- and 5-channel MTS transceivers obsolete. Many of the phone companies use Western Electric surplus disposal channels, some will sell direct to amateurs at bargain-basement prices ($5 to $50), while others take the sledgehammer to used gear and send the remains to the junk yard. Most of the Bell companies are somewhat public-spirited, so AREC or other emergency groups might find a source of low-cost gear as close as the local telephone office.

The MTS Progress-Line unit consists of 4 subassemblies: a 30-watt-output transmitter, a 2-channel receiver, a 4-frequency adapter, and a transistor power supply. The sensitivity of the receiver is typically 0.5 to 0.7 μV for 20 dB of quieting. As the GE units were used for full duplex operation (transmitting and receiving at the same time through a duplexer), the transmitter and receiver decks have the shielding and filtering necessary for repeater use, but the rig requires a number of simple modifications for push-to-talk (simplex) amateur service. These changes consist of the addition of two capacitors to the receiver front end, a change in the output link in the transmitter, addition of a preamplifier and antenna relay, modification of the "busy" circuit to function as a squelch, and a wiring change in the power supply.

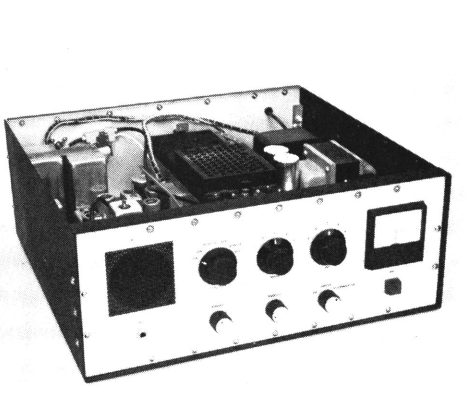


Fig. 11-17 – GE Progress Line decks are used in this station. A 50-0-50-μA meter (Simpson 2123-27507) is employed to monitor various stages in the transmitter and receiver. Sampling is done at the existing test jacks on the GE decks.

Receiver

The rf input transformer on the receiver does not have sufficient range to tune the 2-meter band without modification. This transformer, T301, should be removed. Taking out the oven on one side of T301 and the tube on the other will make the job easier. A right-angle screwdriver with a small blade will help to loosen the mounting bolts. A 2-pF silver-mica capacitor should be added across the input tuned circuit (at the top of the can), and a 5-pF silver mica unit must be soldered across the transformer secondary. Then, the transformer can be reinstalled. With a 2-meter crystal in the oven set both air-variable capacitors in T301 for maximum 1st limiter current with a low-level signal input on the desired channel.

While the sensitivity of the "Prog" receiver is good, the addition of a solid-state preamplifier can produce a worthwhile increase in the signal-to-noise ratio of weak signals. The circuit shown in Fig. 11-5 was constructed and added to the MTS transceiver. The preamplifier/receiver combination will give 20-dB quieting with 0.2 μV of input signal.

The MTS receiver contains a carrier-operated relay (COR) which is used to illuminate a BUSY lamp in the control head when a signal is received. Because tone-coded calling was used by the phone companies, no squelch was included in the MTS units. The COR circuit can be used as a squelch with a simple modification. The existing connections to the relay contacts are removed. A normally-closed set of contacts is used to short out a low-level-audio lead with a capacitor when the relay is not activated (Fig. 11-18A). The BUSY lamp at the head is removed and replaced with a 2500-ohm miniature control, as shown in Fig. 11-18B, to provide remote control of the squelch sensitivity. The lead that formerly fed voltage to the BUSY lamp is used to connect the new control to the COR circuit. As one side of the COR sensitivity control is grounded, only one lead is needed from the control head to the rig.

Audio from the MTS receiver powered a 150-ohm receiver element in a standard Bell handset.

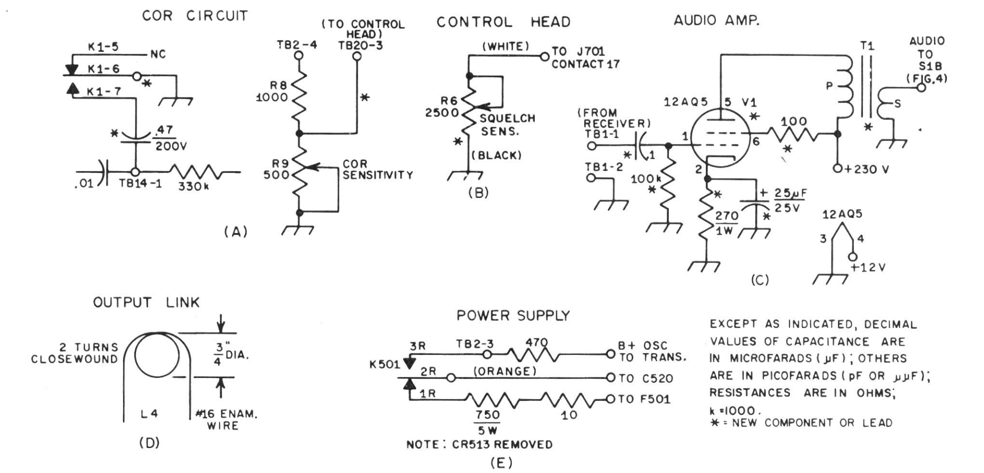


Fig. 11-18 – Modifications and additions to the GE MTS transceiver. Component numbers, except those listed below, are designators used by the manufacturer. An MTS manual will be necessary when accomplishing the changes described in this article – local GE service companies will usually have this manual in their files. Resistors are 1/2-watt composition and capacitors are disk ceramic or mylar, unless otherwise noted. (A) Changes to the COR circuit which is located on the receiver deck and (B) to the remote-control head. R6 is a miniature linear-taper composition control (Mallory type MLC). (C) The new audio stage uses a small output transformer, T1, which has a 5000-ohm primary and 3.2-ohm secondary (Stancor A3309). (D) The existing output link is removed from the transmitter final and replaced with 2 turns of No. 16 enam. wire, 3/4-inch dia with 3/4-inch pigtail leads. (E) Simplex operation of the receiver is accomplished by removing CR513 and connecting the orange wire from C520 to the 2R contact of relay K501.

For loudspeaker use, additional amplification is required. The circuit shown in Fig. 11-18B will provide sufficient output to drive a loudspeaker. The 12AQ5 amplifier stage is constructed on an etched-circuit board and is mounted on the open space at the front end of the 4-frequency deck.

The receiver is left in operation during duplex service. If a speaker is employed, it is necessary to silence the receiver when transmitting. A wiring change on K501 is needed. Various models of the power supply have slightly different connections to the control relay. The modification shown in Fig. 11-18E will allow simplex operation with whatever model you have.

Fixed-Station Use

Subassemblies from the Progress-Line rigs are available as surplus (See Fig. 11-2). These units can be assembled to provide a home station or repeater. A transmitter, receiver, and 4-frequency deck were assembled to be used as a fixed station, portable repeater, or remote-control transceiver. The entire unit is housed in a homemade cabinet. For extra versatility, the transmitter channel-

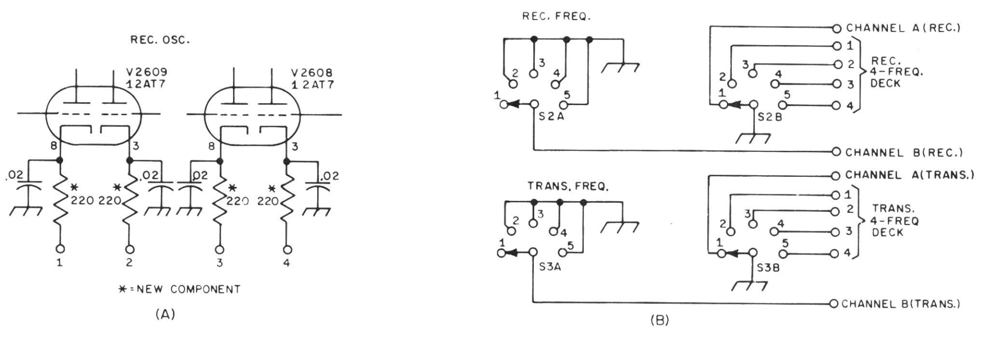


Fig. 11-19 – (A) Modifications to the 4-frequency adapter to permit independent selection of transmit and receive frequencies. The existing leads to the cathodes of V2609 and V2608 are cut and taped. The bypass capacitors at the cathode terminals are retained. A decoupling resistor is added to the cathode lead of each receiver oscillator. (B) Switch wiring to accomplish independent frequency selection. S2 and S3 are 2-pole, 5-position, single-wafer phenolic rotary switches (Centralab PA-1003).

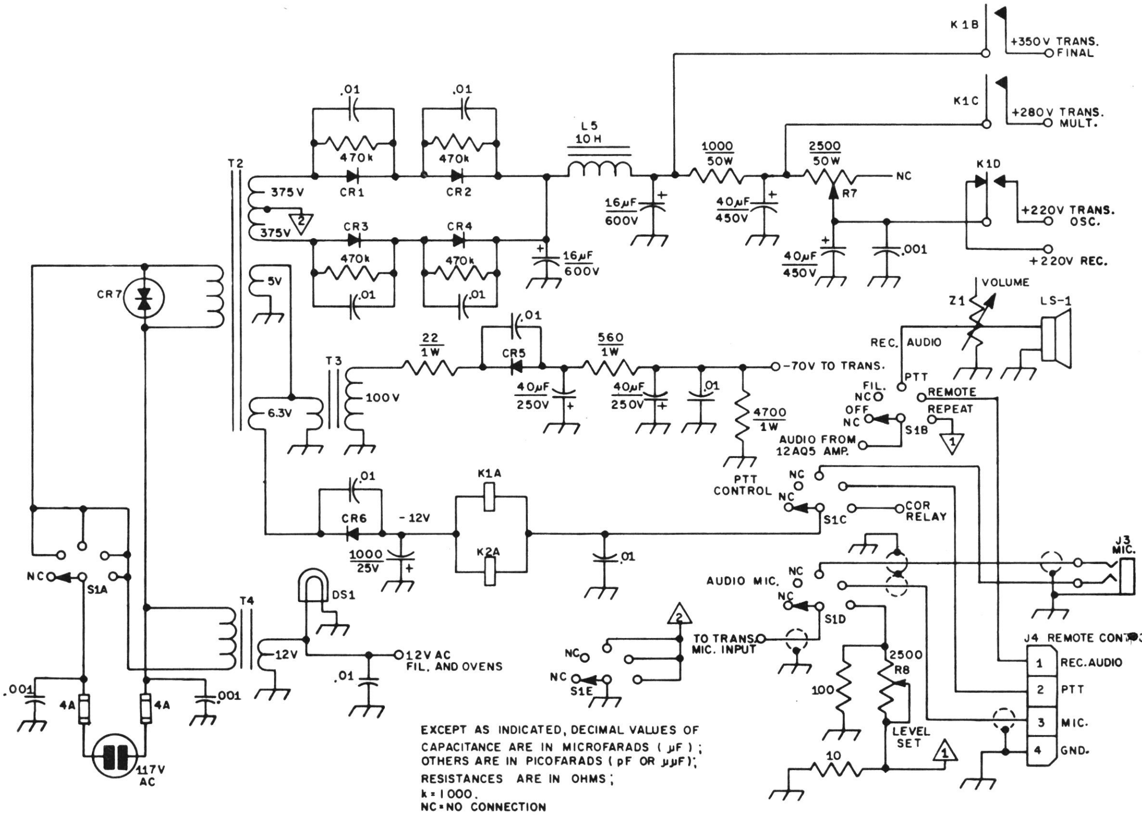


Fig. 11-20 — Homemade power supply for the GE transceiver, plus the audio and control switching. Unless otherwise noted, resistors are 1/2-watt composition and capacitors are disk ceramic, except those with polarity marked, which are electrolytic.

CR1-CR5, incl. — Silicon rectifier, 1000 PRV, 1A.
CR6 — Silicon rectifier, 200 PRV, 1.5 A.
CR7 — Thyrector transient suppressor (GE 6RS20SP4B4).
DS-1 — 12-volt lamp.
J3 — Microphone jack, 3 circuit, nonshorting.
J4 — 4-circuit jack, panel mount.
K1 — 3-pole, double-throw relay, 12-volt coil, 2-A contacts (Potter & Brumfield KA14AY).
K2 — Antenna relay.
L5 — Power choke, 10 H, 200 mA (Allied 6X37VG).
R7 — Wire-wound adjustable-tap, power resistor.
R8 — Linear-taper composition control.
S1 — 6-pole (5 used), 5-position, 3-wafer phenolic rotary switch (Centralab PA-1020).
T2 — TV power transformer (Allied 6K91VG suitable substitute).
T3 — Filament transformer, 6.3-V, 0.6-A secondary (Allied 6K32HF).
T4 — Control transformer, 12-volt, 8-A secondary (Allied 6K80VBR).
Z1 — L pad (Calectro S2-175).

selection function was separated from that of the receiver. As shown in Fig. 11-19, the A and B channel lines from the transmitter and receiver are brought out to front-panel switches. The 4-frequency deck is modified by adding separate selector lines for the receiver oscillators. Also, a panel switch was included to select local, remote, or repeater operation; the connections required are shown in Fig. 11-20. Antenna connections are changed manually before the rig is used as a repeater.

A heavy-duty homemade power supply provides the voltages required by the GE decks. The same circuit can be employed to power other retired mobile rigs. It has been tried with a Motorola 80D and a Motorola T44AAV, as well as the MTS transceiver. The large power transformer, T1, was garnered from an old TV set. T2 powers the bias circuit, while T3 supplies voltage to the tube filaments and oven heaters. R1 sets the receiver B plus at 220 V, and R2 adjusts the level of audio fed from the receiver to the transmitter when the REPEAT mode is selected.

THE RCA CARFONE

With due credit to the equipment designers, the RCA Carfone base station is not the prettiest piece of fm gear in amateur service. Additionally, some of the convenience features that base stations should have are not present in the unconverted unit. Some modifications were added which would provide better service from the transceiver, plus spruce up the outward appearance. The resultant product is described below.

Some Circuit Changes

The Carfone shown here is the 10-watt species which was packaged as a base station. Similar units are available as surplus which provide greater power output, but the circuit modifications discussed here will be pretty much the same for the various models.

In the transmitter setup (Fig. 11-23), the tuned circuit in the plate of the second doubler (6CL6, designated 2V/X4) does not tune down to 146 MHz without adding some fixed-value capacitance. Proper tuning resulted after adding a 3-pF silver mica in parallel with 2L7, the slug-tuned plate coil. This inductor, in combination with the grid coil of the following stage (2V/X5, a 5763) forms a bandpass coupler. The grid coil, 2L8, required the addition of a 5-pF silver mica from its high-*Z* end to ground.

Tuned circuit 2L10, the plate inductor for the 5763 third doubler, requires a 5-pF silver mica from its high-impedance side to ground. No other changes are required in this part of the circuit.

The output link from the PA stage, 2L13, needs additional inductance in order to tune the 2-meter band. Since there was insufficient room for a larger link, a new inductor of the same size was made from No. 10 tinned copper wire. However, in one leg of the new link a 2-turn coil was included to increase the inductance. The two turns are a part of the U-shaped link, and are wound near the end of the link nearest chassis ground. The diameter of the turns is 3/16 inch, ID.

In the model treated here only one crystal channel was wired in. A duplicate of the existing oscillator was wired into the blank space on the chassis, and a double-pole two-position toggle switch was mounted on the panel to allow switching the channels. The cathode circuit of each oscillator is routed to the panel switch so that the desired oscillator can be activated by grounding its cathode.

A microphone connector was wired in parallel with the microphone terminal strip on the back of the chassis. The new microphone jack is mounted on the front panel of the converted unit.

Maximum rf power output from the transmitter was 4 watts prior to modification of the circuit. After the changes were made an output of 13 watts resulted. The operating frequency was 146.34 MHz.

Modifying the Receiver

As was done with the transmitter, an additional oscillator was built into the blank space on the receiver chassis. Channel selection is carried out in the same manner as with the transmitter, and by means of the extra set of contacts on the same switch.

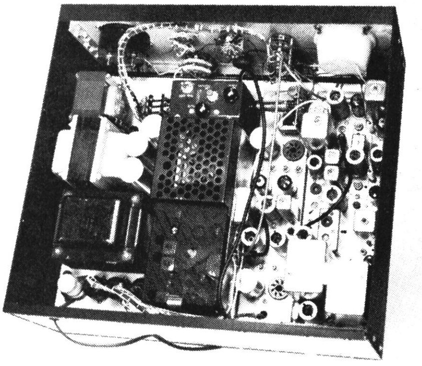


Fig. 11-21 — Decks inside the rig (from l to r) are the homemade power supply, the transmitter, the 4-frequency adapter, and the receiver. The 12AQ5 audio stage is located at the top end of the 4-frequency deck. A baffle is employed around the monitor speaker (upper right) to improve its frequency response.

A case-history problem in the receiver was solved by adding a 10-μF electrolytic capacitor (50-volt rating) from pin 8 of the squelch tube (12AX7, 1V/X13) to ground. This circuit addition cured an annoying ac hum heard in the audio output of the receiver.

An improvement in the squelch range was effected by changing resistor IR50 (connected to pin 8 of the squelch tube) from a 270,000-ohm unit to one whose value is 680,000 ohms.

The remainder of the changes in the receiver entail moving the squelch and af gain controls to the new front panel. Also, a panel control was added to switch a zero-center 50-μA meter be-

Fig. 11-22 — The RCA Carfone fm base station is shown here with its new face. A 10-1/2 X 19-inch aluminum rack panel is used to contain the controls, meter, and speaker. All of the important operating functions are controlled at the front panel. The microphone jack is located at the lower center of the panel. A two-channel frequency selector switch is mounted at the lower right, near the af gain and squelch controls. The meter switch, on-off switch, and pilot lamp are seen at the far left.

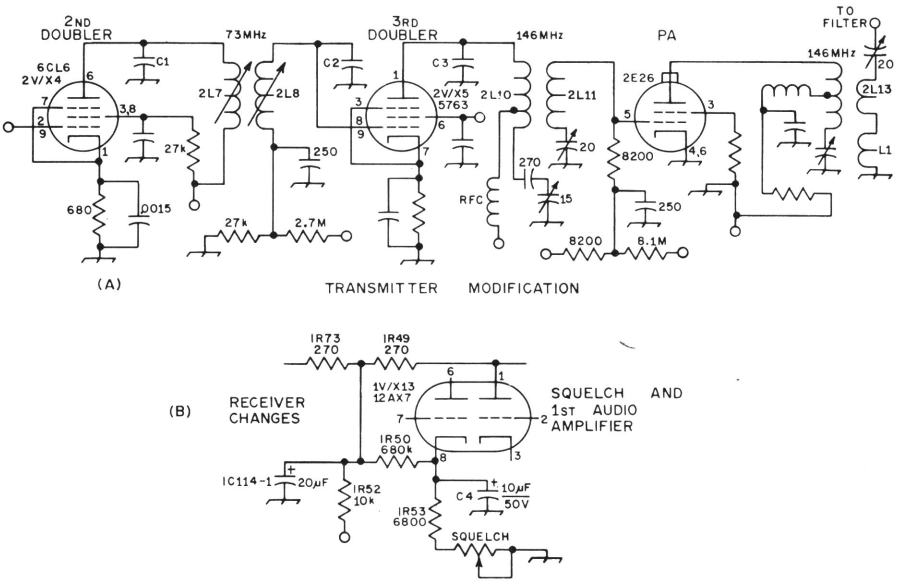


Fig. 11-23 — Changes to the transmitter circuit are shown at A. C1, C2, and C3 are, respectively, 3 pF, 5 pF, and 5 pF. Coil 2L13 is remade (see text) to include additional inductance L1. In the circuit at B the squelch portion of the receiver is modified to include C4, which is a 10-μF electrolytic. Resistor IR50 is changed from a value of 270,000 ohms to 680,000 ohms as shown.

tween terminal 2 of jack IJ2 (first-limiter current) and pin 5 of the same jack (discriminator). A surplus Motorola meter was used in this modification, but any zero-center 50-μA meter will work satisfactorily.

The original speaker was mounted on the new front panel, and is protected from damage by an aluminum grille made from perforated sheet.

Closing Comments

Some dealers sell used Carfones at reasonable prices. Keep a sharp eye out for bargains. The 10-watt units are ideal for use as exciters for high-power amplifiers, but serve nicely as 10-watt base stations when used independently. It is suggested that a thorough check be made of the tubes to assure that they are in good condition. Several "softies" were found in the model described here.

The receiver required very little tweaking to acquire good performance. The final sensitivity was 0.3 μV for 20 dB of quieting . . . not bad for a piece of well-used surplus!

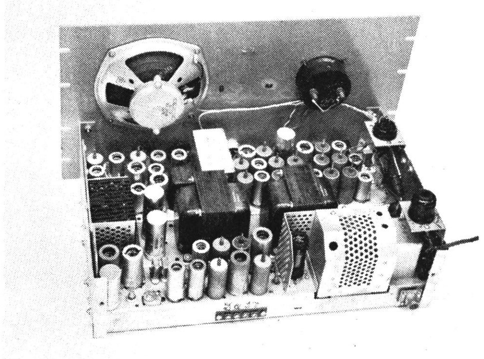


Fig. 11-24 — The original three-chassis assembly is attached to the new panel by means of the original chassis brackets. A metal shield plate is used to enclose the bottom of the chassis. The terminal strip on the rear apron of the transmitter was used originally for the mike connections.

A TUNABLE FM RECEIVER

There are many advantages in having a tunable fm receiver for fixed-station use. Perhaps the greatest benefit is the flexibility of operation afforded by not being restricted to a group of crystal-controlled channels. A secondary reward is that of not having to spend considerable money for commercial-standard crystals.

A tunable receiver enables the operator to listen to input frequencies of repeaters, and to scan the band when searching for spurious signals and interference of various types. Most operators, however, will find such a receiver of greatest value for monitoring the output frequencies of area repeaters, and for use during simplex operation.

Some Features

The project treated here is simplified through the use of a surplus receiver strip. In this instance a GE Progress Line high-band deck (2 meters) is used. The tuning range is continuous from 146 to 148 MHz using a VFO which operates in the 11-MHz region. Output from the VFO is fed into

An afc circuit was added for ease of tuning and improved stability. The afc section used in this example was borrowed in part from an fm-tuner circuit shown in RCA's tube manual. Modifications to that circuit were made and performance is excellent.

The receiver strip has a sensitivity of 0.4 μV for 20 dB of quieting over a range of approximately 500 kHz. Performance deteriorated rapidly when tuning beyond either end of that 500-kHz segment. A 40673 preamplifier was added, and by stagger tuning the overall front-end section of the composite package – preamplifier, rf, mixer, and oscillator chain circuits – good sensitivity was obtained from 146 to 148 MHz (0.3 μV for 20 dB of quieting).

Output from the variable-frequency oscillator is fed into the crystal socket of one channel, and the oscillator cathode in that channel is grounded so that the tube will conduct. Output from the VFO is taken across a 150-ohm resistor so that the grid of the receiver oscillator is swamped to prevent self-oscillation. The circuit of Fig. 11-26 provides an output of 3 volts (rms) across the 150-ohm resistor.

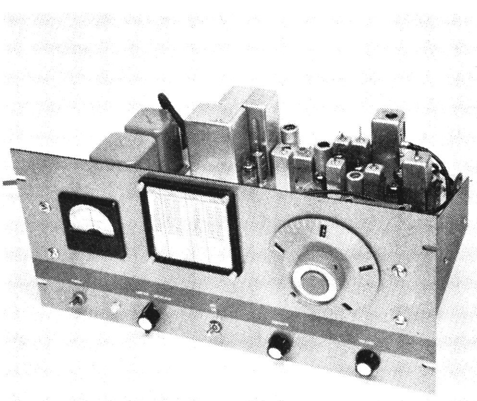


Fig. 11-25 – This tunable 2-meter fm receiver is assembled rack-and-panel style using both surplus and homemade sections. Kurz-Kasch knobs and an old HRO receiver dial dress up the front panel.

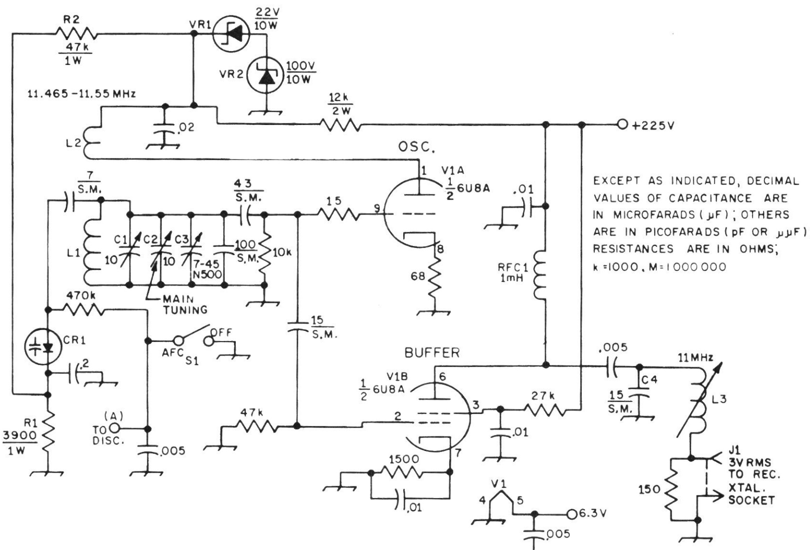


Fig. 11-26 – Schematic diagram of the VFO section of the tunable fm receiver. Capacitors are disk ceramic unless otherwise noted. SM = silver mica. Resistors are 1/2-watt composition unless otherwise indicated.

C1 – 10-pF miniature air variable.
C2 – 10-pF air variable, main tuning (James Millen Co. 19025 with one rotor and one stator plate removed).
C3 – 7- to 45-pF ceramic trimmer, type N500.
C4 – For text discussion purposes.
CR1 – Varactor diode, 33-pF (Motorola HEP R2503 or equiv.).
J1 – Phono jack, single-hole mount.
L1 – Inductor, 0.94-μH. 10 turns No. 18 enam. wire, close-wound on 1/2-inch diameter low-loss form. Alternatively, 12 turns No. 18 enam. wire, close-wound on 3/8-inch diameter low-loss form. (J. W. Miller 43A000CBI ceramic form, with slug removed, used in this model.)
L2 – Tickler winding. 4 turns No. 22 enam. wire close-wound over high-Z end of L1. Reverse leads of L2 if oscillation does not occur.
L3 – 10 μH nominal (J. W. Miller 4506).
R1, R2 – Labeled for text discussion.
RFC 1 – 10-mH rf choke.
S1 – Spst toggle.
VR1 – 22-volt, 10-watt Zener diode.
VR2 – 100-volt, 10-watt Zener diode.

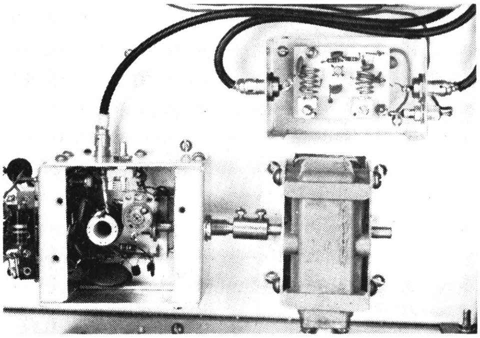


Fig. 11-27 – Close-up view of the VFO and preamplifier boxes with their covers removed. The VFO (lower left) is driven by a National Radio HRO gear box. The 6U8A tube projects out from the left side of the homemade VFO box. A 40673 dual-gate MOSFET is used in the preamplifier (upper right of the photo). Part of the GE receiver strip is visible at the top of the photo.

An old HRO receiver dial with gear train proved itself to be superb in use as a tuning dial because of its resettability to a desired VFO frequency, and because it is free of backlash. Other dial mechanisms would be satisfactory provided they tuned smoothly, were free of backlash, and offered at least a 5:1 tuning ratio. A good substitute would be one of the vernier units from a war surplus TU-6 tuning unit (part of the BC-191 or BC-375 transmitters). Another choice might be the J. W. Miller MD-4 or MD-5 type dials. The chart frame used for containing the calibration scale of this receiver was burgled from the front panel of a TU-6 tuning unit.

A homemade power supply is built on the same chassis that contains the receiver and VFO. Any supply capable of providing 200 to 225 volts dc at 70 mA or more, and 6.3 volts at 4 A will suffice. Operating voltage for the 40673 preamplifier is borrowed from the cathode of the 6AQ5 af output tube in the receiver strip. Approximately 11 volts were available in this model, developed across the cathode resistor.

A zero-center 25-μA meter is used to monitor the discriminator, thus allowing the operator to tune the signals for a zero reading. The same meter is switched to permit monitoring of the first-limiter current. The latter is useful in observing the relative strength of an incoming signal.

The VFO Circuit

Someone is certain to raise an eyebrow over the use of a tube-type VFO in this day of solid-state circuitry. The choice was made strictly to provide compatibility with the power supply. A solid-state circuit would have required that an additional supply be built, thus increasing the cost of the project. The tuning range would have to be changed to cover 11 MHz, or one could excite the receiver oscillator at half that frequency and use that stage as a doubler to 11 MHz.

The triode section of a 6U8A serves as a tickler-coil oscillator. The Colpitts variety of oscillator was not used because the hum modulation common to that circuit when operated in the upper part of the hf spectrum. Supply voltage to the VFO plate is regulated at 122 volts by means of two Zener diodes, VR1 and VR2 (Fig. 11-26). Those wishing to do so can substitute a VR-150 regulator tube for the diodes.

A varactor diode, CR1, is used to provide the automatic frequency control (afc) mentioned earlier. CR1 is connected to the high-impedance end of L1 through a 7-pF capacitor. Reverse bias is applied to CR1 and is taken from resistance divider R1-R2. When the afc is operative S1 is in the open position, thus allowing voltage from the discriminator of the GE receiver strip to be routed to CR1. As the discriminator voltage changes from zero value (plus or minus), the discriminator-derived bias on CR1 changes and shifts the capacitance of the varactor diode to a value greater or less than the nominal value which exists at zero discriminator voltage. The change in diode capacitance raises

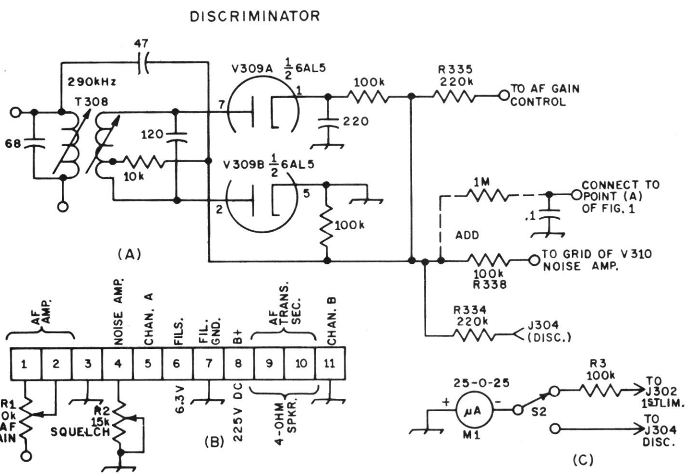


Fig. 11-28 – Diagram of the discriminator portion of the GE receiver (A). Dashed lines indicate circuit addition. Original GE part numbers are used in this drawing. At B, connections which must be made to the GE receiver 11-pin chassis plug. Illustration at C shows how to connect the metering circuit.

or lowers the VFO frequency to keep the received signal in the i-f passband of the receiver. When S1 is closed the discriminator-derived bias is shorted to ground, thus disabling the afc function. If the afc circuit drives the VFO off frequency rather than pulling it on frequency, reverse the secondary leads of the discriminator transformer (T308 of Fig. 11-28).

The pentode half of the 6U8A serves as a buffer amplifier to increase the 11-MHz signal in level, and to offer some isolation between the VFO and the receiver. Output from the VFO is taken across a 150-ohm resistor. If greater output voltage is needed (depending upon the brand and circuit of the fm receiver strip used) the resistor value can be increased. However, it should not be greater than 2200 ohms (approximately) when feeding a triode stage which operates on the same frequency as the VFO. Otherwise, instability is certain to result. If the receiver uses a pentode oscillator, the resistor can be deleted from the circuit.

Inductor L3, in combination with C4 and the capacitance of the coaxial cable feeding the VFO energy to the oscillator stage of the receiver, forms a pi-network plate tank for V1B. A relatively low value of *Q* is used to provide sufficient bandwidth across the range covered by the VFO.

The Preamplifier

The homemade preamplifier was described earlier in this chapter. There is no reason why a commercially built preamp cannot be used. Furthermore, if one wishes to tune but 500 kHz of the band, the preamplifier can be eliminated. This part of the circuit, and the manner in which it is treated, should be a matter determined by the builder, and in accordance with his particular needs.

Receiver Strip

The choice of receiver strips is a matter of individual preference and availability versus cost. The GE "Prog-Line" (No. 4ER25B1) assembly was obtained as surplus. However, some of the surplus fm dealers sell the strips (when available) for as little as \$30 each. Pre-Progress Line receiver strips are sometimes available for as little as \$10. Similarly, Motorola Sensicon strips can be purchased at low cost, and they are capable of doing a good job in this application. The main requirement is that the VFO be tailored to the oscillator frequency of the receiver used. Some receivers require a fairly high crystal frequency in the first oscillator, e.g., 28 MHz. In such an instance it would be wise to operate the VFO at 1/3 or 1/4 the oscillator frequency, then triple or quadruple in the oscillator stage of the receiver. This would enhance the stability of the system by having the VFO operate at a lower frequency.

Fig. 11-28 shows the details for connecting the receiver to the afc circuit. GE part numbers are used to help the reader follow the Prog-Line schematic, if one is available. Information is given in Fig. 11-28B concerning connection of voltages, external controls, and the speaker. Fig. 11-28C illustrates the meter connections for monitoring first-limiter current and discriminator voltage. Those wishing to save the cost of a meter can ignore that part of the modification. Alternatively, one of the low-cost zero-center tuning meters sold by Lafayette Radio can be substituted for M1. A surplus 25-0-25 μA meter is used in the modification shown here. A less sensitive meter can be used. If so, the ohmic value of R3 should be reduced experimentally to obtain the amount of meter deflection desired.

Construction and Power Supply

The VFO is built in a homemade aluminum box which measures 2-1/4 × 3-1/2 × 3 inches. An aluminum thickness of 1/16 inch was selected to assure good rigidity of the box, thereby minimizing mechanical instability. A 4-inch-square plate of 1/8-inch aluminum stock is mounted below the VFO box (under the chassis) to stiffen that section of the chassis. The 6U8A is mounted on one of the VFO enclosures to keep heat outside the assembly.

The complete receiver is assembled on a 12 × 17 × 3-inch aluminum chassis. An 8-3/4-inch rack panel is secured to the chassis by means of the controls and switches, and by attachment of a set of panel brackets. The trim strip on the front of the panel is a length of red Mystic Tape on which white press-on decals have been added to identify the controls.

The preamplifier is built on a pc board, and is housed in a 2-1/4 × 3-1/4 × 1-1/2-inch Minibox. Coaxial cable is used to supply input to the preamp, and to feed its output to the phono jack at the receiver input.

A schematic diagram of the power supply used by the authors is shown in Fig. 11-29. However,

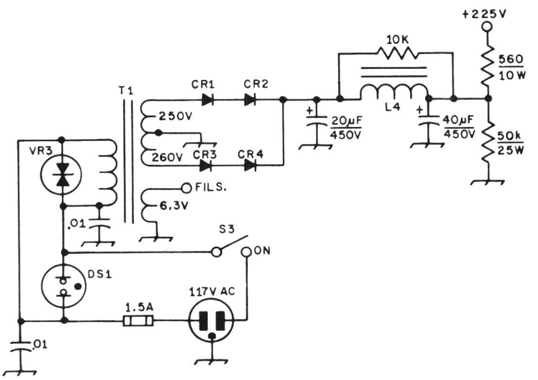


Fig. 11-29 — Diagram of a recommended power supply for the tunable receiver. Polarized capacitors are electrolytic.

CR1-CR4, incl. — 100-PRV, 1-A silicon rectifier.
DS1 — 117-V ac neon panel-lamp assembly.
L4 — 8-H 100-mA filter choke.
S3 — Spst toggle.
T1 — Power transformer. Secondary, 520 volts ct at 90 mA. Fil. winding, 6.3 V at 4 A. (Allied Radio 6K55VG suitable).
VR3 — GE Thyrector No. GE6RS205P4B-4. Not required in installations where normal line voltage and minimum transients exist.

the particular transformer scrounged from a junk box did not have ample current available in the 6.3-volt winding. This caused the transformer to run hot. For this reason a separate 4-ampere filament transformer is used to feed the receiver strip, while the 6.3-volt winding of T1 is used only for the VFO filaments. The additional filament transformer is not shown in Fig. 11-29. The transformer specified in the parts list will be adequate for powering the entire package.

VXO CONTROL FOR FM TRANSMITTERS

A VXO is a variable-frequency crystal oscillator. The principle of operation is well known to many amateurs, but some of the tricks in getting one to function well are not so widely known. But before we get into a discussion concerning how the job is done, let's examine one of the practical applications of VXOs in amateur radio.

The fm and repeater crush is really on at this time. Some areas have numerous repeaters in operation, and many fm operators want to have channel capability for working through all of the local systems. Also, simplex operation (both stations on the same frequency and not operating through a repeater) is becoming more popular as conditions become more crowded on the repeater frequencies. It is very expensive to purchase high-quality crystals for all of the channel combinations one might wish to have at the home station. Therefore, some amateurs are realizing the practicality of changing to variable-frequency control of both the receiver and transmitter. Heterodyne-style VFOs are sometimes stable enough for vhf operation, but few direct-frequency VFOs are satisfactory because of drift problems which are magnified in the frequency-multiplication process from, say, 6 MHz to 146 MHz. (If there is 1 kHz of drift at 6 MHz, the 2-meter signal will drift by a factor of 24, or 24 kHz.) VXOs can be very stable, and are preferred by many operators.

Fig. 11-30 – The solid-state VXO is built in a homemade aluminum cabinet. The outer cover is made of perforated stock, but can be fashioned from solid aluminum sheeting if the builder prefers the latter. Gray spray-can paint was used to finsh the front and rear panels of the VXO. White press-on decals are used for labeling.

How Much Frequency Shift?

A typical circuit for a solid-state VXO is given in Fig. 11-31. It can be seen that two elements (other than the crystal) are used to control the operating frequency. Coil L1 and capacitor C1 are used to "rubber" the crystal across the tuning range. The amount of swing is dependent to a greater extent upon the characteristics of the crystal, and by the amount of unwanted stray capacitance in the oscillator circuit. The latter condition regulates the maximum upper frequency to which the VXO can be tuned. The value of minimum capacitance exhibited by variable capacitor C1 should be the first consideration. How much capacitance exists when the plates are unmeshed will be dependent upon how the capacitor is built. Units with metal end and bottom frameworks should be avoided. Considerable unwanted capacitance will exist between the stator-plate sections and the frame in this type of component. Capacitors with ceramic or steatite ends are preferred in VXO circuits. Furthermore, it is best to mount the capacitor so that its stator sections are spaced well away from the chassis and cabinet walls (at least an inch or more) to minimize capacitance effects.

Reactance coil L1 should be mounted well above the chassis, and with its end bushing secured to a nonmetallic support bracket such as phenolic or plastic. If this is not done, unwanted capacitance will exist between the slug assembly and any metal support bracket that might be employed. Since a medium-*Q* inductor is required for good VXO performance, the builder may prefer to use a toroidal coil. However, the slug is handy for setting the inductance to the precise value needed for the desired circuit operation. The J. W. Miller coil (L1) used in the circuit of Fig. 11-31 has an unloaded *Q* of 150 at 6 MHz. During the development of this circuit it was learned that coils whose unloaded *Q*s were less than 100 provided miserable, inefficient performance. It's better to pay a little more money for a high-*Q* inductor and be assured of good results.

Concerning VXO Crystals

A number of crystal types have been tried in VXO circuits. Surplus FT-243 style crystals are the poorest of performers in a VXO. The holder capacitance is very high, thus limiting the frequency shift. Plated crystals in HC-6/U holders seem to work best. Overtone crystals which are operated at their fundamental frequencies will often provide remarkable swings in frequency when compared to fundamental-type crystals.

Some designers have elected to use several crystals in an effort to provide a large amount of frequency coverage in a particular part of the

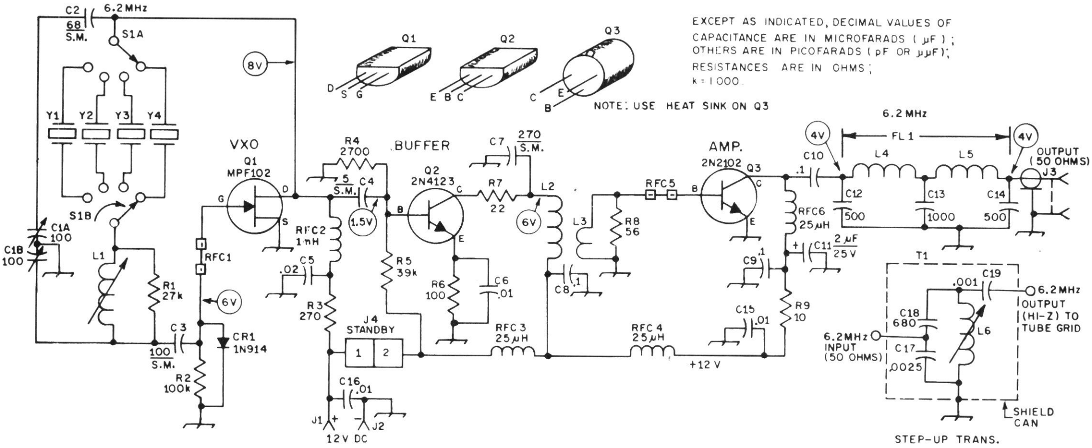


Fig. 11-31 – Schematic diagram of the 6.1-MHz VXO. Fixed-value capacitors are disk ceramic unless noted differently. Polarized capacitors are electrolytic. Resistors are 0.5-watt composition types. Voltage readings inside the circles are rms, measured with a Heath VTVM and rf probe, with J3 terminated by a 56-ohm resistor, and with C1 set for minimum capacitance. Numbered components not appearing in the parts list are so designated for pc-board layout purposes (Fig. 11-33).

C1 – Dual-section air variable. Hammarlund MCD-100-S shown in photo. (See text.)
CR1 – High-speed silicon switching diode.
J1, J2 – E. F. Johnson nylon binding post.
J3 – SO-239 style coax connector.
J4 – Three-circuit phone jack (collar connection not used).
L1 – Variable inductor, 38-85 μH, slug tuned. (J. W. Miller Co. 43A685CBI or equivalent. J. W. Miller Co., P. O. Box 5825, Compton, CA 90224, Catalog No. 72.)
L2 – Toroidal inductor, 2.5 μH 22 turns No.22 enam. wire to occupy entire circumference of Amidon T-50-2 core (Amidon Assoc., 12033 Otsego St., N. Hollywood, CA 91607).
L3 – 6 turns small-diameter insulated hookup wire over 1/3 of L2.
L4, L5 – 1.3-μH inductor. 21 turns No. 26 enam. wire to occupy total circumference of Amidon T-37-10 toroid core.
L6 – Slug-tuned inductor, nominal inductance of 1.2 μH (J. W. Miller 20A156RBI suitable).
Q1 – Vhf JFET (Motorola MPF102 or HEP802.
Q2 – Motorola 2N4123, or any npn with beta of 100 or greater, f_T of 100 MHz or higher.
Q3 – RCA 2N2102 or equivalent. Substitute type should have 2-watt minimum rating, minimum f_T of 120 MHz, and minimum beta of 50 at 1 kHz. Use crown-type heat sink. *Do not operate without load connected at J3.*
RFC1, RFC5 – Vhf parasitic choke made from two Amidon miniature ferrite beads on 1/2-inch length of No. 22 bus wire.
RFC2 – 1-mH rf choke (James Millen Co., 34300-1000. James Millen Co., 150 Exchange St., Malden, MA).
RFC3, RFC4, RFC6 – 25-μH miniature rf choke (James Millen J300-25).
S1 – Low-capacitance double-pole four-position rotary switch. See text. (IRC epoxy two-section rotary wafer No. T315 recommended.)
T1 – See text.
Y1-Y4, incl. – 6.1-MHz-range crystal, selected to provide desired coverage at 146 MHz. (International Crystal Co. type GP-05 in F-605 holder. See text.)

spectrum. This is done with the circuit of Fig. 11-31. However, a few important rules should be observed. The switch used for changing crystals should be of the low-capacitance variety, and should be isolated from the chassis as is suggested for coil L1. Though some builders have used crystal sockets on the selector switch, any socket will introduce additional unwanted capacitance. It's better to solder the crystal pins directly to the lugs on the switch. If possible, eliminate the switch altogether. Mount a crystal socket on plastic and change crystals at the front panel of the VXO.

The Circuit

Oscillator Q1 is a junction FET. It employs two ferrite beads at the gate terminal to prevent vhf parasitic oscillations. The crystal frequency for this circuit is roughly 6.1 MHz. This, multiplied 24 times in an fm transmitter, provides a signal in the 146-MHz part of the 2-meter band. This particular VXO was designed to operate in combination with a surplus GE Progress Line transmitter. It can serve as a frequency-control element for other tube-type transmitters that require 6-MHz crystals. The circuit can be used for controlling the frequency of solid-state transmitters that use 6-MHz crystals, but the rf output voltage from the VXO will have to be reduced to a value suitable for the oscillator in the transmitter. One might put a drive control in the emitter return of Q2 (5000 ohms) if the circuit is to be used with more than one transmitter, each of which may require a different amount of driving voltage.

CR1 is used as a gate clamp to reduce harmonic output from Q1 and to limit the FET's junction capacitance during positive excursions of the rf sine-wave. The diode clips positive peaks above approximately 0.6 volt. This action limits the transconductance of Q1 during positive half cycles, thereby preventing large changes in junction capacitance which would otherwise occur. Installation of CR1 provided an additional 1.5 kHz at the upper end of the VXO tuning range at 6.1 MHz (or an additional 36 kHz at 146 MHz).

Other designers of VXOs have stated that the design rules followed for VFO construction should be applied when building a VXO. This implies that the mechanical stability of C1 should be superb, and that it should rotate smoothly. Also, the coil used for L1 should be wound on a mechanically stable form, and the coil turns must be secure on the coil form.

Still observing VFO design criteria, one should use the lightest possible coupling between the VXO and the succeeding stages. In Fig. 11-31, capacitor C4 is a 5-pF silver mica type. This small value of capacitance is ample for supplying sufficient rf voltage to the base of Class A amplifier Q2. Early during the design period it was noted that the output from Q1 fell off rapidly as the tuning capacitor, C1, was brought toward a fully meshed state. With the plates of C1 open an rms voltage of 8 was obtained at the junction of RFC2 and C4. With the plates of C1 closed the rms voltage dropped to 1.25. A direct connection existed where C2 is now shown. The problem was resolved by opening that leg of the circuit and inserting C2. The upper section of C1 (Fig. 11-31) was acting as a capacitive shunt across the output of the oscillator, thus bypassing some of the 6-MHz energy to ground. Insertion of C2 diminished the effect without impairing circuit performance. The rf output with the circuit shown is about 8 volts rms across the entire tuning range.

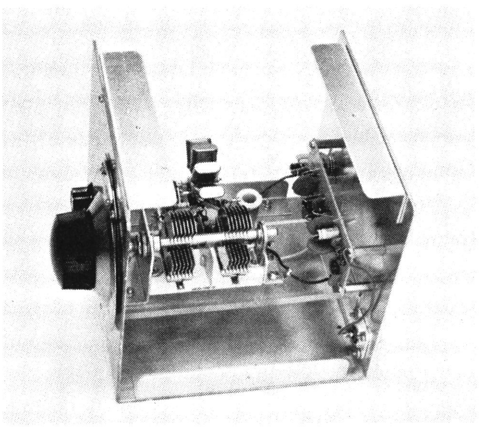


Fig. 11-32 — The tuning capacitor and the oscillator components are assembled on a Plexiglas platform to reduce stray capacitance in that part of the circuit. A phenolic terminal strip is located on the Plexiglas sheet on the far side of the tuning capacitor. The oscillator circuit is wired on that strip. The four crystals are mounted on the selector switch (far center) by soldering their pins directly to the switch tabs. The broad-band solid-state 6-MHz amplifier is mounted by means of four standoff posts (rear wall of the VXO cabinet). L brackets are used as a means to attach the top cover. No. 6 sheet-metal screws are used to secure the cover to the brackets.

Harmonic output from the last stage of the VXO, Q3, is suppressed by FL1, a half-wave 6-MHz low-pass filter. FL1 is designed for a Q of 1, 50 ohms input and output. The collector load impedance of Q3 is on the order of 60 ohms. The slight mismatch is not of consequence. Power output, after the filter, is approximately 0.5 watt. A pure sine wave was obtained across a 50-ohm termination at the output of FL1.

Matching to the Load

The VXO was designed to operate outboard from the transmitter, mainly to keep the operating temperature of the VXO low and constant. A connecting cable made of RG-58/U is used between the VXO output and the transmitter input. The cable can be any convenient length since it sees 50 ohms at each end. A step-up transformer (inset of Fig. 11-31) is used to match the 50-ohm line to 10,000 ohms. The latter impedance is high enough to provide ample rf voltage at the tube grid – approximately 35 volts rms. The transformer was designed for a Q of 5 so that the response would be broad enough to eliminate any need for readjustment over the VXO tuning range.

If this VXO is to be used for exciting a bipolar-transistor oscillator stage it is suggested that the output of FL1 be terminated with a 56-ohm 1-watt carbon resistor, and (as mentioned earlier) a drive control be installed in the emitter of Q2. Alternatively, the coupling capacitor between Q1 and Q2 (C4) can be changed to a 1- to 5-pF variable and used to set the drive level required. Since most small-signal bipolar stages have a base impedance of a few hundred ohms or less, output from terminated FL1 can be taken through a small-value coupling capacitor. No more than 3 volts rms should be needed from base to ground when exciting a transistorized oscillator stage (crystal removed, of course).

A word of caution: Make certain that the feedback components of the transmitter oscillator stage have been disabled when using a VFO or VXO. This will prevent self-oscillation of the stage when T1 is connected to the grid or base. Triode oscillators may break into self-oscillation despite these measures. It is suggested that a low value of resistance be bridged from grid to ground in triode-tube stages, as was done with the tunable receiver crystal oscillator earlier in this chapter. Use no less resistance than is required to assure stability. Transistorized oscillator stages may not need modification for use with VXOs because the circuit impedances are relatively low in value. However, one should check for proper stability before deciding that the feedback components can be left in the circuit.

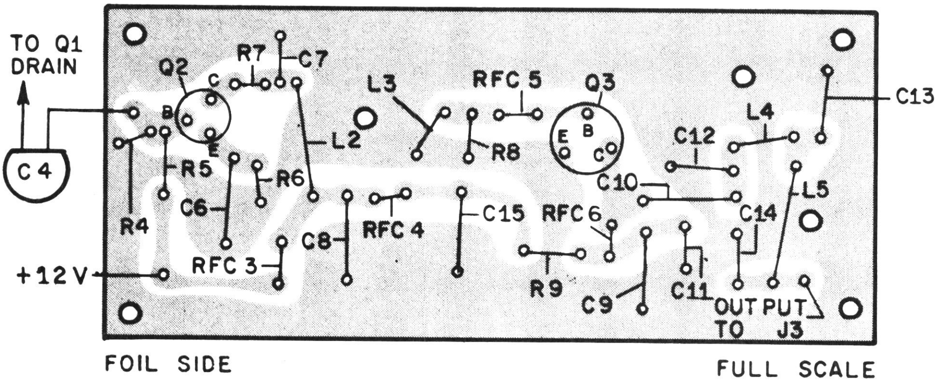


Fig. 11-33 – Scale drawing of the pc-board pattern for the buffer and amplifier stages of the VXO.

Construction Information

The photographs show that a relatively large aluminum enclosure contains the VXO. This is a case of tail wagging the dog, so to speak, because the large National Radio vernier dial needed a specific amount of panel space. Though the dial is somewhat of a relic, it does provide good numerical readout without noticeable backlash. A J. W. Miller type MD dial mechanism would be suitable for this project, or the builder may wish to economize by using the vernier assembly from a war surplus TU-6 tuning unit (part of the BC-375E or BC-191 transmitter).

Heavy-gauge aluminum sheeting, 1/16 inch thick, was used to form the homemade 6-1/2 × 6-1/2 × 6-1/2-inch VXO box. The oscillator components are assembled on a 3-inch-wide sheet of 1/4-inch-thick Plexiglas. This technique minimizes the effects of unwanted stray capacitance between the parts of the enclosure walls. Since the Plexiglas is anchored to the front and back walls of the box it enhances the rigidity of the assembly. The crystal switch is mounted on a sheet of phenolic for the reasons outlined above. Almost any kind of rigid insulating material can be used in place of the Plexiglas and phenolic used by the writer.

The buffer/amplifier section of Fig. 11-31 is assembled on a small pc board. The pattern and parts layout are given in Fig. 11-33. The builder need not use a pc board for that part of the circuit. Point-to-point wiring (using terminal strips) can also be used.

Variable capacitors smaller than the one shown here can be used if the constructor so desires. A James Millen 26100-RM was tried in an earlier circuit and was found to be quite satisfactory. Alternatively, a pair of single-section 100-pF capacitors can be ganged for use at C1, or a 50- and a 100-pF pair can be ganged. If the latter approach is used, eliminate C2 and connect the stator of the 50-pF variable directly to the drain of Q1, and to the crystal.

CONVERTING A DELCO CVT-1

One of the most reliable and easiest to maintain tube-type mobile sets that was used by telephone companies is now becoming available to amateurs. It was designed by the AC Sparkplug Division of General Motors; after its introduction the manufacture was transferred to the Delco organization. Whether you call it an "AChieverfone," a "Delco," or a "Spark Plug" set, it is a dandy.

Two models are available. CVT-1 designates the narrow-band units (5-kHz deviation) while CVT-2 indicates a wide-band set. Considering the years in which they were manufactured, it would appear that most of the units were built for narrow-band standards. You might find a Delco arranged for one-, two-, or three-channel operation, but all can be made to operate on four channels by the replacement of the missing oscillator tubes and crystal ovens. The sockets and wiring for all four channels are in place.

These sets have a few characteristics that leave something to be desired for most ham operation, however. The audio system was designed to work into a 150-ohm telephone handset. The 20 milliwatts of audio output power is not adequate for loudspeaker operation. The Delco transceiver was intended for selective signaling, rather than voice calling, so it is without a squelch circuit in the receiver. The transmitter channels must all be within a spread of only 300 kHz. The receiver is a little broader, permitting the top and bottom channels to be separated by up to 500 kHz. Most hams will be able to tolerate this limitation, however.

On the positive side, the set is light and compact, yet it is unusually easy to work on. Subassemblies are easy to remove. Installation is about as simple as possible in a mobile unit. Most important is that these sets are usually in excellent condition, as they are generally in working order when removed from vehicles. The reason for removal is that the mobile service area is being converted to full-dial operation.

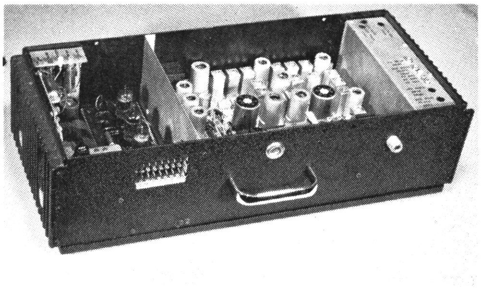


Fig. 11-34 — This is what the Delco set looks like with the top cover removed. Electrical connections consist of one main multiconductor plug and the coaxial antenna connector. The ribbed end panels of the case serve as heat sinks for the power supply and the transmitter final amplifier.

The Conversion

One way to begin the conversion is to decide what frequency or frequencies you want to work on, and order new crystals. Most crystal suppliers will be able to fill your order if you give them the operating frequency and the manufacturers type designation of the set.

The transmitter crystal frequency is multiplied by 24 to arrive at the channel frequency. If you want to operate on the national frequency of 146.940 MHz, your crystal will have to be 6.1225 MHz. The receiver is a double-conversion superhet with a first i-f of 13.455 MHz. The crystal oscillator triples in the plate circuit and is followed by two doublers. The resulting injection voltage is fed to the first mixer. To compute the crystal frequency, then, start with the channel frequency (146.940 MHz) and subtract the first i-f (13.455 MHz). The remainder is 133.485. Dividing this last figure by 12 gives the operating frequency of the crystal; in this case, 11.12375 MHz.

Control Head

A new control unit can be put together using a Bud cowl-type Minibox measuring 3 × 8 × 5 inches. The only loudspeaker available provided a tight fit and approximately 1/8 inch was ground off of two opposite edges of the frame to get it into the box. One or two points about the electrical circuit of the control head may be of interest. You will probably notice that the schematic diagram of the control unit (Fig. 11-35) shows no chassis ground. The ground side of the audio, rf oscillator and low-voltage dc circuits is carried back to the main chassis by means of conductors in the control cable. That is done to avoid the introduction of noise or other problems that might result if the main set and the control unit were mounted on parts of the vehicle that were at different potentials. The pin numbers shown on the schematic diagram refer to the numbering system of the Elco Varicon 16-pin connector. The main power switch could be made a part of one of the controls; alternatively, a switch with a key lock could be used. A slide switch was chosen and located on the bottom of the unit behind the microphone connection. It is easy to use but hard to find unless you know where to look.

You don't really have to do anything other than realign the set to put it on two meters, but it will be more enjoyable to use if you replace the audio decoder and selective-signaling unit with a squelch circuit and a more powerful audio amplifier. The best way to do this is to disconnect the wiring harness leading to the audio decoder chassis and remove the decoder from the main chassis. You can then loosen the four screws that hold the chassis in the case and slide the decoder out through the bottom of the set. Strip all the parts off of the audio chassis. You will be able to reuse one tube, the wiring harness, a few capacitors and resistors from the etched circuit board and the main chassis. Mount the new audio transformer and filter capacitor under the chassis and the new circuit board, Fig. 11-37, on top of it, interconnecting them as required before tightening the bolts and spacers holding the board. A conductor with an insulated shield must be added to the wiring harness when using this circuit. A template

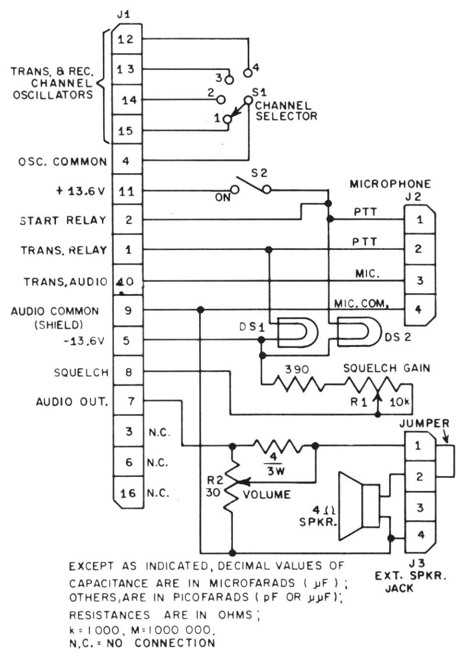


Fig. 11-35 — Diagram of the homemade control head. Resistances are given in ohms; K = 1000.

DS1, DS2 — No. 1815 12-volt lamp.
J1 — Elco Varicon 16-pin chassis-mount connector (see text).
J2 — 4-conductor microphone jack, chassis mount.
J3 — 4-conductor accessory jack, chassis mount.
R1, R2 — Linear-taper composition control.
S1 — Single-pole, four-position ceramic rotary switch, single wafer.
S2 — Spst slide switch.

and parts-layout diagram for the squelch/audio amplifier are available from ARRL for 50 cents and a business-size self-addressed stamped envelope. An etched circuit board is available from Spectronics (See Fig. 11-2).

The circuit function is fairly simple. Noise from the discriminator is fed to the pentode section of a 7060 tube (Fig. 11-37). The gain of this noise amplifier is controlled through the action of the squelch control. Amplified noise is detected in the other half of the 7060; the dc output is amplified by half of a 7058 tube, the output of which is connected to its other half in such a way that the second half can be electrically cut off. The second half is used as a switch in the audio path, turning off the audio output when the noise from the discriminator exceeds a preset level. The 7061 tube serves as an audio output stage. When this circuit is used in early models of the set, the lead that is shown connected to 12 V should, instead, be

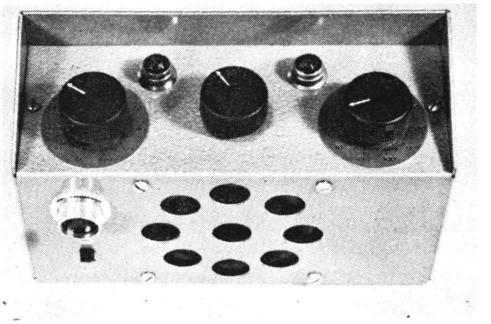


Fig. 11-36 – The volume and squelch controls, together with the channel switch and power and transmit lamps, are on the front panel of the homemade control unit. The microphone jack, power switch and loudspeaker are on the bottom panel.

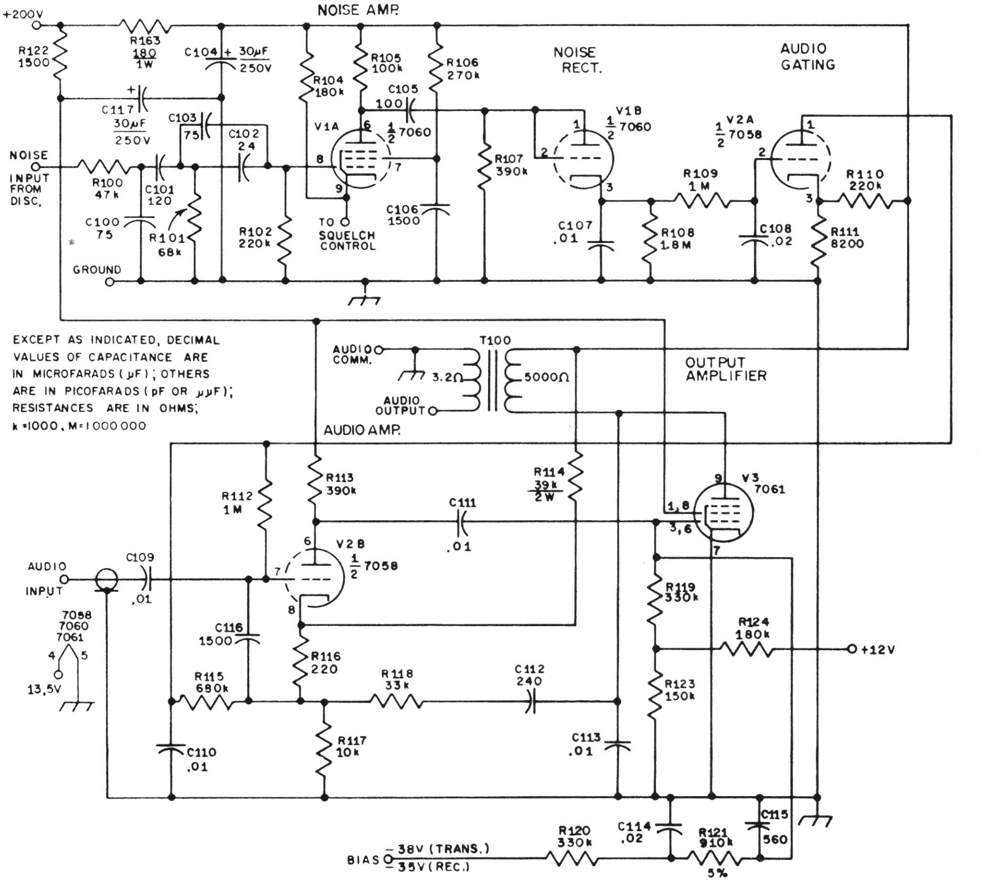


Fig. 11-37 – Schematic diagram of the audio/squelch adapter. Part numbers used are the manufacturer's. Resistors are 1/2-watt, five-percent tolerance composition, unless otherwise noted. Capacitors may be disk ceramic or paper, except those with polarity marked, which are electrolytic.
T100 – Audio output type, 5000-ohm primary, 3.2-ohm secondary.

Color	*Old Use*	*New Use*
Black	Ground	Ground
White/brown	Tube heaters	Tube heaters
White/orange	200 V	200 V
Blue	Audio output	Audio output
Orange	Ringing signal	250 V
White	13.6 V utility	Bias voltage
Slate	Selector reset	Squelch
Yellow	Audio input	Noise input
Shielded lead	(not used)	Audio input

Fig. 11-38 — Changes to the audio-chassis wiring harness.

grounded. That is done so that the 7061 will operate with a negative bias of about 10 volts on its grid. (The early sets had a bias supply of only 22 V.) Insufficient bias on the 7061 will result in high tube current and low, distorted audio output.

Alignment Tips

If you add or remove a tube from the receiver local oscillator when changing the number of working channels, realign Z450, the receiver oscillator tank circuit and Z460, the tripler tank. The plate capacitance of the tube affects the resonant frequency. Some local hams have reported being unable to get the second doubler in the transmitter to peak properly. They had to retune the two preceeding stages to peaks found when the tuning slugs were moved farther down in the can toward the chassis. Some sets are reported to have been modified for private-system use by the addition of a single-tube squelch circuit. It can be removed easily. Some other sets were modified for full duplex operation. In these sets, the transmitter came on when the handset was removed from the cradle; push-to-talk operation was not required. Such modified sets have an rf duplexer network connecting the transmitter and the receiver to a common antenna. If you have one of these sets you can restore it to its original configuration for ham-band use.

When aligning the set for two-frequency operation, tune up the receiver and transmitter on the higher frequency. Use the most nearly centered channel if you plan to use three or more. After that has been done, go over them again and slightly stagger tune the front end for good sensitivity and maximum transmitter output on all channels. Being on the low end of the band for which the set was designed gives you a favorable *LC* ratio for broadbanding, although it results in somewhat less output power than these sets will furnish at 170 MHz.

Installation

Here are some pointers on installation. The set is connected to the auto battery by means of two No. 8 stranded conductors that are part of the standard cable assembly. The conductor with a ridge molded on the jacket is the positive lead. A cartridge fuse (Bussman BAF 20A in a 4515 holder) should be connected in the positive lead close to the battery. Incorrect battery polarity could damage the power supply, so the designers provided a diode that will blow a fuse if battery polarity is wrong. If your set worked on the bench but seems dead in the car, check the 10-A fuse that is located in a phenolic holder just under the top cover of the set. If it is blown, check the polarity of the battery leads before replacing it.

If you have a cable kit but no control unit, you will need a 16-pin male chassis connector to mate with the one on the control cable. The 16-pin connector is available from the manufacturer. Or you might try ordering an 18-pin unit that is stocked locally (an Elco Varicon connector type 01-2118-111, Allied Radio No. 47D5567). It is a simple task to remove one spacer section and two contact fingers to make the 16-pin plug. If you have no cable kit, you will need a female connector to mate with the 28-pin male connector on the set. If you can't get one of the original models, you can assemble one by cutting down two of the female versions of the unit mentioned above. They are the Elco 01-4118-111 and are available under Allied's number 47D5574. Of course, they will have to be rearranged to the 14-pin length and some sort of sheet-metal hood will be needed to hold them together to provide mechanical protection for the cables.

A 220-MHz TRANSMITTING ADAPTER

Anyone who has listened to the fm channels on 2 meters lately will realize that there is a need for frequency expansion. Getting a repeater system going on the neglected 220-MHz band has been hampered by the lack of easily modified equipment, and a reluctance on the part of many amateurs to build a complete station from scratch. The equipment described here uses a varactor quintupler to put an fm signal on the 220-MHz band, with a small investment of time and money.

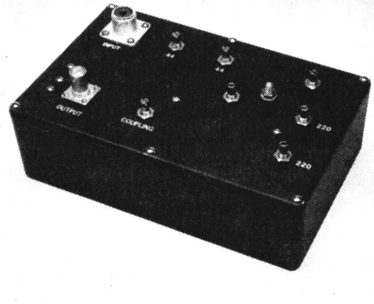


Fig. 11-39 — A cast-aluminum box, 4 1/2 X 7 1/2 X 2 1/4 inches, is used as a housing for the varactor quintupler. A standard aluminum chassis could be used as explained in the text. The two holes in the top cover are for access to coupling capacitors C2 and C7.

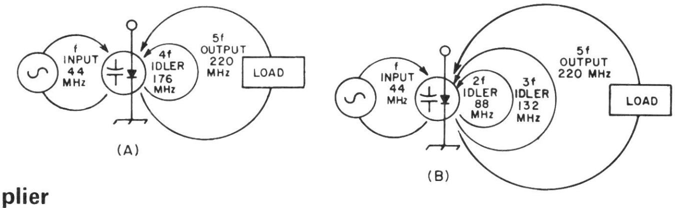


Fig. 11-40 – Signal paths in a varactor quintupler using (A) one-idler and (B) two idler circuits.

The Varactor Multiplier

Varactors have been used as efficient sources of harmonic energy for some time. By applying a driving frequency of 44 to 45 MHz to a quintupler it is possible to get 220-MHz output. Commercially manufactured equipment that does not require modification is available to furnish drive in that range.

In varactor-multiplier discussions, the terms *idler circuit* and *idler frequency* are mentioned often. Let's use an analogy to define the terms without getting too deeply involved in theory. When working with gears or pulleys, an idler is one that is not driven by the power source and does not deliver power directly to the load. It acts as a go-between to assist in the transfer of energy from the source to the load. An idler circuit in a varactor multiplier has a similar go-between function. When we apply drive to a varactor diode, it generates harmonics. By adding a circuit tuned to one of the harmonic frequencies, the amplitude of that harmonic can be increased. This circuit is called the idler circuit. The harmonic we have enhanced is called the idler frequency. By mixing the input signal with the idler frequency we obtain an output frequency equal to the harmonic *plus* the drive frequency. The output signal obtained will be stronger than one produced by conventional harmonic generation alone. Fig. 11-40A shows that by applying an input of 44 MHz (*f*), and tuning the idler circuit to 176 MHz (the fourth harmonic, or 4*f*), the mixing action will produce the resultant 220-MHz output (5*f*). Since the energy in the idler circuit is derived from the action of the diode, the

Useful harmonic output can also be obtained as the result of mixing the frequencies of two idler circuits, as in Fig. 11-40B. One idler is tuned to 88 MHz (2*f*), and the other is tuned to 132 MHz (3*f*). By adding these frequencies we obtain an output of 220 MHz. One advantage of using a design with two idler circuits is that both frequencies are much lower than the desired output frequency and therefore easier for the output circuit to reject.

Construction of a Practical Circuit

A circuit for a varactor quintupler using two idlers is shown in Fig. 11-41. L1-C1 is parallel resonant at 44.8 MHz and L2-C2 is series resonant at the same frequency. C2 can be adjusted to vary the coupling between the circuits. In addition to matching the varactor to the input line, these tuned circuits help prevent harmonic energy from appearing at the input, J1. L3-C4 is an idler circuit tuned to 89.6 MHz. L4-C5 is also an idler tuned to 134.4 MHz. The 224-MHz output circuit consists of series-resonant L5-C6 and parallel-resonant L6-C8. Coupling between the two can be adjusted by varying the setting of C7. L7 is the output coupling loop, and its reactance is tuned out by C9. L6 is a strip of .040-inch-thick aluminum, 7/8-inch wide and 7-3/4-inch long. It is bent as shown in Fig. 11-42. Soldering lugs and small screws are used to connect L6 to C8. Dimensions for L7 are also given in Fig. 11-42. Connect L7 between C9 and J2 and space L7 1/8-inch below L6.

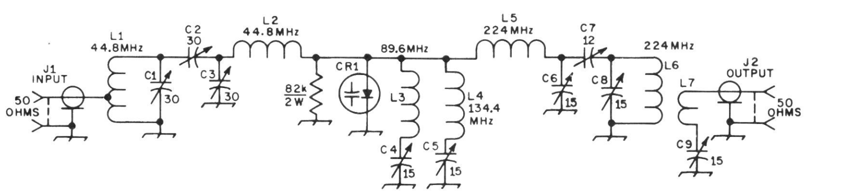


Fig. 11-41 – Schematic diagram of the varactor quintupler. Capacitance is in pF. Resistance is in ohms, K = 1000.

C1, C3 – 30-pF miniature variable (Johnson 160-130 or Hammarlund MAC-30).†

C2 – 30-pF trimmer (J. W. Miller 86MA1).

C4, C5, C8, C9 – 15-pF miniature variable (Johnson 160-107 or Hammarlund MAC-15).

C7 – 3- to 12-pF ceramic trimmer (Erie 557-000A-3-12).

CR1 – Varactor diode (Amperex H4A/1N4885 or equiv.).

L1 – 9 turns No. 18 enam. wire, 1/2-in. ID X 3/4 in. long.

L2 – 13 turns No. 18 tinned wire, 1/2-in. ID X 7/8 in. long (B&W 3003).

L3 – 9 1/2 turns No. 18 enam. wire, 3/8-in. ID X 1/2-in. long.

L4 – 6 1/2 turns No. 16 tinned wire, 3/8-in. ID X 1/2 in. long.

L5 – 4 turns No. 16 tinned wire, 1/2-in. ID X 1/2 in. long.

L6 – Aluminum strip line, 7/8 in. wide X 7 3/4 in. long before bending (see text).

L7 – No. 16 tinned wire, 4 3/8 in. long before bending (see text).

† Hammarlund capacitors are now being manufactured by Cardwell Condenser Corp., 80 E. Montauk Hwy., Lindenhurst NY 11757.

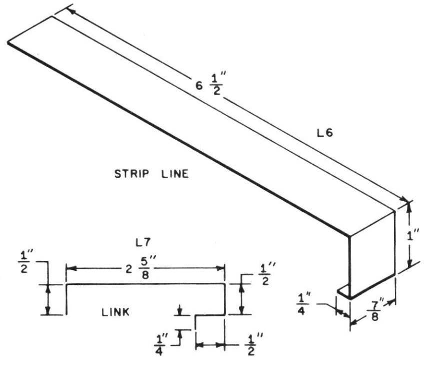


Fig. 11-42 — Dimensions for bending L6 and L7.

circuit is not directly driven from the source. The idler circuit does not furnish power to the load; therefore it is analogous to an idler pulley.

The circuit is constructed on the top cover of a cast-aluminum box. This heavy metal is an excellent heat sink for the diode. A piece of sheet aluminum, cut to fit a standard chassis, can be used instead if an additional heat sink is placed over the varactor mounting stud. A U-shaped piece of sheet aluminum, 2 inches square, with sides one-inch high, is adequate. The top of the box will get warm, but not hot, after several minutes of operation.

The two idler coils are mounted at right angles to each other (and to L2 and L5) to minimize coupling. A sheet-aluminum partition, 1-3/4 inches high by 5-3/4 inches long, runs the length of the chassis to isolate the output strip-line inductor from the input network and idler circuits. The two coupling capacitors, C2 and C7, can be adjusted through holes in the cover.

All of the tuned circuits can be set to their approximate frequencies with the use of a grid-dip meter. C2 and C7 should be set to their minimum capacitances.

Operation

Before applying drive, connect a 50-ohm load to the output. Some method of measuring both the output and the input power is needed. An SWR meter or reflected-power indicator will be ideal for this function. Apply 5 to 10 watts of drive and adjust C1, C2, and C3 for minimum reflected power as measured at J1. Tune C6, C7, C8, and C9 for maximum output, then peak the idler circuits, C4 and C5. Use a grid-dip meter or wavemeter to be sure that the output is at 220 MHz. Readjust the input circuits for minimum reflected power.

At this point you could fall into a trap that has caused some amateurs to have unkind thoughts about varactor multipliers. It is possible to repeak and readjust the circuits to get that last fraction of an increase in output power. Suddenly the output drops sharply, or even disappears completely! Then it is necessary to start all over with the tune-up procedure. What happens is this: As the circuits are adjusted for maximum output, more bias is developed across the diode. This additional bias changes the junction capacitance of the diode. Eventually a point is reached where the diode refuses to respond to the input signal and the junction capacitance

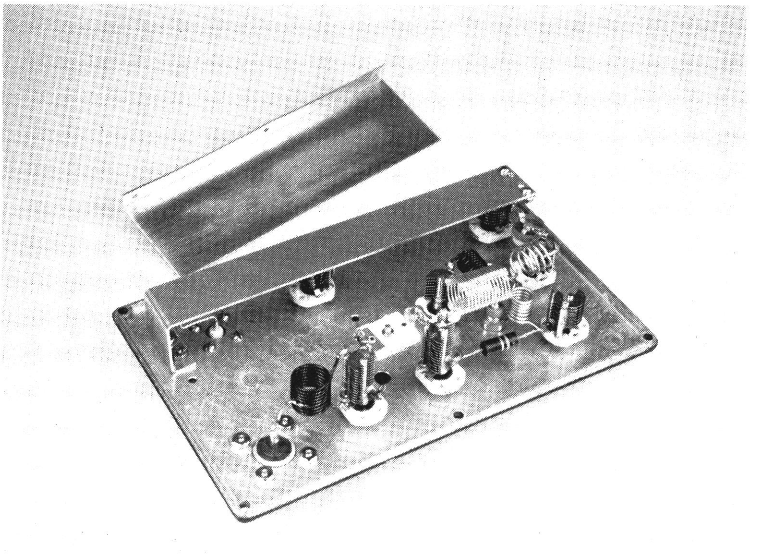


Fig. 11-43 — Inside the varactor quintupler. The partition is removed in the interest of clarity. C2 is connected between C1 and C3 with short leads. The varactor, CR1, can be seen between L2 and the resistor. C7 is fastened by its own leads between the end of the strip line and C6.

reverts to its no-bias value. This is called the "Hysteresis effect" caused by dynamic detuning. At this point the circuits are no longer resonant at the correct frequencies. After the initial tune-up has been done, check for stability by removing and applying drive several times. If the output returns to the same level each time, the tuning is correct.

Efficiency is approximately 50 percent. With 20 watts of drive, the output from this device (after filtering) is slightly more than 10 watts. This is a respectable power level for a base or a mobile station. The output from this unit is more than adequate to drive a medium- or high-powered final amplifier.

Although the output circuit has a strip-line tank for good rejection of unwanted products from the varactor, it is strongly recommended that additional filtering be used after the unit. This can be in the form of a strip-line filter such as the one shown in *The Radio Amateur's Vhf Manual* and *The Radio Amateur's Handbook.* The spurious signals generated could cause interference to other services. Don't guess that these signals are attenuated – be sure they are!

USING 450-MHz SURPLUS RIGS

In the last few years 450-MHz fm gear has become available to the amateur, because of changes in FCC regulations covering wideband equipment. Many units are sold for $25 or less.

It is advisable to get the gear working on its original frequency first before attempting any conversion; then you only have a few small changes to make and you're all set on the amateur frequency. After conversion and alignment of the receiver and transmitter are completed, you may want to make a power-supply conversion to 110-volt operation. All models of each manufacturer are not covered here, but this information should be helpful with most 450-MHz gear. Most manufacturers can supply complete manuals for any rig you may acquire, for a small charge, usually about $2.50 per manual (See Fig. 11-3). It is important when ordering manuals to give as much information as possible: model numbers, chassis numbers (usually stamped in ink on top or bottom of chassis), and numbers for the receiver, transmitter, and power supply. It is always better to include more information than not enough.

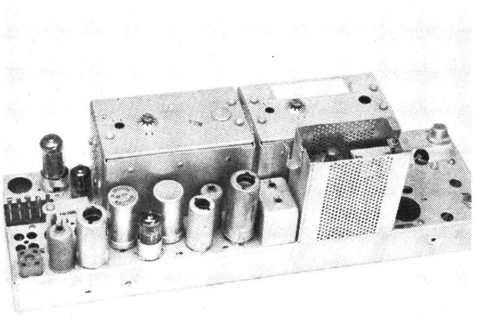


Fig. 11-44 – The transmitter strip from a Motorola T-44AAV transceiver.

LINK MODEL 2975-15 VR D2B MODIFICATIONS

Most receivers require no modifications other than installation of amateur-frequency first-oscillator crystals and a realignment. Crystal warmers or ovens can be utilized but if base-station operation is anticipated ovens may not be necessary for good frequency stability. All receiver front-end circuits in the Link gear will usually tune down to 432 MHz.

In the transmitter, all circuits peak in the amateur band, up to the tripler-driver plate (5894 driver tube). In this circuit, C37 will need 5 to 10 pF more capacitance. A simple way to accomplish this is to bend four copper plates into L shape and solder one to each stator of the driver and amplifier butterfly-type plate capacitors. Space the plates close together but not touching, then try tuning the stage to resonance. Remove tubes to make access to the stators of the capacitors easier. If you prefer, replace the capacitors with 25-pF butterfly capacitors (E. F. Johnson Co.).

Crystal Formulas

Crystal frequencies are determined as follows:

$$F_o = \frac{F_{sig} - 39.01 \text{ MHz}}{48}$$

$$F_t = \frac{F}{36}$$

where F_o = First oscillator frequency
F_t = Transmitting oscillator frequency
F_{sig} = Receiving frequency
F = Transmitting frequency
(All frequencies in MHz)

Numbered terminals on the distribution terminal strip, E-1, as indicated on the lug side of the board, are as follows: 1 – Channel No. 1, 2 – Ground, 3 – Speech B-plus, 4 – Ground, 5 – Microphone, 6 – No connection, 7 – Amplifier high voltage, 8 – Driver B-plus, 9 – Channel No. 2, 10 – Keying, 11 – Receiver B-plus, 12 – Filaments, 13 – Receiver audio, 14 – Not used, 15 – Squelch.

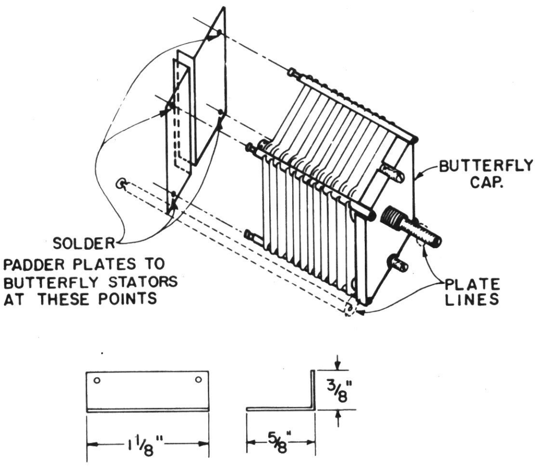


Fig. 11-45 – Method of increasing capacitance of butterfly tuning capacitors in the Link transmitters, to get driver and amplifier plate circuits to tune down to 432 MHz.

Receiver Alignment Procedure

Assuming that your unit was checked out on its original frequency, you should follow this procedure after you have made all modifications and changed crystals. Apply filament and plate voltage to the receiver. Locate receiver test socket B (of two 11-pin sockets located together, it is one to the rear of the chassis. Some Link models have 9-pin test sockets.) Connect a 100-µA meter between pin 11 (count pins backwards when viewing socket from top of chassis) and pin 1 hole, which is the discriminator. The meter should read zero or close to it. Inject a 5-MHz signal at the grid of the first low i-f amplifier (V105, a 6BJ6). This is the first tube from the rear of the chassis on the right side, when viewing the chassis from the front or power-supply end. This signal should cause the meter to go to zero, indicating that your discriminator is aligned properly. Now inject a 39.01-MHz signal at the grid of V102, a 6BH6, first high i-f, located at the back edge of the chassis near L113. Frequency of the injected signal should be adjusted for zero reading on the discriminator, indicating that the second oscillator is working properly. Most receivers have no frequency adjustment on the second oscillator.

On some models, pin 8 of the receiver test socket is connected to the second doubler grid of the receiver oscillator-multiplier string. Put the meter there or across the metering resistor from the second doubler grid, V116. If the crystal is oscillating, a meter reading will be observed. Move the negative lead of the meter to pin 5 of the socket; this is the grid of V118, a 6AK5 tripler. Adjust slugs top and bottom of T115 (located near center of chassis in front of V117, a 12AU7) for peak on the meter. Only a slight peak may be noted at this time. Now adjust T116 and L111 for maximum reading. By now a fair meter reading should be evident, though the amount is not important at this time. Now you should have a multiplier signal up to the 6AK5 grid, V116.

Inject an on-frequency signal into the antenna jack, at a level high enough to brute-force a signal through several untuned stages. Adjust C185 (first-oscillator trimmer capacitor) to set the signal to a zero reading on the discriminator position of the meter. Then move the negative meter lead to pin 2 (first limiter) of the metering socket B; begin receiver front-end adjustments, starting with the first round coaxial circuit, L101, toward the front of the chassis. Release locking devices. The Allen set screw is loosened first, and next the large slotted disk in the center of L101 is backed off two or three turns. Insert a small metal screwdriver into the hole in the center of L101 and make a peaking adjustment while watching the meter reading. Tighten both the large slotted screw and Allen set screws. Repeat this peaking operation for all circuits, L104, L105, and L113. When the meter reading reaches saturation, back off the input signal a bit and repeak, or a true peaking operation may not result. After all circuits have been peaked and the receiver sensitivity is approaching one microvolt for 20-dB quieting, go over the front end and high i-f adjustments and repeak them for best quieting effect with a very weak signal. Best sensitivity is not always obtained at the same point as the maximum meter reading, but it usually is very close. You may be able to adjust for best quieting by ear.

Fig. 11-46 – Link Test Socket Pin Identification

Receiver (Socket B)	*Pin No.*	*Transmitter (Socket A)*
Discriminator	1	First Doubler Grid
First Limiter	2	First Tripler Grid
Second Limiter	3	Second Doubler Grid
Low Frequency Oscillator	4	Tripler Driver Grid
Receiver Oscillator Tripler Grid	5	PA Grid
–	6	PA Cathode
–	7	–
Receiver Second Doubler Grid	8	Rf Output
–	9	–
–	10	–
Ground	11	Ground

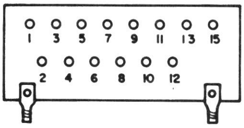


Fig. 11-47 – Arrangement of terminals on strip E1 in Link transmitters. Numbers may not appear on the strip itself. They are shown for the lug side.

If the transmitter is wired for multiple-frequency operation, the crystal must be in the proper socket and the channel selector in the proper position. Terminal 1 of the distribution strip E-1 is Channel 1, and Terminal 9 of E-1 is Channel 2. Grounding one of these points will activate that particular oscillator. A 50 μA meter is used in the first part of the transmitter alignment. One lead should connect to ground and the other to test socket A. Pin 1 is the metering point for L3 adjustment, pin 2 for T1, pin 3 for L4, pin 4 for C29 and 31, and pin 5 for C37 and 36. These adjustments should be done in the order given. A 250 μA meter will be needed while adjusting C44 for a dip. The meter should connect from pin 6 to ground. C45 should be set to maximum capacitance. A power-output meter should be connected to the antenna terminal, and the amplifier loaded by decreasing the capacitance of C45 in small degrees until the rated output is obtained. The coupling of L20 to the amplifier tank is adjusted by moving the loop nearer or farther from the resonant parallel lines. Tuning of C44 and C45, and L20 must be worked in conjunction, to obtain the rated output of 15 watts. This is obtained with approximately 190-mA cathode current.

An alternate method of tuning the final stage is to insert a 50-μA meter between pin 8 and ground to observe output of the transmitter. Tune the amplifier tank for maximum reading in this position. Set the deviation control to the desired deviation.

Motorola T44A6A Conversion

Only commercial-grade crystals should be used for the receiver and transmitter. If your unit has a set of crystals for some commercial frequency, do not discard these as they may be sent to the crystal manufacturer along with your crystal order, to aid the manufacturer in correlating your new crystals. Using the same terms as before, the receiver crystal formula is:

$$F_o = \frac{F_{sig} - Mid.\ i\text{-}f}{42}$$

$$= \frac{446\ \text{MHz} - 8.845\ \text{MHz}}{42}$$

Several second-oscillator crystal frequencies were used in the T44 equipment. If you have a second-oscillator crystal in your receiver and want to know your mid i-f, subtract 455-kHz from the second-oscillator crystal frequency. It is possible to use any mid i-f from 8045 to 8945 kHz (second-oscillator crystal range from 8500 to 9400 kHz). Use the existing mid i-f in your unit, because it will save time in alignment of your receiver. If you have no second-oscillator crystal and do not know what your mid i-f is, simply select a new mid i-f in the previously-mentioned range, possibly 8845 kHz. You may have to realign the mid i-f to conform to the new second-oscillator frequency, unless you were lucky and chose the original mid i-f. The formulas show 446 MHz as the operating frequency. For others, insert your desired frequency in its place and work out the crystal frequencies.

Insert the first-oscillator crystal in the socket provided, apply power to the receiver and connect a 50-μA meter between pin 3 of the receiver test socket and ground. Locate L7 from the receiver layout and adjust its slug for maximum reading, which indicates crystal activity. Move the meter lead to pin 6 and peak T5, top and bottom slug. Insert meter in pin 7 and peak T4 and T3 (top, middle and bottom slugs in triple-tuned cans). Insert meter in pin 8 and peak L5 and L6. (Only one slug in each of these cans.) This completes the oscillator-multiplier tuneup, with the exception of Z302, which is a rectangular circuit near the front-end assembly. Z302 will be adjusted later.

Hold the afc switch in the OFF position. Inject a 69.4-MHz signal near the bottom of L1, and adjust the frequency of the signal to produce a zero reading on the discriminator metering position, pin 4 of the metering socket. Then move the meter to pin 2, adjust L2, L3 and L4 for

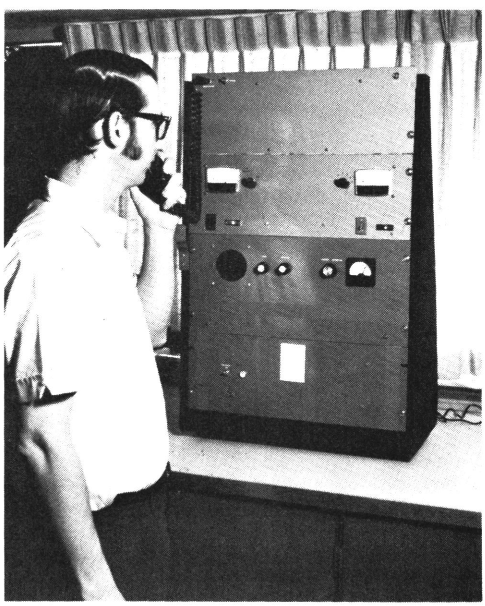


Fig. 11-48 – Here W1FBY tries local control of a 450-MHz repeater constructed using surplus transmitter and receiver decks from a Motorola T-44-AAV.

Fig. 11-49 – Motorola Test Socket Pin Identification

Receiver	*Pin No.*	*Transmitter*
Third i-f – Grid	1	Antenna rf Output
First Limiter	2	Oscillator V_1 Grid
First Oscillator Grid	3	Second Doubler Grid
Discriminator Output	4	Third Doubler Grid
Discriminator Input	5	Tripler Driver Grid
Multiplier – 1 Grid	6	PA Grid
Multiplier – 2 Grid	7	PA Plate
Multiplier – 3 Grid	8	PA Plate
Audio	9	Push-to-talk Relay Circuit
Audio	10	Microphone Audio
Ground	11	Ground

maximum. Also adjust L1 for maximum. Carefully reduce the level of injected signal to keep below saturation. Adjust T4 (top slug) for maximum. Release afc switch. Disconnect high i-f signal from receiver.

To align the receiver front end, hold the afc switch in OFF position. Apply an on-frequency signal to the receiver antenna terminal and make sure the discriminator reading is on zero with this signal applied to the receiver. As mentioned previously, you may have to insert a very high level of signal at first to get any reading on pin 2 of the metering socket, because of several mistuned stages. Adjust the applied signal level to obtain a reading of about 10 μA. Adjust Z301A, B, C, D for maximum reading. Reduce the signal level as needed, to keep from reaching saturation. Adjust Z302 (first-mixer injection) for maximum reading. Now go back over all rf and i-f adjustments and make sure each is still peaked properly, while injecting a weak signal (about one microvolt) into the receiver. A receiver sensitivity of less than one microvolt for 20-dB quieting is possible with this receiver. A good transistor or Nuvistor preamp will bring this sensitivity down to 0.3 microvolt or better.

Transmitter Alignment and Modification

To select transmitter crystal frequencies, divide the desired transmitting frequency by 24. Any amateur frequency you select will be lower than the original frequency; therefore all tuned circuits will be tuned lower, and of course all slugs turned farther in. Insert a 50-μA meter between pin 2 of the transmitter metering socket, J4, and ground. Put the transmitter-tune switch in the TUNE position (reduced voltage on tripler, driver, and final) until tuneup is complete.

A minimum reading of 20 μA should be observed with the transmitter on. This is an indication of oscillator crystal activity and there is no adjustment for this reading. Move the meter to pin 3, adjust L5 (first doubler plate) for maximum meter reading. Move the meter to pin 4, and adjust L6 and L7 for maximum reading. Move the meter to pin 5 and peak C26, L8, and L9. C26 and L8 are in the plate circuit of the 6146, and L9 is the coupling to the 2C39A tripler-driver. Move the meter lead to pin 6 (final grid), adjust Z1, Z2 and L11 for maximum. L11 is coupling loop to the final, Z1 peaks the driver circuit, and Z2 alters its length. Adjust Z2 to a setting that allows Z1 to be set at about 45 degrees, or about midrange. Some juggling will be necessary between Z1 and Z2.

Put the transmit-tune switch in TRANSMIT position. Move the meter between pins 7 and 8, to read the plate current of the final amplifier; about 16 μA is equal to 80 mA. Full output usually is obtained with a PA reading of 12 to 15 on the meter. Peak Z3, Z4, and L13 reading relative power output on pin 1 of the test socket. Output can be peaked up by going back through adjustments of the driver and final. Adjust Z4 to a position that allows Z3 to be at 45 degrees, or in its midrange. Access to Z2 and Z4 is through small holes covered by snap caps on top of the final and driver circuits. L11 and L13 likewise are accessible from the tops of the circuits. Set the deviation control for the desired swing. A good deviation setting on amateur frequencies is that where the first-limiter current on a nearby receiver does not dip when you modulate the transmitter.

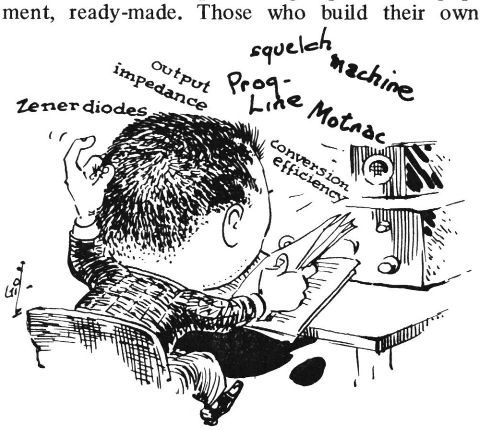
Remove the bottom cover of the transmitter. Locate Z5 circuit under the final and tripler assemblies. Disconnect leads to Z5 on input and output and connect a length of RG-58A/U coax in place of the Z5 circuit. This is done to eliminate the possibility of Z5 causing any restricted output. Repeak the final and set the transmitter on frequency by adjusting L1, near the transmitter crystal. Depending on your tubes, power output from 8 to 15 watts may be obtained from this transmitter. Replacing the selenium rectifiers in the power supply with silicon diodes will raise plate voltage and power output. Only a few watts output is necessary on 450 MHz to do a very creditable job.

Tips on Buying FM Gear

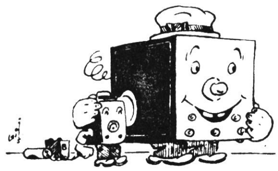
THE NEWCOMER to fm is often one of the most perplexed individuals to come hiking down the trail, at least when it comes to selecting his first fm equipment. It is unfortunate that so few amateurs are willing to build their own fm gear. Factory-built transceivers still lure many a prospective fm-er to the equipment counters of local ham stores, whereupon reasonably large sums of money change hands, and the happy amateur goes whistling off with his new gadget under his arm. On the opposite side of the flounder, the home-constructionist spends considerably less money, requires a bit more time to get on the air, but has a feeling of pride when his homemade equipment is finally putting out that "full-quieting" signal. There is much to be said both pro and con when discussing commercial gear versus homemade equipment. The decision is for the reader to make. Some of the hints and philosophies offered here may help the prospective fm operator to decide which course is best for him.

HOMEMADE EQUIPMENT

There is still a great deal of satisfaction to be experienced by the amateur who prefers to "do it himself." Aside from the increased knowledge one acquires when designing and building – or simply duplicating – there is the challenge of garnering the parts for a project. The latter is a facet of amateur radio which is enjoyed by some as much as is the act of operating. Seeing how many parts can be gotten through bargain hunting, substituting, and swapping, can truly be a monument to one's ingenuity and glibness of tongue. Additionally, it is often possible to build a rig for much less money than when purchasing equivalent equipment, ready-made. Those who build their own transmitters and receivers generally know much more about servicing the gear than do those who purchase "appliances." Further, the owner of home-built apparatus does not have to fear – a specter, indeed – spoiling the resale value of his factory-built equipment.



. . one of the most perplexed individuals . . .



. . solid-state gear is usually more compact . .

Homemade equipment can consist of tube or transistor circuity, or a hybrid mixture of both. The circuit used should be dictated by two things – how the gear is to be used (portable/mobile or fixed station), and by the amount of rf power the builder wants. A modern outlook is that transistors should be used in applications where they are as good as or better than vacuum tubes, at least in small-signal circuits. Integrated circuits should be considered in the same light as are transistors, of course, since they are all of the solid-state family.

The dividing line becomes significant when a certain rf power level is reached. Above, say, 50 watts rf power output (144 MHz and higher), tubes begin to look more appealing from a cost point of view. Ac power supplies for high-power solid-state transmitters become rather costly and sophisticated when they must provide the required high current for such units. Good regulation is essential, and the supply must be low in ripple and transient energy. A high-voltage power supply for use with tubes can be less expensive and less critical to build.

Solid-state equipment is usually more compact than is tube-type gear, it operates more efficiently, runs cooler, and has fewer break-down problems.

What Power Level is Best?

One could haggle forever over the question of power levels for use on vhf and uhf fm. Good judgement should be the rule – whether the rig is store-bought or home constructed. Those who are within the primary coverage area of a repeater can do very well from a fixed location with one or two watts. Less power is needed if a directional gain antenna is being used at the "base." It is well to remember that the repeater is most often located in a geographically ideal spot with respect to average terrain, so its height will make up for the power you may lack. Likewise, a few watts is usually ample for reliable mobile operation, assuming you're concerned mainly with the primary contour of the repeater's range. A properly adjusted repeater will "hear" about as far as it will be heard. If the mobile operator can barely hear the repeater, there is little advantage in having it hear his signal loud and clear. Therefore, if a power amplifier is added it is likely that a low-noise preamplifier will be needed ahead of the mobile receiver (if it does not already have one) to match the transmitting and receiving capabilities of the mobile unit. Some mobile operators feel it necessary to run 60 or 100 watts from the car, even when using a repeater two or three miles (or less) away. The folly of this is that it's a complete waste of rf and dc power. Worse yet, high-power mobiles very often key up more than one repeater at the same time, causing unnecessary QRM. FCC rules call for the use of only that amount of power which is required to effect and maintain satisfactory communications. So, if two watts will do it why run 100 watts? A satisfactory all-around power output level for mobiles is 10 or 12 watts under normal conditions. One can stretch this a point and say that 25 or 30 watts is suitable too, since many commercial two-way surplus transmitter strips are set up for that power class.

To enhance the useful range of a mobile station it is better to perfect the antenna system than to simply jack up the power output. A simple quarter-wavelength whip, clipped to the rain gutter of a car, is probably the worst radiator to use. A quarter-wavelength whip which is mounted in the center of the car roof is much better. A 5/8-wavelength vertical, placed on the trunk lid or center of the roof, is preferred by many operators. The latter has an *effective* gain of 3 dB over a quarter-wavelength spike, and will exhibit considerably less signal flutter or "picket-fencing" effect than will a quarter-wave whip. It is not unusual for a 2-watt-output 2-meter transmitter (mobile) to provide a completely readable signal through a repeater which is 25 or 30 miles distant, especially if a good antenna with minimum SWR is part of the system.

HOW MANY CHANNELS ARE NEEDED?

Another subject that can generate considerable controversy among fm operators is "How many channels should one's rig have?" A question like that is about as hard to answer as one which asks, "How much money should I have in the bank?."

If the operator does very little traveling, then equipping his transceiver for the primary local repeaters should suffice. If the operator is interested in fm for purely technical reasons, and wishes to experiment rather than ragchew, crystals for one local repeater will be enough.

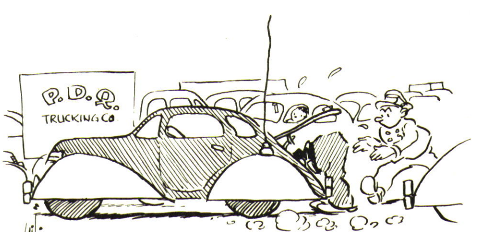
The newcomer to fm is frequently terrified at the prospects of having a crystal-controlled, or channelized station, especially if he is accustomed to operating in the hf bands with a tunable receiver and VFO-controlled transmitter. Therefore, he is tempted to purchase crystals for all of the popular channels across the country, only to learn later that he may never use some of them. Good crystals are expensive, and a synthesized rig is costly too. So, what's the best path to follow?

Some experienced fm operators advise that the beginner in fm equip his rig with the so-called national pairing of 146.34/146.94 MHz, thus being able to utilize a number of repeaters across the USA which use that combination. There is considerable repeater activity on 146.34/146.76 MHz, though this split-channel pairing (not 600 kHz in separation) is fast becoming obsolete through the good efforts of various frequency-coordinating committees. In some remote sections of the country there are no repeaters in operation, so simplex operation is popular there on 146.94 MHz and on 146.52 MHz. Therefore, transmitting and receiving crystals for those pairings might be handy. The remainder of the channel space in the transceiver can be used to hold crystals for one or more of the repeaters in one's local area. Transceivers equipped with concentrically-arranged switch shafts are the most popular because they permit utilization of several channel combinations with a given set of crystals (e.g., 146.34/146.94-MHz operation, and 146.34/146.76-MHz operation with a single 146.34-MHz transmit crystal). The important thing to remember when purchasing crystals is not to shop for bargains. Spend a little money and buy commercial-grade crystals ground to the specifications peculiar to the equipment in use. Good crystals will hit frequency and stay there. Inferior crystals seldom meet specifications, and tend to drift off frequency. Most repeaters will not accept a signal that is more than one or two kHz off the receiving frequency. Being off frequency will make your signal sound distorted, or worse, unreadable. Use quality crystals!

TRUNK-INSTALLED OR DASH-MOUNTED MOBILE RIG?

As far as pilferage goes, trunk-installed mobile gear is the safest. Most surplus two-way commercial radios are designed to be installed in the automobile trunk. They are bulky and lacking in eye appeal, so the trunk is the best place to put them. When using gear of this kind it is necessary to route large cables under the car and into the engine compartment for connection to the battery. Also, control wires must be brought from the trunk into the passenger compartment where they can be attached to the mobile radio control head. Aesthetically, at least, this type installation is best, for only the control head is visible.

Most of the small commercially built transceivers (American and foreign) are approximately the size of a cigar box and can be made to fit under



MOST SURPLUS TWO WAY RADIOS ARE DESIGNED TO BE INSTALLED IN THE TRUNK the dashboard. They have no remote-control heads, so it is almost mandatory that they be placed within easy reach of the operator. Radio equipment which is so located is tempting bait for a would-be thief, and plenty of gear is stolen when installed "up front." Various methods of locking the equipment in place under the dashboard have been contrived in an effort to thwart thieves. No system is foolproof, so one should ponder the foregoing remarks before deciding what type of installation will best serve his purposes.

SELECTING SURPLUS GEAR

One may wonder, "How good is surplus land-mobile radio equipment?" Let's look at it this way: if it was once in good operating condition, it can be restored to provide good service again. The redeeming feature of buying surplus transceivers is the moderate cost of these units. Solid-state surplus rigs are the most expensive – Motrans, Motracs, and such. Tube-type gear, depending on its vintage, can cost between $15 and $250 for the complete package . . . rig, cables, relays, and control head. Some of the 6-volt dc transceivers (early model G.E. "Pre-Progs" for one) are suitable for conversion to ac operation, and will give good base-station service. The 12-volt mobile units which use tubes may be equipped with vibrator, dynamotor, or "T" supplies (transistorized dc-to-dc converter supplies). The last of the three is the more efficient. The dynamotor is the biggest power grabber. So, here again, one must balance cost against efficient operation: the more modern the power supply, and thus the more efficient, the higher will be the price tag.

Surplus-Gear Features

Most of the commercial surplus available to amateurs was retired from land-mobile service because it did not meet current FCC specifications. That is, it was wide-band equipment (30 kHz i-f bandwidth), and because it did not provide the reliability (because of its age and wear) desired by fleet owners. Also, most of the older equipment was designed for single- or double-channel use, which is no longer adequate for some commercial services. Narrow-band operation (5 kHz deviation and a 10- to 12-kHz receiver i-f bandwidth) is now required in commercial service, and some of this narrow-band equipment has appeared as surplus. Most of the newer repeaters in the amateur service are narrow-banded, so surplus gear that meets that requirement is in great demand.

When buying surplus it would be wise to learn first what the bandwidth characteristics of the local repeaters are, then choose accordingly. A wide-band transceiver will work with a narrow-band repeater, but the audio recovery of the receiver will be poor. The transmitter can be adjusted to 5-kHz deviation by merely cutting back on the deviation control, so no problem in that regard. Some surplus houses sell narrow-band receiver filters, making it possible for the operator to modify a wide-band receiver by changing filters and making a few other minor circuit alterations.

The greater the channel capability of the surplus transceiver (number of crystal-controlled frequencies possible) the greater will be its cost. However, the amateur can "channel up" a single- or dual-frequency unit to meet his requirements if he is willing to build his own multifrequency decks for the transmitter and receiver sections of the rig.

Good audio quality is an objective that most amateurs appreciate. Carbon microphones can provide readable, speech-quality audio if the carbon element is in good condition, and provided the deviation amount (and crystal frequency) is properly adjusted. Many of the surplus transmitters come equipped with carbon microphones. Other units are designed for use with dynamic microphones. The latter will assure good audio fidelity, thereby making the signal more pleasant to listen to. It should be mentioned, however, that it is not difficult to add a speech amplifier for use with a dynamic microphone, and thus modify a carbon-mike input circuit for the purpose of improving the speech quality.

Some surplus equipment comes with crystal ovens for both the receiver and transmitter decks, while others do not use ovens (another consideration). Those living in areas where the year-around temperature does not vary significantly – Florida, Southern California, Puerto Rico, and the like – may be able to keep their equipment on frequency without the aid of ovens. In regions where temperatures change markedly with the time of day, or the season, ovens are highly recommended. Once the oven brings the crystal up to nominal temperature (usually within 5 minutes), the transmitter and receiver oscillator frequencies should vary but a hundred hertz or so above and below the nominal frequencies to which the oscillators have been set. The variance occurs as the ovens go through their heat cycles. Crystal ovens can usually be added to non-oven rigs if chassis space permits.

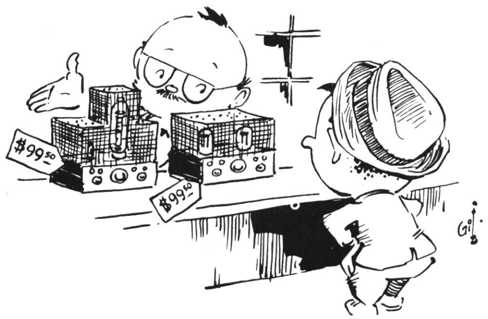
WHAT BRAND OF SURPLUS EQUIPMENT?

Each brand and model of two-way mobile gear has its good and bad features. Listing the faults and good points is far beyond the scope of this book. One of the best ways to make a decision is to ask the local fm-ers what they prefer, cost versus reliability and performance. The G.E. and Motorola equipment seems to be the most popular of the lot, nation wide, but some report good results with RCA and Delco equipment.

The quality of a given mobile transceiver becomes more critical when operation on 450 MHz is contemplated. Expensive tubes are generally used in the power stages of transmitters built for uhf operation. Therefore, the typical life span of such tubes is a matter of more than academic interest to the owner. Another consideration is that of frequency stability. Some uhf transceivers are extremely unstable, while others are reported to be superb. The latter is not so important a consideration if the 450-MHz repeater being used is a wide-band type (many are), but with narrow-band systems the frequency-control circuit must be a good one. G.E. Progress Line 450-MHz transceivers are very popular, and seem to provide reliable service when used in mobile applications. Many amateurs report good results with late-model Motorola 450-MHz equipment too, so the choice might best be made on the advice of local operators who have had personal experience with the various units. Your friendly two-way radio serviceman may be willing to offer some advice concerning which surplus rig to buy, so do not overlook that source of information.

IMPORTED EQUIPMENT

Because there are many brands and styles of imported amateur fm transceivers available in the USA it can be a difficult task to choose between them. Before purchasing a piece of equipment which has been designed and built outside the U.S. one should weigh the possibilities that he may face: (1) Where can the buyer receive service on the equipment? (2) Are the transistors and other parts used capable of being replaced by reasonable American equivalents? (3) What problems, if any, will be encountered in getting the warranty honored? (4) How long will the U.S. distributor carry the product line? (5) Has the circuit been designed to meet the engineering standards required by FCC.



. . it can be a difficult task to choose between them .

The foregoing points were not mentioned for the purpose of discrediting the manufacturers or distributors of imported fm gear. Rather, we want to bring the various possibilities to the fore so that the prospective buyer will be aware of the complications he might encounter. The resale value of discontinued equipment is very low, and this is but another matter to be pondered (situations of that kind have already taken place in the USA).

AMERICAN PRODUCTS

There are a number of American-made fm transceivers available in this country. Some are simply "spinoffs" of an existing marine-radio line, tuned for operation in the two-meter band. Most of the brands that fall in this category have been reviewed in *QST*, and have appeared in *QST* advertisements. Since these commercial transceivers were tailored to marine service, they are generally thought to be reliable and well engineered, and we have no reason to doubt that they are. Furthermore, they have passed FCC type-acceptance tests, assuring that spurious energy is well below the carrier level, that frequency stability is up to commercial standards, and that the hum level is within acceptable limits.* The foregoing is not assured in purchasing some foreign-made products.

Other American manufacturers of fm equipment have modified their land-mobile line for use from 146 to 148 MHz, and such units also meet FCC specifications. Interestingly enough, some of the American products under discussion cost no more than do the imported ones. For that matter, some are even *less* expensive! There can be comfort in the knowledge that the factory is in the U.S., and that parts can be obtained when replacements are necessary.

Circuit Features to Watch for

The prudent amateur, who plans to purchase a factory-built fm transceiver, should talk to others in the area about the virtues of the various rigs. Here again, personal experiences of others can help to guide the buyer. If a product line has a set of case-history troubles, avoid it. Of course, there are "lemons" in all product lines, be it automobiles, household appliances, or radio equipment.

Ask the dealer to let you study the schematic diagram of the set. Also, ask to see the inside of the transceiver so that you can inspect the workmanship. If facilities are available at the store, ask for a demonstration of the equipment.

When it comes to circuit features of importance one should determine whether or not the rf amplifier and mixer stages of the receiver use bipolar transistors or FETs. (Field-effect transistors offer better immunity to overloading and cross-modulation effects.) Check to see what the i-f filter bandwidth is – 10 kHz or 30 kHz. The narrow bandwidth is preferred in areas where there is a lot of repeater activity. The narrow filter will help to prevent spillover in the receiver from a repeater on a frequency closely related to the one you are listening to. Also, the narrow filter is required for best results when using repeaters with 5-kHz deviation.

Inspect the diagram to learn if a harmonic filter is used after the last stage of the transmitter. TVI and interference to commercial services will be less apt to occur if the transmitter contains a low-pass filter. This is particularly true if the last stage is solid-state.

Another important matter to consider is that of the receiver's limiting characteristics. A skimpy receiver circuit (a minimum number of stages) may not provide sufficient overall gain to assure proper limiting. Poor limiting will become evident when operating in areas where man-made noise is present. Since a properly operating limiter will clip amplitude-modulation peaks (noise pulses are of the a-m class), ignition noise and similar short-duration, high-amplitude pulses will not be heard in the receiver output. The receiver should have an rf stage ahead of the mixer, and several i-f stages ahead of the first limiter (or two or more high-gain IC stages) to assure good limiting.

* This is not to imply that FCC type-accepted equipment is required for use in amateur service, but rather to indicate the relative quality of the equipment and the high standards of engineering that have gone into it.

Inspect the circuit to see if the speech-amplifier section of the transmitter includes a clipper. Clipped and filtered audio is necessary to prevent over-deviation, and will assure that a high average level of audio reaches the modulator.

Two kinds of fm modulators are presently in vogue – varactor modulators connected to the crystal circuit, and phase modulators which follow the crystal oscillator. Which method is best may be a moot question, but many prefer the phase-modulation technique. Varactor modulators, if properly designed, can do a fine job of swinging the crystal frequency plus and minus the required amount to provide the needed deviation. However, some varactor modulators do not change capacitance linearly when the voice energy is impressed upon them. This leads to a dissymmetry of deviation, and therefore distortion. Furthermore, a varactor modulator can cause a poorly designed oscillator to swing out of oscillation on voice peaks, sometimes before the desired deviation amount is realized.

Audio Output and Speakers

A serious weak point in some mobile installations is that of insufficient undistorted audio output from the receiver. Because ambient noise levels in most automobiles are high (especially in summer when the windows are open) the mobile receiver should have a large speaker and at least 2 watts of audio output with no more than 10 percent distortion. The greater the audio capability the better. One of the important details to investigate before buying a transceiver is that of how powerful the audio channel in the receiver is. Inspect the speaker too, and don't settle for a 1-1/2- or 2-inch diameter internal speaker, unless there is a jack available that will enable you to use an outboard speaker of larger size. If the unit has a 3-inch diameter or larger speaker, check the size of the magnet. If it is tiny, chances are that it will not be capable of delivering high amounts of audio without causing distortion. In other words, if the receiver has a 5-watt audio channel and a 1-watt-rated speaker, the powerful audio will be of no value.

Protection Circuits

Damage can occur to the transistors in solid-state transceivers under certain conditions of misuse. The output transistors in the transmitter portion of the circuit can be destroyed if the antenna does not provide a proper load, or if the SWR is higher than, say, 2:1. Some modern transistors are able to withstand reasonable periods of mismatch (30 seconds to one minute, typically) if they are the ballasted or BET (balanced-emitter-transistor) variety. Regardless of the output transistor type, some kind of SWR-protection circuit should be incorporated in the design of the transmitter. Look for this feature before purchasing your equipment.

Check to see if the transceiver has a protection circuit to prevent damage to the semiconductors if the supply voltage (dc) is connected for the wrong polarity. Frequently, a large silicon diode is used in series with the 12-volt dc line which feeds the transceiver. The diode will allow the passage of positive voltage, but will block the flow of negative voltage if the operator mistakenly cross-connects the supply leads.

Make certain that the rf-amplifier transistor in the receiver is protected from large-signal damage. Most well-designed circuits employ a pair of high-speed switching diodes (connected back to back) between the input line to the rf amplifier and chassis ground. If the equipment does not have a protective circuit, one can add a pair of 1N914 diodes at the receiver input. Be sure to install the diodes on the receive side of the transmit-receive relay contacts.

WHAT ABOUT ANTENNAS?

Some mention about mobile antennas was made earlier in the chapter, and the recommended types were discussed. In selecting the antenna for use at home or on the automobile, look for good workmanship and ruggedness. The whip portion should be of stainless steel. If a 5/8-wavelength radiator is chosen, purchase one that has a spring-mount base. This type antenna will be approximately 46 inches tall, overall, with its base coil, spring, and whip section. The spring base will prevent damage to the antenna and car when the whip hits tree limbs and the like.

Some newcomers to fm attempt to use horizontally polarized mobile antennas – halos, big wheels, turnstiles, and such. Those antennas will suffice for operation in the primary signal contour of repeaters which use vertical antenna systems, but will fail miserably when used at distant points. The polarization loss will be very high, so invest in a vertical antenna.

When purchasing an antenna for fixed-station use it must be decided beforehand what kind of range is desired. In locations where one or more repeaters are nearby (30 miles or less), a 5/8-wavelength vertical, a vertically polarized half-wave dipole, or a quarter-wavelength ground-plane will often suffice. The antenna should be mounted as high as possible, and low-loss feed line should be employed. Operators who desire to use simplex channels for communicating with distant stations will be wise to purchase and install a beam antenna and rotator. An installation of that kind will be useful to those who are a long way from a repeater, or are obscured by land masses. A single 10- or 11-element Yagi, vertically polarized, will provide good results. A 16-element collinear antenna is the choice of many fm-ers for DXing the repeaters. The watchword in buying a directional antenna is to select one that is solidly constructed, can be properly matched to the feeder, and which can provide the gain it should for the number of elements and spacings used. Homemade beam antennas are usually less expensive than commercial ones, and can be fun to build and adjust. In addition to those described in this manual, *The Radio Amateur's Handbook, The ARRL Antenna Book,* and the *VHF Manual* all contain information on building vhf and uhf antennas.

Chapter 13

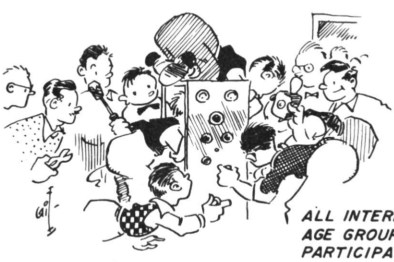
Repeater Club Organization

WHEREVER THERE are amateurs there should be an amateur radio club. Amateurs in an area operating without organized association with each other are not realizing the full advantages of information exchange and the fraternal spirit of amateur radio.

Our purpose here is to consolidate as much useful information as possible on organizing and operating a successful repeater club, based on ARRL's more than 50 years of experience. This information may be supplemented by lists of training aids, a sample constitution, and other items available directly from ARRL Headquarters, 225 Main Street, Newington, CT 06111.

ORGANIZATION

The membership of most repeater clubs includes many types of people. Ages vary from under 16 to over 60. While the older members are usually called upon for leadership and guidance, the younger members need "action." The key to a successful club is having all interest groups and age levels participate in club activities.



ALL INTEREST AND AGE GROUPS CAN PARTICIPATE

Every club experiences ups and downs in interest and activity. It is therefore of the utmost importance that a club organization be planned carefully and executed to effect a long existence.

Most clubs start out by a group of amateurs deciding to set up and operate a repeater for mutual benefit. The membership most likely will consist of amateurs interested in repeater operation not only from the technical aspect, but from the operating activity, and public interest points of view. Generally, the membership will be solicited from among those amateurs known to specialize in fm and repeater work.

If the club is being started by an individual (which is usually not the case) he will probably designate himself as a temporary chairman, send out post cards or circular letters to all possibly interested amateurs in the area announcing the meeting time of the first gathering. This procedure gets things started. If the initial steps of organization are taken by a group, one member should take on the responsibility of chairing the first meeting, but any announcement of a gathering should be signed by the entire group. The temporary chairman of the group should be the amateur who has the most experience and is best known, since this in itself will be a drawing card for prospective members.

Clubs are sometimes a result of a one-man operation growing beyond the control of a single individual whereby he starts the club to divide some of the responsibility and financial support of the system.

THE FIRST MEETING

The first meeting is very important because its tone may well decide whether the club will succeed or fail. It can be held in a school, a church, a Red Cross building or Civil Defense quarters, or even a restaurant. A private home can be used if one is available having sufficient facilities. Frequently, businessmen in a town may make their place of business available. The enterprising group should not overlook the possibility of using school and manufacturing plant auditoriums. In many cases, state government buildings have meeting rooms which might suit the size of the group quite well.

After a decision is made on where to hold the first meeting, send out announcements leaving plenty of time between the arrival of the notice and the meeting date. Always mention that those unable to attend, but who are interested in the project should notify the temporary chairman so that future activities can be passed along to the prospective members. Getting the word out is very important. If there is a local repeater, this is the place to get the best coverage for a meeting announcement. Bulletin boards in public places are helpful, particularly at schools and churches, and a notice at the local electronics supply store is desirable. Invite a member of the local press to "cover" the meeting; this could result in more publicity.

If a program, other than the humdrum business of getting things started, can be arranged for the first meeting, so much the better. Perhaps a talk or slide show about other repeater groups would be in order. It may help to draw attendance. Before any program is initiated at the first meeting, however, the business details must be completed. A set of temporary officers must be elected, and arrangements for drawing up a set of bylaws must be covered. Usually a temporary committee can be appointed by the chairman to handle the production of these initial governing documents.

The larger the first meeting is, the more formal it will have to be. But the meeting should not be stiff or stilted; it is much better to be somewhat informal while maintaining sufficient order to accomplish the original objectives of organization.

The objectives of the first meeting should be clearly stated at the beginning. First, an election must take place. Even if the election is for the purpose of selecting temporary officers, it should be the first order of business. In some cases, a large percentage of the members may be unfamiliar with one another, and electing permanent officers could be undesirable. Additionally, some of the persons attending the first meeting may be there for curiosity only. Although they may vote in the first election, the officers chosen may not be the ultimate choice of the permanent membership. Nevertheless, such officials are necessary to serve as a steering committee to get the club "off the ground."

Election of temporary officers or a steering committee can be accomplished in several ways. The most common way is to simply ask for nominations from the floor (requiring seconds), then voting either by secret ballot or a show of hands.

Another way that is often followed and is becoming increasingly popular because it encourages the more timid members to express their choice, is requesting everyone to write the name of his choice for each office on a piece of paper. The ballots then may be collected and tabulated. If any one person has a *majority* of votes, he is declared elected without further balloting. However, if none of the persons named receives a majority of votes, the two highest are then candidates for the final ballot.

Selecting a name for the club at the first meeting is not necessary. Again, the permanent membership should be allowed to make the choice, without influence from the casual attendee at the first meeting. But it never hurts to mention the point and ask all amateurs present to think about it. By the time the second meeting is held, some ideas should be available for consideration by the group, and a selection could be made at that time.

The ARRL Hq. has available a sample constitution which may be used as a guideline for a club. It is not intended that it be used directly, but only for assistance. Most clubs will have special circumstances which will require certain modifications of the League sample document. Some special requirements of a repeater club might cover dues payments, membership eligibility, special officers and posts, dates for elections, and terms of official positions.

In many situations, it is desirable to have a constitution, which covers the broad objectives of the club, and a set of bylaws, which are designed to be flexible (and a little easier to amend). As an example, a change in the bylaws could be a simple majority vote held at any meeting while changing the constitution normally takes acceptance by two-thirds of the full membership.

Drawing up the constitution and bylaws is the principal task of the temporary officers or steering committee. It must be done with the utmost care. The wording should be constructed to allow little doubt as to the meaning. A "legal" sound is not necessary. When the document is completed, it should be made available to the membership for comments before ratification. If it is felt that changes are necessary, the steering committee can do so. When the document is finalized, each member should be presented with a copy for review. A vote can be taken at the next meeting, or a mail vote can be authorized by the temporary chairman. When the constitution and bylaws are accepted by the membership, it is time to elect permanent officers and collect a nominal fee for dues. Among other things, this procedure eliminates those amateurs who are not seriously intending to join the organization.

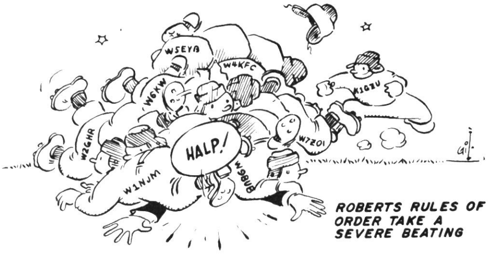
COMMITTEES

Certain club functions can be placed in the hands of standing committees. The constitution and bylaws should be specific and state the names of the committees, their functions, how many members shall serve, and how the members are selected. Examples of typical repeater club committees are finance, technical, business, planning, and program. From time to time, special committees are needed and the officers of the club can make special provisions to cover these. Standing committees provide an excellent means of keeping many members interested and active in club affairs.

MEETINGS

Most clubs meet on a regular basis. But this is by no means a key to success. In many cases, members are spread over such a large geographical area that regular (bimonthly) meetings present a hardship. For this reason, many groups hold get-togethers on an irregular basis, calling for meetings only when, in the view of the officers, it is necessary.

Meetings should be conducted in an orderly, but not too firm, fashion. *Robert's Rules of Order* take a severe beating at most club meetings. The important thing is to keep control of the meeting. If it gets out of control, nothing is accomplished.



ROBERTS RULES OF ORDER TAKE A SEVERE BEATING

When a member has the floor, no one should be allowed to interrupt him; if he becomes long winded, the chairman or president should call it to the speaker's attention. A meeting should not bog down because of procedural arguments. The chairman must keep order and should be allowed great latitude to accomplish this end.

When a guest speaker is attending a meeting as part of the program, it is courteous to keep the business portion of the meeting as short as possible. Generally, the membership wants to hear what the guest has to present, and the guest has no real interest in the business functions of the club. A skillfull chairman can cut through the earlier part of the meeting quickly, if adequate plans are made beforehand.

DUES AND FINANCES

Each repeater club has specific needs, and the financing program will have to be tailored to each situation. Some guidelines, however, are necessary if the club is not to falter. If the standing-committee system is employed, a finance committee is certainly desired. This group should consist of the club treasurer as well as a member or two from the technical committee. This group of amateurs is charged with the responsibility for accurately estimating the cost to operate the repeater and accessories, along with other incidentals, such as insurance, license fees, telephone service, rent, routine maintenance, and possible equipment updating. It is necessary to determine at the outset how the club is to acquire the revenue to pay the bills. If the number of club members is high, and the cost of repeater operation is reasonable, each member may be charged (in terms of dues) an equal share of the duty. Any additional funds raised by increased membership can be applied to the following year cost estimate (for a reduction in dues) or can be held in escrow for emergency. If the dues program is broken down into a quarterly plan, the finance committee can make adjustments in dues according to an updated plan developed during the operating season. The most important point here is that all members should pay an *equal* share, and that the amount of the dues should not exceed what most members are willing to pay. On the same hand, there is no reason the treasurer should pay out of his pocket for bills which the club treasury is not prepared to cover.

Collecting dues is a problem for any club. There are several techniques, each having distinct advantages and disadvantages. First, dues can be collected on a yearly basis. This program hits the membership with a relatively large bill once, and then it can be forgotten. Collecting this one large amount can be a chore for the treasurer, however! Once the member pays his dues, he can "coast" for the entire year – not a bad feeling to have among the membership.

An alternative method is to collect dues at every meeting. The advantage is obvious. But the disadvantage is that a member who has not attended several consecutive meetings is likely to shun a meeting since he knows it is going to cost money to attend. This does not help meeting attendance.

There is always some question as to the amount of dues that should be collected. It should be pointed out here that a large treasury is not necessary. Proper planning of repeater finances will allow the treasury to break even at the end of the year. If the treasury falls short, services of the repeater are compromised (or someone is paying out of his pocket!). If there is an overflow (allowing for small reserve) the members may have been overcharged during the year and objections (along with discontent) may be voiced.

Nonpaying members must be dealt with in a very diplomatic manner. The easier way to handle this facet of club operation is to insert specific rules about dues in the bylaws. Provision for action against members who become too far delinquent is desirable.

The costs for running a repeater can run into the hundreds and perhaps as much as a thousand dollars per year. If the membership is somewhat limited, the donation per member can get substantial. In some cases fund raising events to help bolster the treasury are helpful. Any club officer with imagination can develop several ways of generating funds. Auctions, prize drawings, donations, and social affairs all can be used as a method for providing supporting income. For many amateurs, taking a "chance" on a door prize, or attending a social affair run by the club is a much better expenditure than just paying out dues money for which there is no immediate or direct benefit.

CLUB PROPERTY

Generally speaking, a repeater club will own property – or at least be responsible for some property (equipment, tower, telephone, outbuilding, as well as real estate). Ownership of the equipment being used as a part of the setup should be defined clearly in the club inventory records. The secretary (or some other designated individual, perhaps a member of the technical committee) should be responsible for logging pertinent information on all equipment. It is wise to keep records on relative value, who owns each unit, serial numbers, and manufacturer. In the event there is a theft, accident, or termination of the club, there should be no question as to who owns what. If it is necessary to make an insurance claim, of course this information is quite valuable. It also may be wise to have a form letter available so that donations to the club may be documented by the donor for club records. Word-of-mouth transactions may become questionable when an appreciable amount of time passes!

OPEN AND CLOSED REPEATERS

Most repeater clubs will operate what is referred to as an "open" machine. Any open repeater is one which can be activated by anyone having the capability of transmitting on the repeater input frequency and receiving on the repeater output channel. Crystal-controlled receivers and transmitters are used for convenience and accuracy (or dependability) in determining the operating frequency.

The term "closed" refers to repeaters which require special methods of activating the input. Generally, a special tone on the repeater inpu frequency is required. The technical aspects of th type of operation are covered elsewhere in manual.

From the club point of view, there are several advantages to the "open" type of operation. Membership will not be limited to a few, but will encourage newcomers to become active with the local repeater and of course, eventually join the club. A "closed" repeater discourages new members.

Since the main function of a repeater club is to keep a repeater operating, it is understandable that the main concern of the club is to finance the operation. The larger the membership, the less the cost to the individual member. In a "closed" repeater setup, the membership will be limited and the cost of operation per member may be somewhat higher.

A closed repeater has the advantage of limiting the number of participants to a relatively small figure. The purpose for limited activity is usually based on the experimental aspect of operation in that a closed repeater group could be testing concepts, propagation, or any number of other specialized techniques. These experiments could be hampered from random use by amateurs not interested in the specific operation.

AFFILIATION WITH ARRL

Since 1919 it has been the constant aim of ARRL to maintain a bond of affiliation with local radio societies of kindred aims and purposes, since at different times in the League's history this has made possible unity of action and strength in representing amateur views successfully and forcibly in legislative and regulatory matters. Thus, affiliation is mutually beneficial, both to the club itself and to the national organization of amateurs of which it is a part.

Affiliation has a number of advantages, aside from the principle one of being a "member of the family." ARRL directors often depend heavily on club sentiment in their continued attempts to keep in touch with the viewpoints of the members in their divisions. Consequently, directors often visit affiliated clubs, as do members of the headquarters staff, in preference to non-affiliates. First call on items in the ARRL Film Library and other training aids is another advantage. The club gets numerous bulletins from headquarters. Each payment of ARRL membership dues through the club merits a 50 cent rebate to the club's treasury.

The process of affiliation is simple. The application forms (available from ARRL Hq.) consist of a questionnaire form and a "Resolution of Affiliation" form which must be acted upon formally by the club. The club also submits their constitution and a complete list of members, which are checked against the ARRL membership files to assure compliance with the 51% requirement. (In general, 51% of the club membership must be made up of licensed amateurs and 51% of the voting members must belong to the League.) Once these requirements are met, the application goes to the division director for approval. It is then held for the next meeting of the ARRL Executive Committee where affiliation is formally consummated. The club then receives a letter from the communications manager notifying it of affiliation and later receives a handsome charter of affiliation personally signed by the League's president.

The affiliation "kit" is available from ARRL, 225 Main Street, Newington, Connecticut 06111.

Operating Practices—FCC Rules

WIDESPREAD USE of fm on the vhf amateur bands began in the early 1960s with the appearance on the surplus market of used equipment from the land mobile services. This commercial equipment utilized crystal-controlled receivers and transmitters, push-to-talk, and squelch circuitry to cut off the receiver audio output in the absence of a signal. The "channelized" techniques were borrowed from the commercial user along with their gear. The result is a mode of operation quite different from past amateur custom.

Operating Procedure

For one thing, fm frequency (channel) designations are usually abbreviated in conversation; for example, 146.52 MHz becomes "five two." A repeater uses a *pair* of frequencies, of course – one input, one output. Repeater pairs are always specified with the input frequency given first. Thus a repeater receiving on 146.34 MHz and retransmitting on 146.94 MHz is referred to as 34/94 repeater.

Hand-held portables can be of enormous value in disaster work, especially when used with a repeater running on emergency power.

Some of the familiar old operating practices are discarded. You will never hear someone call CQ on an fm channel. To indicate that you are looking for a contact, simply press the microphone button and announce your call and the frequency you are listening on: for example, "This is KL7ELA, mobile 1, monitoring five two." If you require special help such as directions or highway assistance, indicate that as well. One of the advantages of fm is that there are usually several stations monitoring the local channels, even when they are quiet. They may not have time to engage in a casual contact when you call, but they will always render assistance if needed.

The best one-word description of good fm operating procedure is "concise." Long calls and monologues simply have no place in this realm of crystal-controlled, squelched receivers. Short, to-the-point transmissions should be the rule. This is not to imply that long, friendly conversations are necessarily frowned upon, except on the busier frequencies; it simply means that natural give-and-take dialogue is better than having stations take long turns transmitting at one another!

On cw, "concise" means lots of abbreviations, Q signals, and so on. On fm, it is almost always easier and faster to use everyday words rather than our peculiar ham dialect. For example, there is no point to asking "What's your QTH?" when "What's your location?" takes the same number of syllables, is technically more correct, and cannot be misunderstood. The RST system of signal reporting has no relevance on fm; with a good receiver, it takes only a couple of microvolts of signal to produce "full quieting" in the speaker, and such a signal is indstinguishable from one generated by the station down the block! If the signal is noisy, degrees of readability are better expressed as, for example, "90% copy" or "missed 10%" rather than a less-precise "Q3." If the signal has hum or faulty modulation, or is off frequency, these conditions can be described easily without resorting to a coded reporting system.

COMMONLY USED FM TERMS

Autopatch – Electronic device for interfacing the repeater with the phone lines.

Carrier Tail – Repeater carrier that remains after transmitting station stands by (must drop out in less than 5 seconds).

Channel – Operating frequency of the repeater, or frequency used by two stations communicating on simplex.

Circulator – Device used between the repeater transmitter and the duplexer or antenna to permit transmitted signal to reach the antenna, but to prevent signals coming down the feed line from entering the last stage of the transmitter (a one-way ferrite device to reduce IMD in the PA stage).

Closed Repeater – Repeater financed and operated by a group of amateurs for their private use. Nonmembers usually are not welcome.

Control Station – Committee member of the repeater group or club who is authorized by FCC to control repeater remotely by wire-line or radio.

COR – Carrier-operated relay. Controlled by signal-derived voltage in repeater receiver and used to activate and turn off repeater transmitter at the beginning and end of transmissions.

Cross Link – Interconnection of two repeaters or a remote receiver and a repeater transmitter by means of radio (generally on 450 MHz).

CTSS – Continuous Tone Squelch System.

Deviation – Amount of frequency swing of an fm carrier, plus or minus center frequency.

Down Link – Radio link that transmits repeater input signals down from the site to some remote point. Frequency must be above 220 MHz.

Duplex – Simultaneous transmissions between two stations using two frequencies.

Duplexer – Passive device used to permit the repeater receiver and transmitter to operate at the same time, and while employing a single antenna and feed line. Usually consists of several high-*Q* cavities.

Full Quieting – A receiver condition during which the received signal is strong enough to fully silence the internal noise of the receiver.

Hard Limiting – Receiver condition during which a further increase in received-signal level does not cause additional saturation of the limiter stage.

High Band – 148 to 174 MHz. Also, the two-meter band.

Intermod – Intermodulation distortion (IMD) in receiver front end or transmitter PA stage caused by nonlinear operating conditions. Causes spurious signals to be heard or transmitted.

Isolator – A Ferro-Magnetic device designed to isolate transmitters from each other or from a reactive load. Similar to circulator.

Low Band – 30 to 50 MHz. Also, the six-meter band.

Machine – Composite repeater station or remote base.

Narrow Band – Fm receiver or transmitter characteristic when adjusted for narrow deviation amounts (generally 5 kHz).

Open Repeater – Repeater available for use by any licensed amateur, club member or not.

Ovens – Voltage-operated heating element used to house transmitting and receiving crystals to maintain a relatively constant operating temperature.

Picket Fencing – Flutter on a mobile signal as the transmission path is blocked or reflected momentarily by trees, utility poles or other obstructions.

PL – Private Line. A Motorola trade name. Specific tone that must be transmitted to activate repeater. Receiver at repeater has sensing circuit that responds to only that tone.

Pre-Prog – Common term for GE equipment made before they developed the Progress-Line.

Prog-Line – Short for Progress Line, a GE trade name.

Remote Base – A remotely controlled station, usually operating on simplex.

Simplex – Alternating transmissions between two stations using the same frequency.

Split Channel – Repeater frequency pairing that is not 600-kHz in separation, or pairing that does not conform to accepted national pairings.

Squelch Tail – Noise burst transmitted by repeater between transmissions (normally less than one second in duration).

Squelch Relay – Another name for a COR.

Timer – Electronic or mechanical device at repeater which limits transmissions to 3 minutes or less. Resets only when signal disappears from input frequency.

Tone Access – Method of preventing a repeater from being activated unless a specific tone frequency is transmitted at the beginning of a transmission.

Tone Burst – Short-duration tone used to turn on tone-access repeaters.

Up Link – Radio link from remote point to repeater for purpose of controlling repeater or for communications.

Vault – Building used to house repeater.

Whistle-On – Another term for Tone Access.

Wide Band – Transmitter or receiver characteristic established for receiving or transmitting wide amounts of deviation (usually 15 kHz).

During periods of short exchanges, FCC regulations require that you identify your own station once every ten minutes and at the beginning and end of each contact. The call of the station you are working need be given only at the end of the contact. Full identification at the beginning and end of each transmission is unnecessary and wastes circuit time.

To break into a conversation, simply wait for the brief pause between transmissions and announce your call. Do not say "break" – this word is usually reserved for special situations. A single "break" means that time is critical for you. A double break (break-break) indicates that you have urgent traffic, such as a request for highway assistance. A triple break signifies an emergency situation, and is reserved for use when the safety of life or property is involved.

Repeater Operating

Operating through one of the hundreds of repeaters now on the air usually follows the procedures outlined above, but there are some features of repeater operation which require additional comment. The most obvious of these is that a repeater will usually have many more users than a simplex channel, so courtesy is even more important; more on this later.

The FCC-authorized purpose of any repeater is to extend the *intra-community* radiocommunication range of other amateur stations. Individuals and groups of amateurs install repeaters for different purposes, but the usual one is to increase the range of mobile and hand-held portable rigs. Operation through repeaters by fixed stations is actively discouraged by sponsors in some areas. Even where such operation is permitted, mobiles and hand-held portables have priority, especially during commuting hours when mobile activity is highest.

Many repeater installations provide access to telephone lines through an "autopatch" system. Such a system responds to audio tones generated by a telephone Touch-Tone pad connected to the user's rig. The utility of this feature of repeater operation is astonishing; for example, you can call the police directly from the scene of an accident without the need for an intervening operator. One word of caution, though; the use of an autopatch (or any amateur station, for that matter) for the conduct of personal business is not permitted under FCC regulations, and an operator who uses a repeater for this purpose is jeopardizing not only his own license, but also those of the repeater and control station licensees. Control stations must be especially alert for misuse of an autopatch, and must be prepared to shut down the repeater if a violation occurs.

For incoming calls via autopatch – that is, calls originated through the phone lines and directed to repeater users – the system must be arranged so that the control operator can intercept the call before it goes on the air. No incoming call – not even a signal tone – may be transmitted before the call is screened by the control operator. Otherwise, a licensed amateur is not in control of the transmission, which may interfere with communication already being conducted on the repeater.

The Touch-Tone pad is useful in other ways. Besides using it for initial access (see Chapter 8), many repeater systems have such features as an auxiliary input frequency, a link with another repeater, etc., which can be called into service with a Touch-Tone pad. It pays to become familiar with the features of the repeater you are using!

Maintaining a good repeater system can be expensive as well as time-consuming for the principals involved. Most successful repeaters are operated and financed by local clubs and it goes without saying that, if you are using a club's repeater, you should lend the club whatever support you can. While most groups welcome operation on their repeaters by amateurs visiting the area, this same welcome is usually not extended to freeloading local amateurs. Repeater clubs are discussed more fully in Chapter 13.

Above all, when using a repeater, remember that you are using someone else's station as well as your own, and your conduct reflects on him as well as you. Through a well-sited repeater, your one-watt mobile signal may be heard for over a hundred miles!

Courtesy and Cooperation

As in all amateur operating, courtesy is of paramount importance on fm. Where equality of right to operate is the guiding principle, some incidental interference must be expected; indeed, in many areas the repeater portions of the bands are saturated with fm signals to the point where interference is unavoidable.

Your repeater may have an output frequency identical to another some miles away, and you may have been there first, but this gives you no inherent right to interfere with their operation. There is *never* justification for operating deliberately in such a way as to disturb the communication of others. Similarly, amateurs should realize that interference on the amateur bands is seldom deliberate, and that the surest way to aggravate the situation is to accuse the other party of causing malicious interference! Very few differences are irreconcilable if both sides will get together in good faith and with a willingness to compromise.

While some fm frequencies are used infrequently, others – especially the popular repeater channels – are in constant use. On a busy frequency, there may be dozens of people monitoring or waiting to transmit; courtesy to them requires that transmissions be kept to a minimum. FM operating is similar to a party line telephone system, except that the fm "party line" users must listen to all of the conversations of the other "subscribers"! A station monitoring the frequency you are using has four choices: he can join your conversation, listen to it (often forcing his family to listen as well), change channels, or turn off his rig. This situation places obvious limits on the kinds of communication you can engage in.

The Communications Act of 1934 requires that all radio stations use the minimum power necessary to carry out the desired communication. In order to emphasize the importance of this principle in repeater work, the Commission has made it a part of the amateur regulations (Section 97.67(b)). Many fm rigs have low power modes (one watt or less) which can be used to meet this requirement for local work. In addition, common sense dictates that stations not run great amounts of power on repeater input frequencies, thereby keying up more than one repeater at a time or activating a distant repeater which cannot be heard locally. Stations able to communicate on simplex (single channel), especially fixed stations, should not tie up a repeater and deny its use to stations who may be unable to hear one another on simplex.

Hilltopping is an enjoyable tradition on vhf, but when the result is the simultaneous keying of two or more repeaters, the practice becomes selfish and undesirable. Also, the regulations emphasize the *intra-community* nature of repeater operation. If you want to work DX on fm, do it on simplex.

Repeater operators should be aware of their responsibilities with regard to using high power, and well-sited antennas. FCC has said that a repeater whose transmitting coverage is far greater than its receiving range would be in violation, even if it conformed to the limitations of effective radiated power spelled out in Section 97.67(c).

Frequency Coordination

On other modes, where vfo control is almost universal, operators are relatively free to move about the bands as they please in order to find a clear spot on which to operate. Even today, most fm rigs have a limited number of crystal-controlled channels available, on receive as well as transmit. The result is that it is inconvenient and expensive to be moving continually in an effort to find an interference-free frequency. This is especially true in the case of repeaters; a repeater output makes simplex operation on that frequency a virtual impossibility, while simplex operation on a repeater input ties up the machine unnecessarily. A repeater output on the input of a nearby machine would be the ultimate chaos! Also, whenever a repeater changes frequency, dozens of users must obtain new crystals for their rigs. It is therefore not only desirable, but just about mandatory, that there be some vehicle for regional agreements on the use of the band segments set aside for repeaters and fm. There are some regional associations of repeater groups which serve this purpose; other areas use less formal liaison methods. If you do not know who is the frequency coordinator in your area, check with ARRL headquarters. In any event, don't plan on using a particular frequency, either for a repeater or for specialized simplex work, until you have checked with other fm users in your area; they may have already agreed on a use for that vacant frequency you have your eye on.

The importance of solving interference problems by voluntary regional amateur cooperation cannot be overemphasized. The amateur service has flexibility unparalleled by any other, and freedom from specific frequency assignments, equipment type acceptance, and so on. But this very freedom carries a responsibility to do an effective job voluntarily, to obviate the need for government intervention.

TABLE 14 - I THE FM SPECTRUM

Band	*Freqs. for FM*	*Description for Use*	*Spacing (kHZ)*
28 MHz	29.55 — 29.70	Simplex; 29.60 most popular (29.45-29.55 reserved for satellites)	40
50	52.50 — 54.00	Simplex; repeaters. 52.525 national calling freq.; others begin at 52.60 (53.10, 53.20, 53.30, 53.40 53.50 reserved for model control.)	40
144	146.00 — 147.00	Simplex; repeaters (see Fig. 1)	30
	147.00 — 148.00	Simplex; repeaters (see Fig. 2)	30
220	220.30 — 222.00	Control links	40
	222.30 — 223.40	Repeater inputs; channels begin at 222.34, outputs 1.6 MHzhigher; in/out may be reversed, by regional agreement.	40
	223.40 — 223.90	Simplex; channels begin at 223.42; national calling frequency is 223.50.	40
	223.90 — 225.00	Repeater outputs (inputs 1.6 MHz lower)	40
420	420.00 — 422.00	Auxiliary links; channels begin at 420.05	50
	422.00 — 431.00	(Reserved for wide band modes: TV, simple modulated oscillators, etc.)	
	431.00 — 435.00	(Reserved for narrow band modes other than fm: cw, ssb, a-m.)	
	435.00 — 438.00	(Reserved for satellite work; control links and auxiliary links are prohibited.)	
	438.00 — 442.00	Control links; channels begin at 438.05	50
	442.00 — 445.00	Repeater outputs or inputs, by regional agreement; channels begin at 442.00 (output 5.00 MHz from input)	50
	445.00 — 447.00	Simplex; control links; channels begin at 445.00 (446.00 national calling freq.)	50
	447.00 — 450.00	Repeater inputs or outputs, by regional agreement; channels begin at 447.00	50

Band Plans

For the convenience of travelers and for the sake of uniformity, it would be best to have a national plan for the use of fm and repeater frequencies. A consensus has been reached on which portions of our bands are to be used for fm work (see Table I) and progress has been made toward standardizing repeater channels within the special repeater allocations, especially on two meters. The pattern of direct and repeater frequencies illustrated in adjacent Figs. 1 and 2 has gained widespread acceptance, with the exception that there is considerable simplex activity on 146.94 MHz in those areas where this frequency is not used as a repeater output. On the other bands, the regions with the greatest activity have achieved local standardization.

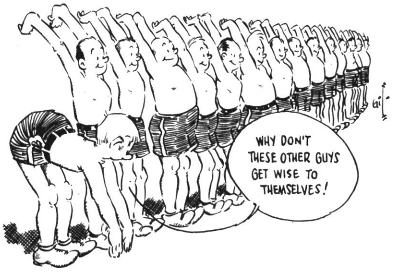
If you are planning to operate fm, your local standard must take precedence over the suggested national standard illustrated in Fig. 1, though it is hoped that variations from region to region will eventually be minimized. If you are unfamiliar with activity, obtain a Repeater Directory from ARRL headquarters and check the listings in your area. Details on how to obtain a Repeater Directory are at the end of this chapter.

Logging Requirements

The present FCC regulations concerning station logs are considerably less stringent than those previously in force. All amateurs should be familiar with revised sections 97.103 and 97.105. In fact, if you haven't looked at the regulations lately, you should; the changes which went into effect late in 1972 are a significant departure from previous Commission rules. The changes affected all amateur operation, and are not limited to repeaters or fm.

In addition to the call sign of the station and the signature of the licensee, each station is required to have the following information in its *written* log:

1) The signature of the control operator on duty and the call sign of his primary station. Note that in the case of a remotely controlled station, this portion of the log (and the rest of the written log, as a matter of convenience) will have to be entered at each control point.



. . the repeater using a non-standard pair . .

2) The location of the station. Mobiles may enter the word "local" when they operate within 100 miles of the address shown on the station license. Otherwise, the location of the station at the beginning and end of each day's operation must be logged. If you are required to file notice of portable operation under Section 97.97 (discussed in a subsequent paragraph) your log should indicate your compliance.

3) The *input* power to the final amplifying stage, the type of emission, and the frequency or sub-band used by your transmitter. The frequency entry should be specific enough to demonstrate that the operation was within the sub-band authorized for the control operator's class of license.

The following information is not required to be in written form, but it must be in a form which can be readily transcribed:

1) The dates of operation.

2) Except for repeater stations, the names of persons other than the control operator using the station, either directly or indirectly. Anyone who operates, or whose voice is transmitted by, your equipment, should have his name logged.

3) A notation of third party messages sent or received, including names of all participants and a brief description of the message content. This includes phone patches and informal traffic as well as formal messages.

4) The call sign of each station actually contacted, or other purpose of the transmission. If a transmission is made for testing or experimental purposes, your log should so indicate. Mobiles and repeaters are exempted from this requirement. Control stations enter the call of each station in the control link, and an auxiliary link station enters the call of its associated stations.

5) The time that the station is put into, or taken out of, service.

Logs must be preserved for one year and retained in the possession of the licensee. In the case of remote control stations, periodic forwarding of its portion of the remote station log to the licensee by each control station should meet this requirement.

Who Can Operate?

The revised Section 97.97 liberalizes the amateur regulations with regard to operation of a station by other than the licensee. The licensee need not be present; he may authorize any other amateur to be the control operator in his absence. The privileges authorized for the class of license held by the *control operator* determine the frequencies and modes which may be used; these may exceed those of the station licensee, provided proper identification is used (see below). In addition, any person may now participate in the operation of an amateur station, provided that a control operator is present and continuously monitors the communication.

Station Identification

Section 97.87 explains the exact requirements for the identification of an amateur station. You must identify *your* station at the beginning and end of each transmission or contact and at ten-minute intervals in between. You must identify the

Fig. 1 – 146 to 147 MHz standard direct and repeater frequencies. (A) 146.70 MHz is recognized nationally as an AFSK radioteletype calling and working frequency. This leads to the designation of 10/70 as a dedicated pair for radioteletype repeater use only. (B) 146.52 MHz is designated as the common direct and DX frequency. Repeaters and other automatic transmitting devices are never located on that frequency.

station you have contacted at the end of the contact. If you have been in a net or roundtable, you need only send the call of one of the stations in the groups, plus your own, at the conclusion of the communication.

If you visit the station of another amateur, you must use the call assigned to his station when you operate. However, you may operate to the full extent of your operator privileges. If you operated a Novice's station on fm, for example, you would send his call followed by your own: i.e. WN4XYZ/W4XX.

When operating portable or mobile, transmit your station call sign followed by the word "portable" or "mobile," as appropriate, and the number of the call sign area in which the station is being operated.

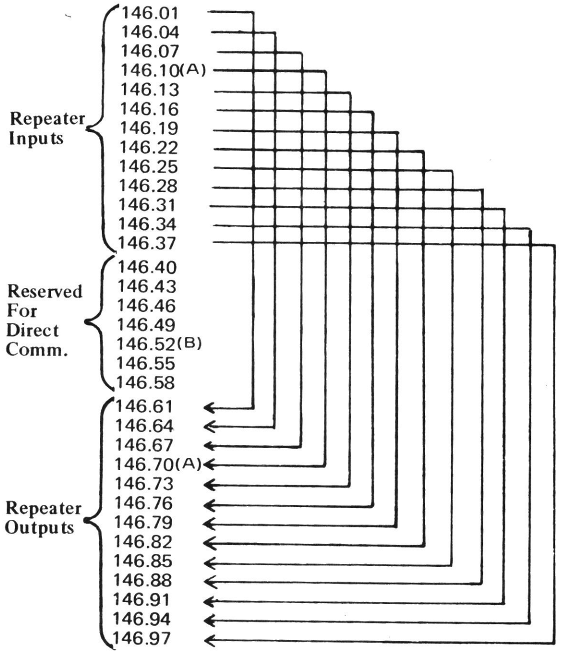
Repeaters must identify at least every five minutes while in service. The identification may be by telegraphy or or telephony, and it must be readable through the repeated transmission. If the identification is accomplished on telegraphy by automatic means, the code speed may not exceed 20 words per minute.

Additional Station Licensing

Each new and renewing amateur radio licensee is issued, in addition to his operator license, a primary station license. This license authorizes him to establish a station in a specified location, or to operate that station portable or mobile. If he desires, he may apply for *additional station* privileges in order to establish a permanent station in another location *(secondary station)* to conduct remote control of another amateur station *(control station)*, to automatically relay signals from one specific land location to another *(auxiliary link station)* or to automatically retransmit the signals of other amateur stations for the purpose of extending their intra-community communication range *(repeater station)*. Repeater stations are identified by calls beginning with the distinctive prefix WR.

All licensees should be familiar with Part 97 of the FCC Rules and Regulations. Applicants for additional station licenses (other than secondary station) and for any remotely controlled transmitter license should pay special attention to the following Sections (bold face indicates a Section which details a required part of the additional station license application):

Standard Direct and Repeater Frequencies



Standard Direct and Repeater Frequencies

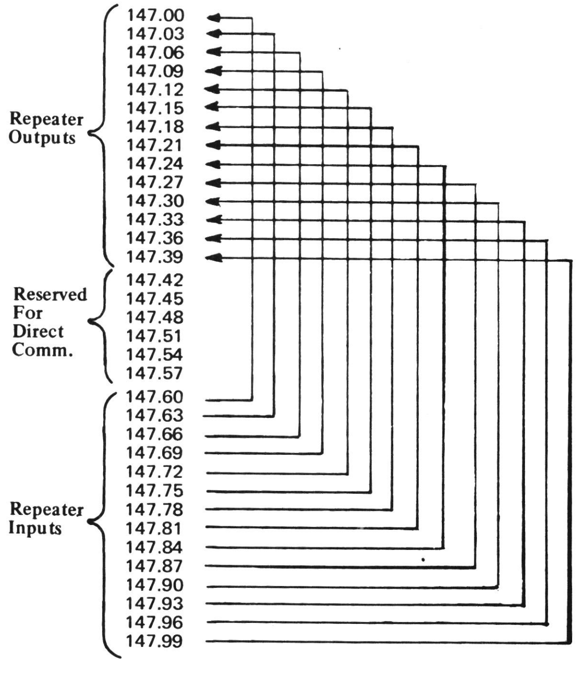


Fig. 2 – 147 to 148 MHz standard direct and repeater frequencies.

Any remote control license: 97.3(n), 97.3(o), 97.3(v), **97.41(c), 97.41(d),** 97.43, 97.47(d), 97.47(e), 97.108, 97.109.

Control station: 97.3(i), 97.3(v), 97.40(c), 97.40(d), **97.41(a), 97.41(b), 97.41(c), 97.41(d), 97.41(e),** 97.47(d), **97.67(b),** 97.87(f), 97.87(h), 97.89(d), 97.103, 97.108, 97.109.

Auxiliary link station: 97.3(i), 97.3(v), 97.40(c), 97.40(d), **97.41(a), 97.41(b), 97.41(c), 97.41(e),** 97.47(e), **97.67(b),** 97.87(g), 97.87(h), 97.89(d), 97.103, 97.110.

Repeater station: 97.3(i), 97.40(c), 97.40(e), **97.41(a), 97.41(b), 97.41(f),** 97.61(c), **97.67(b), 97.67(c),** 97.87(e), 97.87(h), 97.89(c), 97.91, 97.103, 97.108, 97.111, **Appendix 5.**

FCC has additional information available to help amateurs in the filing of complex additional station applications. Write: Chief, Amateur and Citizens Division, Federal Communications Commission, Washington, D. C. 20554.

Complete FCC Rules

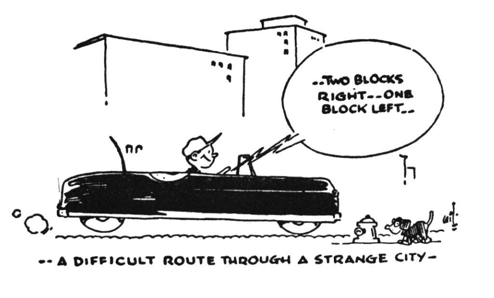
Complete amateur rules and explanatory comment are contained in the *Radio Amateur's License Manual,* available from ARRL, Newington, CT 06111, for $1.00, postpaid.

Mobile and Portable Operation

Whenever an amateur station is likely to be in portable operation at a single location for a period exceeding 15 days, the licensee must give advanced written notice to the FCC office in the district in which he is planning to operate. If this portable operation continues for a period exceeding one year or if any of the particulars of the original notice are changed, a new one must be filed. The notice must contain the following information:

1) Name of licensee.
2) Station call sign.
3) Authorized station location shown on license.
4) Specific geographical location of station when in portable operation.
5 Dates of the beginning and end of the portable operation.
6) Address at which, or through which, the license can be readily reached.

The regulations no longer require notification for mobile operation.



-- A DIFFICULT ROUTE THROUGH A STRANGE CITY -

The addresses of the 24 FCC district offices are listed in the back of the ARRL *Radio Amateur's License Manual.* Or you can obtain a form listing all of the information required for filing your notice from ARRL headquarters. Ask for form S-43 and enclose an addressed, stamped envelope.

Operating in Other Countries

Canada: U.S. hams holding a Conditional or higher class license can get permission to operate while in Canada. (Since there is no Canadian equivalent of the U.S. Novice and Technician Classes, holders of these licenses are not eligible.) You may request the necessary form (entitled *Application for Registration of Radio Station Licensee of United States of America)* from the Regional Superintendent, Telecommunications Regulation, Department of Communications nearest to the area of proposed operation: Vancouver, B. C., Winnipeg, Man., Toronto, Ont., Montreal, P. Q., or Moncton, N. B. The completed application should be filed with the same office at least 60 days prior to the date you will enter Canada. These forms are also available from ARRL headquarters. A reminder: if you will be away from home for more than 15 days, you must also notify the FCC Engineer-in-charge in your home district of your planned operation. (†97.95(6)(3), 97.97)

Canadians coming south can get applications from the Federal Communications Commission, Washington, D. C. 20554, or from ARRL headquarters. Ask for FCC Form 410. VEs also notify FCC Engineers in the districts in which operation is contemplated, in the same manner as U.S.

Other countries: Operating permission is obtainable by foreign licensees in many countries. It is *always* necessary to obtain the permission of the appropriate authorities of the host government before operating any amateur equipment, even low-power hand-held units. There are no exceptions! Details on obtaining operating permission in other countries appear regularly in the "IARU News" section of *QST*. If the information you need does not appear, write to ARRL headquarters.

In most countries outside the Americas, there is no six-meter amateur band and the two-meter band extends only from 144 to 146 MHz. Two meter repeaters are in operation in many countries, though the frequencies vary widely. In the larger cities, you may be able to obtain crystals for the local channels for the more popular equipment.

ARRL Repeater Directory

If you are planning a trip with your fm equipment, or if you are unfamiliar with repeaters in your area, obtain a Repeater Directory from ARRL headquarters. The directory lists area frequency coordinators, the addresses of the current ARRL Vhf Repeater Advisory Committee members, and details on all repeaters and remote bases registered with ARRL in the past year. To obtain one, send a 6 × 9 inch (or larger) addressed envelope with sufficient postage for three ounces of first class mail.

CANADIAN REPEATER RULES

The following are guidelines established by the Canadian Department of Communications. The licensee may designate up to three qualified persons to share the responsibility of controlling the amateur automatic repeater. Automatic shutoff is required after five minutes of continuous transmission, rather than after three. Repeaters in the 50-54- and 144-148-MHz bands have to be identified by a keyed-tone transmission at reduced amplitude at two-minute intervals, instead of every minute as before.

1. *General.*

As a result of a review of policy concerning the operation of repeaters in the amateur experimental service including point-to-point tandem operation, it was decided to permit the development of such repeater systems on a trial basis with the object of developing a firm policy at a later date. On the basis of experience and comments received to date and pending the incorporation into the regulations, the interim guidelines are revised to read as follows.

2. *Definition.*

1) An amateur automatic repeater is a station in the amateur experimental service providing for the automatic reception and retransmission of amateur radiocommunications.

2) For the purposes of these guidelines, the term amateur automatic repeater refers to "terrestrial" repeaters only and does not include "satellite" repeaters or "remotely controlled base stations."

3. *Responsibility of the licensee.*

1) Responsibility for the technical operation of an amateur automatic repeater lies with the licensee and shall include the maintenance of a technical log showing malfunctions, servicing and on-the-air tests, etc.

2) For purposes of continuity of operation and maintenance of more effective control over the repeater, the licensee may, in consultation with the local Telecommunications Regulation office, designate not more than three qualified persons to share with him the responsibility of controlling the amateur automatic repeater.

3) The licensee, or persons so designated by him, shall provide a means to automatically disable any repeater transmitter, regardless of frequency, when on-the-air time exceeds five minutes and shall be responsible for its reactivation by physical or remote control means.

4) Unless specifically authorized by the Department of Communications, the licensee of the amateur automatic repeater shall not permit the repeater to be used for the delivery of traffic to or the acceptance of traffic from external points by means other than radio.

5) Amateur automatic repeaters may be controlled by means other than radio where it is practical to do so.

4. *Identification*

1) All emissions from amateur automatic repeaters on 50-54 Mc/s or 144-148 Mc/s shall be identified by a keyed tone transmission of the station call sign at reduced amplitude at intervals not exceeding two minutes. Such identification is not required on point-to-point circuits between repeaters (above 220 Mc/s).

2) Users of the repeater shall continue to identify their respective stations in the usual manner.

5. *Frequency Bands Available.*

1) Amateur automatic repeaters shall transmit in the 50-54 Mc/s or higher frequency amateur bands.

2) Remote control emissions shall be within the 50-54 Mc/s or higher bands.

3) Point-to-point circuits between repeaters shall use the frequency bands 220-225 Mc/s, 420-450 Mc/s or higher frequency bands.

6. The Department of Communications will apply these guidelines to all automatic repeaters authorized after February 1, 1971 but will exercise discretion in applying them to repeaters authorized before that date.

SUGGESTIONS FOR COMPLETING FCC APPLICATIONS . . .

For Control Station
For Auxiliary Link Station
For Repeater Station
For Remotely Controlled Station

The basic application for any amateur station license is made on FCC Form 610 (Form 610-B for club or military recreation station). The following is a general description of the additional information required to be submitted for certain types of station licenses. The enclosures accompanying the Form 610 should be on 8-1/2 × 11-inch sheets, with each sheet bearing a heading identifying its content and the applicant's name, address, and telephone number.

TYPE OF STATION

On the Form 610, enter in item 5.E. after the words "Additional Station License," the type of license applied for: secondary station, control station, auxiliary link station, or repeater station.

SYSTEM NETWORK DIAGRAM

If the application is for a station having one or more associated stations, i.e. control station or auxiliary link station, it must be accompanied by a system network diagram. This diagram should be in the form of an outline map showing the location of each station, and the distance between stations.

REPEATER STATION

Repeater stations are identified by the distinctive call sign prefix WR. Suffixes will be issued in sequence beginning with AAA. Except for short tests, such a call sign may not be used by a station not operating as a repeater. Therefore, a separate station license is required for every repeater site.

It is no longer necessary to file information on height above average terrain, antenna configuration and effective radiated power with the application for a repeater license. Thus, the repeater antenna system can be changed at will by the licensee without notification to FCC. However, the information on these parameters must still be compiled and kept as part of the repeater station log, as required by Section 97.111(f), page 229. Whenever changes are made, the log should be updated. And effective radiated powers remain limited to the values shown in Section 97.67(c), also on page 229.

REMOTELY CONTROLLED STATION

Any form of control, other than direct electrical connection between the control device and the transmitter with all elements of the station on the same premises, is regarded as remote control. Submit the information required in Section 97.41(d). Include the name of the responsible person and the address for each control point. For radio remote control, photocopies of the control station and auxiliary link station licenses, or the applications for these licenses must be attached.

The process can be simplified by using one of the accepted ARRL Control Methods (July, 1974 *QST*). This information can also be obtained by sending a large, stamped, self-addressed envelope to League headquarters with your request for Repeater Licensing Package.

CONTROL STATION OR AUXILIARY LINK STATION

An existing station license (except repeater station) may be modified to include the privileges of control station or auxiliary link station, or a new secondary station license may be requested. The frequency band used for control must be above 220 MHz and must be specified in the application. The band 435 to 438 MHz is not available because of its international use for amateur satellites. Also describe the provisions for monitoring the transmitter frequency, if this frequency is in the 220 to 225 MHz band. Include an analysis showing that the minimum necessary transmitter power will be used in the control link. If remote control of an auxiliary link station is desired, submit the information required in Section 97.41(d).

STATIONS ON LAND UNDER U.S. JURISDICTION

Applications for stations to be constructed on land under the jurisdiction of the U.S. Forest Service, U.S. Department of Agriculture, or the Bureau of Land Management, U.S. Department of the Interior, must include the information required by Sections 97.41(b) and 1.70, the latter in Volume 1, Part 1 of the FCC rules.

PERTINENT EXCERPTS FROM FCC RULES

(NOTE: This information, presented as a convenience for readers, is accurate at press time. However, readers are urged to check later sources, such as the current edition of the *License Manual* and recent issues of *QST*, for changes.)

97.3 Definitions.

The following definitions are used in this part:

(i) *Additional station.* Any amateur radio station licensed to an amateur radio operator normally for a specific land location other than the primary station, may be one or more of the following:

Secondary station. Station licensed for a land location other than the primary station location, i.e., for use at a subordinate location such as an office, vacation home, etc.

Control station. Station licensed to conduct remote control of another amateur radio station.

Auxiliary link station. Station, other than a repeater station, at a specific land location licensed only for the purpose of automatically relaying radio signals from that location to another specific land location.

Repeater station. Station licensed to automatically retransmit the radio signals of other amateur radio stations for the purpose of extending their intra-community radiocommunication range.

(n) *Remote control.* Control of transmitting apparatus of an amateur radio station from a position other than one at which the transmitter is located and immediately accessible, except that direct mechanical control, or direct electrical control by wired connections, of an amateur radio transmitter from a point located on board any aircraft, vessel, vehicle, or on the same premises on which the transmitter is located, shall not be considered remote control within the meaning of this definition.

(o) *Control link.* Apparatus for effecting remote control between a control point and a remotely controlled station.

(p) *Control operator.* An amateur radio operator designated by the licensee of an amateur radio station to also be responsible for the emissions from that station.

(q) *Control point.* The operating position of an amateur radio station where the control operator function is performed.

(r) *Antenna structures.* Antenna structures include the radiating system, its supporting structures and any appurtenances mounted thereon.

(s) *Antenna height above average terrain.* The height of the center of radiation of an antenna above an averaged value of the elevation above sea level for the surrounding terrain.

(t) *Transmitter.* Apparatus for converting electrical energy received from a source into radio-frequency electromagnetic energy capable of being radiated.

(u) *Effective radiated power.* The product of the radio frequency power, expressed in watts, delivered to an antenna, and the relative gain of the antenna over that of a half-wave dipole antenna.

(v) *System Network diagram.* A diagram showing each station and its relationship to the other stations in a network of stations, and to the control point(s).

97.40 Station license required.

(a) No transmitting station shall be operated in the Amateur Radio Service without being licensed by the Federal Communications Commission.

(b) Every amateur radio operator must have a primary amateur radio station license.

(c) An amateur radio operator may be issued one or more additional station licenses, each for a different land location, except that repeater station, control station, and auxiliary link station licenses may also be issued to an amateur radio operator for land locations where another station license has been issued to the applicant.

(d) Any transmitter to be operated as part of a control link shall be licensed as a control station or as an auxiliary link station and may be combined with a primary, secondary, or club station license at the same location.

(e) A transmitter may only be operated as a repeater station under the authority of a repeater station license.

97.41 Application for station license.

(a) Each application for a club or military recreation station license in the amateur radio service shall be made on the FCC Form 610-B. Each application for any other amateur radio station license shall be made on the FCC Form 610.

(b) Each application shall state whether the proposed station is a primary or additional station. If the latter, the application shall also state whether the proposed station is a secondary, control, auxiliary link or repeater station.

(c) When an application(s) is made for a station having one or more associated stations, i.e., control station and/or auxiliary link station, a system network diagram shall also be submitted.

(d) Each application to license a remotely controlled amateur radio station, whether by wire or by radio control, shall be accompanied by a statement giving the address for each control point. The application shall include a functional block diagram and a technical explanation sufficient to describe the operation of the control link. Additionally, the following shall be provided:

(1) Description of the measures proposed for protection against access to the remote station by unauthorized persons.

(2) Description of the measures proposed for protection against unauthorized station operation, either through activation of the control link or otherwise.

(3) Description of the provisions for shutting down the station in case of control link malfunction.

(4) Description of the means to be provided for monitoring the transmitting frequencies.

(5) Photocopies of control station license(s) and auxiliary link station license(s), or the application(s) for same if such stations are proposed for the system network.

(e) Each application to license a control station or an auxiliary link station in the amateur radio service must be accompanied by the following information:

(1) The station transmitting band(s).

(2) Description of the means to be provided for monitoring the transmitting frequencies.

(3) The transmitter power input and justification that such power is in compliance with 97.67(b)

(4) If remote control of an auxiliary link station is proposed, all of the information required by paragraph (d) of this section shall also be provided.

(f) [Reserved].

97.61 Authorized frequencies and emissions.

(c) The following transmitting frequency bands and the associated emission authorized in paragraph (a) of this section are available for repeater stations, including both input (receiving) and output (transmitting):

(MHz)	
52.0 – 54.0	
146.0 – 148.0	
222.0 – 225.0	any amateur frequency
442.0 – 450.0	above 1215 MHz.

The frequency band 29.5 – 29.7 MHz may be authorized upon a special showing of need for repeater station operation in this band for intracommunity amateur radio communications.

97.67 Maximum authorized power.

(a) Except for power restrictions as set forth in 97.61, each amateur transmitter may be operated with a power input not exceeding 1 kilowatt to the plate circuit of the final amplifier stage of an amplifier-oscillator transmitter or to the plate circuit of an oscillator transmitter. An amateur transmitter operating with a power input exceeding 900 watts to the plate circuit shall provide means for accurately measuring the plate power input to the vacuum tube or tubes supplying power to the antenna.

(b) Notwithstanding the provisions of paragraph (a) of this section, amateur stations shall use the minimum amount of transmitter power necessary to carry out the desired communications.

(c) Within the limitations of paragraphs (a) and (b) of this section, the effective radiated power of a repeater station shall not exceed that specified for the antenna height above average terrain in the following table: [See chart next page]

97.88 Operation of a remotely controlled station.

An amateur radio station may be remotely controlled only from an authorized control point, and only where there is compliance with the following:

(a) The license for the remotely controlled station must list the authorized remote control point(s). A photocopy of the remotely controlled station license must be posted in a conspicuous place at the authorized control point(s), and at the remotely controlled transmitter location. A copy of the system network diagram on file with the Commission must be retained at each control point. The transmitting antenna, transmission line, or mast, as appropriate, associated with the remotely controlled transmitter must bear a durable tag marked with the station call sign, the name of the station licensee and other information so that the control operator can readily be contacted by Commission personnel.

(b) The control link equipment and the remotely controlled station must be accessible only to persons authorized by the licensee. Protection against both inadvertent and unauthorized deliberate emissions must be provided. In the event unauthorized emissions occur, the station operation must be suspended until such time as adequate protection is incorporated, or there is reasonable assurance that unauthorized emissions will not recur.

(c) A control operator designated by the licensee must be on duty at an authorized control point while the station is being remotely controlled. Immediately prior to, and during the periods the remotely controlled station is in operation, the frequencies used for emission by the remotely controlled transmitter must be continuously monitored by the control operator. The control operator must terminate transmission upon any deviation from the rules.

(d) Provisions must be incorporated to limit transmission to a period of no more than three minutes in the event of a malfunction in the control link.

(e) A remotely controlled station may not be operated at any location other than that specified on the license without prior approval of the Commission except in emergencies involving the immediate safety of life or protection of property.

(f) A repeater station may be operated by radio remote control only where the control link utilizes frequencies other than the repeater station receiving frequencies.

97.89 Points of Communications.

(c) Notwithstanding the provisions of paragraph (a), no more than two repeater stations may operate in tandem, i.e., one repeating the transmissions of the other, excepting emergency operations provided for in 97.107 or brief periods to conduct emergency preparedness tests.

(d) Control stations and auxiliary link stations may not be used to communicate with any other station than those shown in the system network diagram.

97.109 Operation of a control station.

(a) Amateur frequency bands above 220 MHz, excepting 435 to 438 MHz, may be used for emissions by a control station. Frequencies below 225 MHz used for control links must be monitored by the control operator immediately prior to, and during, periods of operation.

(b) Where a remotely controlled station has been authorized to be operated from one or more remote control stations, those remote control stations may be operated either mobile or portable.

97.110 Operation of an auxiliary link station.

(a) An auxiliary link station may use amateur frequency bands above 220 MHz excepting 435 to 438 MHz for emissions. Frequencies below 225 MHz used by an auxiliary link station shall be monitored by the control operator immediately prior to, and during, periods of operation.

(b) An auxiliary link station may only be used for fixed operations from the location specified on the station license, and only when its associated station(s) is operated from its authorized land location.

97.111 Operation of a repeater station.

(a) Emissions from a repeater station shall be discontinued within five seconds after cessation of radiocommunication by the user station. Provisions

Antenna height above average terrain	Maximum effective radiated power for frequency bands above:			
	52 MHz	*146 MHz**	*442 MHz*	*1,215 MHz*
below 50 feet	100 watts	800 watts	Paragraphs (a) and (b)	
50 to 99 feet	100 watts	400 watts	Paragraphs (a) and (b)	
100 to 499 feet	50 watts	400 watts	800 watts	Paragraphs (a) and (b)
500 to 999 feet	25 watts	200 watts	800 watts	Paragraphs (a) and (b)
above 1,000 feet	25 watts	100 watts	400 watts	Paragraphs (a) and (b)

*** Includes frequencies above 222 MHz.**

Section 97.67 (c) in part

to automatically limit the access to a repeater station may be incorporated, but are not mandatory.

(b) The transmitting and receiving frequencies utilized by the repeater station shall be continuously monitored by the control operator immediately prior to, and during, periods of operation.

(c) A repeater station may be concurrently operated on more than one frequency band. Crossband operation of repeater stations is prohibited, i.e. both input (receiving) and output (transmitting) frequencies for a particular repeated transmission must be within the same frequency band. Operation on more than one output frequency on a single frequency band is prohibited except when specifically approved by the Commission. Repeater stations authorized to operate in conjunction with one or more auxiliary link stations may utilize an input frequency in a different frequency band provided the input frequency of the auxiliary link station(s) is in the same frequency band as the output frequency of the repeater station.

(d) A repeater station shall be operated in a manner so as to assure that the station is not used for one-way radiocommunication other than provided for in 97.91.

(e) A station licensed as a repeater station may only be operated as a repeater station, excepting for short periods for testing or for emergencies.

(f) When in operation, the log of a repeater station must also show the following information for each frequency band in use.

1) Location of the station transmitting antenna, marked upon a topographic map having a scale of 1:250,000, and contour intervals.[1]

2) The transmitting antenna height above average terrain.[2]

3) The effective radiated power in the horizontal plane for the main lobe of the antenna pattern, calculated for maximum transmitter output power.

4) The transmitter output power.

5) The loss in the transmission line between the transmitter and the antenna, expressed in decibels.

6) The relative gain in the horizontal plane of the transmitting antenna.

7) The horizontal and vertical radiation patterns of the transmitting antenna, with reference to true north (for horizontal pattern only), expressed as relative field strength (voltage) or in decibels, drawn upon polar coordinate graph paper, and method of determining the patterns.

[1] Indexes and ordering information for suitable maps are available from U.S. Geological Survey, Washington, DC 20242, or Federal Center, Denver, Colorado 80225.

[2] See Appendix 5.

APPENDIX 5

DETERMINATION OF ANTENNA HEIGHT ABOVE AVERAGE TERRAIN

The effective height of the transmitting antenna shall be the height of the antenna's center of radiation above "average terrain." For this purpose "effective height" shall be established as follows:

(a) On a United States Geological Survey Map having a scale of 1:250,000, lay out eight evenly spaced radials, extending from the transmitter site to a distance of ten miles and beginning at 0°T (0° 45° 90° 135° 180° 225° 270° 315°T). If preferred, maps of greater scale may be used.

(b) By reference to the map contour lines, establish the ground elevation above mean sea level (AMSL) at 2, 4, 6, 8, and 10 miles from the antenna structure along each radial. If no elevation figure or contour line exists for any particular point, the nearest contour line elevation shall be employed.

(c) Calculate the arithmetic average of these 40 points of elevation (5 points of each of 8 radials).

(d) The height above average terrain of the antenna is thus the height AMSL of the antenna's center of radiation, minus the height of average terrain as calculated above.

Note 1: Where the transmitter is located near a large body of water, certain points of established elevation may fall over water. Where it is expected that service would be provided to land areas beyond the body of water, the points at water level in that direction should be included in the calculation of average elevation. Where it is expected that service would not be provided to land areas beyond the body of water; the points at water level should not be included in the average.

Note 2: In instances in which this procedure might provide unreasonable figures due to the unusual nature of the local terrain, applicant may provide additional data at his own discretion, and such data may be considered if deemed significant.

INDEX

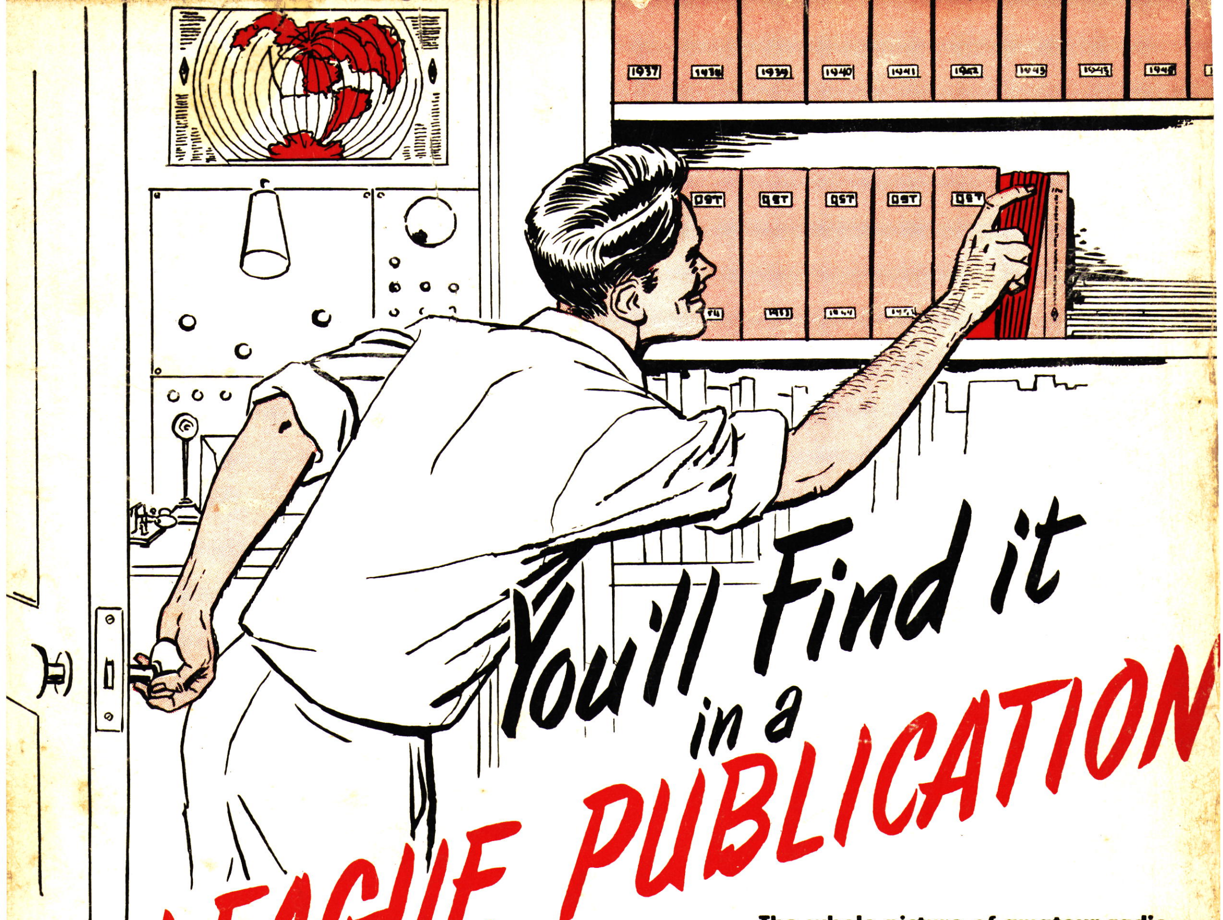
Charts and Tables

A

B

C

D



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