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RADIO AMATEUR'S

F-M REPEATER

HANDBOOK

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Preface

F-m is rapidly becoming to vhf what ssb was to the high frequencies a few years ago. The unprecedented trend toward f-m by amateur radio operators (particularly those from the vhf ranks) has surpassed even the ability of writers to keep pace, with the result that newcoming f-m amateurs find themselves in the thick of a whole new world of communications—but without a reliable technical-information source.

This handbook is no panacea by any means, but it does serve as a good "jumping-off" point. It contains information that will prove invaluable to the f-m'er who intends to participate in a project involving a repeater, an even more awesome and undocumented aspect of amateur radio.

Nearly all metropolitan areas in the United States and Canada are active around two-meter repeaters, or relay stations, that automatically retransmit signals that are heard on a set frequency. An attempt at standardization has enabled the f-m'er, who typically operates through a repeater in his own area, to travel to other states and retain the usefulness of his equipment. Since not all cities have repeaters, an f-m'er who wants to get the most out of his equipment will select an f-m unit with two-channel transmitting capability. In this way, we will probably be able to use existing repeaters or operate straight point-to-point.

Although most amateur f-m stations use the 12-kHz standard (wideband), increasing numbers of them are switching to narrowband, which uses a standard deviation of 5 kHz. There are many arguments by proponents of both standards, but it is safe to say that neither exhibits any significant advantage over the other. Wideband commercial radio equipment is somewhat easier to come by because it is older and can be acquired on the surplus market. In areas where two standards are in vogue (wide and narrow), f-m'ers often can reach a compromise by lowering the deviation of the wideband units and stretching the deviation of the narrowband rigs.

This is f-m as it is today. In the near future, this will no longer be applicable, because the world of f-m is in its infancy. This book shows the ways in which f-m as an amateur mode is developing, and describes the means by which you can participate in this growth. You will find f-m as exciting today as the galena crystal was yesterday, and as challenging as the science of tomorrow.

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Acknowledgements

This handbook is something that had to be written—if not by me, then by someone else. I have a list of amateurs who helped make this book happen faster. Their interest and response turned the task of preparation into what could almost amount to a community project. A few of them—there just isn't the space to list them all—are listed here.

A sort of extra special credit goes to my friend Don Milbury, WA6YAN. He was the prime impetus when the text bogged down. He provided me with a vast storehouse of valuable information by feeding me information on everything imaginable in communications from his bountiful files. He was my silent editor, with whom I argued (sometimes violently), pleaded, and generally ultimately agreed. Not a single page was considered finished until it had been blessed by this man. Unhappily, he was always right.

And finally, a very special and deeply personal acknowledgment is due my good friend and associate Mike Van Den Branden (WA8UTB) of Grosse Pointe, Michigan. With little acclaim and no fanfare whatsoever, Mike acts as the brains and muscle behind FM, the monthly magazine from which originated a goodly portion of the ideas and concepts appearing in this book. Mike carried his magazine unstintingly through its expensive and lean years, never losing faith in the growth of that segment of amateur radio in which he was most interested. He may not have been the first to realize that f-m and repeaters were here to stay. But he WAS the first to do something about making it happen that way!

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Contents

CHAPTER 5

CHAPTER 6

APPENDIX 1

APPENDIX II

APPENDIX III

Chapter 1

Introduction To Repeaters

If it can be said that amateur radio, like civilization, is characterized by eras, it must then be admitted that vhf amateur radio is at the dawn of the age of repeaters. Over the past few years more and more vhf amateurs have become inquisitive about police agencies, taxi companies, and ambulance services. How do these municipal services manage to get virtually 100-percent communications reliability anywhere in the city? The amateur, regardless of the extent to which he optimizes his mobile installation, always finds "dead spots" where his receiver cannot seem to overcome the noise to pull in copyable signals. He may be in the same general frequency range as the city police, and he may be using a more sensitive receiver. His radio contact might be physically closer to him than the city dispatcher is to the police vehicle; yet, the police vehicle gets loud, noise-free signals every time. Why?

1-1. WHAT IS A REPEATER?

The answer is usually the fact that the police, taxi company, or any other agency requiring high-reliability communications, is using a **repeater**—an intermediary transmitting and receiving station designed to relay signals automatically to and from mobile units **regardless of their physical location in a given area.**

When a mobile unit depends on a repeater for communications, its transmit and receive frequencies are usually separated by at least several hundred kilohertz. The mobile unit normally transmits on the lower frequency. The signal is received at the repeater, and is retransmitted simultaneously on the higher frequency. Thus, the mobile unit in a low-signal area is afforded the same basic signal-producing capability as the repeater station.

The system works the same in reverse. Signals from other mobiles or the police dispatcher are received and retransmitted by the repeater, so the poorly situated mobile can pick them up anywhere within the usable range of the repeater.

A vhf repeater system allows a much greater total radio range than a conventional vhf simplex system, but it is a great deal more expensive because the user must set up an automatic relay in a tall building or on a nearby hilltop. A repeater takes advantage of height to circumvent the unfortunate principle that radio signals degenerate rapidly with distance when the path between communicating stations is not "line-of-sight." The criterion of performance with a repeater is thus based on whether or not the communicating stations are within a straight line-of-sight path to the repeater itself.

Repeaters normally employ very-high-gain omnidirectional antennas so that very little of the signal is radiated upward or downward and a maximum signal is radiated in all directions at an angle parallel with the ground. Repeaters use receivers that are characterized by superior sensitivity, a high degree of selectivity, and well-aligned intermediate-frequency stages for maximum intelligibility under all signal conditions.

Amateur radio vhf operators have found that installation and maintenance of a repeater is not nearly so formidable a project as it might at first sound. A cooperative effort—as by a local radio club or any group of participating amateurs—not only reduces the expense, but it increases the chances of a repeater's ultimate success. Where one amateur may vainly try for months to acquire a suitable site to mount a repeater, a recognized body of amateurs might find immediate success. The landowner or penthouse lessee who eventually allows his property to be used for a repeater will likely be immune to the requests of a single individual. But when asked by a group, he may be public-spirited enough to feel that he will be contributing something to amateur radio in general.

1-2. REPEATER TYPES

An amateur repeater can be shaped into any one of a variety of system concepts, but there are only two basic categories of deployment: open and closed. An open repeater is one which has been installed for the benefit of all who wish to use it for communications; a closed repeater is one which is designed to selectively benefit a specific group of users. Both types are in widespread use throughout the United States. Most popular open repeaters are vhf/a-m (continuous transmit) and vhf/f-m (carrier-operated).

VHF/A-M Open Repeater

The typical vhf/a-m open repeater continuously transmits on a given frequency even though there may not be intelligence on the carrier. With this type of repeater, the audio portion of a continuously operating receiver monitoring an adjacent "input" frequency is coupled to the repeater transmitter. All signals "heard" by the receiver portion of the system are thus automatically relayed by the transmitter.

This type of open repeater has certain advantages, but suffers from the disadvantage that the transmitter wastes power by operating even during periods of non-use, thus shortening the lifespans of the transmitter components and needlessly consuming expensive commercial power. The advantages in some instances, however, outweigh these drawbacks. As an example, the continuous transmit signal is a ready indication of the repeater's output frequency. If mobiles within useful range of the repeater can tune in the signal, they can be fairly certain of being heard by the repeater receiver. The steady signal also serves as an indication that the repeater is operational. Without it, the repeater input and output frequencies might find themselves in frequent use by unsuspecting amateurs during crowded band conditions.

Vhf/a-m open repeaters have come to be heavily relied on in many metropolitan areas. Many amateurs need the repeater to relay signals into and out of some poor-signal area. Others, who may be reluctant to run more than a moderate amount of power because of the possibility of television interference problems, like to reduce transmitter power to just the amount required to operate through the repeater. There are as many reasons for using repeaters as there are amateurs who operate through them, and they are all equally valid. As a result, the vhf/a-m open repeater has established itself as a vital part of American amateur radio.

One of the most well known a-m repeaters of the open type is the K6MYK facility in Los

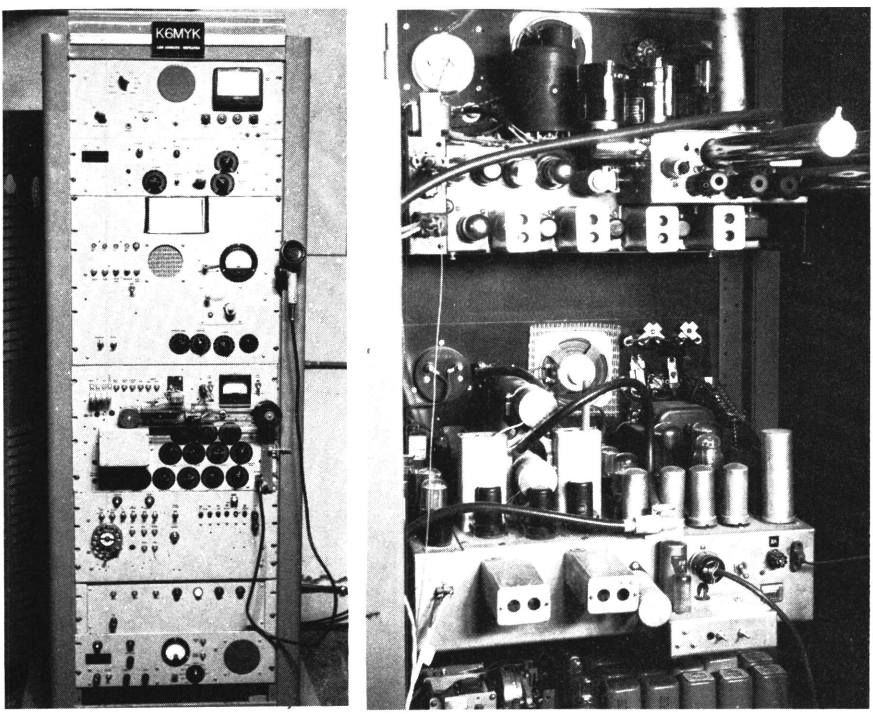

Fig. 1-1. K6MYK remote receivers and control equipment. The Mt. Lee site includes a-m repeater receiver for two meters and f-m control receivers on 220 MHz and 450 MHz.

Angeles (Figs. 1-1 and 1-2). Established by Arthur Gentry in 1956, the system has been in more-or-less constant use by two-meter a-m operators since then. The K6MYK repeater situated on Mt. Lee provides coverage throughout the greater Los Angeles basin, an extended area covering more than 600 square miles. Local amateurs rely on the reliable repeater output not only for individual communications, but for periodic "one-way" broad-

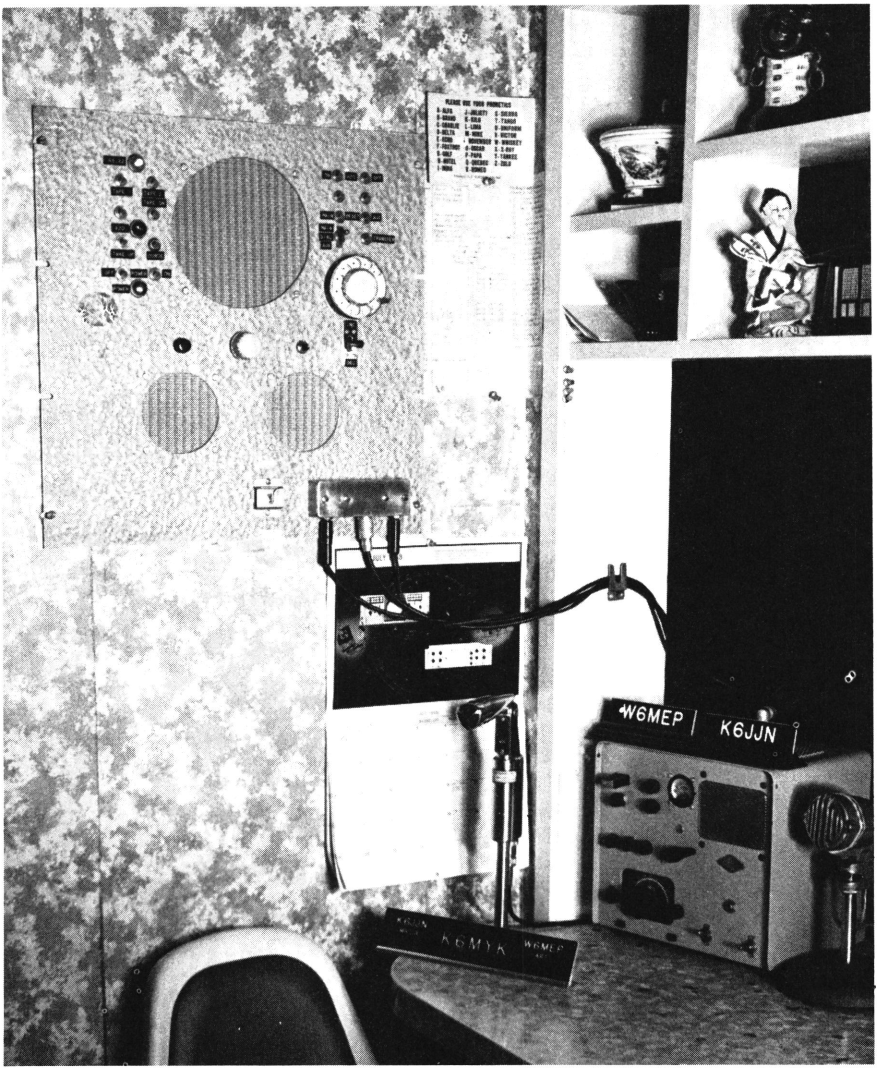

Fig. 1-2. K6MYK "Kitchen Kontrol." Uhf station at control point (W6MEP's kitchen) includes built-in command and control circuitry, as well as a two-meter a-m transceiver for monitoring the a-m repeater output. Microphone at the left of the *Gonset Communicator* allows voice access to the repeater from uhf control frequency.

casts of bulletins and messages from various agencies and groups directed to all radio amateurs. K6MYK receives on 146.98 MHz with a bandpass of about 12 kHz, and transmits on 145.22 MHz. The average transmitter input power is 20 watts.

The VHF/F-M Open Repeater

An ironic fact is that there are a great many more f-m repeaters in use today than a-m types—in spite of the fact that a-m operators outnumber f-m operators in the vhf bands by about 20 to 1. As it happens, f-m lends itself particularly well to this application, and a repeater "project" is a very natural development in the evolution of local f-m activity.

Frequency modulation is a completely different concept of operation from what the typical amateur is accustomed to. Gone are the vfo's and tunable receivers, the QSL's and hissing speakers. Instead, the f-m'er uses crystal-controlled transmitters and receivers. He operates the same frequency (or channel) day in and day out, and finds himself conversing with the same individuals regularly on an "intercom" basis. His receiver is squelched so that the speaker never functions until a signal appears. The f-m amateur might not like to admit it, but his mode of operation closely resembles that of a typical Citizen's-Band station.

When a group of individuals find themselves in more or less constant touch with each other, they often become better acquainted than might their a-m or ssb counterparts. And this acquaintanceship generally leads to cooperative "club" ventures such as a combined effort to install a repeater for the members' mutual benefit.

For the a-m and ssb amateurs, use of a repeater calls for a change in operating habits. The long-winded ragchewer makes few friends when there are a dozen others waiting to use the frequency. And a vfo can be more of a hindrance than a help when the operation is restricted to a critical slice of spectrum no wider than that of a healthy signal.

But the f-m amateur has the operation down pat, even without a repeater. His transmissions are usually short because he knows that his listeners are all crystal-controlled. They don't have the capability of shifting to another frequency. He knows he must stop transmitting before someone else can begin. The f-m operating procedure will remain virtually unchanged, whether a repeater is being used or not.

A vhf/f-m open repeater, like the a-m type, is usually positioned at a sufficient altitude to provide greatly enhanced range and coverage over what might be obtainable by an ordinary base station or mobile unit. The primary difference between the a-m and f-m types is the fact that an f-m open repeater is virtually **always** carrier-operated. This means that the repeater transmits **only** with an incoming signal. When the incoming signal disappears, there are no clues as to the existence of an operational repeater (other than the distinctive "squelch tail," a characteristic short sound denoting recovery of the repeater receiver).

The increasing prevalence of open f-m repeaters on two meters across the country has resulted in a fairly standardized pair of frequencies for repeater input and output. The frequency of 146.34 MHz has been unofficially adopted as the "national repeater input channel," although there are admittedly a great many successful repeaters using other inputs. The frequencies of 146.94 and 146.76 are fighting for first place as the national repeater output channel. Along the eastern seaboard, and along the northern Pacific coast, 146.76 is gaining favor; elsewhere 146.94 MHz has the edge. Here, too, there are a number of "maverick" repeaters whose frequencies were selected without apparent rhyme or reason.

An f-m open repeater output will almost always take the form of one or the other of two basic operational concepts: It will be used as a channel **talkback** or as the channel **prime.** The differences are subtle but very significant. The talkback repeater is set to monitor a popular active f-m channel already in existence; in this application, the output is usually on a seldom-used channel in an inactive portion of the band.

The prime repeater, for some reason, is the more popular. It accepts signals from a nearby off-channel and retransmits them on an established frequency that may or may not be already populated. Typical of this type are the 146.34-to-146.94 MHz repeaters in current vogue. A none-too-gentle controversy smolders continuously between the proponents of 146.94 as a national point-to-point channel and the advocates of it as a repeater output. The chief problem with prime repeaters is that they cause an endless variety of signals to be dumped onto a channel that may be in more or less constant use by amateurs not using the repeater.

One of the more heavily publicized (and extremely successful) prime repeaters is the "Loud Voice of Tulsa," WA5LVT, installed at a local TV station as a cooperative effort on the part of the Tulsa Repeater Association. WA5LVT (Figs. 1-3, 1-4, and 1-5) serves as a dual repeater system in that it consists of two complete repeaters operating simultaneously, one in the six-meter band and the other on two meters. The six-meter repeater relays wideband f-m signals from 52.68 MHz to 52.525 MHz. (This output frequency is a nationally adopted wideband amateur f-m channel.) The two-meter portion of the system is the traditional 146.34-to-146.94 type. Like many other successful joint repeater efforts, Tulsa's WA5LVT is maintained from the dues of its more than 80 subscribers.

An example of a typical talkback repeater is W6FNO, located at 3300-foot Radio Ranch in the hills outlying Los Angeles. This repeater was installed in an area where a great many f-m channels are in almost constant use. Since a prime repeater in such a situation would only serve to create a chaotic mass of interference, the repeater "co-op" elected to choose an inactive channel for the output. In this way, channel inhabitants are already operating on the repeater input. With an investment of no more than it takes to buy a new crystal any operator can, at his option, take advantage of the "big ear" on the hill.

The Radio Ranch repeater accepts signals from the active local AREC channel of 146.82 MHz, and relays them to the inactive channel of 146.70 MHz. To make sure the repeater is used only when needed, the designers have included a unique "whistle-on enabling system.

Fig. 1-3. A transmitter antenna atop one of the highest buildings in the city makes WA5LVT the "Loud Voice of Tulsa."

To energize the repeater initially, an operator on 146.82 MHz must simply whistle a short note that encompasses an audio frequency of 1700 Hz. When this has been done, the repeater operates on a 100-percent carrier-activated basis for as long as the channel is active. When no carriers appear on the input channel for two minutes, the repeater shuts down completely and must

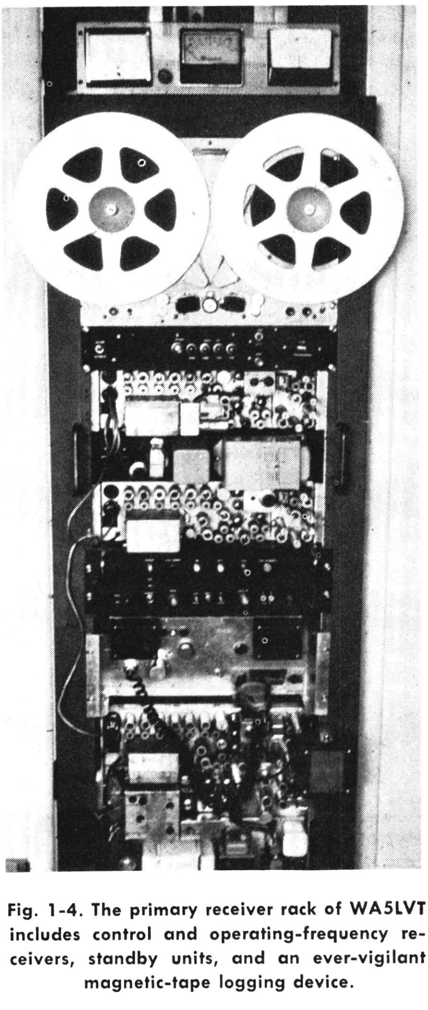

Fig. 1-4. The primary receiver rack of WA5LVT includes control and operating-frequency receivers, standby units, and an ever-vigilant magnetic-tape logging device.

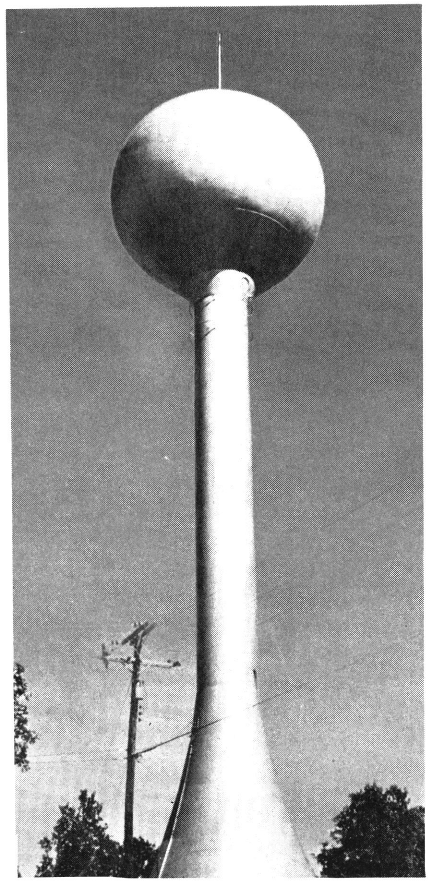

Fig. 1-5. WA5LVT uses several receiver sites such as the one pictured here. The distance from transmitter to receivers is great enough to preclude the disadvantage of repeater desensitization.

be commanded from the input to restart the cycle.

The Radio Ranch repeater is unique among repeater installations. Where most such systems are supported by the revenue of a group of users, this one is the result of donations of a few interested amateurs.

Most f-m repeaters have one characteristic in common: their input and output channels are spaced in multiples of 60 kHz. Nonrepeater operation—known as simplex or point-to-point—takes place on established f-m "channels" which occur at 31 places in the upper portion of the two-meter band. These are spaced at 60-kHz increments, with the lowest in frequency being 146.04 MHz. When repeaters are set up, they are usually crystalled to use two of the already established f-m channel frequencies. The six-meter band has not been quite so universally apportioned; its only nationally accepted frequency is 52.525 MHz, which is used for simplex, repeater outputs, and repeater inputs.

The 31 frequencies allocated as f-m channels by two-meter f-m amateurs are:

146.04	Ch 1	147.00	Ch 17
146.10	Ch 2	147.06	Ch 18
146.16	Ch 3	147.12	Ch 19
146.22	Ch 4	147.18	Ch 20
146.28	Ch 5	147.24	Ch 21
146.34	Ch 6	147.30	Ch 22
146.40	Ch 7	147.36	Ch 23
146.46	Ch 8	147.42	Ch 24
146.52	Ch 9	147.48	Ch 25
146.58	Ch 10	147.54	Ch 26
146.64	Ch 11	147.60	Ch 27
146.70	Ch 12	147.66	Ch 28
146.76	Ch 13	147.72	Ch 29
146.82	Ch 14	147.78	Ch 30
146.88	Ch 15	147.84	Ch 31
146.94	Ch 16		

The VHF/F-M Closed Repeater

The name implies the true function of a closed repeater: to give the benefits of repeater coverage to a select group of subscribers or users. To the uninitiated, a closed repeater might seem a legal improbability on an American amateur band. But such repeaters are in widespread use throughout the country; and they are indeed legal.

When a group of individuals cooperate to install a repeater for the mutual benefit of those participating in the endeavor, they usually incorporate special "selective" devices to reject all signals other than those for which the system was designed. This function is almost universally achieved with a system of **access tones,** whereby a specific tone on the incoming signal is a prerequisite to being automatically relayed to the repeater output. There are two common methods for tone access:

1. The incoming signal must be accompanied by a steady very-low-frequency note of 120 Hz or below. A decoding device is employed that allows the repeater to respond only to signals bearing this tone. This system is called **continuous-tone squelched** or PL (for "Private Line"). Decoders of this type are usually amplitude- as well as frequency-sensitive, so that a few decibels or hertz one way or the other may make the difference between keying the repeater and operating simplex.
2. The incoming signal must be accompanied by a short high-frequency **tone burst** of a few milliseconds. In this case, the decoder at the repeater receiver allows the

transmitter to be energized only when signals bear the proper tone. This coded-access approach, called **single-tone,** is used in a variety of ways to achieve the same purpose. Most single-tone systems are relatively noncritical and can usually be defeated by operators with a good ear for tone and a talent for whistling.

The FCC recognizes the existence of closed repeaters, and offers no publicized objections. As a matter of fact, when interference cases come before the Commission (whereby an "outsider" gains repeated unwelcome access to a closed system), official sympathies are usually with the repeater owners. The FCC considers a closed repeater to be the private station of one amateur or group and seeks to protect the rights of privacy of that individual or organization.

There are some contradictions in the FCC Amateur Rules and Regulations, Part 97, with respect to closed repeaters. There are prohibitions against codes and ciphers as well as laws forbidding control of a repeater at frequencies below 220 MHz, but the FCC apparently believes that tone access on any vhf band is in the best interest of amateur radio. This is borne out by a recent FCC declaration which states of vhf repeaters, that " . . . the repeater licensee may limit access by other amateur stations (mobile, fixed, or portable) by the installation of appropriate circuitry such as that which may be actuated by subaudible tones."*

Closed repeaters, for obvious reasons, are never the object of

* "FCC Speaks Out on Repeaters," **FM Magazine,** July 1968.

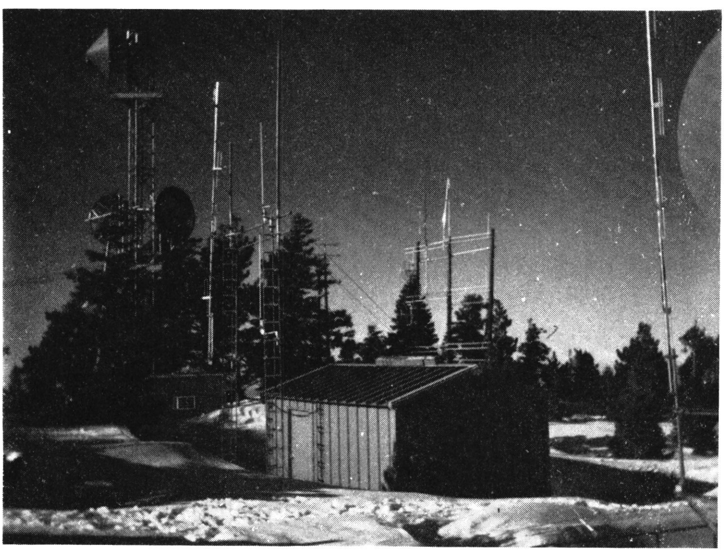

Fig. 1-6. WB6SLR's remote installation at a commercial facility atop 8500-foot Blueridge Summit in California. Equipment is shown in Fig. 1-7.

a great deal of publicity. Members of closed repeater groups keep access information a closely guarded secret. Publication of a closed repeater's access-tone frequency and input/output criteria would doubtless result in some unwarranted—and unwanted—repeater activity. Repeater systems of the closed type are usually restricted for good reasons. The participants have expended what might well have amounted to large sums of money for the equipment and site; they have pooled their labor to construct the system for their own use. "Outsiders" are too often willing to use the repeater but reticent about sharing the expenses of construction and upkeep.

Also, where a repeater might seem a valuable asset to the communications capability of a given area, much of the incentive for its installation may be destroyed when one considers that heavy repeater usage might prevent access by those very people who were responsible for its existence. The tone-access approach precludes this and restores the incentive for repeater construction. Closed vhf/f-m repeaters make up about 20 percent of the nation's existing automatic amateur relay systems.

The UHF/F-M Private Repeater

Of all the repeater types in common use today, none is subject to more open controversy or FCC scrutiny than the private repeater. This type of system is typically set up as a completely functioning repeater with various added control capabilities in the 220- or 450-MHz amateur regions. The uhf spectrum is used because: (1) it provides for the legal operation of remotely controlled radios and other devices, and (2) it allows for a certain degree of privacy due to the "exclusiveness" of these generally ignored ham bands.

The general lack of activity in the uhf spectrum is a factor which in itself serves to render repeaters in these bands "closed" types, even without the traditional tone-access devices. And in many metropolitan areas, certain segments within the uhf amateur bands have been set aside by the amateurs themselves for private uhf repeater and control use. In Los Angeles, the area between 440 and 450 MHz is

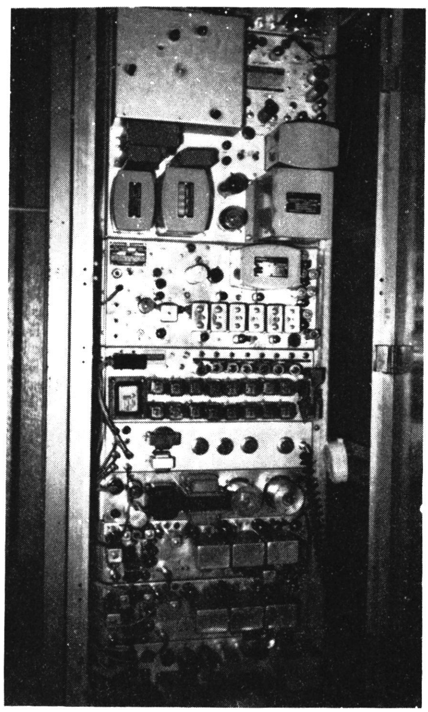

Fig. 1-7. Equipment of WB6SLR's repeater.

intentionally ignored by the typical hobbyist in an unwritten "agreement" between the repeater users and other amateurs. Additionally, those frequencies above 440 MHz are "coordinated" by an individual who maintains an accurate account of all repeaters in use. Prospective repeater builders are referred to this coordinator, who "assigns" specific frequencies for repeater input and output in such a way that no interference among repeaters will be likely to occur. This frequency coordination is a process borrowed from the nearby commercial spectrum (above 450 MHz), where channels are allocated according to activity, locale, and anticipated class of operation.

Many amateurs have sidestepped the coordinator only to find themselves with a big investment in crystals that bring about operation on a frequency already in use. The coordination approach was a necessary result of a growing number of unpublicized "private repeater" systems. Repeater owners in the uhf range usually want to keep their input and output frequencies a secret, but they also do not want anyone accidentally operating on these channels. They respect other repeater owners' private listings, too, and are normally totally unaware of the repeater frequencies in use. So to preclude the possibility of interference and frequency clashes, the single coordinator was allowed to keep a complete index of all uhf repeaters. His position is one of trust and he is expected to keep the confidence of those he serves.

Private repeaters are made for private uses, and there are as many individual uses as there are repeaters. The most common use of a private repeater, however, is the vehicle for control of a remotely situated radio station. In this respect, the operation is similar to that of a vhf/f-m closed repeater. The uhf private repeater, however, affords a considerable degree of added capability. As an example, a uhf repeater might control a fixed-frequency two-meter transmitter and receiver tuned to a highly active local f-m channel. When the

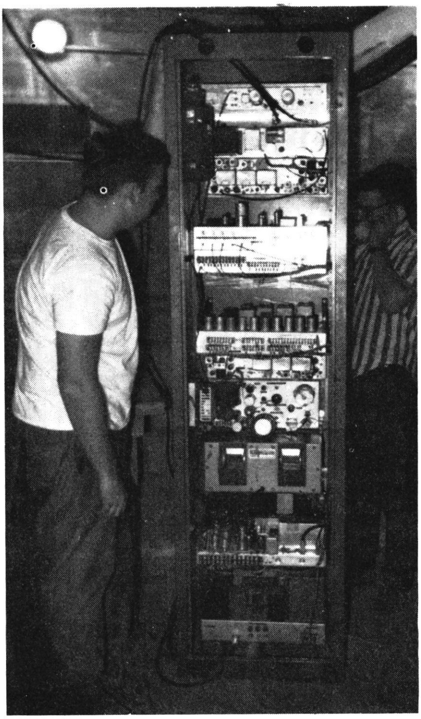

Fig. 1-8. Chuck Jackson (WB6NRF) and Glen Drager (WB6PWJ) check out the equipment of the WB6CZW repeater on Santiago Peak (at 6000 ft.) before leaving the site. Trips to the area are rare because of the desolate remoteness of the site.

repeater operator tires of working the f-m channel, he has the option of shutting down that function with specially transmitted control signals, but he retains his private repeater capability.

A remote station differs markedly from a repeater, although very often the two are combined in various ways to form a more complex but more flexible system. A remote can best be described as an ordinary transceiver operated by some means of remote control, either by wire lines or by radio. In its simplest form, a remote might be a radio unit in the garage that is controlled by a few wires extending into the kitchen. In its more complex form, a remote is a fixed-frequency unit situated on an isolated mountaintop and which has been rigged up to transmit and receive on command. Of course, this application must include provision by which the operator can be transmitted the information heard by the mountaintop receiver. It must also include provisions for receiving audio signals from the remote operator so they can be transmitted over the actual frequency of interest. The transmitter and receiver portions of a remote unit do not necessarily operate simultaneously, as in the case of the repeater. Here is how a remote system might work for you:

Let's say that your complete base station is installed on a hilltop or in a high building. The base station operates on a fixed frequency of 146.94 MHz f-m. When you are operating from your car, you want your remote station to retransmit your signal on 146.94 MHz. You also want your remote 146.94-MHz receiver to relay to you in some way all the signals it hears. So you install the private uhf repeater to effect the two-way link between your car and the remotely situated station.

The uhf repeater, for example, operates on the frequencies of 442 and 448 MHz. You transmit from your car on 442 and receive signals in your car on 448 MHz. At the hilltop site, a 442 receiver hears your input signal and retransmits it on 448. But it also keys the 146.94-MHz two-meter

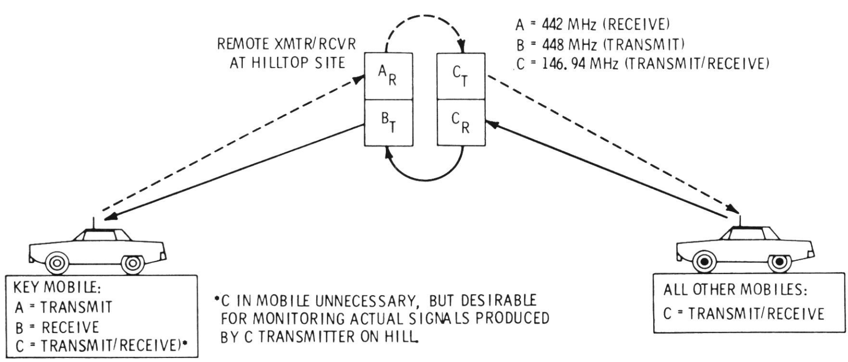

Fig. 1-9. Operation of repeater and remote base stations.

transmitter and feeds the audio into it. When you stop transmitting, your 146.94-MHz receiver on the hill is operative again, and it again begins to feed signals down to you on your control frequency. The complete system is illustrated in Fig. 1-9.

The FCC rules state that a remote station must be controlled from a fixed site. To many hams this automatically obviates the possibility of setting up a control system in the mobile unit. But close observation of the ruling (Part 97.43) shows that no mention or prohibition of mobile control is included at all. And the reverse side of any amateur license is proof enough that a control point is considered fixed even though operated portable or mobile.

One of the most popular applications for the private uhf/f-m repeater is the installation of an automatic telephone-patching system (Fig. 1-10). The FCC's recent legalizing of phone attachments has spurred amateur activity in this area even more.

The interconnection of an automatic phone patch (or **autopatch**) with a uhf repeater can give a mobile-telephone capability to each and every user of the repeater. Such a system offers a number of advantages over even the telephone company's mobile phone concept, because (1) calls can be initiated by dialing, (2) calls can be received in vehicles directly (without operator intervention), (3) calls can be initiated and received at no more expense to the originator than calls from a conventional telephone, and (4) the telephone provides an additional means of system control.

The telephone companies frown on amateur installations involving telephone equipment, but they may be at long last all but powerless to prevent such use **unless the amateur causes tangible problems.** For this reason, it is extremely important that autopatch users be especially cautious when setting up the system. Impedance mismatches, excessive levels, unwarranted line loads, ringer problems, and the like are ready-made excuses for the phone company to terminate service.

An amateur connecting an autopatch should be discreet about his system (don't embarrass the phone company), he should avoid problems on his line at all costs, and he should be very prompt to pay his bills each month. If a single rule could be applied to cover all aspects of autopatch operation, it would probably be "Don't make waves!" The phone company should be notified of an amateur's intention to interconnect so a special terminal can be installed. (Tariffs now in effect obligate the user to make his connection at the terminal supplied by the telephone company.)

1-3. WHY VHF?

There is good reason why repeaters are installed to operate in the uhf and vhf regions and not on the lower amateur bands. First, the primary aim of a repeater is to give **reliable** coverage of a given area. On the higher frequencies this is achieved easily by making sure the transmitters and receivers which will be communicating with one another are within a line-of-sight range. As long as the distance from the repeater to the user is line of sight, two-way communication can be assured. On the higher frequencies, repeater emissions that propagate at a high angle of radiation are for the most part absorbed in the ionosphere and other spheric layers. Low-angle radiation can be consistently used by all receivers within range, almost without regard to such conditions as inversion, sunspot activity, and sporadic-E buildup.

With the lower frequencies, high-angle radiation becomes an important part of the overall system. Reflected signals are necessary to effect the long-haul communications typical of a low-band transmitter/receiver setup. But on the lower bands, the destination and distance of the transmitted signal are inconsistent. A signal that might be saturating the receiver one night may be totally uncopyable the next; and no amount of care in receiver placement and antenna design could change this fact. Even line-of-sight communications on the lower frequencies cannot be relied on under all conditions. An ordinary high-frequency signal transmitted during an atmospheric inversion, for instance, would give better groundwave coverage than the same signal transmitted at some other time. And receivers in the high-frequency range would be just as apt to hear long-distance signals from low-power mobiles as they would be to hear the intended signal from a hilltop repeater.

Where "skip" is minimal, line-of-sight communication is more reliable. This is not to say that vhf and uhf signals travel farther on a line-of-sight path; it simply means that the transmitted signals will exhibit essentially the same characteristics, day in and day out. And where the characteristics are more or less constant, reliability is always greatly enhanced.

Suppose, for instance, that a distance of 40 miles separates point A (the repeater site) from point B (the user mobile). On vhf, if a well designed mobile at point B cannot communicate through the repeater on one day, he will be unlikely to do so the next. To improve the situation, some definite modification would be required at the repeater or in the mobile. A mobile "range" check will give an accurate indication of the coverage to be expected of the repeater.

In the high-frequency spectrum, however, a mobile's inability to communicate one day will not necessarily mean a **consistent** inability. At point B the mobile might provide a saturating signal one day, a "spotty" signal the next. And at times, the high-frequency mobile might be competing with skywave DX for command of the repeater. Thus, reliability is defined better as consistent performance than long-distance communications capability.

1-4. WHY F-M?

Amateur a-m operators using a repeater frequently ask the repeater owners why they use f-m for control. A great many more amateurs wonder why so many repeaters start out as a-m types and get converted to f-m. The reasons are nearly as numerous as valid. In brief, f-m offers at least these advantages:

1. Audio does not degrade with diminishing signal strength.
2. Superior receiver performance (better signal-to-noise ratio, less susceptibility to noise and random-

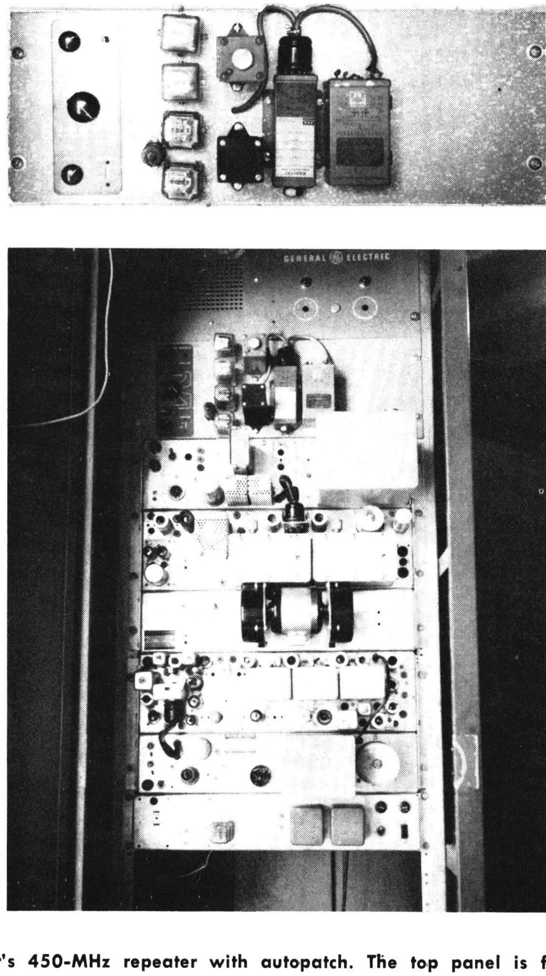

Fig. 1-10. Author's 450-MHz repeater with autopatch. The top panel is for local control, and contains speaker, volume and squelch controls, and pilot lamps. The panel below it (shown in the blowup) is the automatic telephone patch. The balance of the panels make up the repeater system. For normal operation, the cabinet serves as a conventional uhf repeater; on command from the control operator, however, the telephone patch panel provides interconnection with a telephone line so that the control operator can answer incoming calls or initiate outgoing calls. The autopatch panel contains relays and timers as well as a commercially built phone patch. The relays and timers allow a number of automatic fail-safe functions so that the transmitter will shut down when trouble occurs even if the operator loses control. The autopatch circuit is described in detail in Chapter 5, Remote Applications and Functions.

pulse interference).
3. Better, more positive "squelch" action.
4. Better potential for high-quality audio.
5. Transmitter power can be increased without consideration to audio circuits.
6. Surplus gear is generally available (and lower in cost than ham gear).
7. Equipment is generally superior to a-m gear of equivalent design date.

Of all those listed, the first entry is the most important. The audio "seen" by the repeater receiver "looks" much the same whether the transmitting station is 20 feet from the receiver or 20 miles. With f-m, as the signal degrades with distance, the noise increases but the audio quality remains essentially the same. This characteristic has made the use of S-meters on f-m units meaningless.

Amplitude-modulated stations typically give signal reports according to a "readability" standard, or S-meter. With frequency modulation, a copyable signal is virtually always a readable signal, and the corresponding report is based on dB of quieting.

An unsquelched f-m receiver in the no-signal state will have much the same sound as an a-m receiver: a highly audible hiss representing latent band noise. Any incoming f-m signal, however, will reduce that noise to some extent. A strong signal will squelch it completely; an extremely weak one will reduce it by a few dB. Unlike a-m, the audio characteristics of the incoming f-m signal remain substantially unchanged regardless of its strength. And this fact becomes extremely important when the repeater is used to accept audio-frequency commands for control of functions.

Frequency-modulation receivers are typically capable of better performance than their a-m counterparts. This is partially attributable to the fact that f-m receivers in general use were designed almost without regard to cost, and partially because of certain inherent advantages of f-m with respect to noise-rejection and signal-to-noise capabilities.

It is difficult to compare any given f-m signal with an equivalent a-m signal, but there are accepted standards for both modes. An a-m signal of 50 microvolts is generally considered to be S9. An f-m receiver typically yields the equivalent signal (20 dB of noise quieting) at an input strength of 0.5 microvolt. Under ideal band conditions (absence of latent noise), an a-m signal might be detectable at lower input strengths than an f-m signal on comparable receivers, but the f-m receiver would always provide a **readable** signal longer.

Typical mobile pulse interference such as that from the ignition system or generator have little effect on the performance of an f-m receiver, because the discriminator of the receiver is practically insensitive to the amplitude variations of the noise. Noise components may take their toll on the signal in terms of receiver sensitivity, but they are seldom reproduced by the speaker where they would compete with the audio intelligence.

F-m receivers are better equipped for repeater use in yet another area: The built-in squelch circuitry provides an excellent means for automatic switching of functions in the presence of a signal. An a-m receiver typically uses a diode arrangement to provide squelch action through audio clipping. This system is inadequate because sudden noise bursts "break" the squelch and indicate to the audio circuits that a signal is present. As a result, the listener is subjected to occasional audio bursts of noise. Weak signals, on the other hand, are kept from getting to the a-m receiver's audio circuits.

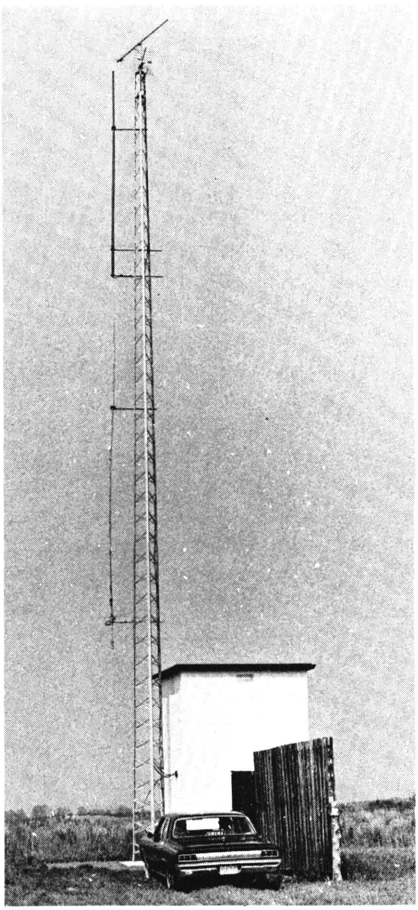

Fig. 1-11. Across the continent, scenes like this are becoming more commonplace. Photo shows the repeater shack, tower, and transmit-receive antennas for Toronto's VE3RPT. The array at top is the antenna system for the 450-MHz control link.

The typical f-m receiver uses noise to effect its whole squelch system. A special amplifier accepts and amplifies existing no-signal noise, and drives a rectifier whose output keeps the audio amplifier in a cutoff state. Since the noise disappears when a signal is present, the noise amplifier's input is removed along with control of the audio gate. With this system, the higher the level of noise, the less chance the squelch will be opened. The existence of this circuitry simplifies the interconnection of carrier-operated devices, such as relays that provide contact closure with each incoming signal.

Although consistently referred to as frequency modulation, the mode used by most f-m amateurs is, in reality, **phase modulation.** The differences between true f-m (frequency modulation) and phase modulation are subtle enough to make them insignificant insofar as the receiver is concerned, because both modulation methods involve variations of both the frequency and the phase of the transmitted signal. Frequency modulation is accomplished by variation of the oscillator frequency in proportion to the variations of the applied audio signal; phase modulation (variation of the carrier current's actual phase) is accomplished by applying a modulating signal to one of the transmitter amplifier stages. Both modulation methods cause deviation of the output frequency (and phase), but only phase modulation allows the output frequency to be "deviated" without variation of the basic oscillator frequency. Phase modulation is advantageous because it allows the use of a highly stable crystal oscillator without restricting the ultimate deviation capability of the transmitter.

Phase modulation has been popularly called f-m by manufacturers, professional servicemen, and amateurs for so long that any attempts to change the situation now would be futile as well as pointless. So f-m it will stay, even though the ensuing discussion of modulation refers to the phase/frequency rather than the basic oscillator frequency of the transmitted signal.

Since the phase/frequency of the transmitted signal is varied in proportion to the intelligence (modulation), transmitter construction is simplified. Amplifying the power of an amplitude-modulated signal requires an amplifier that is linear enough to accept the full range of amplitude variations without distortion. This results in a compromise in rf amplifier efficiency, because amplifier gain must be sacrificed for linearity. For this reason, the high-efficiency class-C amplifier cannot be used to amplify a-m signals. In order to use the nonlinear class C for a-m work, the modulation must be impressed on the signal **at the amplifier,** and the level of the audio (or its power) must be commensurate with the input rf power of the amplifier itself.

The situation is quite different with f-m, where the amplitude of the signal is a constant. Since amplifier linearity need not be a design consideration, very efficient nonlinear amplifiers can be used to increase the rf power of a fully modulated signal. Any conventional class-C amplifier that could be used for continuous-wave (cw) signals could be used equally well with a frequency-modulated input.

In terms of applied voltage and current, a class-C amplifier must be derated when it is to be amplitude-modulated. An f-m signal, however, will appear to the class-C stage as a continuous-wave input, and the maximum ratings of the tube or transistor (for continuous-wave service) can be used without detrimental effects.

Another important factor contributing to the widespread use of f-m for repeaters, command, and control applications is the equipment itself. A rather paradoxical situation is the fact that there are virtually no sources for new amateur radio gear of the vhf/f-m class,* yet manufactured equipment is not only readily available, but it is inexpensive as well. Amateurs who are vhf and

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* Two exceptions are ICE, Inc., a San Antonio, Texas firm and Varitronics, Inc., of Phoenix, Arizona, both of which are currently engaged in the manufacture and sale of wideband crystal-controlled f-m transceivers for amateur use.

uhf/f-m "regulars" consistently manage to obtain their gear from the always-abundant commercial surplus market. Typical sources are taxi companies, municipal governments, large industrial firms, ambulance services, and any business equipped with two-way land mobile communications service. And there are yet other sources: There are at least a dozen large business concerns across the country specializing in the mail-order sale of used/surplus commercial two-way vhf and uhf/f-m equipment to amateurs.

The commercial f-m equipment that finds its way to the amateur market is ordinarily ideal for ham use. As a rule, the only reason the equipment is available on the surplus market in the first place is because it no longer complies with the FCC's ever-more-rigid constraints with regard to the commercial bands from which it originally came. With more and more commercial users crowding the existing allocations, the FCC has been forced to impose increasingly constricting bandwidth restrictions and stability requirements that would be meaningless to the amateur radio operator. As a consequence, he can usually pick up the surplus commercial equipment for a fraction of its original value. Fifty to one hundred dollars for a unit which sold initially for nearly a thousand is not at all uncommon.

Frequency modulation gained a spurt of popularity immediately following World War II, then quickly fell from favor because the mode was not totally compatible with a-m. This basic incompatibility still exists, of course, but now there's no need for compatibility, because of the ease with which complete f-m transmitters and receivers can be obtained. The reasons for the incompatibility, however, warrant mention: An amplitude-modulated signal sounds far superior to a frequency-modulated signal of the same strength **when the receiver itself is designed for a-m reception.** The same f-m signal on an f-m receiver, however, will make the a-m signal seem puny by comparison. The effect is so pronounced that many feel vhf/f-m will eventually make a-m obsolete.

Today, f-m is a well-accepted mode among vhf amateurs, and the number turning to this as a regular operational mode is growing almost exponentially. There are hundreds of independent amateur f-m organizations and a well established national f-m journal of amateur radio.*

1-5. LOCAL VERSUS REMOTE

A repeater can be deployed as a functional system at the residence of the control operator or it can be set up at a distant vantage point and controlled by signals dispatched by wire or radio. The individuals whose signals are repeated may detect little or no difference between the two operational modes, but as any repeater owner will attest, the two are worlds apart.

The most significant difference between a local and a remote

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* **FM Magazine,** VDB Publishing Company, 2005 Hollywood Street, Grosse Pointe, Michigan 48236

repeater is in the licensing requirements. A local repeater (one that is controlled by an amateur on the premises) needs no special license other than the valid amateur license of the operator himself. On the other hand, a repeater to be controlled remotely must be approved by the FCC before installation. In addition, the operator who will be responsible for control and monitoring of the remote repeater must be specially licensed. To receive his license, the prospective control operator must demonstrate to the FCC's satisfaction that he is capable of maintaining control of the remote unit at all times.

Obtaining a license for radio (as opposed to wire) remote control can become a gargantuan task if the applicant is unfamiliar with some of the requirements. Here are typical points which must be adequately specified:

1. Who owns the property where the repeater will be situated? If other than self-owned, written authorization must be obtained from owner.
2. What is exact location of remotely situated transmitter, in latitude and longitude, if no address is available?
3. How will logging be performed?
4. How will compliance to FCC rules be assured? Show methods for shutting down repeater when emissions deviate from FCC rules. Show "fail-safe" features to prevent other stations from "capturing," or locking out licensed control operator.
5. Show system block diagrams and all other data that will help FCC officials in evaluating proposed remote repeater.
6. Describe all methods of compliance with terms cited in FCC Rules and Regulations, Part 97.43.

Experience tends to show that an adequate original submittal may involve from 10 to 50 pages of typewritten text and drawings.

Obtaining a license for wire control of a remote repeater is a great deal simpler than getting one for radio control. The points outlined above should be covered in the wireline control application, too; but the ultimate evaluation will likely be less thorough. After all, wire control is in reality merely an extension of a local control system; and **positive** control is likewise easily demonstrated.

Wire control is done by electrically controlling remote relays and circuits with a "hard pair," or a two-wire line extending from the control point to the remote site. The "pair" may be homebrew or it may be leased from the local telephone office.

Amateurs using wire control normally use a metallic pair, although telephone companies usually offer nonmetallic pairs as well as metallic. A metallic pair consists of a single dc circuit from the start of the line to its terminal point. The dc circuit is maintained even though the pair may be fed through special loop amplifiers at the central telephone office or at other strategic places along the wire path. A nonmetallic pair terminates in a separate dc circuit from its point of origin, even though the pair may carry no other circuit than that of an amateur's control.

Obviously, dc signals cannot be used for control over nonmetallic pairs, and the control operator is forced to use such audio-frequency methods as vibrating tone reeds and their related combination signaling techniques. Tone systems are expensive because they require utilization of specialized encoders and decoders, and thus they are undesirable for basic control.

FEDERAL COMMUNICATIONS COMMISSION
Washington, D. C. 20554

January 11, 1965

In Reply Refer To:
7523

Mr. Barney L. Dewey
411 Fullerton Avenue
Newport Beach, California 92660

Dear Mr. Dewey:

This is in reply to your recent letter regarding Section 97.103(b) of the Amateur rules when your station is repeating the transmissions of another amateur station. To satisfy this section of the rules, it is only necessary that you include a statement in your log to the effect that your station is operating as a repeater and transmit your call sign at the required intervals.

Very truly yours,

Ben F. Waple

Ben F. Waple
Secretary

Fig. 1-12. Letter to Mr. Barney L. Dewey from the FCC in response to inquiry on logging.

A metallic pair reproduces at the terminal point essentially everything that was transmitted at the input, regardless of the signal mode. So, ordinary dc control signals can be used as well as the regular ac signals of voice transmission.

Don't make the mistake of licensing a prospective repeater for wire control and actually using radio. Your license will specify the type of control you are authorized to use; any other use will only lead to trouble.

If you are planning a repeater installation, but are undecided as to how to control it (local, wire, or radio remote), here are the points to consider: If your resi-

October 3, 1966

Honorable Ben F. Waple, Secretary
Federal Communications Commission
Washington, D. C. 20554

Dear Mr. Waple:

The Houston Radio Relay Club station is used as a repeater only, i.e., no transmissions originate at this station except the automatic identification signal. At present we are running a full-time tape recorder for logging purposes. The time entries make it impractical to voice control the tape mechanism.

As you can appreciate, this tape logging is a terrible burden to us. The enclosed communication #7523 appears to indicate a much more simple and practical logging procedure. Are we misinterpreting this letter? This view of the requirements seems reasonable, since the repeater users' logs contain all the necessary data.

I would appreciate an early reply clarifying this matter.

Sincerely yours,

Michel T. Halbouty, Director
Houston Civil Defense Dept.

Leon Vice
Communications Officer

MTH:LV:ahs
Encl

Fig. 1-13. Letter from Leon Vice to FCC requesting clarification of logging requirements.

dence is at a good radio vantage point (for example, on a hilltop or one of the high floors of a tall building), you will probably be better off with local control. Remember, though, your operation will be illegal if there is no licensed amateur at the site during all periods of use.

If you find it necessary to operate a repeater or base station by remote control, you should weigh the relative advantages of wire versus radio control. Wire may have the edge if the distance from the control point to the transmitter is not excessive. A metallic pair typically leases for

FEDERAL COMMUNICATIONS COMMISSION
Washington, D. C. 20554

May 5, 1960

Address All Communications
To The Secretary

In Reply Refer To:
7400

Mr. Tim Huntley
Deputy Chief of Communications
Los Angeles Office of Civil Defense
6501 Fountain Avenue
Hollywood 28, California

Dear Sir:

The Los Angeles field office referred your letter of March 8, 1960, regarding the operation of amateur (repeater) station K6MYK, to this office for reply.

The operation described in your letter appears to be in substantial compliance with the Amateur Rules except that the log of K6MYK should also show the call signs of all amateur stations using the repeater facilities.

Very truly yours,

Ben F. Waple

Ben F. Waple
Acting Secretary

Fig. 1-14. Letter to Tim Huntley expressing FCC's view on logging. Original letter to Leon Vice, which was not available for publication, contained essentially the same data.

a monthly fee of $3 for the first quarter-mile and $1 per quarter-mile thereafter. Most telephone companies also charge an installation fee of $15 at each end of the line. At significant distances between the control point and the remote site, it is usually felicitous to plan on a radio-control system.

Logging

The logging requirement imposed on amateurs by the FCC has been a weighty burden for years. As a result, many remote operators have vainly searched for loopholes in the vaguely written Rules and Regulations. Each gap, however is tightly sewn shut by the FCC as quickly as someone finds it.

Remote operators across the country gleefully abandoned their logs when FM Magazine published an FCC letter that ostensibly made repeater log keeping unnecessary! The famed letter (Fig. 1-12) was written to Mr. B. Dewey, in response to an inquiry on logging requirements. The general "loglessness" was short-lived, however, because another amateur, Art Gentry (W6MEP), subsequently furnished incontrovertible evidence to the journal that all stations using any repeater must be logged in some way as a permanent record of station activity. Gentry furnished another letter, consisting of an inquiry to the FCC written several years earlier by someone who had read the famous Dewey Letter and wanted confirmation (Fig. 1-13). The FCC response to this letter (Fig. 1-14) dispelled all doubts about repeater logging. The explanatory letters of Figs. 1-13 and 1-14 were published in the national FM journal, but not until after hundreds of remoters were relieved of a few months' logging requirements.

Several large organizations have petitioned the FCC to dispense with the requirement for repeater log keeping, and one group, the Buffalo Repeater Association, Inc., went so far as to recommend relaxed control requirements. The FCC has failed to act on any of these appeals, and the requirement to maintain a complete log of all station activities is still in effect, regardless of whether the amateur station is a mobile, a base facility, or a repeater.

Chapter 2

Control Techniques

2-1. THE CARRIER-OPERATED RELAY

In a class by itself is the basic control element of most amateur repeaters: a busy but quiet device called the **carrier-operated relay** (COR). Actually more than a mere relay, the COR is a "squelch-responding" circuit that provides a relay closure with each signal that occupies the channel. This contact closure is used to key the push-to-talk circuit of the remote transmitter so that the "repeat" operation is fully automated.

Since nearly every type of repeater application is functionally dependent on the presence or absence of carriers, the COR can be used in a variety of ways to perform a number of on-off functions, from the firing of "passive control" timers to the activation of a mobile telephone system (q.v.). In practice, the normally closed contacts of a COR are as often used as the normally open.

The mechanical relay of most vacuum-tube COR circuits is a standard current-activated plate relay with a coil resistance of 8 to 10K. A delicate device, it should never be used for any function other than driving a heavier relay with multiple contacts (with normally open and normally closed capability). If this rule is strictly adhered to, the COR's service life will be lengthened and its operational reliability enhanced.

Fig. 2-1 shows a well designed COR which uses a 5963 tube as the control element. Variations of this circuit have been widely used in a great many commercially produced units in the past. It should be noted, however, that this circuit is not applicable to all

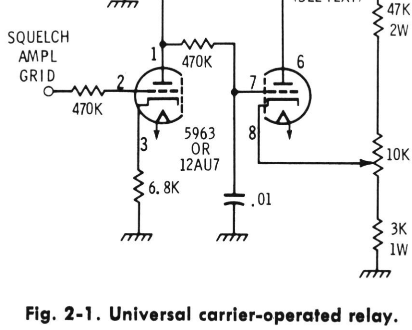


Fig. 2-1. Universal carrier-operated relay.

squelch types. It is ideal for use in most **Motorola** and **GE** receivers, for example, but cannot be used on many **RCA** and **DuMont** units without modification.

The principal requirement of the receiver is that a no-signal condition must be indicated by a positive signal at the grid of the squelch amplifier. (The signal at this point is not really critical, and can be at "zero" potential or even **slightly** on the negative side.) When a carrier appears on the input channel, the polarity of the voltage on the squelch-amplifier grid must swing to a definite negative value. If the idle no-signal voltage on the squelch-amplifier grid is significantly negative, some means of compensation must be employed in order to use the illustrated COR circuit.

The principle of operation of a typical COR is actually quite simple: When no carrier is present, noise would ordinarily appear at the speaker. A good f-m receiver couples the higher-frequency components of this noise to a noise amplifier, the output

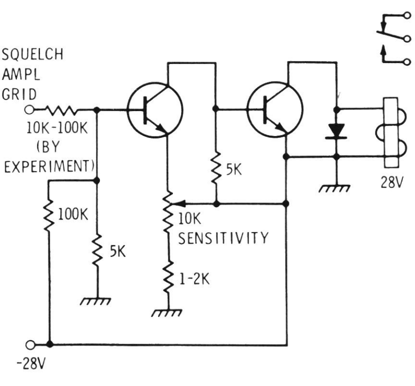


Fig. 2-2. Solid-state COR for tube-type f-m receivers.

of which is rectified and fed to a squelch amplifier which keeps the audio amplifier in a cutoff state as long as the noise is present. But when the noise disappears, indicating the presence of a carrier on the frequency, the audio amplifier comes on. Since a standard dc amplifier with a sensitive relay in series with the plate lead can be driven with the same signal supplied to the squelch amplifier, a separate contact closure can be obtained when a legitimate signal occupies the frequency.

The 5963 tube in the circuit has the same operating parameters (and pin layout) as a 12AT7, which is also usable in the circuit. The 5963 is more adaptable to COR applications, however, because it is constructed with a built-in capability for being held in a state of cutoff for extended periods.

Fig. 2-2 shows a two-transistor COR which uses a conventional 28-volt dc relay rather than a current actuated plate relay. The circuit, designed by Jerry Schneider of Los Angeles, California for incorporation into his uhf mobile telephone repeater, can only be used with vacuum-tube receivers such as the **GE** and **Motorola** units for which the circuit in Fig. 2-1 was designed. Although the basic operating principles are the same for both tube-type and transistor receivers, the pictured circuit must be modified for adaptation to a solid-state squelch amplifier.

The 28-volt power requirement should prove no problem at all in most repeater installations. A standard transmitter bias supply provides an ideal source. Even if no bias voltage is available, most repeater control systems employ a 28-volt dc source to drive a stepper, timers, or relays.

There are no critical components in the solid-state COR. The transistors can be any NPN type capable of switching at a collector current of greater than 50 mA. The only criterion for the relay itself is the ability to pull in with a voltage lower than the supply voltage.

The low impedances and critical polarity requirements of transistors impose certain constraints on squelch and COR design. Unfortunately, the COR designed for compatibility with one transistor squelch circuit may not be compatible with another. Most transistor squelches do have one characteristic in common, however: they exhibit a very small voltage change from the signal to the no-signal state. The voltage swing might be as small as 1.0 volt; the squelch amplifier on the **Motorola** DCN series hand-held units, for example, has a no-signal potential of approximately +0.5 volt. An incoming signal causes the voltage to swing to a negative value of −0.7 volt. Such small signal changes cannot be used with conventional COR circuits, but they are quite compatible with low-signal devices such as Schmitt triggers, which can themselves be used for relay control.

Fig. 2-3 shows a partial solid-state COR driver circuit such as the type employed by **GE** in its **MASTR** series of two-way f-m units. Presence of a signal on the receiver channel of interest

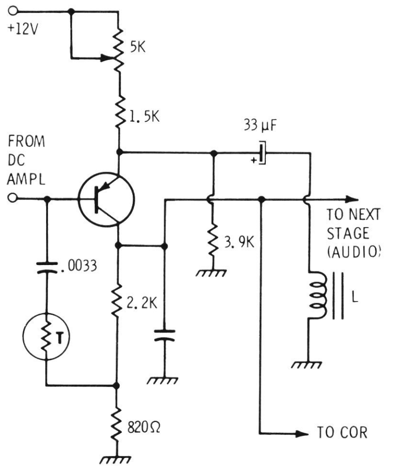


Fig. 2-3. GE's *MASTR* series COR driver.

causes a sharp increase in the negative squelch-amplifier output voltage. This distinct rise in negative voltage can be used as a bias source to hold a transistor or diode gate open for COR control. The **GE** approach, which uses a variation of this approach, is shown in Fig. 2-4.

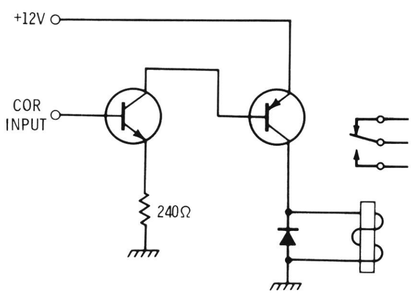


Fig. 2-4. GE's *MASTR* COR circuit.

2-2. ACTIVE FUNCTIONAL CONTROL, RADIO

Whether a repeater is to be deployed as a locally controlled system or set up on some remote hilltop, automatic control will almost certainly be an integral element of the overall operation. There are two basic types of control in common use by amateurs: active and passive. Active control refers to functions that are commanded by radio from the actual site of operation, whether it be mobile, portable, or fixed. Passive control includes the planned features that take place automatically—without regard to operator commands. This latter category consists of automatic timeout devices, shutdown systems, frequency-priority selectors, etc.

There are four commonly used approaches for effecting active control of remote systems by radio, and at least two other types for controlling by wire. Without exception, the radio-control schemes are based on the transmission of specific and precise audio-frequency signals. A wire-line control system may either employ tone signals or straight dc transmittal.

Almost invariably, an audio-frequency control system employs a tone generator of some sort and a tone-to-dc converter. The portion of the system that will perform the actual control is usually no more than a relay device which pulls in when a specific tone appears on the radio frequency being monitored. The tone generator is called an **encoder**; the responding relay is called a **decoder**.

There are generally several functions to be performed by radio command, so a simple decoder relay closure is often insufficient in itself. As a consequence, remote operators frequently devise methods for getting multiple-function performance from a single decoder. This can be done by judicious use of timers. ratchet relays, or stepper switches.

The four most common audio-frequency (tone) control techniques are:

1. Multitone (**Touchtone**®, binary, etc.)
2. Dual-tone (generic term for **Secode**® and other similar techniques).
3. Single-tone (tone-burst entry or digital pulse train).
4. Continuous-tone (often called **PL**®, for "private line").

Multitone includes a variety of systems in which several tones are transmitted for control of a multitude of functions. This category includes "reed-relay" banks, binary systems, and Bell Telephone's most recent entry, **Touchtone.** Until recent years, the binary system was the most common of the multitone schemes, because it allowed ready control of seven functions with a three-tone encoder/decoder system, and allowed the functions to be placed in a numerical format corresponding to a standard binary system. By selectively sending one, two, or all three tones, any function could be selected without the use of mechanical contrivances. In Table 2-1, assume each "1" is a tone transmitted and a "0" is the absence of a tone. If a separate decoder is triggered by each tone, it is easy to see how a diode matrix at the receiver could be used in a "relay-tree" configuration to provide discrete function selection. The

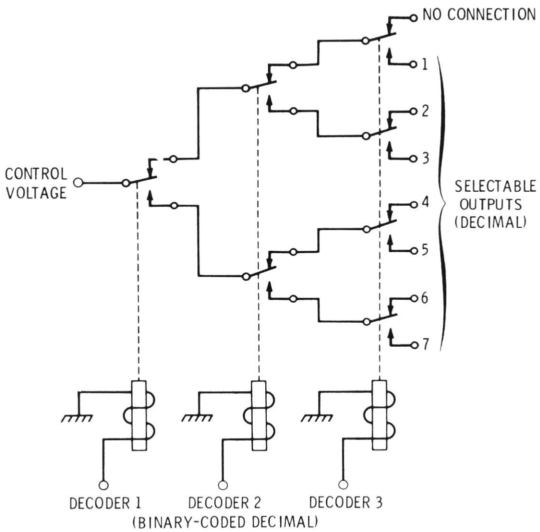


Fig. 2-5. "Relay tree" for selecting seven functions from three coded inputs.

equivalent mechanical relay tree is more often used because of its higher power-handling capability; this circuit is shown in Fig. 2-5.

The binary decoding approach is dropping from favor among amateurs, but through no fault of its own. The **Touchtone** system is squeezing it out because of its universal applicability in terms not only of standardization, but of its adaptability to radio systems involving the employment of automatic phone patches.

2-3. TOUCHTONE

The **Touchtone** approach is gaining wide acceptance because of its inherent compatibility with existing telephone systems. **Touchtone** command signals are generated with a conventional **Touchtone** telephone dial which has an integral multitone encod-

Table 2-1. Functions of a Three-Tone System

100 Hz	600 Hz	1500 Hz	
0	0	0	No function
0	0	1	Function 1
0	1	0	Function 2
0	1	1	Function 3
1	0	0	Function 4
1	0	1	Function 5
1	1	0	Function 6
1	1	1	Function 7

er; this combination dial/encoder is referred to in the telephone industry as a "pad."

In the telephone service for which **Touchtone** was designed, two tones are dispatched to the central phone office for each digit selected. The lost time of waiting for the 10-pps pulse train after dialing of a digit is regained because the system does not require the sequential transmission of a single series of contact breaks as do old dial types. The ensuing enhanced reliability when applied to an amateur control system is readily apparent.

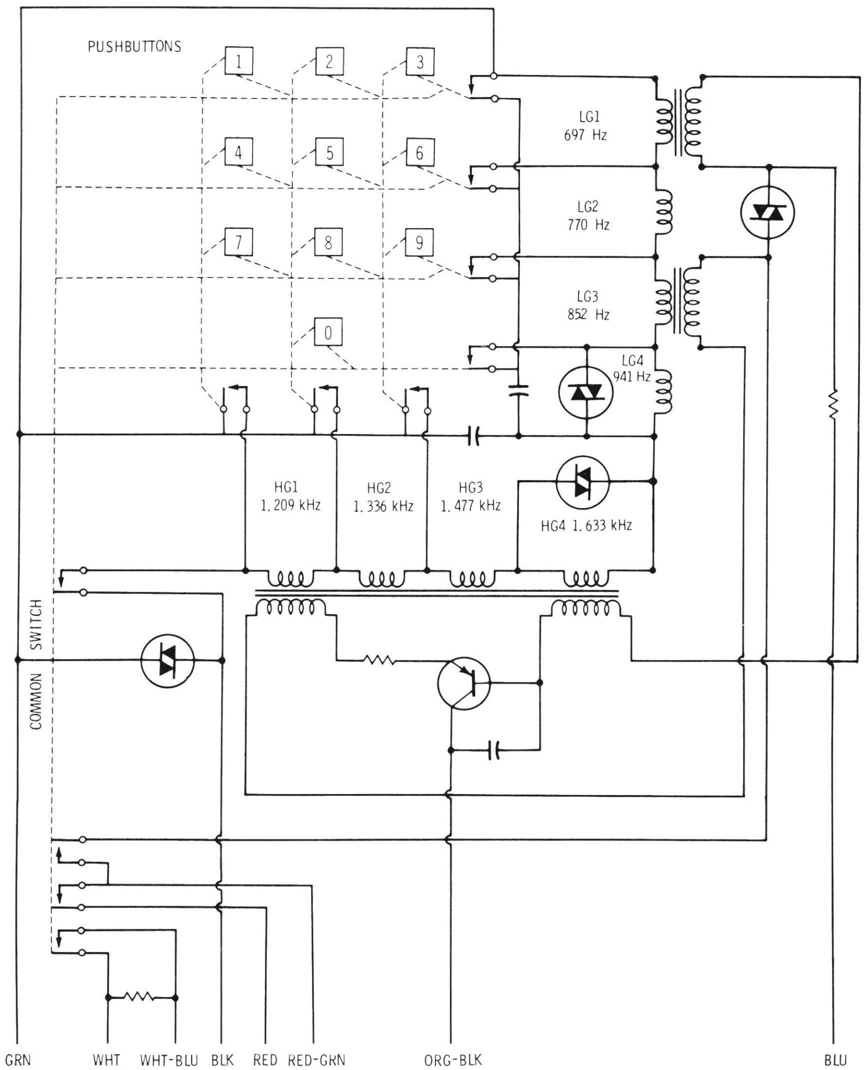


Fig. 2-6. 25A3 *Touchtone* pad.

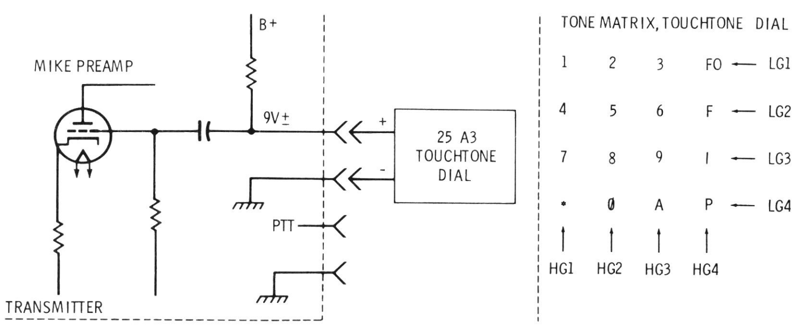
Touchtone Encoder

Touchtone consists of eight discrete (individual) tone frequencies arranged in two groups of four tones each (a high group and a low group). Sixteen digits can then be represented by the combination of one tone from the high group with one from the low. The individual frequencies and various combinations are illustrated in Fig. 2-6, which is a schematic of the standard 25A3 10-button **Touchtone** pad. Many **Touchtone** pads have been made available to the surplus market, ranging from the 25A3 to the 12- and 16-button military and computer versions. The telephone "standard," however (the 25A3), has seven leads terminating at the connector. These leads may be used as indicated in the schematic to convert the system to two-wire operation in an arrangement similar to a transistor/microphone interconnection scheme. The supply voltage is fed to the dial over the same path as the output of the tones.

Fig. 2-7 shows a method by which the **Touchtone** encoder pad might be used with an f-m transmitter. In Fig. 2-7A, the transmitter microphone amplifier is shown along with the input connector. Operating voltage is 9 to 12 volts across the pad. Fig. 2-7B shows the matrix pattern of the tones, including the fourth column (HG4, 1633 hertz) used on 16-button pads.

By this time, it has probably become pretty clear that **Touchtone** is a relatively complex approach in comparison to other techniques in vogue. For example, the signals require more circuitry for decoding than do those of the single-tone pulse-train systems enjoying current popularity in amateur remote-control applications. Completely ignoring the advanced technology of **Touchtone** and its compatibility with modern telephone systems, the system is highly versatile and is unique in that it has the lone potential of becoming a truly universal control scheme.

One very concrete advantage lies in the simplicity when only a few control functions are required. When less than seven functions are to be selected, there is no need to decode the dual



(A) Connection to microphone amplifier.

(B) Matrix pattern of the tones.

Fig. 2-7. ***Touchtone*** **pad interconnection to control transmitter.**

tone frequencies. If two buttons on the pad are pressed simultaneously, a single (rather than a dual) tone results. Making a slight modification to the pad so that the 941-Hz tone can be produced independently will allow the generation of seven independently decodable tones.

Touchtone Decoder

The block diagram of the tone receiver (Fig. 2-8) shows a standard telephone-company system. Since f-m amateur applications do not normally require the stringent tolerances of commercial service, it is possible to simplify the decoder without detriment.

The process of decoding the **Touchtone** signal after it arrives at the receiver is an area where there are a number of successful methods in current use. The most sophisticated—and probably the most complicated—is that which was originally proposed by Bell and is used in Bell equipment. It consists of separating the two-tone combination (via band-elimination filters) into groups consisting of all applied frequencies except the high-group or low-group sequence that is to be eliminated. This is done so each tone component can be regulated separately, hard limiting successfully applied, and each group treated discretely after this point in decoding.

After group limiting, selective filters separate the individual tones. Each filter has a corresponding detector and output circuit as well as an output timer

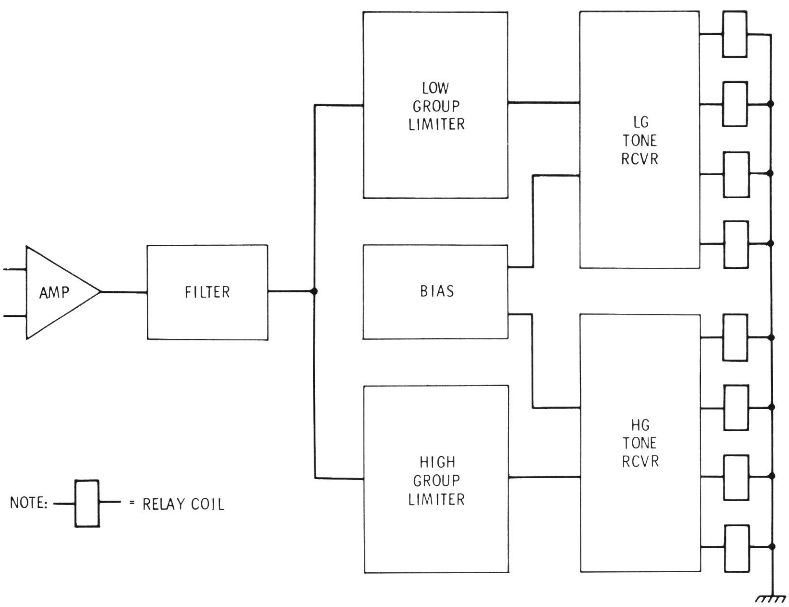


Fig. 2-8. ***Touchtone*** **receiver block diagram.**

and checking circuitry. The active elements are solid-state components of standard design.

As might be expected, this decoder represents an "optimum" design approach. The time required for the decoder to recognize a valid digit combination is a quick 40 milliseconds. The number of false indications due to voice energy or noise tripping is next to none.

For those who refuse to look at anything less than the absolute ultimate, this is **THE** decoder, already neatly designed and optimized. The only hangup is the fact that Bell is somewhat reticent about making available various critical parts used in the design. Fortunately, there are ways by which the amateur can circumvent this problem. One such method is to use a system which departs from the Bell decoding scheme, but one which retains compatibility with the local telephone service. Such was the approach used by the Tulsa repeater group (WA5LVT).

The Tulsa repeater converted its automatic phone patch to **Touchtone** and its users were so amazed by the increase in reliability over the single-tone system that the repeater engineering group decided to use **Touchtone** exclusively for the complete control system.

Since Bell Telephone's central office equipment is not readily available to most groups, the first chore was to design a decoder which would give the desired degree of reliability yet be relatively inexpensive to build. The ultimate system was described by Pat Devlin (WA5BPS) in an article which appeared in the September 1968 issue of FM magazine.

After considerable research into various decoding methods, the group came up with basic design shown in Fig. 2-9. A printed-circuit board was designed for the decoder since in the WA5LVT repeater there are five sites where control functions are necessary.

While each board in itself is a complete two-tone decoder and can be used by itself for a single function, it was necessary in the WA5LVT system to have a variety of control functions at each site. Rather than build a board for each function (which would be rather expensive) the WA5-LVT group decided to use computer techniques for recognition of the individual tone outputs from each board and combine them to give an output for each digit decoded. Thus, only four boards are needed to decode all digits. With 10- and 12-digit decoders, one-half of one board is not used since it is necessary to recognize only seven different tones.

Components were picked for their cost and availability. The only critical components in the decoding system are the 88-mH telephone toroids and the accompanying capacitors. These toroids are the low-cost variety readily available on the surplus market; the capacitors are metalized paper capacitors such as the Sprague **"Vitamin Q"** type.

On each board (Fig. 2-10) there are two individual circuits, each used for recognizing one tone out of a dual-tone pair. The out-

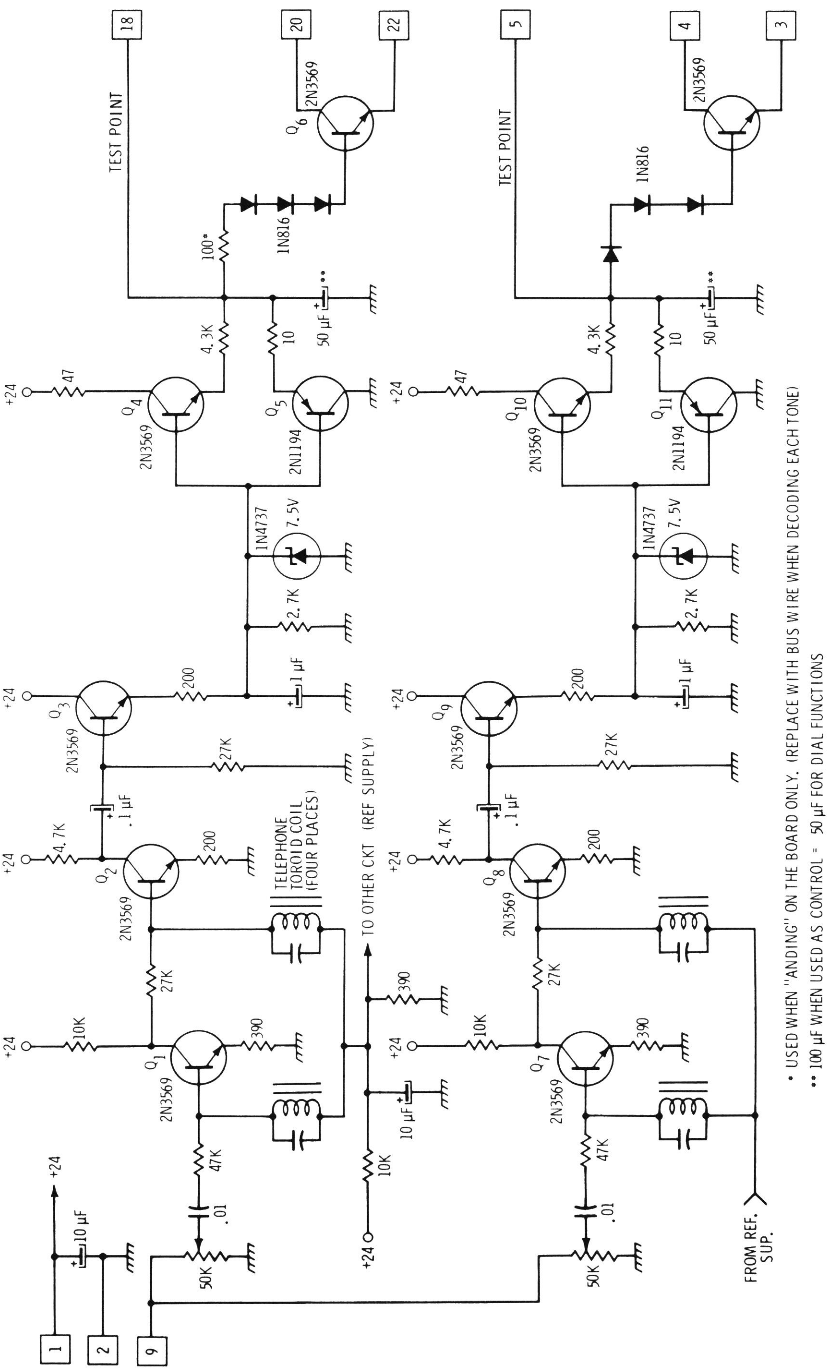
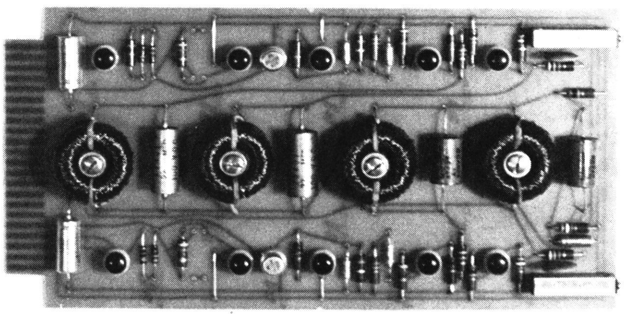


Fig. 2-9. WA5LVT repeater *Touchtone* decoding circuit.

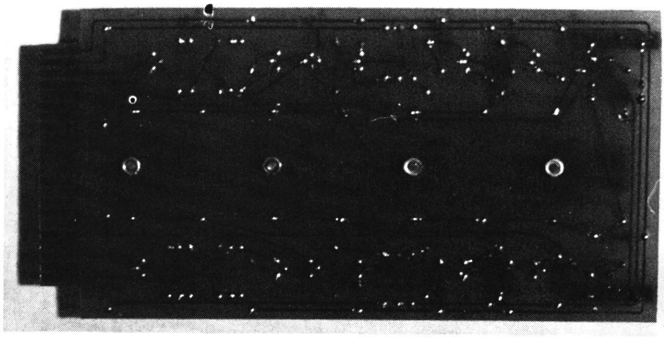
puts of these circuits are kept separate; thus, each tone can be decoded separately for **AND**ing in various combinations to produce all ten digits. To decode one **Touchtone** digit (tone pair), it would only be necessary to series the two output stages by connecting pin 22 to pin 4 and grounding pin 3. This would cause pin 20 to go to ground only when both tones were present. By connecting a relay or other appropriate load from pin 20 to some plus supply (+ 24 volts) a single function is accomplished.

Each circuit on the decode board breaks down into a high-gain audio amplifier with parallel-resonant traps on the first two stages. These traps are high-Q types providing an amplifier bandwidth of approximately 1.5 percent at the 50-percent points. Transistor Q_3 provides a very efficient rectifier circuit for producing a voltage when a tone signal passes the first two trap stages.

Transistors Q_4 and Q_5 work in a complementary circuit to process the voltage into a sawtooth charge-and-reset waveform. The function of this sawtooth circuit



(A) Top view.



(B) Bottom view.

Fig. 2-10. *Touchtone*-type decoder built on a standard circuit board. Top view shows the layout of the four toroids on the card.

is to produce a slow response and quick reset to any unwanted signals (noise) that might activate the decoding stages. The output of this sawtooth circuit drives an amplifier which has a sharp threshold level (approximately plus 2.25V).

A test point is provided for monitoring the voltage drive to the base of the amplifier. When connected to the typical f-m receiver with its squelch open (noise), the voltage at the test points will run approximately 0.25 to 0.5 volt positive and will saturate at + 2.5 volts when a tone is properly decoded. The output stage is capable of driving relays or integrated-circuit logic directly.

Where the Bell System divides the tones into the high group and low group, this decoder does not attempt to do this. Each tone is recognized individually throughout. Where the full bank of decoders is utilized, preliminary bandpass filters could be used ahead of the tone groups. The bandwidth of the decoder is approximately the same as the Bell version. Speed of recognition is slightly slower than the Bell version—less than 100 milliseconds (still plenty fast for amateurs).

The Tulsa repeater designers have gone one step further: After the tones are detected and processed to individual outputs, a diode matrix system and simple timing device provides ten separate "exchanges," each having 112 functions. (The repeater group has committed the last two digits for use in its automatic phone patch, thus reducing the total number to eight exchanges.)

Special Considerations

What are the special problems involved in sending and decoding **Touchtone** signals? The first basic consideration is one that applies to both encoding and decoding: Whenever a two-tone combination needs to be limited, be prepared for trouble! If hard limiting occurs (as in the case of transmitter audio clipping), exit **Touchtone.** One of the characteristics of extreme instantaneous limiters or clippers is to accentuate any differences in level that were already a part of the tone combination. Thus, it is important to be sure the transmitted tone amplitude is such that no audio clipping occurs when the transmitter is set for correct deviation on voice.

Because amplitude differences are naturally quite low as a result of encoder design—and because all the tone components are within the flat frequency response area of most f-m equipment—there will be no decoding difficulties if limiting does not occur (assuming all other portions of the system are functioning normally).

2-4. DUAL TONE

The dual-tone system (often associated with the trade name **Secode®**) is not really an ideal approach for an amateur radio system unless the operator can be satisfied with no more than a few selectable functions. The approach does offer one big advantage over other tone-control methods, however: security. Where the single-tone system provides a contact closure with

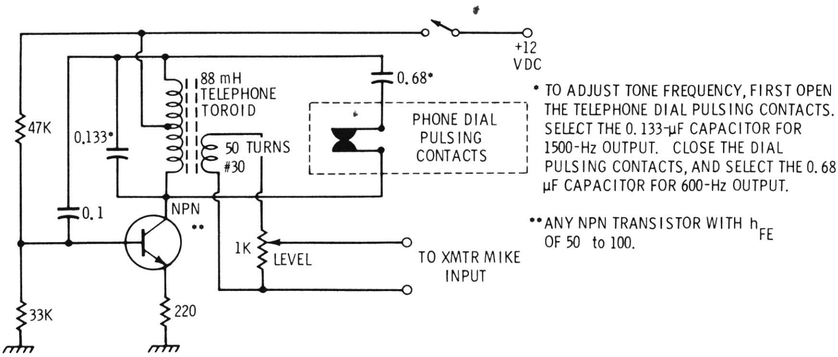


Fig. 2-11. Secode-type 600/1500-Hz oscillator.

each tone received (or with interruption of each tone received), the dual-tone system, when used with conventional decoders, allows selected relay closures only at the culmination of a multiple-digit access code.

The tone frequencies for dual-tone systems are typically 600 and 1500 Hz. Fig. 2-11 shows a schematic for an encoder capable of providing a sequential transmission of these two tones. The circuit was designed by Gary Hendrickson (W3DTN) especially for this handbook. The frequency-variation technique is described on the schematic.

The decoders currently available in the surplus market employ a mechanical switching arrangement that cannot be duplicated by home construction methods.

Solid-state equivalents can be designed, of course, but in practice, the complexity does not seem to warrant the effort, considering the ready availability, reliability, and economy of the electromechanical devices. (Surplus cost of combination encoder/decoders is about $25—considerably less than the cost to construct such devices.) In the dual-tone pulsing system, one of the tones is initiated as the dial is released (from the finger stop); the other pulses with the dial as it returns to "home." In professional installations the initial tone has no function of itself, and must be used with the second tone. The combination of tones (the rapid switching from tone 1 to tone 2) causes a rotary wheel at the decoder to step to a position corresponding with the number of pulses transmitted.

2-5. SINGLE TONE

The single-tone approach will always be popular among amateurs because of its versatility. When a conventional telephone dial is used in conjunction with a single-tone encoder, ten discrete digital codes can be initiated by pulsing the encoder according to the numbers on the dial. A stepper switch can be connected to the decoder at the remote location so that any desired stepper position may be accessed on command. In most cases the stepper is wired so as to reset automatically after a function has been selected so that a new number can be dialed immediately.

The single-tone technique has one very significant advantage when used with a telephone-dial pulsing system: The pulses are sent serially, and usually at the rate of ten pulses per second (to maintain compatibility with telephone pulsing schemes), to initiate a reliable command of some function the remote receiver must "hear" all pulses of a transmitted sequence. When the controlling station is mobile it is often difficult to maintain a full second of good-quality signal into the repeater. If the signal disappears at the repeater even for no more than a few milliseconds, the result is a misdial and perhaps the initiation of some unintended function.

There are two basic types of single-tone pulsing schemes. One is function-selection by a series of tone pulses; the other is function-selection by a series of interruptions in a fixed-frequency tone.

Single-Tone Encoders

The encoder circuit shown in Fig. 2-12 was designed by Bob Mueller (K6ASK), of Arcadia, California, as a standard, but stabilized, simple pulsable audio oscillator. The circuit features a very high Q for stability, a single transistor for simplicity, and tiny components for the utmost in miniaturization. The circuit can be constructed on a circuit board or the more readily available perforated phenolic sheet.

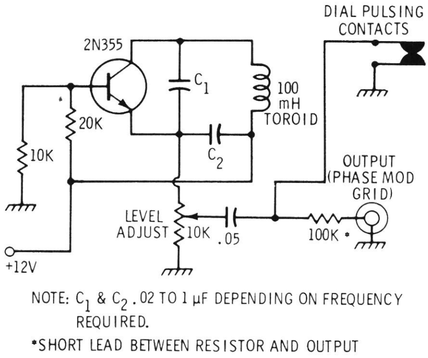


Fig. 2-12. Transistor version of a single-tone oscillator.

The most critical element of the encoder circuit is the distance from the 100K series resistor in the output to the input of the mike amplifier (or phase modulator grid) of the transmitter. The most satisfactory installation will be achieved if the resistor can be mounted proximal to this point. Leads should be kept as short as possible, of course.

The actual frequency of operation is governed by selection of C_1 and C_2. Their values will be somewhere between 0.02 and 1.0 μF, determined on the basis of experimentation.

The July 1968 issue of FM Magazine carried a construction article by Gary Hendrickson (W3DTN) which gave detailed circuit data for two ubiquitous single-tone encoders that are designed to work with "interruption" pulsing (rather than straight tone pulsing). One was a hand-held job that could be used to generate an audio signal for transmission through a conventional microphone; the other—a little more complex—was de-

Fig. 2-13. W3DTN's portable single-tone encoder unit.

signed for permanent mounting in a mobile transmitter.

The hand-held version can be built small enough to be used anywhere—at the fixed station, in a mobile, or with a walkie-talkie; yet it retains the desirable characteristics of simplicity and high reliability. As shown in Fig. 2-13, the speaker on Hendrickson's portable sender is the receiver element from a conventional "500" series telephone handset. He reportedly tested several types and found that the "500" most easily drives a microphone to full modulation without added amplifier circuitry.

Fig. 2-14 shows the schematic for the portable sender. The single transistor is of a noncritical type, and any PNP with an h_{FE} of 50 to 100 can be readily substituted. An NPN transistor can be used if all supply voltages, diodes, and other polarized circuit elements are reversed. The 88-mH toroid is the standard telephone "loading" coil familiar in RTTY circles. It consists of two windings; the adjacent ends at the center are tied together to obtain the centertap.

The frequency-determining capacitors should be good-quality **Mylar** types for best temperature stability. Small values can be paralleled here to produce the precise oscillating frequency de-

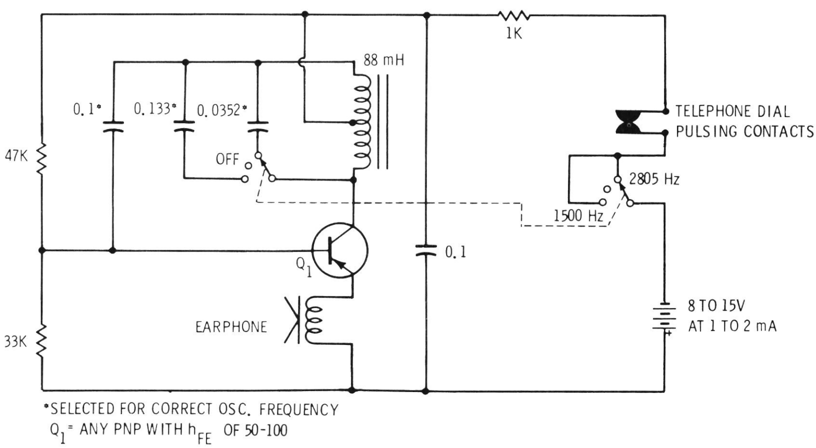


Fig. 2-14. Schematic of the W3DTN portable encoder unit.

sired. The two tone frequencies shown (1500 and 2805 Hz) are standard with commercial single-tone pulsing systems.

Fig. 2-15 shows the more complicated single-tone encoder for use in permanent mobile installations. In this version relays K_1 and K_2 can be a single unit since they operate together. The two-transistor Schmitt trigger is an automatic-shutoff timer which can be set for just that amount of time required to perform a dialing sequence. The purpose of the timer is to key the transmitter as soon as the dial is moved and hold it on the air until the dialing sequence has been completed.

The 100-μF capacitor in the mobile sender can be changed to effect variation of the period if the shutoff time is unsuitable. As the circuit is shown, the period is 2.0 seconds. (The transistors for the Schmitt trigger can be of the same type as those used for the oscillator itself.)

It is often simpler to use a tube-type oscillator circuit with base stations, where the dc control voltage required for transistors may not be available. Fig. 2-16 shows a reliable single-tone encoder circuit which uses a 6C4 as the tone oscillator. As with the semiconductor oscillators, the high impedance of the output stage of the encoder requires that shielding be used and that leads be kept as short as possible.

The circuit shown in Fig. 2-16 is the same as the **Motorola** encoder used with that company's pretransistorization two-way units. The oscillator coil, a stan-

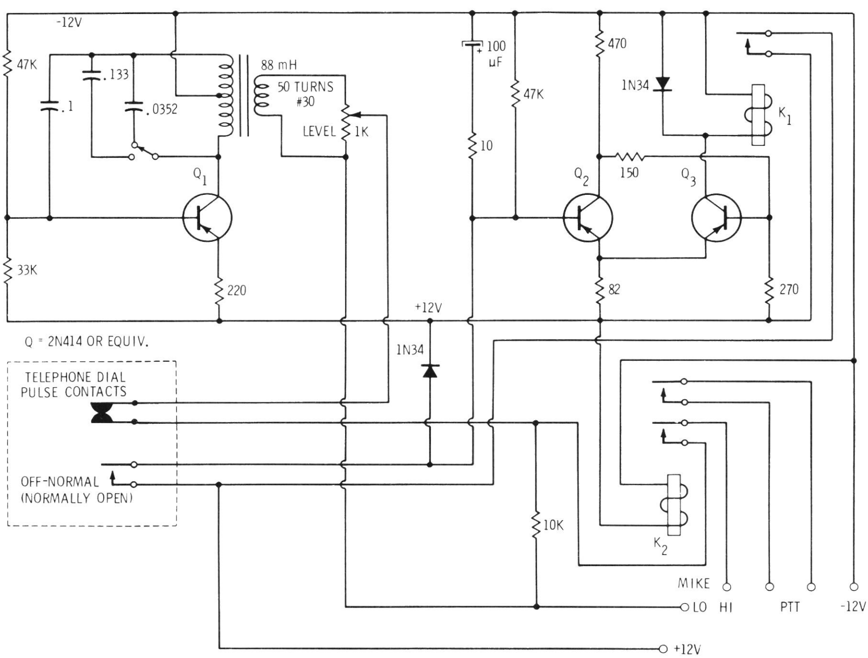


Fig. 2-15. Schematic diagram for mobile *Secode*-type encoder unit.

dard **Motorola** part, is still available from **Motorola** distributors throughout the country.

Encoder Interruption Considerations

Standard decoders are designed for operation with 1500-Hz tones. This frequency is low enough to cause decoder actuation from ordinary voice inputs occasionally. One of the key advantages of tone interruption (as opposed to tone pulsing) is that accidental function selection by voice-tripping can be easily avoided.

The "interruption" method works like this: As the dial is moved from its home position, the tone is initiated. When the dial is released, the dial contacts open a number of times proportionate to the digit dialed, causing interruption of the continuously transmitted tone. If a second digit is required in the control scheme, the tone continues (and is interrupted again in accordance to the second input digit). When the pulsing process is complete, the tone is removed, either manually or with a timer arrangement as described in Hendrickson's en-

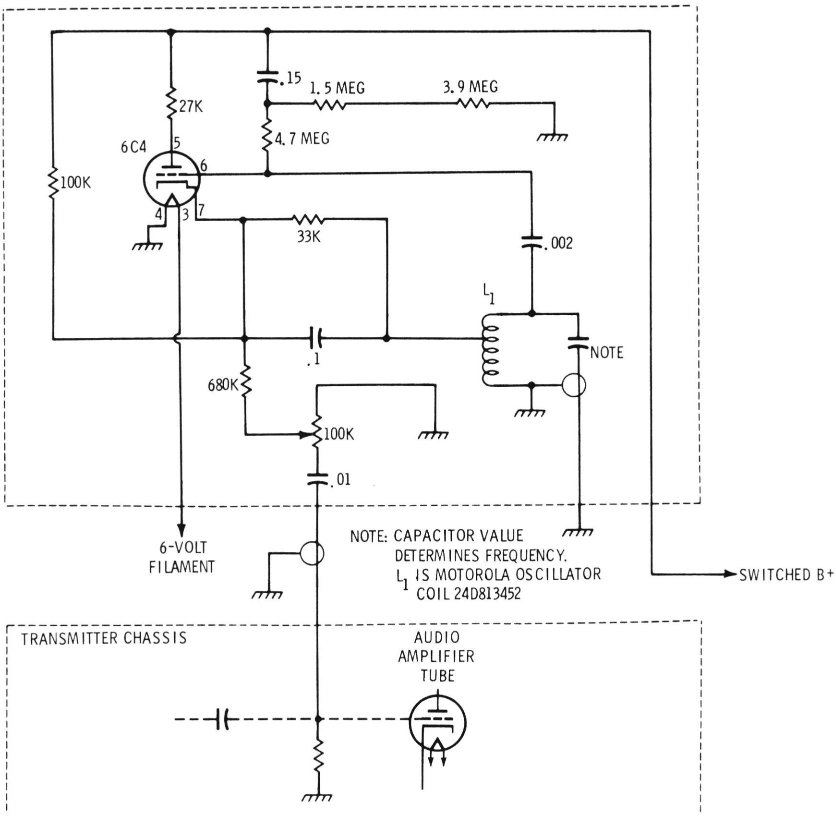


Fig. 2-16. Tube version of the single-tone oscillator.

coder. Final removal of the tone triggers the selected function.

Since voice signals can create momentary pulses at a frequency of 1500 Hz, the decoder will of course respond. But function selection by these pulses is impossible if a timer of, for example, 0.5 second is employed as part of the decoder/control system. With such a device, a 0.5-second continuous tone **must** precede a series of interruptions, and the system is thus immune to inadvertent tone pulses.

Tone pulsing (rather than interruption) is easier to manage, but it does have the disadvantage of being susceptible to voice tripping when low tone frequencies are employed. In multidigit systems, or where high-frequency tones (above 2 kHz) are used, voice triggering will pose no problems.

Encoder Pulsing Considerations

If you have ever looked very closely at the contacts on a conventional telephone dial, you have noticed that the pulsing contacts are normally closed; they open only during the dialing process. Since the encoder must generate tone signals only during pulsing, the dial may at first seem incompatible with a remote system—it isn't. Examine the encoder circuit of Fig. 2-12. The encoder is "on" at all times, but the normally closed contacts of the pulser are used to keep the encoder output at ground potential. (The 100K resistor in series with the tone output keeps the grounded line from affecting transmitter audio level.) When the contacts open (during the dialing process),

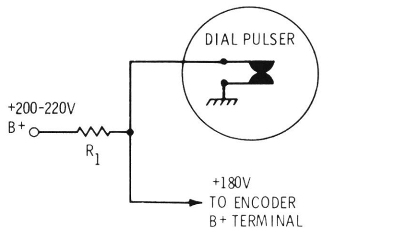


Fig. 2-17. B-plus biasing to key encoder for pulsing.

the ground is removed and the signal is allowed to feed into the transmitter modulator.

The same concept can be applied to the tube-type encoder circuit of Fig. 2-16, although it might be more satisfactory to switch B+ rather than audio. The B+ supplied to the tube is fed through a resistor in series with the B+ lead (Fig. 2-17). The resistor value must be such that the resistor accepts the B+ load during the no-dial state. When the dial pulses, the ground is removed and B+ is fed to the decoder.

As shown in Fig. 2-18, a telephone dial is equipped with a set of contacts in addition to those used for pulsing. These "control" contacts close at the initiation of a dialing sequence and do not open until the dial has come to rest. This feature makes them ideal for push-to-talk control. The control contacts may include several contacts that close at slightly different times during the dialing sequence. An important point to remember when connecting the push-to-talk to the dial contacts is to use the set that "makes" first and "breaks" last;

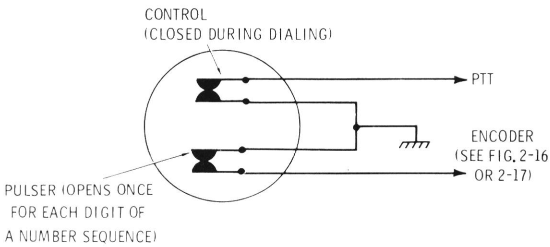


Fig. 2-18. Dial interconnection.

otherwise, you may find that the transmitter will not stay on the air long enough to allow the complete pulse train to be transmitted.

To provide the most consistently reliable control, the dial should be capable of generating pulses at the rate of 10 pulses per second. But this repetition rate is no more important than the pulse duration. The ideal pulse train for control will contain pulses of longer duration than the spaces between pulses. Getting the proper "pulse ratio" is nearly as important as obtaining the proper pulse frequency. New dials create pulses that are of ideal length and spacing. Dials that have seen considerable service in telephone use may require adjustment.

There are several methods for determining pulse spacing of dials, but the simplest is to compare the dial in question with one known to be accurate. This can be done by connecting a resistor and capacitor across the dial and monitoring the pulse readings on an ohmmeter (Fig. 2-19).

Use the known-to-be-accurate dial first and monitor the low reading after a zero is dialed. The same low should be indicated with the questionable dial. If the spacing is too long between

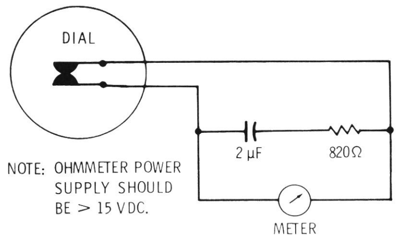


Fig. 2-19. Using capacitive load for checking dial pulsing characteristics.

pulses (pulses too short), the indication will be too low; if the spacing is too short, the reading will be higher than the reference.

The speed of the dial should also be checked. There are several methods for doing this, but the simplest is to monitor with a stopwatch the time it takes for the dial to return to "home" after a "0" has been dialed. It should be 1.0 second, although a variation of 5 percent is satisfactory. If necessary, the speed can usually be adjusted by slightly bending the flywheel arms at the back of the dial for more or less friction as the dial spins. Some dials do not have the flywheel, but close examination of the mechanism will undoubtedly reveal a means for varying the dial speed.

Single-Tone Decoder

In its simplest form, the single-tone system is often used to operate a closed repeater. At the repeater site, a single-tone decoder causes a relay to close with each short tone burst. The relay is used to "enable" the repeater for **only the duration of the ensuing transmission.** With this approach, no stations can operate through the repeater unless their signals are accompanied by an initial tone of the correct frequency and duration. This is called **tone-burst entry,** and is the easiest to defeat of all control systems. Since the tone duration time is normally very short and the frequency not too critical, nonequipped stations can usually manage to gain access to the repeater by whistling at the outset of each transmission.

With more complex systems, ratchet relays, timers, or steppers are used with the decoder to give a wide latitude of selection capability. Stepper switches are particularly well suited to digital control because they are readily available and at the same time easily adaptable to a variety of control schemes. The pulse-and-reset stepper shown in Fig. 2-20 is the most universally used, but the **Strowger** (a two-axis equivalent) is gaining in popularity. The **Strowger** is a bit more complex than a conventional stepper, but it is extremely reliable and offers the advantage of built-in resettability, two-digit operation, and a multiple-function capability. The **Strowger** is still in common use by telephone companies as line finders, selectors, and "seekers." Without special modification, a conventional stepper will restrict the user to ten functions (the number of digits on a telephone dial); the **Strowger** two-digit system allows the selection of 100 discrete switch positions. Fig. 2-21 shows the functional elements of the **Strowger** switch.

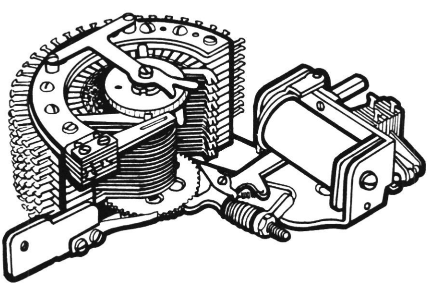


Fig. 2-20. Standard rotary stepper switch.

To summarize: Since the function of a single-tone decoder is nothing more than that of providing a contact closure with each incoming signal, the **Strowgers** and steppers are readily wedded to a decoder for effective multifunction control.

The most important parameters of a good decoder are frequency stability and signal selectivity. Frequency stability assures that the decoder will respond to proper signals during virtually any climatic conditions; selectivity affords a degree of security in that a selective decoder will not respond to signals out of a narrow bandpass.

The transistor circuit shown in Fig. 2-22 makes an ideal candidate for control because it does have the desirable characteristics of stability, selectivity, and it has the additional quality of being inexpensive to build. K6ASK designed this unit as a simplified version of **Motorola's** commercial single-tone decoder unit. The schematic shown is the third generation in a family of progressively improved decoders of K6-ASK's design. The unit has a variable gain control on the input for establishing the proper sensitivity of the decoder, and a dc amplifier on the output for providing solid drive to the pulser relay.

The decoder is designed for use with a 28-volt dc power source. When properly driven, the unit will respond to pulses within a bandwidth of less than 100 Hz (depending on sensitivity setting), and will reject all other tone signals.

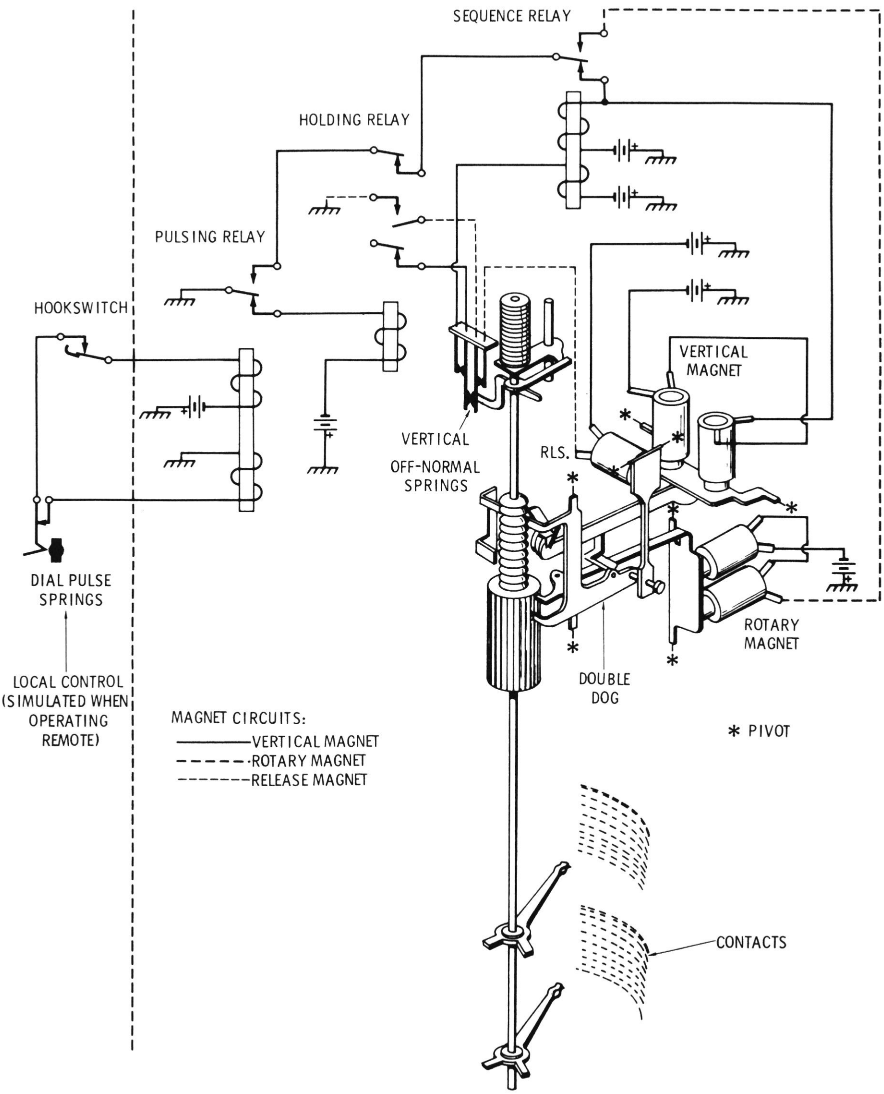


Fig. 2-21. Functional mechanisms of the *Strowger* two-axis stepper.

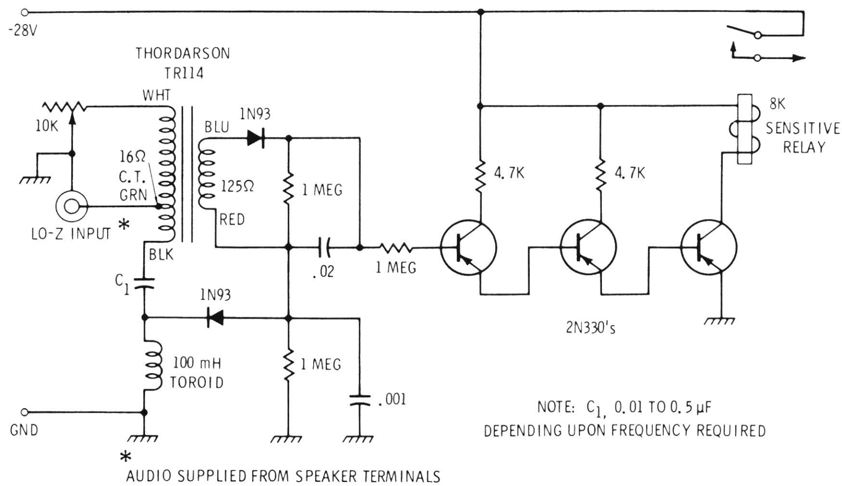


Fig. 2-22. Single-tone decoder unit.

The decoder is designed to accept tone signals directly from the speaker terminals of the remotely situated receiver (or from the audio amplifier if no speaker is used). Signals of the proper frequency and level are passed through the frequency-sensitive circuitry to the dc amplifier to key the current-operated "sensitive" relay at the output. This relay provides the pulses for controlling the mechanical stepper, **Strowger** switch, or other device. (Note: The current-operated relay is not used to drive the stepper directly because of the delicate structure of its contacts; instead it is used to pulse a husky relay which in turn does the actual pulsing of the stepper.)

2-6. CONTINUOUS TONE

By far the most common of all active control schemes is the continuous-tone squelch system. This approach is known by such terms as **CTS** (for continuous-tone squelch), **PL** (private-line), and various others, most of which have been coined by manufacturers. Since CTS involves the sending and decoding of low-level, low-frequency ($\approx$100 Hz) tones generated by resonant-reed relays, it does not lend itself to the accessing of functions by remote control. But it does provide an ideal system for restricting a repeater's use to a select group of operators. In actual use, a very precise tone accompanies each transmission of a user. The tone —having the characteristics of a low-frequency hum—is decoded at the repeater to key a relay which turns on the repeater transmitter.

If the low-frequency tone were the only element of control, the repeater's security would be only partially assured. A listener, for instance, might make a tape recording of the audio note and, by experimentation with playback levels, gain unauthorized access to the repeater. But the beauty of CTS is its capability of being filtered at the remote site. In practical use, the continuous tone is picked off the discriminator of the repeater receiver to accomplish its intended function. The receiver has no need for the tone at following stages, so the signal is processed through a filtering network designed to pass only those voice frequencies falling above the range of the tone.

The transmitter stages of the repeater also occasionally include circuits to provide additional filtering and place audio "emphasis" in the area eliminated by the tone. The output signal will then carry an apparent full range of voice frequencies, but without the telltale tone used for repeater control.

Special Considerations

Repeater designs incorporating continuous-tone control schemes are subject to certain special parameters inapplicable to other tone methods. The pulse modulator of an f-m transmitter is frequency-sensitive, for example; a very-low-frequency tone must provide more drive to the transmitter's audio circuits than a high-frequency tone for a given deviation level. (F-m, again, refers to phase modulation rather than true frequency modulation. With true f-m, which consists of modulating the basic oscillator frequency, the level of tone applied is independent of tone frequency.)

The continuous-tone spectrum extends from around 65 Hz to approximately 250 Hz. The low end provides tones that are easy to filter but which might have difficulty in sufficiently deviating the control transmitter. The high end provides easy-to-use tones, but they are in a range that is extremely difficult to filter adequately without affecting the quality of the audio in the voice spectrum. On the crowded commercial channels there is often little choice of continuous-tone frequencies. Users sharing a radio channel must select a tone frequency that is not being used by others on the channel. This fact may require a user to establish his tone system at one of the extremes—the high end or the low. For this reason, several manufacturers of tone equipment also produce "frequency-modulator" kits to extend the low-frequency capability of the user's equipment. The frequency-modulator kit is nothing more than a varactor device which is placed in the transmitter crystal circuit. After installation, the tone is applied to the oscillator so that the end signal will be frequency-modulated with tone, even though phase-modulated with speech.

The varactor approach is usually unnecessary in the amateur bands, where congestion on a single control channel is not a problem. The most satisfactory approach in the amateur spectrum is to select a tone frequency that is high enough to drive the phase modulator adequately without distortion yet low enough to allow easy filtering, usually somewhere near the center of the continuous-tone spectrum (between 100 and 160 Hz).

Another limit on selection of tone frequency is imposed by the amateur band in which operation is to occur, since total deviation is increased by the number of multiplier stages in the transmitter. The August 1967 issue of **Communications** included an article by Barry Kaufman, engineering director at Vega Electronics Corporation, in which Kaufman cited an empirical formula to be used as a "rule of thumb" for predicting the approximate peak f-m deviation (without undue distortion) that could be expected with a typical transmitter:

$$f_p = \pm 0.45 m f_t$$

where,

f_p equals maximum peak f-m deviation in hertz,
m equals transmitter multiplication factor,
f_t equals tone frequency in hertz.

With a little figuring, it is easy to see why continuous-tone systems are not usually employed on six meters. For example, suppose a six-meter transmitter with a multiplication factor of 16 were to be tone-equipped with a 100-Hz system. From Kaufman's data, $\pm 0.45 \times 16 \times 100 = \pm 720$. If it is assumed that the tone must be capable of deviating 15 percent of a narrow-band limiting signal (or 10 percent of a wide-band signal), it becomes obvious that the tone deviation level is insufficient to allow reliable control on the frequency of interest, if the transmitter is set for wide-band operation.

Most amateur stations adhere to a 15-kHz deviation standard, though there are groups who have adopted 5 kHz as a standard. A satisfactory continuous-tone signal in both cases would be one which has a deviation capability of approximately 1.5 kHz (for the 15-kHz unit) or 750 Hz (for the 5-kHz unit). To provide a satisfactory tone level at six meters for a 15-kHz system, the control-tone frequency would have to be higher than 400 Hz, or totally out of the normal continuous-tone range.

CTS Encoders and Decoders

The requirement for mechanical resonant reeds in CTS units complicates the construction of vacuum-tube encoders and decoders, since reed types are matched to specific manufactured circuits. This is not to say that a homebrew CTS system using vacuum tubes cannot be successfully designed, but several key factors weigh heavily in favor of using commercially designed and built units:

1. As likely as not, the surplus f-m radio you buy will already be equipped with CTS equipment.
2. Used CTS encoders and decoders (and encoder/decoder combinations) are both readily available and inexpensive.

For the diehard do-it-yourselfer, however, Fig. 2-23 shows a highly stable encoder with an output impedance of 8K to 10K. The output can be used to drive a matching transformer or an emitter-follower stage if the stated output impedance is unsatisfactory for a given application.

In the schematic, the value of C_2 is selected according to the

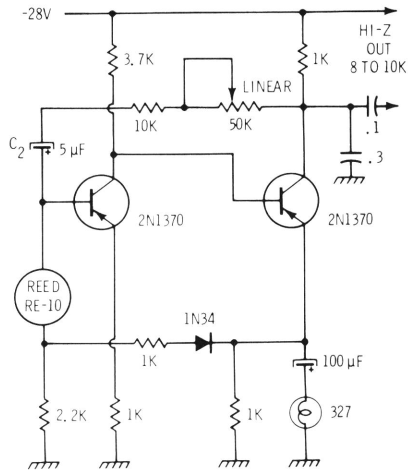


Fig. 2-23. *CTS* encoder circuit.

frequency of oscillation required. The circuit is designed for use with **Bramco*** RE-10 reeds, which may be ordered for the precise operating frequency.

Fig. 2-24 shows a very simple yet effective CTS decoder circuit using three inexpensive NPN transistors. The audio input requirement is 200 mV (rms); as long as the applied tone is above this level, a "drive" voltage appears at the output. The output can be used to switch small loads (such as relays) up to a maximum of 50 mA. The resonant-reed device in the decoder is a **Bramco** RD-10, which may be ordered for any precise frequency between 67 and 300 Hz. CTS units can be constructed using LC networks in place of the resonant-reed relay, but this approach is not recommended. Frequency stability is the key to a successful CTS system, and the resonant-reed relay is the only device that can assure precision in this regard under virtually all environmental conditions.

*__Bramco Controls Division,__ Ledex, Inc., Piqua, Ohio

CTS Filtering

Filtering the CTS tone from the incoming signal so that it will not be retransmitted enhances the security of a repeater, but it also keeps the output channel free of the CTS often-objectionable hum. The simplicity and effectiveness of a tone-elimination filter combine to make its use a virtual necessity in any CTS installation.

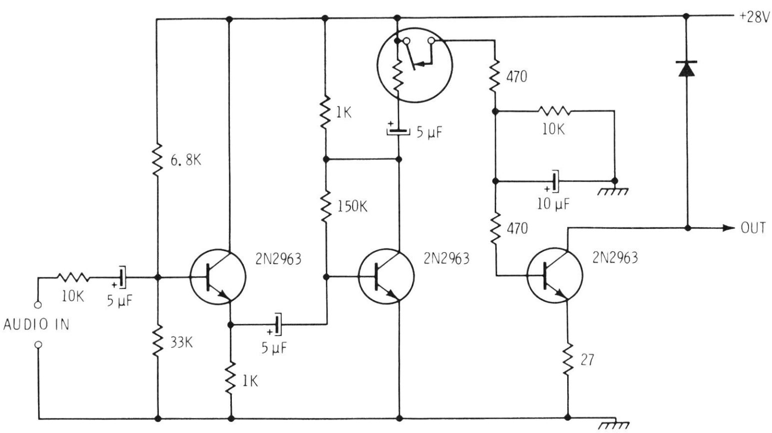


Fig. 2-24. *CTS* decoder circuit.

It is true that some filtering (6 to 8 dB) can be achieved by modification of the receiver de-emphasis characteristics. But the probability of voice-quality degradation tends to make filter installation a more attractive approach.

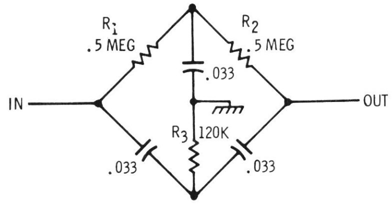
Fig. 2-25 shows an RC bridge configuration (twin-T) in which three resistors and three capacitors may be connected to filter tone signals between 115 and 136 Hz. As shown in the diagram, the values can be adjusted to filter tones below 115 Hz in frequency.

Use of the CTS filter on a receiver tends to improve the intelligible-audio recovery (and, hence, the signal-to-noise ratio) to the extent that often the result is an effective increase in receiver sensitivity. Occasionally receivers equipped with CTS filters yield considerably reduced thermal noise (squelch open, no signal), but the audio level with normal signal input will remain unchanged.

The CTS filter should be installed in one of the receiver early audio stages, such as between the volume control and the first audio amplifier. The important thing to remember is to process the tone from the discriminator for use in the decoder before it arrives at the tone filter.

2-7. TIMER CONTROL

One of the simpler techniques for multifunction control involves the use of timing devices in conjunction with any tone encoding/decoding system. In application, the timer is either a delay relay (or its equivalent), a time-interval, or a delayed-dropout relay (or equivalent), and is energized directly by the decoder control-voltage output. After the control tone has been continuously transmitted for the required period, the relay closes (or opens) to perform the function. Through judicious selection of timers and timed sequences,



NOTE: TO FILTER 90-110 Hz, USE 0.05 CAPACITORS AND 470K RESISTORS (R_1 AND R_2); R_3 REMAINS UNCHANGED

Fig. 2-25. *CTS* filter for the control receiver.

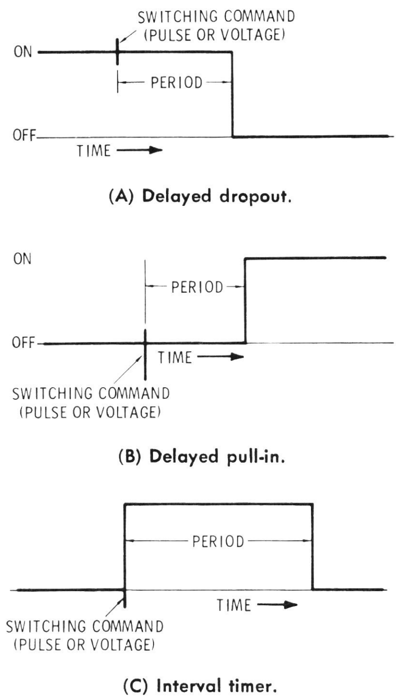


Fig. 2-26. Period descriptions of basic timers.

an impressive number of functions can be reliably and effectively achieved.

There are a large number of timing-device types, the most popular of which are thermal, pneumatic, motorized industrial types, capacitor, and solid-state. The circuits presented in this book are shown as "relay" devices for the sake of simplicity and easy recognition, though in most cases any type of timer would be satisfactory. The basic timing devices, whose functions are illustrated in Fig. 2-26, are delayed pull-in, delayed dropout, and interval timers.

(1) Delayed pull-in: Time-delay relay with pull-in taking place after voltage has been applied for the required period. After pull-in, the delay relay remains energized as long as coil voltage is present.

(2) Delayed dropout: Time-delay relay with instant pull-in on a voltage pulse. Relay will release after prescribed period, which begins only when voltage is removed from coil.

(3) Interval timer: Time-delay relay with instant pull-in application of coil voltage. If coil voltage is removed before the end of the timer period, the switching function will not take place. Device switches after specified period when coil voltage is applied for the complete duration of timer period. Reset does not take place until coil voltage is removed from device.

Thermal Delays

The thermal delay is an inexpensive device incorporating a thermostatic element as its functional mechanism. When the coil temperature reaches a predetermined point, the contacts make (or break, but rarely both). Thermal delays are usually small enough so that a great many can be mounted on a single chassis or panel. They can be purchased with standard pins to match conventional miniature tube sockets.

The chief disadvantages of the thermal delay are excessive recovery time and concomitant undependability, and heavy current requirements. A thermal timer energized too soon after a previous use will cause premature switching of the function that is to be delayed. For repeater applications, these devices should never be employed where the time period is critical or where instant resettability might at some time be a requirement.

Pneumatic Timers

The pneumatic timer is an exceptionally accurate, highly reliable (but often quite expensive) device that is particularly well suited to remote applications. These devices employ a variable-tensity pressure diaphragm that provides positive pull-in after the specified period.

The ***Agastat** line of pneumatic timers achieved vast popularity with California amateurs and repeater builders in recent years because of the sudden availability of hundreds on the local sur-

*Trademark of **Elastic Stopnut Company,** Elizabeth, New Jersey plus markets. Interestingly (but to no one's surprise), prices followed the demand. The first few were sold for fifty cents apiece. The price went to a dollar—and finally to five dollars. As the demand increased, the supply went down at a rate almost inversely proportional to price. Let it suffice to say that **Agastats** are perfect for repeater applications. In addition to having that rare capability of being instantly reset and retriggered (with no significant period variation), they have double-pole contacts (double-make, double-break) and are capable of carrying high currents of both resistive and inductive loads. And the coil current drain is not even worth considering.

Motorized Timers

There are two basic types of motorized timers. The most common (and least expensive) is the **spring-clutch** type which typically has an integral microswitch arrangement as its operational element. To energize the timer sequence, a voltage is applied to the motor, which begins to pull an arm toward the microswitch. If the voltage is not removed before the end of the period, the arm makes contact with the switch to effect the function. The timer period begins anew whenever the voltage is reapplied, regardless of the time between applications.

Although this time-delay device is extremely accurate, it is basically unreliable for long-term use. Parts to go sour include the motor itself, the clutch assembly, the mechanical spring-tension mechanism, a number of small gears, and the switch assembly. They are also relatively expensive devices, typically selling on the surplus market for 3 to 8 dollars each.

Another motorized timer type is the photographic (or industrial) timer, which possesses capabilities unmatched by all other mechanical devices. Although quite expensive, the photographic timer has the capability of being preset for any period from a few seconds to a quarter-hour or more. It is instantly resettable and can switch very high-current loads.

The cost of the photographic timer is prohibitive for general use, but it is uniquely suitable for transmitter-protection control. In this passive control application, the photo timer can be used to shut off the B+ to the repeater transmitter final when a carrier remains on the input channel for unduly long periods. When the carrier disappears, the timer resets instantly.

Of course the photographic timer suffers from the same basic lack of reliability that all mechanical devices share, but in such instances as transmitter protection, the fault may be well worth the tradeoff. Many such timers have 115-volt ac outlets, too, which makes them immediately adaptable to applications where full shutdown is a desirable timed function.

Capacitor Timing Devices

Ubiquitous and inexpensive, but limited in application—these are the most descriptive adjectives for capacitor devices. They usually consist of nothing more than an electrolytic capacitor shunting a conventional relay coil to effect a short delay in relay dropout. Resistors can be added to the circuit to delay the pull-in time as well. Fig. 2-27 shows several delay circuits using capacitors for the delay function. The value of the capacitor determines the period of the delay in each case. (This value is selected on the basis of coil inductance and resistance, but can usually be determined experimentally.) Capacitive delay devices are particularly useful where very short timed periods are required, but they are not always satisfactory for primary control, where periods may be long enough to require excessively high values of capacitance or where precision of period is of paramount concern.

Solid-State Delays

The solid-state timer, with all its various semiconductor circuits, is the ideal; it can be as accurate as required, and can be used for interval timing, delayed pull-in, delayed dropout—for short periods or for long, and for high-current switching of either ac or dc loads. It has all the combined advantages of other timing devices and shares but two of the disadvantages. Unfortunately, the dual disadvantage is no small thing: complexity of fabrication and expense of components.

While the complexity and expense of solid-state timers may be significant enough to preclude their use for all timed sequences, it should not forbid their use in certain key timed functions. Fig. 2-28 shows a proved circuit (with a nice compromise in complexity) for a solid-state interval timer capable of being actuated by either a pulse or a continuous voltage. The timed period, varied by selection of the key resistor (R_1), may be anywhere from 0 seconds (no resistance at R_1) to 15 seconds (approximately

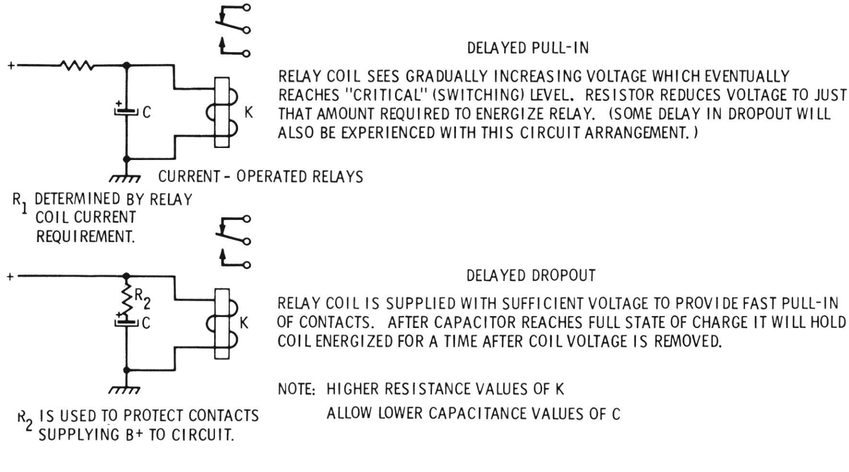


Fig. 2-27. Use of relays and capacitors to control noncritical timed-switching sequences.

220K). And, by using a 100K resistor for R_1 and increasing the value of C_1, the period can be upped to several minutes.

Although the advantages of this solid-state interval timer are obvious in terms of dependability, period repeatability, and general imperviousness to environmental conditions (such as extremes of temperature, humidity, and vibration), one can readily see the economical drawbacks where a large number may be required in a given set of control applications.

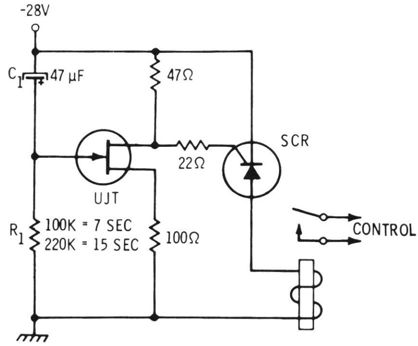


Fig. 2-28. Solid-state interval timer is keyed by continuous voltage or pulse.

Control Applications

As a primary control element, the timer offers a uniquely simple means to attain effective, efficient, and flexible control. For example, a timer's normally open contacts can be used to supply primary power to any remotely established and interconnected unit. In such an application the timer is supplied drive voltage directly from the decoder contacts. The proper tone, transmitted for the proper period, causes the timer to activate the function. Fig. 2-29 is a schematic presentation of timers used for control of a typical remote system.

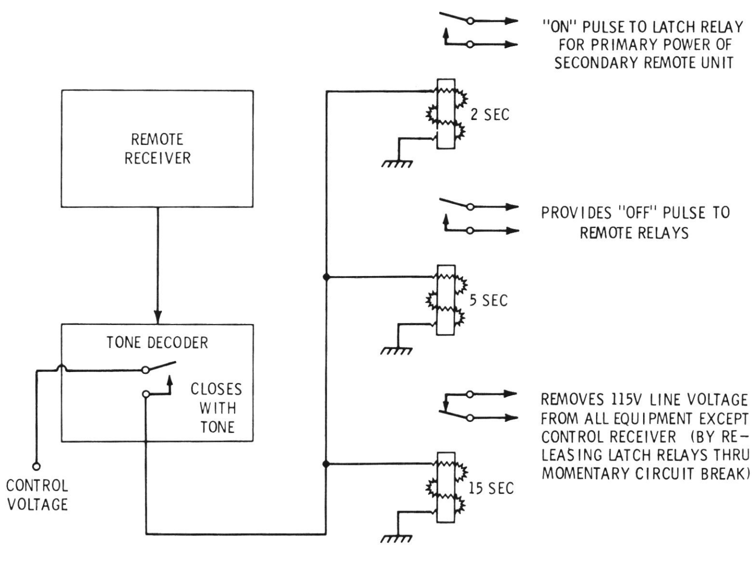


Fig. 2-29. Means for using timers as prime remote-control elements.

2-8. ACTIVE FUNCTIONAL CONTROL, WIRELINE

There are a number of instances where wireline control becomes economically or technically more feasible than radio control. Similarly, a number of radio-controlled sites will incorporate certain wireline-controlled elements. While many of the tone-control techniques previously described are readily adaptable to wire transmission, certain additional factors (for example, levels, impedances, etc.) must be considered when using leased telephone pairs. This section outlines the basic applications of wireline "links" and describes the principal methods for assuring reliable control capability and consistent, effective communications.

The three basic applications for amateur use are direct control and communication, indirect control and communication, and telephone command for emergency control. The direct-control approach, more common with commercial users than amateurs, involves the direct transmittal of signals to a remote site via the wireline. Indirect control is the use of a wireline as a link, ordinarily employed to interconnect two remote facilities. The "telephone command" is related to the other control approaches only in the sense that all employ a wire pair as the medium of signal transfer.

Direct Control

The direct-control system has never been particularly popular with amateurs because its use restricts control (and often operation) of the remote facility to an operator at a single predeter-

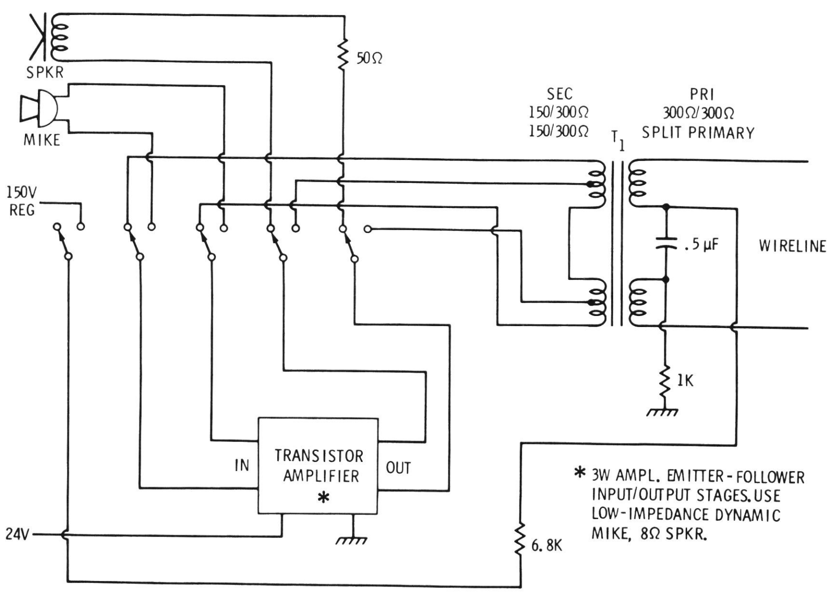


Fig. 2-30. Remote-control unit, primary termination.

mined fixed site. The trend to mobility—in both control and communication capability—has resulted in the modern amateur all but ignoring the use of wirelines for control.

The wireline's compatibility with an open repeater system and its built-in security from unauthorized control access should qualify it for serious consideration as a primary control mode in repeater systems which are still in the design stage. Where the remote site is situated only a short distance from the control point, the technical and economic advantages of wire can often outweigh those of a system controlled solely by radio. The single pair of a leased wireline circuit is used to convey all the elements for control and communication; in most cases the wireline's dc transmittal capability obviates the need for tone encoders and decoders.

Each end of a wire is referred to as a termination. The control point is the **primary** termination and the remote site is the **secondary.** Illustrating the simplicity of a straightforward primary termination is the control system pictured in Fig. 2-30, which consists of a microphone, speaker, and signal-decoupling components.

The basic circuit shown has no capability for switching functions other than power on/off and simple transmit and receive commands, but it is adaptable to multifunction control using any one of a number of available control schemes.

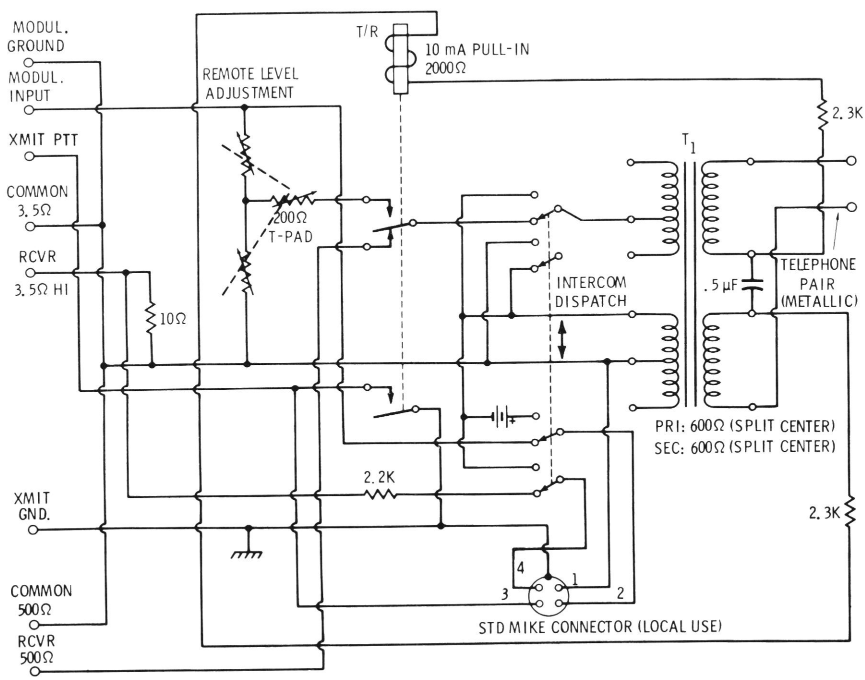
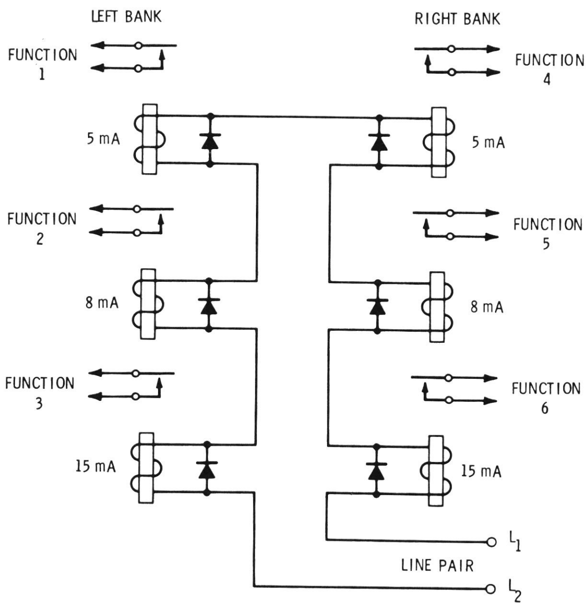


Fig. 2-31. Remote-control unit, secondary termination.

At the remote site (where the transmitter and receiver are located), the secondary termination incorporates the actual elements of control. The circuit shown in Fig. 2-31 shows how on-off and push-to-talk control is effected with a maximum of built-in capability (such as on-site local control, intercom, etc.). The terminations described in Figs. 2-30 and 2-31 are simplified versions of existing commercial designs.

An imaginative remote operator can readily adapt a variety of selective control systems for wireline use. Controlled use of current-operated relays, for example, will allow the selection of a number of functions so long as the sequence of selection is compatible with the functions selected. Fig. 2-32 illustrates this concept, which uses polarized relays of differing current sensitivities to respond to functional commands. Diodes across the relay coils serve as the polarizing devices, as shown. Depending on the polarity of the voltage on the line (L_1, L_2), relays from either the left bank or the right bank (Fig. 2-32) can be energized in sequence. (But relays from both sides cannot be energized at the same time.)

After selecting the bank and polarizing the line according to the table in Fig. 2-32, the control operator allows transmittal of no more voltage than is necessary to pull in the most sensitive relay of the bank. To key the next function, the voltage is increased to the point where the second relay pulls in. Function 1 may be keyed independently from function 2, and the right bank can be



FUNCTION	ACTION	RELAY CURRENT
1	L_1 = pos, L_2 = gnd	5 mA
2	L_1 = pos, L_2 = gnd	8 mA
3	L_1 = pos, L_2 = gnd	15 mA
4	L_1 = gnd, L_2 = pos	5 mA
5	L_1 = gnd, L_2 = pos	8 mA
6	L_1 = gnd, L_2 = pos	15 mA

NOTE: USE CURRENT-LIMITING RESISTORS AT LINE SOURCE

Fig. 2-32. Selection of six functions by controlling polarity and current of transmitted dc signal.

used without energizing the left (and vice versa); but the big disadvantage is that when a relay is energized on a given bank, all other lower-current relays **on that bank** will also be engaged. Thus, the functions for which this control system can be adapted are limited.

In practice, it is usually better to have no more than two relays on each bank, and select relays which have pull-in sensitivities that are at least 10 milliamperes separated, one from the other.

Indirect Control

Perhaps the most "natural" application of a wireline in a repeater system is between a transmitter and a receiver site when the two installations are separated by a short distance (usually less than a mile). This constitutes indirect control in that no operator monitors or provides direct control at either terminal point of a single wire pair.

Fig. 2-33 illustrates this concept and shows how it may be used in combination with a radio-controlled repeater system. By using control techniques described previously, the control operator may connect or disconnect the wireline or perform any other off-on function at repeater site A.

Site B (where the receiver is deployed) is coupled, via the wireline, to site A through the radio-control circuitry. Signals from site B to site A, such as COR closures and audio, are processed through subcontrol circuitry installed at site A.

Particularly in indirect control applications, repeaters using

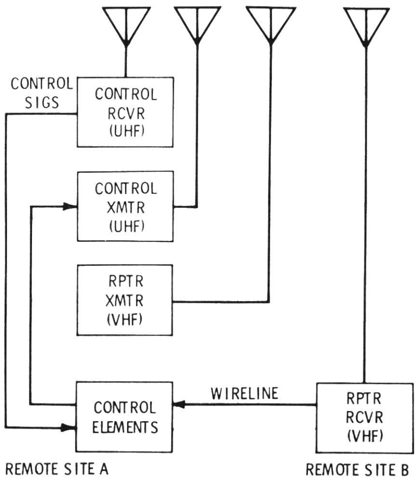


Fig. 2-33. Indirect wireline control system for site interconnection.

wireline often employ the use of dc signals to effect control. Such systems take advantage of the fact that audio-frequency signals can be superimposed on (and extracted from) dc-bearing lines without modifying the character of either the ac or the dc component. With such a system, the COR is positioned at the receiver (site B). Contact closure of the COR causes a B+ signal to be sent down the line along with the audio-frequency signals from the receiver. At the transmitter location (site A), the ac is picked off the line through a matching transformer whose centertap is comprised of a dc-blocking capacitor. The dc signal is used to trigger a current-operated relay to turn on the repeater transmitter. Fig. 2-34 illustrates this scheme.

Wirelines present special problems to the amateur. One of the most noteworthy of these is maintaining an audio level which allows satisfactory operation without hum pickup but which does not cause inductive crosstalk in other adjacent lines. The simplest way to avoid trouble with "line neighbors" is to keep the level within the standards established by most telephone companies; that is, at a level which does not exceed +1.0 dB above 1.0 milliwatt into a line with a 600-ohm termination (+1 dBm).

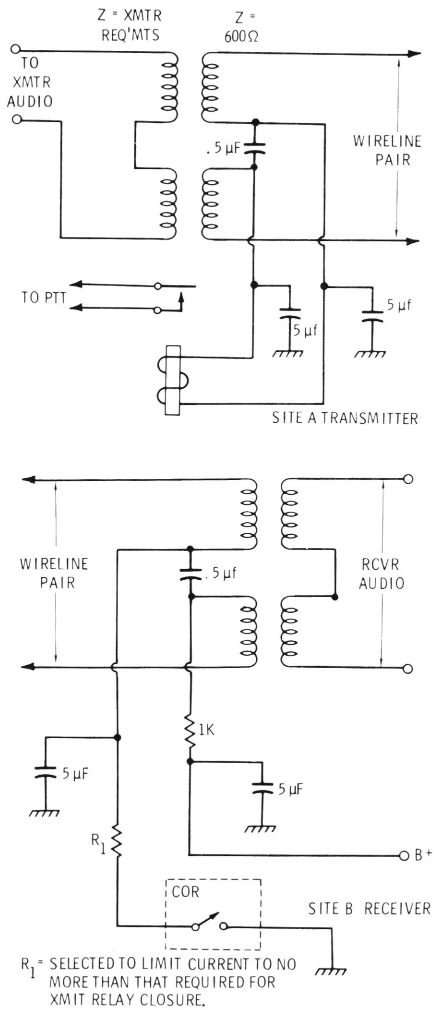


Fig. 2-34. Wireline terminations.

Determining actual dB level is a very simple process which can be accomplished with the aid of any good voltohmmeter which has an "output" range. Here's how: When the wireline has been installed, open the squelch at the receiver so that the latent squelch noise is fed continuously into the line. At the terminal point (transmitter location, site A), disconnect the line from the transmitter and connect a 600-ohm resistor across it **on the line side of the transformer.** Monitor the reading of the noise on the dB scale of your voltohmmeter (ac mode, output probe). The level should be approximately 0 dB. If the level is less than −3.0 or greater than +1.0, reduce the audio **at site B** and recheck.

Special Considerations

In some wireline installations, hum can become a serious problem. The telephone companies have ways of minimizing hum (for example, twisting the pair to cancel fields, phase cancellation at loop amplifiers, etc.), but often the problem cannot be eliminated entirely by the phone company's universal methods. One example of a typical "hard case" might be where the leased line traverses poles shared with high-voltage lines. The induced ac voltage on each line of the telephone pair can be as high as several hundred volts when referenced to ground.

The wireline user can further reduce the likelihood of hum problems by "balancing" the wireline pair. A wire pair is said to be balanced when both leads have the same resistance over their length and the same voltage to ground at all points along the route. Balancing can be effected in the termination circuitry at each end of the wireline by bypassing the dc input signals to ground and by keeping the dc input as well as the wireline away from a ground reference.

When a conventional line transformer is used (as in Fig. 2-34), the transformer itself provides a balancing method by virtue of the transformer coils through which each dc leg must pass. This method effectively negates the differences in resistance (to ground) at the dc input and allows the use of available dc voltages at the site (such as B+ and ground). An unbalanced condition would exist if the dc signal were to be coupled directly to the wireline without the benefit of the series transformer winding.

Telephone Command

A not-too-often considered means of remote control is the telephone itself (assuming a telephone is available at the remote site). As a principal control element, the telephone has certain disadvantages, but as a backup system the telephone has no equal. There is no feeling quite as comfortable to a remote or repeater owner as the knowledge that he can shut down his system regardless of what happens to the hilltop transmitter or receiver and regardless of where he is. For he knows that to accomplish shutdown, he need only go to the nearest telephone and dial the remote number. When the remotely situated telephone rings, the shutdown function will occur.

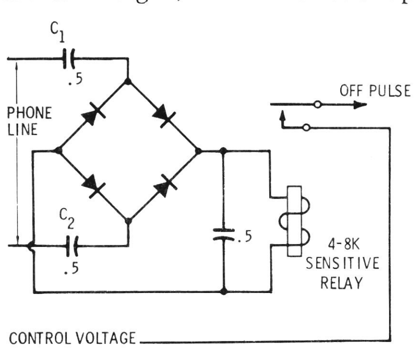


Fig. 2-35. Telephone command of single function.

The circuit of Fig. 2-35 shows how the telephone ringing voltage can be used to trigger a selected function without causing interference to the phone line. The ac ringing voltage is isolated from the phone lines through C_1 and C_2 and rectified to produce a dc signal which triggers the current-operated relay. Omission of C_1 and C_2 would cause excessive loading of the phone line and would result in hum, level problems, and dc entry. The filter capacitor must be low enough in value to allow full charging during a one-second ring so that enough power is available to pull in the relay.

It is easy to see the difficulties that could arise if the telephone number were commonly known, since any ring would cause immediate interruption of repeater service. This problem can be avoided by adding the extra circuitry required so that the system will shut down only when the phone rings a specific number of times. This circuit is shown in Fig. 2-36.

In the case shown, the desired function occurs when the phone has rung exactly twice. The first ring prevents the stepper from reaching the right point. If a third ring occurs, the function is canceled.

The function occurs only when the phone has rung two times and the stepper rests on position 2. Ringing of the phone energizes the timer and moves the stepper; the stepper will automatically reset after it has been energized. The period of the timer should be selected to allow sufficient time for the stepper wiper to come to rest on the coded "off" contact with a few seconds to spare.

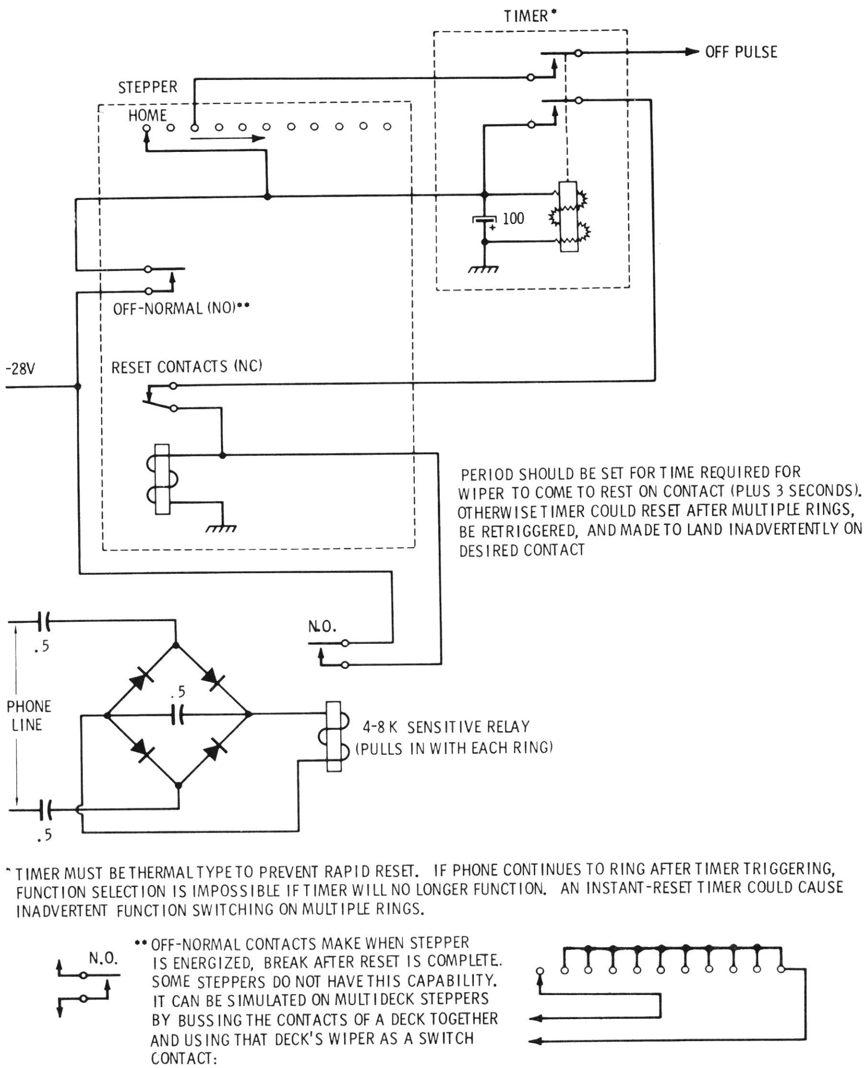


Fig. 2-36. Telephone control with planned code for function switching (to the "off" state).

Incorporation of an automatic phone patch into a remote system (see Chapter 5) will introduce some interesting (and somewhat amusing) control possibilities. Most telephone areas have individual numbers which can be dialed to make the initiating telephone ring. Using this capability, a remote operator can initiate a call to this "ringback" number, hang up, then let his on-site telephone ring the specific number of times required to perform the intended "off" function.

For obvious reasons, telephone control should be reserved exclusively for "off" commands. The FCC would frown (to say the least) on a remote system that opened the possibility for a "wrong number" to turn on repeater equipment.

2-9. PASSIVE FUNCTIONAL CONTROL

A passive control function is one that happens by design, but automatically, as a result of certain preestablished conditions. Functions in this category include timer-limited transmission periods, automatic shutdown when an input carrier dominates the control channel for prespecified periods, automatic function selection, and an almost numberless variety of other operations.

Passive Diode Control

From the point of view of equipment protection and operator error probability, passive diode control is by far the most important feature that can be worked into a command selection system of a repeater. An example of the need for passive control is where more than one transceiver is to be operated remotely on a single band and only one antenna is available. With active control only, the operator would change from one unit to another by initiating a command from the remote-control site to shut down the first unit, then a command to apply power to the second, and finally a command to transfer the antenna from transceiver 1 to transceiver 2. If he were to forget to change antennas, the second transceiver would be damaged; if he were to forget to shutdown the first transceiver, it would be damaged. The use of passive control, however, precludes these eventualities.

With a passive "secondary" control system, the operator may activate either transceiver with the knowledge that the other will be shut down, and the antenna will be connected to whichever of the two transceivers has last been energized.

Passive control is achieved very effectively in control systems which use pulses to activate the various functional elements. A diode matrix of **OR** gates can be connected so as to pulse any desired function or group of functions when any of several other functions is pulsed.

In the example with the transceivers and the single antenna, transceiver 1 would shut down when it is commanded (by the control operator) to shut down, **or** when transceiver 2 has been activated, **or** when the antenna has been switched to the second transceiver. This approach totally eliminates the possibility of damage to the first transceiver by a control oversight on the part of the operator.

The diode matrix of Fig. 2-37 shows how passive control is effected in the author's Radio Ranch remote facility, which uses negative pulses for all relay keying functions. A negative pulse may be thought of as a "traveling" entity. When a pulse is initiated at its source (a stepper contact or frequency-sensitive relay), it travels along all wires connected to that point until it reaches its intended destination, where it is used to pull in and latch a relay or perform some other short-duration function. When diodes are connected in series with one of the wires carrying a pulse, they act as valves. If a negative pulse is allowed to enter the cathode end of a diode first on its way to its destination, the diode will appear as an open gate. If the pulse enters the anode end first, the diode will appear as a closed gate, and the pulse cannot get through.

When the anodes of more than one diode are connected to a single bus and the cathodes are connected to individual buses, the circuit is an **OR** gate when negative pulses are used. In the matrix schematic, diodes D_1 and D_2 comprise one **OR** gate, while diodes D_3, D_4, D_5, and D_6 make up another. In the D_1-D_2 case, a pulse will trigger the low-power relay when LO has been dialed (or otherwise commanded) **or** when

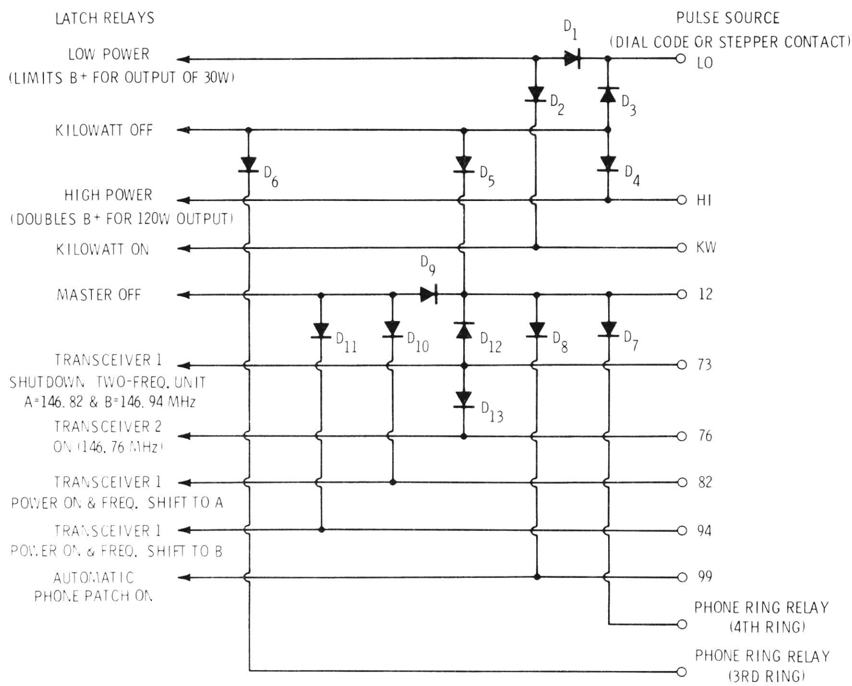


Fig. 2-37. Diode *OR* gate matrix for passive function in K6MVH remote-control system.

W9CR

the kilowatt amplifier has been activated. (The basic transmitter in this case must drop to a specific low-power level to keep from overdriving the kilowatt final amplifier.)

The **OR** gate of D_3, D_4, D_5, and D_6 shuts down the kilowatt when the low-power function (D_3) is commanded actively (though not when the function occurs passively) **or** when the high-power (120 watts) function is commanded (D_4) **or** when the driver transmitter is shut down (D_5) **or** when the telephone at the remote site has rung three times (D_6).

Passive Timer Control

As you design your control system, you will see that timers of one form or another are indispensable. Where you cannot afford to take chances by depending on your repeater users to manually perform the necessary switching functions, and where there is a likelihood that "command" control may not at all times be capable of being achieved, you will find timers the answer.

Suppose you want to remotely engage a kilowatt amplifier for the hilltop transmitter. One of the requirements is that no B+ be applied before the filaments of the mercury-vapor tubes heat up. (This is of course an arbitrary function, but one that can be applied to a number of operational variations.) What better way is there to be sure than to incorporate a timer to see to it that B+ is not inadvertently and prematurely applied?

There are a great many very common uses for passive timer control. Fig. 2-38, for example, is a circuit that uses two timers to perform a dual control function: that of (1) shutting off the transmitter B+ supply when an input transmission exceeds two minutes, and (2) shutting down the transmitter (or repeater) completely when it has not been used for a period of one-half hour.

Many of the passive switching tasks of timers are more subtle than those shown in Fig. 2-38. Such uses will become obvious as you examine the repeater applications data presented in

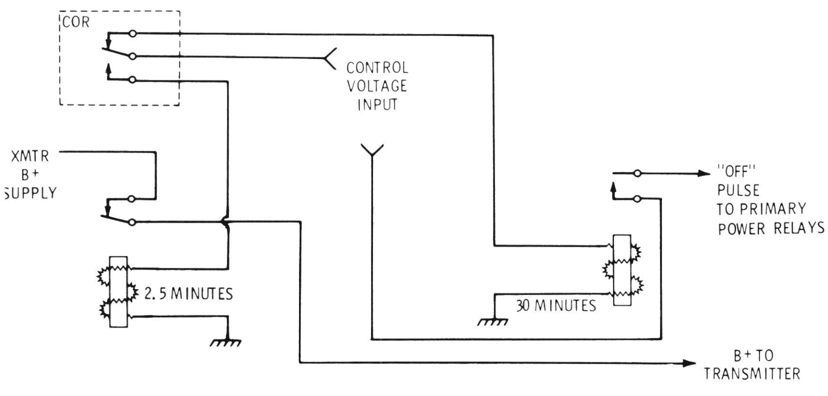


Fig. 2-38. Timers in typical passive-control applications.

Chapter 5 of this handbook, where timers are used for such purposes as connecting and disconnecting phone patches, energizing identification systems, disabling control systems, and a variety of other functions, many of which may not appear to involve "time" as a critical (or even necessary) element.

Chapter 3

Preparing for a Repeater

Regardless of how well engineered a repeater is, its ultimate success will depend largely on its location, and the seeking out and acquiring of a good repeater site can sometimes present problems that seem almost insoluble. Anyone who has experience with vhf will know how to choose a site—pick the highest, most vantageous point in the area. Knowing where to put a repeater, however, may prove a great deal easier than getting authority to put it there.

In mountainous terrain, the mountaintop is the ideal choice; but who gives the OK? In the city, the highest centrally located building is the answer; but whom do you approach? In outlying regions, local TV stations have tall towers that might be used for a repeater; but, again, who will open the right door for you?

3-1. GETTING THE SITE

A cursory analysis was conducted to determine the legwork that went into the installation of such notable and successful repeaters as those in Tulsa, Las Vegas, Wichita, and Phoenix. All have two common denominators: They are geared to provide emergency communications as needed by the local public, and they are at least partially deployed on local TV towers. These factors point to a spirit of cooperation on the part of the local community **when the proposed repeater has something to offer the community.**

If you (or your group) happen to be eyeing a local TV tower as a potential repeater site, it would seem advisable to lay out a complete proposal on paper. The proposal would then show exactly what you need in terms of space and access and would describe the benefits you would provide the community.

In the case of the Wichita repeater, the initiators prepared a hard plan for repeater mobilization during emergencies, for monitoring the repeater as a routine function, for maintaining direct communications with the local weather bureau, and for maintaining an organized net with a single data-flow center.

Those responsible for deciding on whether or not to allow the amateur group to share the tower were shown: (1) the coverage (and range) to be provided by the repeater, (2) the protection it would offer the community in terms of advance warning for tornados, (3) the organized "communications capability" that could be placed at the disposal of any city or county government office, and (4) the civil defense training for amateurs that could be a part of the repeater's daily operation.

A few proofs as to the reliability of the proposed installation, that access to the site would be carefully controlled, that the repeater would in no way interfere with the tower's primary communication function—all proved to cinch the deal for the amateurs. And one of the best known repeaters in the country was born.

There is no need to go into the detailed preparatory plans of the other cases, for their stories are all markedly similar: the amateur repeater **offers to the public** a service that **exceeds in scope the service required by the repeater.**

Where the public service capability applies to the acquisition of local government and communications-media sites, it may not be applicable to "land" sites such as mountaintops. But in many cases these areas, too, can be placed in the hands of responsible amateurs.

It would be a difficult task to estimate to any degree of accuracy the number of amateurs taking advantage of the U. S. Government's special land-leasing policy. But one thing is certain: the number is growing.

A few years ago the Forest Service (a branch of the U. S. Department of Agriculture) established a policy by which licensed amateurs could lease (at very low annual rates) choice parcels of accessible hilltop land for the express purpose of installing remotely operated amateur radio stations. From reports received from several lessee amateurs, the cost varies from one site to another, but it is never too much for the average ham group —even if the group consists of but one person!

At one California site (in the Angeles National Forest) a 19-acre plot of prime land was turned over to the amateur radio community for the total annual lease fee of $25 per participating amateur or group. The lessees were permitted to improve their property and erect the necessary towers and buildings to contain the remotely controlled equipment. Before they were permitted to construct their building, the Angeles National Forest ham groups were asked by the Forest Service to submit detailed building plans for approval, including drawings and prints. Following this approval, official red tape was minimal and the building went up without further scrutiny. A photograph of the facility as it appears today is shown in Fig. 3-1.

The Forest Service appears very willing to issue land to amateurs, and seems anxious to participate in any way that might prove beneficial to the general public. Such use of U. S. Forest Service land seems to be at the discretion of the local district ranger.

In the Angeles National Forest case, Mr. Royal Mannion, the district forest ranger, has expressed a personal desire to contribute

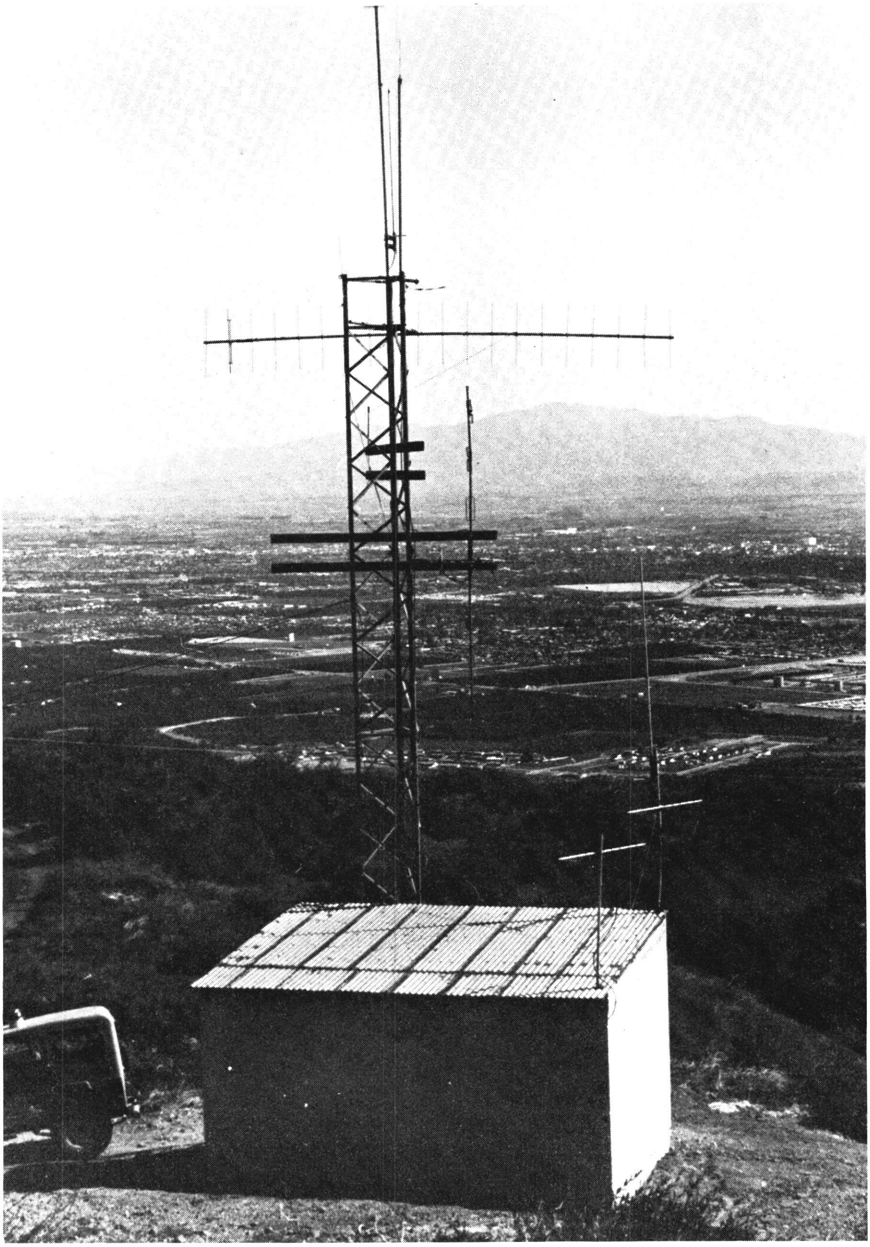


Fig. 3-1. Amateur's 10-foot × 15-foot concrete block building at Radio Ranch in the Angeles National Forest. Building was constructed on a tract of land leased by the U.S. Department of Agriculture to amateurs for $25.00 per year.

toward the general advancement of amateur radio communications.

Although not an amateur himself, Mr. Mannion feels that every remote installation is a potential disaster communications central, and that he can serve the public by providing the means whereby an amateur radio emergency communications system can be exploited with the most efficacy. Rangers in other areas would likely express the same attitude if properly approached at the outset.

The amateur radio world has a good strong rapport with the Forest Service, and participating hams are eager to maintain this healthy relationship. As a result, most lessee groups have adopted a general set of self-policing rules. Here are a few of the more typical ones:

Stay away from the site unless absolutely necessary. When a visit must be made, don't go in a large group. (Most forest installations are in closed, high-fire-hazard areas; excessive visits make forest officials nervous.)

Leave no gates or entranceways unlocked.

Keep the site cleaned and the grounds policed. Remove all weeds and brush within 30 feet of building.

Protect the forest; discourage trespassers. Report all violations to the nearest Forestry office.

The government has conditions and rules, too. They are too numerous to list but they are not in the least hard to live with. For the most part, the Forest Service's rules are based on the les-

JOHNSTONE RADIO SITES

The following fire plan will become a part of the above designated permit:

1. All federal, state and county fire regulations and ordinances pertaining to the operation of a radio relay site shall be complied with by the permittee.
2. All internal combustion equipment shall be equipped with an approved spark arrester.
3. All buildings and structures shall be cleared of all flammable and combustible material for a distance of 30 feet.
4. A 5-lb. dry chemical or 20-lb. CO^2 fire extinguisher shall be placed on the inside at all buildings.
5. No smoking will be allowed except in designated areas. The designated area for your site will be the interior of building only.
6. No open fires will be permitted.
7. A permit shall be obtained for all welding and/or cutting operations.
8. In the event of fire on the area, or adjacent thereto, the permittee shall immediately notify the Forest Service and take reasonable action to suppress all such fires and to remain with the fire until relieved by the Forest Service.

Fig. 3-2. Typical Forest Service fire rules for amateur leasing.

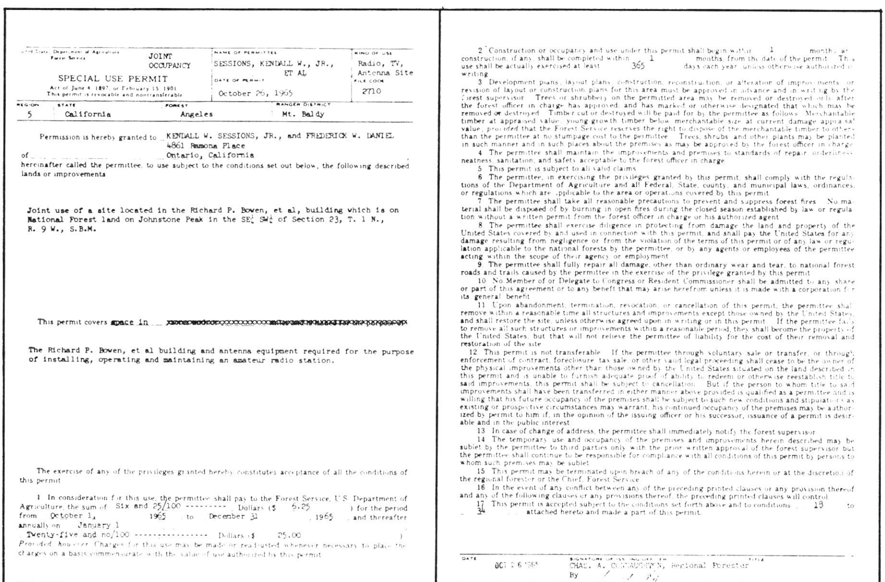
see's use of good common sense and sound judgment. A few of the typical fire rules are shown in Fig. 3-2. Fig. 3-3 is a photocopy of a typical Forest Service amateur radio permit.

If you have your eye on a good spot of national forest land in your own area, it might pay off to check with the nearest USDA Forestry office. If there is none locally, write to:

U. S. Department of Agriculture
Forest Service
Washington, D. C.

3-2. ESTIMATING COVERAGE

Until very recently it was generally believed that coverage and range predictions could never be made with a reliable degree of accuracy because of the overwhelming number of variables involved in the overall repeater system. A few writers began to find ways to compensate for some of the variables in advance, and the radio industry moved in to help reduce "coverage estimation" from the realm of speculation to a process at least resembling a science. Before any real attempts were made to prepare realistic coverage estimates commercial users were given "degree of confidence" figures. A 100-watt transmitter with an antenna at 500 ft. on 150-MHz f-m, for example, might be said to have a 90-percent probability of providing thorough coverage over a 20-mile radius. Now, thanks to the abundance of comprehensively prepared analyses by modern communications engineers, much more reliable predictions can be made with a consistently higher degree of accuracy. Today's coverage estimates can be calculated



JOINT OCCUPANCY

SPECIAL USE PERMIT

NAME OF PERMITTEE: SESSIONS, KENDALL W., JR., ET AL
KIND OF USE: Radio, TV, Antenna Site
DATE OF PERMIT: October 26, 1965
FILE CODE: 2710

REGION	STATE	FOREST	RANGER DISTRICT
5	California	Angeles	Mt. Baldy

Permission is hereby granted to KENDALL W. SESSIONS, JR. and FREDERICK W. DANIEL
4861 Ramona Place
of Ontario, California
hereinafter called the permittee, to use subject to the conditions set out below, the following described lands or improvements

Joint use of a site located in the Richard P. Bowen, et al, building which is on National Forest land on Johnstone Peak in the SE¼ SW¼ of Section 23, T. 1 N., R. 9 W., S.B.M.

This permit covers space in

The Richard P. Bowen, et al building and antenna equipment required for the purpose of installing, operating and maintaining an amateur radio station.

The exercise of any of the privileges granted hereby constitutes acceptance of all the conditions of this permit

1 In consideration for this use, the permittee shall pay to the Forest Service, U S Department of Agriculture, the sum of Six and 25/100 --------- Dollars ($ 6.25) for the period from October 1, 1965 to December 31, 1965, and thereafter annually on January 1 Twenty-five and no/100 ---------------- Dollars ($ 25.00) *Provided, however* Charges for this use may be made or readjusted whenever necessary to place the charges on a basis commensurate with the value of use authorized by this permit

2 Construction or occupancy and use under this permit shall begin within 1 months, and construction, if any, shall be completed within 1 months, from the date of the permit. This use shall be actually exercised at least 365 days each year unless otherwise authorized in writing

3 Development plans, layout plans, construction, reconstruction, or alteration of improvements, or revision of layout or construction plans for this area must be approved in advance and in writing by the forest supervisor. Trees or shrubbery on the permitted area may be removed or destroyed only after the forest officer in charge has approved, and has marked or otherwise designated that which may be removed or destroyed. Timber cut or destroyed will be paid for by the permittee as follows: Merchantable timber at appraised value; young growth timber below merchantable size at current damage appraisal value; *provided* that the Forest Service reserves the right to dispose of the merchantable timber to others than the permittee at no stumpage cost to the permittee. Trees, shrubs and other plants may be planted in such manner and in such places about the premises as may be approved by the forest officer in charge

4 The permittee shall maintain the improvements and premises to standards of repair, orderliness, neatness, sanitation, and safety acceptable to the forest officer in charge

5 This permit is subject to all valid claims

6 The permittee, in exercising the privileges granted by this permit, shall comply with the regulations of the Department of Agriculture and all Federal, State, county, and municipal laws, ordinances, or regulations which are applicable to the area or operations covered by this permit

7 The permittee shall take all reasonable precautions to prevent and suppress forest fires. No material shall be disposed of by burning in open fires during the closed season established by law or regulation without a written permit from the forest officer in charge or his authorized agent

8 The permittee shall exercise diligence in protecting from damage the land and property of the United States covered by and used in connection with this permit, and shall pay the United States for any damage resulting from negligence or from the violation of the terms of this permit or of any law or regulation applicable to the national forests by the permittee, or by any agents or employees of the permittee acting within the scope of their agency or employment

9 The permittee shall fully repair all damage, other than ordinary wear and tear, to national forest roads and trails caused by the permittee in the exercise of the privilege granted by this permit

10 No Member of or Delegate to Congress or Resident Commissioner shall be admitted to any share or part of this agreement or to any benefit that may arise herefrom unless it is made with a corporation for its general benefit

11 Upon abandonment, termination, revocation, or cancellation of this permit, the permittee shall remove within a reasonable time all structures and improvements except those owned by the United States, and shall restore the site, unless otherwise agreed upon in writing or in this permit. If the permittee fails to remove all such structures or improvements within a reasonable period, they shall become the property of the United States, but that will not relieve the permittee of liability for the cost of their removal and restoration of the site

12 This permit is not transferable. If the permittee through voluntary sale or transfer, or through enforcement of contract, foreclosure, tax sale, or other valid legal proceeding shall cease to be the owner of the physical improvements other than those owned by the United States situated on the land described in this permit and is unable to furnish adequate proof of ability to redeem or otherwise reestablish title to said improvements, this permit shall be subject to cancellation. But if the person to whom title to said improvements shall have been transferred in either manner above provided is qualified as a permittee and is willing that his future occupancy of the premises shall be subject to such new conditions and stipulations as existing or prospective circumstances may warrant, his continued occupancy of the premises may be authorized by permit to him if, in the opinion of the issuing officer or his successor, issuance of a permit is desirable and in the public interest

13 In case of change of address, the permittee shall immediately notify the forest supervisor

14 The temporary use and occupancy of the premises and improvements herein described may be sublet by the permittee to third parties only with the prior written approval of the forest supervisor but the permittee shall continue to be responsible for compliance with all conditions of this permit by persons to whom such premises may be sublet

15 This permit may be terminated upon breach of any of the conditions herein or at the discretion of the regional forester or the Chief, Forest Service

16 In the event of any conflict between any of the preceding printed clauses or any provision thereof and any of the following clauses or any provisions thereof, the preceding printed clauses will control

17 This permit is accepted subject to the conditions set forth above and to conditions 18 to 34 attached hereto and made a part of this permit.

DATE: OCT 26 1965
SIGNATURE OF ISSUING OFFICER: CHAS. A. CONNAUGHTON, Regional Forester
By

Fig. 3-3. USDA Forest Service special use permit.

on the basis not only of such factors as power, antenna height, band of operation, and mode of transmission, but of such elusive elements as terrain type, vegetation, propagation characteristics, rf-diffraction potential, transmission-line length and type, and many others.

The Communication Products Department of General Electric has incorporated most of the principal criteria in the calculations onto a slide-rule device so that prospective GE customers can decide for themselves what performance must be expected from the equipment to attain a desired radius of coverage.*

An elaborate mathematical analysis of anticipated coverage can be precluded, of course, if a radio transmitting system is already in use at the proposed site. In this case, several mobile units can make coverage surveys by monitoring the output of the transmitting station throughout

*__Range and Signal Strength Calculator,__ available from GE, Commercial Products Department, Electronics Park, Syracuse, N. Y.

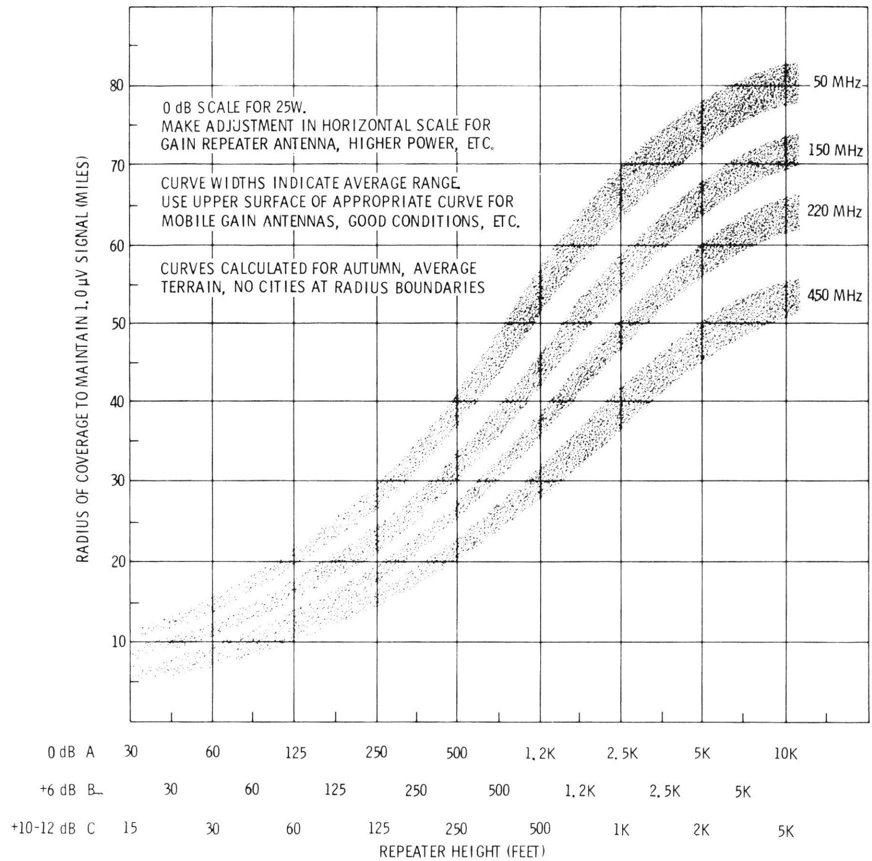


Fig. 3-4. Range chart to determine approximate coverage of repeaters in popular amateur vhf and uhf bands.

the areas of desired coverage and noting the periodic limiter-current readings. Later, power differences and antenna-gain differences between the existing station and the proposed station can be accounted for by correcting the actual readings in accordance with standard dB scales.

Fig. 3-4 is a graph which shows the range to be expected for various repeater heights. For the calculations on which the graph was plotted, these prior assumptions were made: Terrain of coverage is relatively flat, with no cities or structural complexes at radius boundaries. Foliage density is average. Transmitter power output is 25 watts with no losses calculated in the transmission line. Standard dB adjustments for gain antennas can be made using one of the three horizontal scales for range correction.

There are a few basic differences between dB indications, depending on whether the gain or loss is calculated for a receiver or a transmitter. The transmitter, of course, is rated in watts, where a doubling in power results in an increase of approximately 3 dB. Receiver signal strength is measured in voltage, and a voltage doubling results in an increase of some 6 dB. (Doubling the voltage doubles the current, which quadruples the power to yield an increase of 3 dB × 2.)

These signal characteristics illustrate the importance of receiver sensitivity in a repeater system and show the need for maintaining as high a field strength as possible in the area of coverage. A mobile receiver which typically yields a partially quieting signal with an input of 1.0 μV at the antenna may not even "hear" a signal whose strength is 0.5 μV (equivalent to quartering the transmitted power). On the other hand, improving a mobile receiver's sensitivity from 1.0 μV (for 20 dB of quieting) to 0.5 μV is the same as quadrupling the power of the repeater transmitter.

3-3. CHOOSING THE FREQUENCY

The characteristics of an rf signal differ greatly for a given area depending on the frequency of transmitter operation. In general, here are the prime signal characteristics:

50 MHz—The 50-MHz (low-band) spectrum allows better rf diffraction than any other vhf signal; the physical length of the wave is long enough to afford a degree of "bending" by the atmosphere to allow signals to follow the earth curvature to some extent. This frequency range also is characterized by ionospheric reflection during some seasons, which tends to reduce the groundwave usefulness (because long-distance "skip" signals can cause interference with intended signals). The 50-MHz region is near the center of the noise-intensity spectrum too, which tends to negate the advantages of over-the-horizon capability. That is, the wavelength of a 50-MHz signal is such that extremely long ground distances could be covered if noise were not a factor.

150 MHz—This wavelength (called high band by commercial users and amateur f-m'ers) offers a good compromise between the advantages of low band and uhf (450 MHz). High-band signals do not diffract through the atmosphere as readily as low-band signals, so the theoretical maximum groundwave range is somewhat less. But the relative absence of noise in this region results in superior receiver performance, and the net outcome is coverage that is indistinguishable from low band, all other factors being equal. Trees and foliage in the vicinity of the receiving antenna tend to reduce the field strength due to an rf absorption that is typical of the higher frequencies. This absorption effect may be of so little significance that its mention might seem meaningless, but the signal loss is nonetheless very real, albeit small. Man-made structures such as tall buildings, bridges, and other objects of metal and mortar tend to further reduce signals in the 150-MHz range. Consequently, repeater users operating mobile in a nearby city are likely to find a number of dead spots where satisfactory operation proves impossible regardless of receiver sensitivity and transmitter power.

450 MHz—The 450-MHz range (uhf) offers the most predictable performance of the three bands. Uhf communication is virtually "line-of-sight." As a consequence, a uhf repeater may seem to offer less to users than, say, high band or low band. But uhf does offer many distinct advantages when the repeater is well situated.

City coverage is generally better, for example, because the extremely short waves allow bouncing of signals between buildings without the phase and multipath cancellation that is characteristic of the lower frequencies. All radio signals bounce, but when two bounced signals arrive at an antenna out of phase with each other, they cancel. On low frequencies, the waves are long enough to allow an out-of-phase condition to exist for a long enough time period to prevent meaningful communication. On uhf, however, an out-of-phase condition might be corrected by simply moving the antenna a few inches. The slow fade and mobile QSB of the lower frequencies become a rapid (sometimes almost unnoticeable) flutter or "chop," which does not necessarily interrupt communications on uhf bands.

The deleterious effect of foliage on received signals is considerably more pronounced on uhf than on vhf, and repeater users will notice a seasonal fluctuation in communicability—extended in winter, reduced in spring. The effects of heavy foliage are so severe that the vegetation of the general area must be taken into account by uhf repeater planners if a successful repeater system is to be expected.

3-4. EQUIPMENT SELECTION

To the newcomer, the most formidable aspect of a repeater project will be the acquisition of the various transmitters and receivers that will comprise his "system." The questions most often asked by repeater aspirants are these:

- Where can I buy the equipment?
- How will I know what brand to buy?
- How can I recognize vintage of a piece of used equipment?
- How will I know that what I buy will be in good repair?
- How will I know how much to pay?
- How will I get the equipment operating properly in the ham band?

There are no pat answers to all these questions, but a little knowledge of the equipment, the sales outlets, and the market will assist immeasurably in allowing you, as a prospective repeater owner, to provide some of your own answers.

Where to Buy

Unless you are independently wealthy, the gear you buy will be used commercial equipment, probably removed from service by its inability to meet the FCC's ever-tightening restrictions. Since most of these restrictions do not apply to the amateur bands, you will likely find that most equipment currently available is ideal for your use.

The amateur market for used commercial two-way f-m equipment is not of such magnitude that it would support distributors in all major cities across the country. As a consequence, a small number of large distributors supply the nation's amateur market through a mail-order business approach.

Most of the equipment distributors recognize the misgivings you might have when it comes to laying out cold cash for equipment you haven't seen, so they have instituted policies for your protection. Mann Communications,* a West Coast distributor, sells all equipment with a 10-day satisfaction guarantee; you have 10 days to look over what you buy to determine whether or not it is what you expected. If you are not happy then, you can return it for full credit. Gregory Electronics,** Mann's east coast counterpart, has a similar plan: it offers a five-day guarantee, and offers further protection by bench-testing every item whose sales price exceeds $45. Both Mann and Gregory are high-volume distributors who supply periodic catalogs of the equipment they have on hand.

What to Buy

When you look over the used-equipment catalogs, you will note a marked inconsistency in pricing structure. A late-model **DuMont** base station, for example, might sell for a fraction of the price of an equivalent **Motorola** unit. Or a 10-year-old GE unit may be listed at many times the price of a near-new **ITT.**

GE and **Motorola** command consistently higher prices than

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*__Mann Communications,__ 18669 Ventura Blvd., Tarzana, California 91356 (213) 342-8297

__Gregory Electronics,__ 249 Route 46, Saddlebrook, New Jersey 07662. (201) 489-9000 other makes. **But the higher price does not necessarily mean the GE and Motorola units are superior. GE and **Motorola** are the two biggest names in two-way radio. But **RCA, Dumont, Kaar, Aerotron,** and **Bendix** are common, too. Why, then, are **GE** and **Motorola** so sought after?

The amateur buys with the thought of selling, for one thing. And he knows that any amateur with **any** experience in f-m has experience with **Motorola** or **GE.** So when he buys, he tries to buy something other f-m'ers have used or serviced.

Another contributing factor is documentation. Handbooks, schematics, troubleshooting procedures may or may not be available from the manufacturer, but every f-m'er knows he can get access to most **Motorola** and **GE** manuals simply by visiting the nearest commercial two-way service center.

But perhaps the principal reason most amateurs select **GE** or **Motorola** is **general familiarity.** When an inexperienced amateur runs into some trouble trying to service a **GE** or **Motorola** unit, he can feel pretty sure of getting experienced help from other local f-m amateurs who have worked on similar units with similar problems in the past. Interchangeability of components might be another consideration in favor of the big two. For a number of years, **GE** and **Motorola** (and one or two other manufacturers) have employed the module concept in the manufacture of their two-way equipment. For a given model year, for example, the manufacturer will produce singular transmitter and receiver designs. The transmitter, receiver, and power supply are constructed on individual removable chassis. Thus, for a given radio model, a transmitter "strip" from a mobile unit may be interchanged with a transmitter from a base station; or a base station receiver "strip" can be used in the equivalent model mobile unit.

The lower price of **RCA, DuMont**, and the others, however, can make a strong case against the two big names. The ultimate decision, of course, must rest with you, the buyer. If you feel confident that you will be able to handle your own service problems and that you will not be trying to make a quick sale on your equipment, it might pay to weigh a purchase purely in terms of performance versus dollars. The secondary names in the two-way industry have also manufactured gear of extremely sound basic design and good quality workmanship.

Identifying Motorola Equipment by Model Number

The model numbers of some manufacturers can provide a great deal of information about the equipment itself. **Motorola,** for example, has for at least the past decade employed a model numbering system that gives the type of equipment (mobile or base), method of mounting (trunk or dash), rf power, frequency range, vintages of receiver and transmitter, and type of power supply. A familiarity with these numbering systems will help immensely in evaluating a given piece of equipment.

Motorola model numbers assigned after initiation of the descriptive system include six basic characters in this sequence: letter, digit, digit, letter, letter, letter. The first character tells whether the unit is for portable, mobile, or base-station use and (if a mobile) describes the method of mounting:

H—Handie-Talkie®
P—Hand-held (portable) unit, larger than Handie-Talkie
L—Tabletop base station
D—Dash-mounting mobile unit
T—Trunk-mounting mobile unit
U—Universal (dash- or trunk-) mounting mobile unit
J—Tall cabinet, weatherproof enclosure
B—Tall cabinet, indoor use
W—Western Electric (mobile telephone)
R—Railroad (usually higher dc power supply voltages than mobile units)

The second character (digit) describes maximum rf input power. The following list shows general ranges (there are a number of exceptions).

1—less than 5 watts input
2—5-10 watts input
3—30-45 watts input (10-15 watts out)
4—80-85 watts input (18-35 watts out)
5—150-180 watts input (40-65 watts out)
6—250-300 watts input (85-100 watts out)
7—150 watts out
8—250 watts out
9—300 watts out

The third character (digit) identifies the frequency of operation:

1—Low band (50 MHz)
2—Midband (70 MHz)
3—High band (150 MHz)
4—Uhf (450 MHz)

The next two letters of the sequence identify the model of the transmitter and the receiver, respectively. The last character (letter) identifies the power supply type:

B—Base station (115 Vac)
T—Transistor (mobile, 12V)
V—Vibrator (mobile)
D—Dynamotor (mobile)
N—Nickel-cadmium battery pack

Identifying GE Equipment by Model Number

The **GE** numbering system is not quite as descriptive as the **Motorola** procedure. The **Progress Line** system was an improvement over that of the **Pre-Prog,** but the almost numberless variations made it impossible to accurately identify a unit by its model number alone. In the interest of completeness, however, Table 3-1 describes all **GE Pre-Progress** units and shows the differences between models.

Summary

It is difficult to establish rules of thumb regarding the pricing structure of used two-way radio equipment, but there are a few applicable generalizations it might pay to remember: Used-equipment prices tend to be reasonably stable. Motorola and GE units, particularly the later models, seem to stay somewhat in demand, and are thus usually easy to sell. Two-piece units (separate transmitter and receiv-

Table 3-1. GE Pre-Prog Units

Freq.	Number	RF Power Out.	DC Input Voltage	Description: Type of mount	Description: Type of power supply
152-174 MHz	LPH6/12	3W	6/12	single-unit	vibrator
	LPH24	3W	19-30	single-unit	dc-ac converter & ac ps
	LPH32	3W	26-40	single-unit	dc-ac converter & ac ps
	LPH64	3W	60-84	single-unit	dc-ac converter & ac ps
	MC203	10W	6	single-unit	vibrator
	MC-203-LP	LPI(1W)	6	single-unit	vibrator
	MC204	50W	6	single-unit	dynamotor & vibrator
	MC205	35W	6	single-unit	dynamotor & vibrator
	MC206	25-30W	6	single-unit	dynamotor & vibrator
	MC208	20-25W	6/12	single-unit	vibrator
	MC213	10W	12	single-unit	vibrator
	MC213-LP	LPI(1W)	12	single-unit	vibrator
	MC214	50W	12	single-unit	dynamotor & vibrator
	MC215	35W	12	single-unit	dynamotor & vibrator
	MC216	25-30W	12	single-unit	dynamotor & vibrator
450-470 MHz	MC306	20W	6	single-unit	vibrator
	MC316	20W	12	single-unit	vibrator
Base Stations					
152-174 MHz	SC221	50W	—	local	floor
	SC222	50W	—	remote	floor
	SC223	250W	—	local	floor (double enclosure)
	SC224	250W	—	remote	floor (double enclosure)
	SC225	——	—	local	desk (auxiliary receiver)
	SC226	50W	—	remote	pole
	SC227	50W	—	local	desk
	SC228	50W	—	remote	desk
	SC229	50W	—	local	pole
	SC230	50W	—	repeater	pole
	SC231	10W	—	local	ac mobile
	SC231-LP	LPI(3W)	—	local	ac mobile
	SC233	250W	—	local	floor
	SC234	250W	—	remote	floor
	SC241	25W	—	local	ac mobile
405-425 MHz or 450-470 MHz	SC321	20 or 30W	—	local	floor
	SC322	20 or 30W	—	remote	floor
	SC325	——	—	local	desk (auxiliary receiver)
	SC326	20 or 30W	—	remote	pole
	SC327	20 or 30W	—	local	desk
	SC328	20 or 30W	—	remote	desk
	SC330	20 or 30W	—	repeater	pole
	SC337	20 or 30W	—	local	**Desk-Mate**
	SC338	20 or 30W		remote	**Desk-Mate**

er) are usually a bad buy at any price; the transmitters often do not incorporate limiter circuits to stabilize the audio output, and the receivers are typically far too broad for effective application where adjacent frequencies are likely to be active. One-piece units (of modular construction) are particularly desirable because they provide the means for "system" tailoring to individual requirements and allow a considerable degree of freedom for component/module interchange. For mobiles, vibrator or transistor power supplies offer a significant advantage (in terms of efficiency and power consumption) over dynamotors.

One additional point, in case you plan to buy one of the "off-brand" makes. Be sure the tubes it uses are standard enough to be generally available. The 6939, for example, a fairly common miniature tube for some RCA and Comco units, cannot be found in the usual "used" or "reconditioned" tube markets—and the replacement cost is a fat $16. The cost of only a few at that price might pay for a complete and fully tubed rig of another make.

3-5. PREPARING CONTROL STATIONS

It is important to remember the distinction between repeaters and remotes, because their individual requirements often overlap to a confusing degree. Remote stations, unless controlled by a wireline, will always involve a control link. Repeater stations will involve a control link if the repeater is to be deployed at a remote site. A control link is defined as the set of ultrahigh frequencies reserved for control and monitoring of the remote equipment; a control station is the uhf transmitter/receiver set up for control and operation of a remote repeater or other communications system.

Control Link

To be entirely successful, the control link should itself be a complete and independently operable repeater. Using 450-MHz f-m as the control link simplifies construction of the repeater portion of the remote station because the equipment is inexpensive, handbooks and circuits for the used commercial gear are readily available, and usually no special rf shielding is required.

The most commonly available makes of used 450-MHz f-m gear are GE and Motorola, though occasionally one finds a "fleet" of such makes as DuMont (Fairchild), Kaar, Aerotron, or RCA. They are all relatively well known, but documentation for GE and Motorola is easiest to come by. Used mobile units sell for about one-half to one-third the price of a 115-volt unit (called a base station), so it is practical to use a mobile unit for the base station by building up an ac supply. A typical mobile transceiver, such as Motorola T44 or GE's pre-Progress Line (Pre-Prog) requires around 500 volts at 150 mA (minimum) for the final amplifier, 350 volts at 60 mA for the final multiplier, and 250 volts at 150 mA for the oscillator, multiplier, and receiver section. A negative bias voltage of around

25 volts is also required for the transmitter.

Tuning up commercial f-m units is a breeze. Each stage that requires tuning terminates at a test point designed to accept the probes of an ordinary VOM. GE Pre-Prog units are the epitome of simplicity. Each test point is plainly marked and is positioned in proximity to the adjustment point. Tuning of transmitter—and in many cases, receiver—stages involves monitoring of the test point with a 0- to 3-volt dc meter and adjusting the adjacent slug for maximum meter deflection.

The test points of Motorola T44's are pin jacks of a standard 11-pin socket, and are designed to be monitored with a 0- to 50-μA meter.

This handbook will not go into such items as power-supply construction or detailed radio tune-up, as these are aspects which will vary according to the vintage and make of the f-m rig.

The transmit frequency of the control-link repeater should be judiciously selected so that no multiple of the oscillator frequency falls within pull-in range of any of the receivers (including i-f's). Without consideration of these factors, the emission of one of the transmitters can seriously desensitize the control-link receiver.

GE units often come equipped with cavities, which help greatly to eliminate adjacent-channel interference. If the two control-link frequencies are well spaced, however, you should not need a cavity. Two antennas must be provided for the control link, too. These should be **vertically** separated as far from one another as possible.

Control Station

The requirements of a control station often differ somewhat from those of a standard mobile or base station; occasionally, these requirements are unique. A conventional station, for example, requires a single antenna for the conventional sequence of receive and transmit. The control operator must always hear his repeater, however, even when he transmits. So he will need two antennas—one for his continuous receive function, the other for transmit.

But, of course, there are certain aspects of control that apply to all two-way radio units. Such areas are the crystaling, tuneup, and receiver alignment.

The 1950-1960 vintages of Motorola and GE uhf equipment have become the accepted standards for amateur control equipment because of their ready availability and low cost. But both brands were characterized by a number of design deficiencies during the early and middle 1950's—and these are now the legacy of amateurs converting them for use in the 420- to 450-MHz region.

Oddly, GE's chief problem is its MC-306 Pre-Prog receiver; Motorola's is the T44 (A7 version) transmitter. The GE is curable; the Motorola is not. In the Motorola unit, the final plate-tank circuit is difficult to keep in resonance because of the poor design of the driver and tuning mechanisms. Both the final and driver are built into special cavity sections with removable covers. Tuning is accomplished by varying the capacitance from the cavity cover to the plate of the tube (2C39). Since the cover must be removed periodically to change tubes, in time the cover-to-case fit becomes sloppy; the holes for the cover hold-down screws get widened and the threads strip. Inevitably, the cover-to-case resistance gets erratic and the internal capacitance begins to shift, causing the driver and the final to stray from their positions of resonance.

An even more serious problem is the locking system. The tunable screw-type capacitor is secured by tightening a lever that binds the capacitor shaft. As the shaft is secured, it is forced to move slightly from its resonant position. Plate current goes up and output power drops just enough to shorten tube life and impair efficiency of the transmitter output stages.

The GE equivalent to the Motorola T44, in terms of model vintage, is its model MC-306 pre-Progress Line unit. This GE Pre-Prog transmitter has never been plagued with the T44's problems because some bright engineer designed the capacitance tuning into the sides of the cavities, rather than into the covers. And knurled knobs were incorporated for easy hand-adjusting. But the design engineers apparently were so engrossed in the transmitter that they were blinded to the problems which were developing in the receiver.

The Pre-Prog 450-MHz receiver is typically very broad and highly unstable. The oscillator is characteristically low in output—it peaks about 0.75 volt when measured at the test point (J306) with a dc voltmeter. Temperature extremes turn the oscillator into a vagabond; it may wander as much as 150 kHz between dawn and midday. The built-in afc allows the oscillator to be pulled by any signal within 60 kHz of its design frequency. But the drifting problem is often so severe that even the afc does not help.

These problems are annoying and frustrating when the receiver is being used in repeater service. Transmitters must be tweaked and crystals "rubbered" to chase the receiver across the spectrum. But in a mobile application, the situation can, and usually does, get downright intolerable.

Since the Pre-Prog is probably the most common single piece of equipment in use by amateurs for the 420-450 MHz band, a number of amateurs have made changes to improve the receiver's performance. These changes vary in complexity, from reducing the afc's pull-in range with diodes, to completely redesigning the oscillator circuit.

The afc pull-in range is reduced in order to keep the receiver from responding to adjacent-frequency signals. This is done by simply cross-connecting a pair of diodes so the anode of the first one attaches to the cathode of the second, and the cathode of the first attaches to the anode of the other. This diode pack is then connected from the afc bus to ground.

Probably one of the most effective circuit improvements is the oscillator modification designed by James J. Lev (K6DGX) of Norwalk, California. His modified Pre-Prog oscillator circuit is compatible with a design by which several oscillators may be used with the single GE multiplier for converting the Pre-Prog to a two- or three-frequency system. But the most important feature of his oscillator design is its stability.

The K6DGX modification involves total removal of the oscillator chassis plate from the Pre-Prog receiver and building a new oscillator which will use a Progress Line crystal AND OVEN. The result is a receiver stability of 0.0005%. (The Progress Line was GE's next step in uhf two-way design, and was a dramatic improvement over the old Pre-Prog.) Fig. 3-5A shows the configuration of the original Pre-Prog oscillator as it came from the factory. Fig. 3-5B shows the modification. As can be seen, the new oscillator is actually somewhat simpler than the original.

The thing to remember when modifying the Pre-Prog oscillator circuit is to reorder the receiver crystal. The old one will oscillate in the new circuit, but it will be around 150 kHz low in frequency. Also, it will not have the same 0.0005% frequency-stability characteristics of the new one. When ordering the new crystal, specify the following information:

Receive frequency.

Crystal frequency:

$$f_{xtal} = \frac{f_{rcvr} - 48}{36}$$

Crystal holder F605.

GE "Progress Line" oscillator circuit for 4ER26 receiver.

85°C crystal oven.

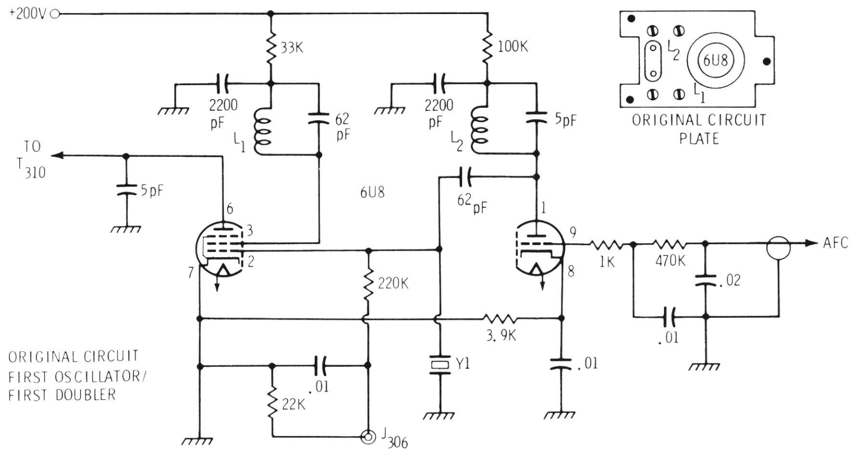
Non-afc use.

There will be no room on the original circuit plate for the crystal oven. But there is an abundance of plates on the Pre-Prog receiver, so the oven can be easily mounted onto the adjacent plate. Chassis holes through which the original tuning coils were mounted can be used for the new variable capacitor and slug-tuned coil. The tuning range of the variable capacitor is not critical, and can be anywhere in the general region shown in the sketch.

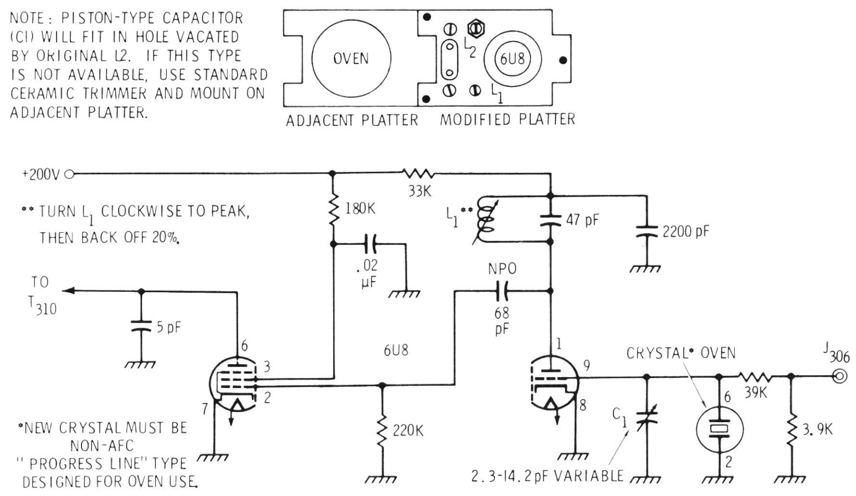
There really is not much that can be done about Motorola's T44 transmitter problems. Corrective action would involve a major mechanical redesign. Most owners of the T44 simply grit their teeth and live with the problems. They probably feel that the design discrepancies of the transmitter are more than compensated for by the excellent stability, selectivity, and sensitivity of the T44 receiver. And they may well be right.

Crystal Ordering

The f-m'er is characteristically frequency-conscious. His transmitter and receiver are crystal controlled, so he wants no slipups in frequency when his unit is ready to be put into operation. As a consequence, f-m operators



(A) Original oscillator circuit.



(B) Modified oscillator circuit.

Fig. 3-5. PreProg original oscillator circuit and modifications.

typically shun the traditional "rock houses" and end up paying a premium for precision crystals from a known quality-conscious manufacturer, such as Sentry Manufacturing Company*, or International Crystals, Inc.** Both firms specialize in supplying crystals to the commercial two-way industry, and will "tailor" the crystals for the circuits in which they will be used.

A fact little known to amateurs (but well known by the crystal specialist) is that a crystal

*Sentry Manufacturing Company, Crystal Park, Chickasha, Oklahoma 73018.

**International Crystals, Inc., 10 North Lee, Oklahoma City, Oklahoma 73102.

is not the sole frequency determinant. The two prime determinants of actual oscillating frequency are crystal current (drive level) and oscillator load capacitance. If you order a crystal when you are not sure of these factors, you will have no way of knowing how close to your desired frequency you are going to be.

Most commercial f-m two-way radios are designed with a variable capacitor in the crystal circuit so the crystal can be "rubbered" to frequency once it has been installed in the oscillator circuit. But this gives only a finite amount of latitude, and often it is not enough for an erroneously ordered crystal.

Table 3-2 shows the actual operating frequencies of a crystal cut for use in a 32-pF circuit of a parallel-resonant oscillator. The first column shows the actual design frequency (which is the end frequency when the crystal is used in the proper circuit). Note how the frequency drops as the load capacitance increases. The last column shows the resultant frequency of the crystal when used in a series-resonant circuit.

TABLE 3-2. Frequency Variations When Single Crystal Is Used in Several Oscillator-Circuit Types

32 pF Load	15 pF Load	40 pF Load	100 pF Load	Series Resonant
1000	1000.125	999.975	999.915	999.865
3000	3000.625	2999.880	2999.565	2999.315
5000	5001.325	4999.730	4999.020	4998.225
7000	7002.225	6999.525	6998.250	6997.250
9000	9002.835	8999.400	8997.800	8996.500
13500	13503.800	13499.270	13497.250	13495.750

In a series-resonant oscillator, the crystal is in series with a resistance. The crystal appears resistive, and load capacitance is no longer a determining factor with respect to frequency of operation. But unless the crystal is ordered specifically for a series circuit, the user will probably find himself considerably lower in frequency than he wants to be.

In parallel resonance, the crystal is placed in series with a capacitance, so it appears as an inductive element to the external circuit. Any change in circuit reactance will affect the frequency of oscillation. This mode is of characteristically high impedance and the resulting frequency is higher than that of the series-resonant crystal. The frequency of the crystal may be lowered by increasing the series capacitance or raised by decreasing it.

In most cases, the process of ordering proper crystals involves nothing more than a few minutes of simple arithmetic (assuming, of course, the equipment manufacturer's specifications and crystal particulars are available), but sometimes the task of determining crystal frequencies can be quite fierce. A typical case in point is the Motorola T44, a uhf two-way unit with an unholy number of variables. The T44 receiver was manufactured for a period to use 30-MHz oscillator crystals. Then, due to a change of heart at the factory, the units were produced to use 10-MHz oscillator crystals.

As if this weren't enough of a problem, Motorola engineers arranged for individual receiver second-oscillator crystals to partially determine operating frequency. In this way, Motorola could supply units to any commercial 450-MHz frequency while only stocking 40 different crystal frequencies. By selecting one of twenty first-oscillator crystals and matching it with one of twenty second-oscillator crystals, any T44 receiver can be made to receive on any conventional commercial channel.

This concept was no doubt a great boon to Motorola, but it proves a gigantic pain in the neck to amateurs wanting to crystal up a T44 on the ham bands. It won't do for a T44 owner to merely order a 30-MHz (or 10-MHz) crystal for the oscillator. He must also: (1) know what the second-oscillator crystal frequency is and compensate for it in the first-oscillator calculation, (2) arbitrarily select a second-oscillator crystal to operate in its intended range, then consider that frequency in calculation of the first-oscillator crystal frequency, or (3) give up entirely and allow the crystal supplier to determine both crystal frequencies based on oscillator range data provided by the user.

Fortunately, most receivers do not cause such problems. Mr. George Beyers, president of Sentry Manufacturing Company, says his company is as anxious to supply on-frequency crystals as most amateurs are to receive them, and that his company would be happy to correlate the frequency of a crystal circuit if enough information were made available in each case. So that provides at least **one** way to be certain of frequency; if you want to operate on a specific frequency and you have not ordered your crystal yet, determine the fundamental crystal-frequency range and the desired operating frequency. Then make a copy (even a sketch will do) of your oscillator schematic; send the information to Sentry and wait for your crystal to be returned by mail. You can rest assured it will be exactly on frequency.

If you have no frequency-measuring equipment, but a known-to-be-accurate signal is available, you can vary your existing crystal capacitance until you zero-beat the known signal. This is a particularly useful solution for a group of amateurs who intend to operate through a repeater.

For f-m units without variable oscillator capacitors, variation of the crystal capacitance to effect frequency adjustment may be accomplished by replacing the load capacitor (between one side of the crystal and ground) with a trimmer. The original capacitor value should fall approximately in the center of the trimmer range. In some oscillator circuits, the fixed capacitor that must be replaced is across the crystal itself. The proper capacitor will not be hard to find, in any case; a little experimentation should yield fruitful results.

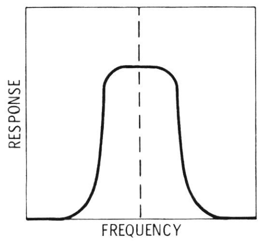
Aligning the Receiver

Aligning an f-m receiver is a great deal more complex than getting the oscillator on frequency and peaking the various stages to an on-channel signal. Yet this is precisely what many amateurs (and, unfortunately, many commercial service technicians) actually do.

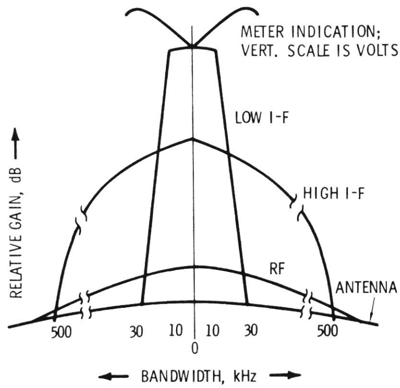
When an f-m receiver is tuned up using this procedure (we'll call it the "tweak" method) the technician is making a number of raw assumptions which may or may not be valid. First, he is assuming that the low i-f's and the discriminator are correctly aligned to their respective frequencies. Second, he is assuming that the sealed bandpass filter is properly tuned to its design frequency. The latter can generally be a safe assumption, even though it is not uncommon for these filters to change or shift a bit in frequency as a result of excessive vibration, shock, or other abuse.

What happens when the tweak method is used for tuneup? It is, admittedly, a quick-and-dirty process by which a receiver can be made to operate. The brutal truth, however, is that the primary receiver qualities of selectivity, sensitivity, and stability are interrelated. The tweak method is an optimum compromise of the three based on the initial setting of the second converter and the low i-f circuits.

Selectivity (and gain, of course) is broadly determined by the number and state of the tuned circuits in the receiver chain from the antenna itself to the discriminator. Each frequency-sensitive element adds somewhat to the selectivity and affords at least some degree of gain. An important point is that each of these elements must be centered on the frequency of operation. To assure proper tuneup of a receiver, the selective circuits (rf,



(A) Overall response curve.



(B) Ideal composite selectivity curve.

Fig. 3-6. Receiver i-f response curves.

high i-f, and low i-f) must be aligned so that desired signals can pass through the center of each selectivity curve. Equally important, the configurations of the various curves must conform to their design shapes. The proper combination of these shapes will yield an overall response curve that looks like that of Fig. 3-6A. The sketch of Fig. 3-6B shows how the ideal composite selectivity curve is obtained. In this sketch, the centerline represents an incoming on-channel signal. The flowing V at the top is the discriminator slot. The low i-f passband is the steep-sided peak with the broad plateau across the operating frequency.

The broader curve with the sharper arc in the frequency range of interest is the selectivity curve of the high i-f. The rf amplifier and antenna are shown as low broad arcs. The curves are plotted as bandwidth (horizontal) versus gain (vertical).

At this point, it would be wise to say that i-f alignment usually is not necessary unless:

A component has been replaced in an i-f filter;
The circuits have been subjected to tweaking without proper test equipment.

Unfortunately, the latter is more usually the case with amateur f-m equipment. No amateur should ever try to tune up an f-m receiver unless he has a schematic diagram of his equipment so he will know where **NOT** to tweak. Even in commercial service, the most common source of i-f misalignment is unnecessary tweaking on the part of an incompetent or inexperienced serviceman.

Realignment is usually required if the i-f passbands are not centered on the incoming signal of interest, if the passbands are asymmetrical (not the same on both skirts), or if the bandpass is too narrow. The presence of high impulse noise on weak signals is one symptom of an off-frequency passband. This is due to the fact that the ringing frequency of the filters is not coinciding with the discriminator center frequency. An even more apparent indication of this type of misalignment is "chopping out" of signals, or undue distortion of signals which are being deviated at a near-maximum level. The chopping-out effect is the sudden vanishing of a strong signal with each voice peak. Neither of these conditions is tolerable in repeater applications.

Off-frequency filters usually produce a high discriminator "idle" reading. If an inexperienced tweaker has been at work, though, he has probably already compensated for this condition by changing the discriminator to get a zero indication (and thereby throwing the receiver even further out of alignment).

So, what do you do when you are certain your receiver needs alignment? The first thing is to be **doubly** sure. If you have no doubts, then get a signal generator and start warming up the receiver. If your receiver is equipped with afc, disable it. Set up the signal generator to produce a stable signal on the operating frequency, and keep it well below the limiter saturation point.

For units which use double-coil i-f transformers (such as GE and DuMont), the resistor loading method is perhaps the most effective means for obtaining a good receiver alignment. This procedure is a bit complicated but not too difficult. Remember to keep the input signal dead on frequency and below saturation. Tune each stage to the exact peak as described below, then repeat the entire sequence.

The response of an i-f transformer changes with the loaded **Q** of its resonant circuits. By loading one of the coils with a resistor, its response is lowered to a nonresonant point. The undercoupled coil can then be tuned for maximum deflection of a meter on the first limiter. If the coil is coupled to other coils immediately adjacent to it, both adjacent coils must be similarly loaded.

The value of the resistor must be low enough to produce a sharp peak during tuning, but not so low as to make precise tuning difficult. (The lower the resistance, the broader is the peak.) Keep the resistor leads short enough to prevent the introduction of stray capacitance into the circuit, and peak one coil at a time.

There are other methods for alignment, but the above procedure is probably the most satisfactory for the amateur, where the preponderance of such test equipment items as oscilloscopes and sawtooth generators is the exception rather than the rule.

If the discriminator needs adjustment and you are set up with a crystal-controlled i-f generator of some kind, you are in business again. (The generator must be capable of holding a test signal to within 100 Hz of the low intermediate frequency.) The procedure described here is not applicable to all discriminator circuits, but is ideal for receivers using Foster-Seeley discriminators (GE and DuMont again).

First, monitor the discriminator current with the proper test meter (0 to 50 μA for DuMont, and 0 to 2.5 V for GE). If possible, disable the second oscillator to prevent receiver "garbage" from causing erroneous readings. Apply a low i-f signal to the first-limiter input and adjust the signal level to saturate the second limiter. Then tune the secondary of the discriminator transformer for a near-zero meter reading, and repeak the primary.

Move the test signal 10 kHz above the low i-f and note the reading; then move it the exact amount below the i-f. If the signals do not deflect the meter the same each side of zero, adjust the primary until equalization occurs. You will have to rezero the secondary and adjust the primary several times to make certain the discriminator is properly aligned.

3-6. DUPLEXING THE CONTROL MOBILE

While it may not be particularly important on two or six meters, duplex operation is a near necessity for the 450-MHz repeater user. Without it, the operator has no indication as to when he is "making it" or when his signals are marginal in the repeater. A 450-MHz mobile as an access to a two- or six-meter remote base station loses much of its effectiveness when the control operator cannot hear his own "talkback" signal as he is transmitting.

What is duplexing? In the strictest sense duplex operation is transmitting on one frequency and receiving on another. But for the purpose of this handbook, it is receiving on one frequency the repeated signals that are being transmitted on another at the same time. A completely duplexed unit allows telephone-type operation, whereby each person can hear what the other transmits at any time. With repeaters, this does not allow "telephone" operation between repeater users, but it does allow it between any of the mobiles and the repeater base station, and between any of the users and the base station. When an automatic phone patch is incorporated into the system, all users can also enjoy full duplex telephone operation (though not all at the same time).

How do you duplex a 450-MHz f-m mobile? Since the integral vibrator supply of the stock unit is inevitably unable to handle the added load of the receiver during transmit, the only logical course of action is to build up a transistor supply to power the receiver on a continuous basis. When the added supply has been incorporated, there remains but one stock lead to reroute (if the 450-MHz unit is a Motorola T44 or a GE Pre-Progress Line MC-306).

Design Simplicity

The average transistor power supply (referred to industrially and commercially as a dc-to-dc converter) employs a very simple switching circuit which comprises nothing more than two inexpensive transistors, a couple of resistors, and a special transformer with an added feedback winding.

Since there are no moving parts, very high switching speeds can be attained; the higher the speed is, the less filtering is required. Switching frequencies of 5 kHz are by no means uncommon. Motorola's **MOTRAC** series of commercial f-m units uses power supplies with a 5-kHz switching frequency.

Miniaturization

The components of a medium-power dc-to-dc converter are usually small enough to allow mounting on an already existing chassis. This is a particularly attractive feature when the mobile equipment is a trunk-mounting unit. There is usually ample space on the power-supply chassis of a trunk-mount rig to accommodate at least an add-on receiver supply, even without modification of the unit's built-in vibrator power source. The existing chassis normally provides an excellent means for dissipating the excess heat generated by the power transistors because of the large surface mass. If a special chassis is required, it can be made quite small. It must be borne in mind, however, that power transistors **must** have adequate heat protection. Thus, a small chassis usually means that an external heat sink must be employed.

Miniaturization is also enhanced by the increased switching speed. As the ac supply frequency increases, the transformer size requirements diminish. At a switching frequency of 5 kHz, the size of a medium- to high-power transformer is impressively tiny indeed. A transformer capable of delivering 200 watts will fit nicely in the palm of the hand and will easily weigh less than a pound. Since filtering requirements are also reduced, capacitors on the secondary can be made smaller. In most cases, filter chokes and other reactor devices can be dispensed with entirely.

Obtaining a good circuit should be no problem, regardless of the transistor types your junkbox is stocked with. There is little difference between circuits except for the values of the starting and feedback resistors. Fig. 3-7 is a typical circuit using a **Triad** TY-81 (or TY-82) toroidal-core transformer. In this circuit, the output is more than adequate to power any f-m mobile communications receiver. Additionally, all **Triad** TY-series transformers come packaged with at least two basic supply circuits and a wide list of usable transistor types. When the flat **Triad** transformer is used, there will be plenty of room on the underside of most chassis for mounting this as well as the other circuit components (Figs. 3-8 and 3-9).

Selection of Transistors

While the parameters of a given transistor type need not be matched, it is not a good policy to use two different transistor types. The operation can result in an output waveform which is unbalanced to such an extent that the audio-frequency tone generated by the transformer becomes overcoupled from the transformer to the adjacent circuitry. The result of this is an irrepressible, loud, and irritating whine. Un-

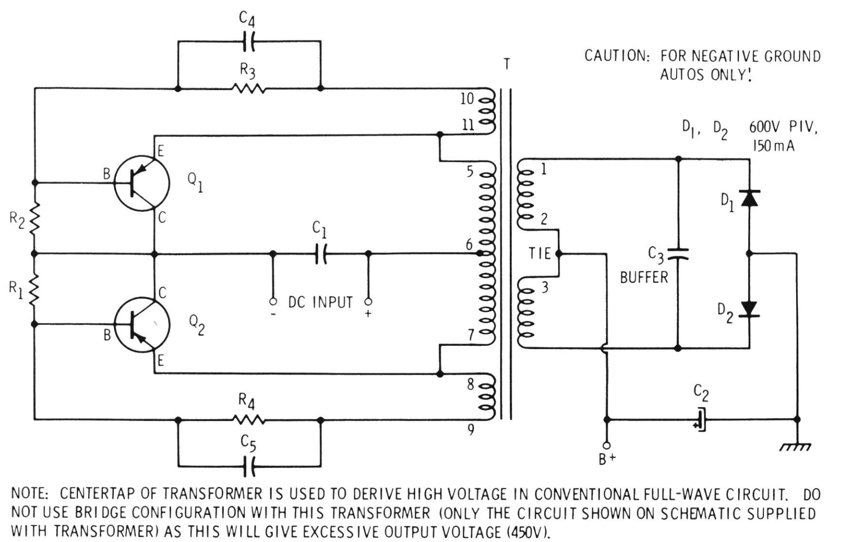


Fig. 3-7. Receiver power-supply circuit in which transistor cases may be in direct contact with radio chassis.

PARTS LIST

R_1, R_2—125 ohms, 5 watts
R_3, R_4—5 ohms, 1 watt
C_1—250 μF, 25 volt
C_2—1 μF, 1kV
C_3—0.005 μF, 1.6 kV
C_4, C_5—2 μF, 25 volt
T—*Triad* TY-81 or TY-82 (Either will provide adequate receiver voltage.)
Q_1, Q_2—2N277, 2N278, 2N1160 or any others of similar characteristics.

matched transistors also can result in overheating during one of the operational half-cycles. If the heat sink is incapable of coping with the excess, the added heat causes an exponential temperature rise similar to thermal runaway, and the transistor is soon destroyed. A sound approach would be to use any transistor that will operate without overheating, but keep both transistors the same.

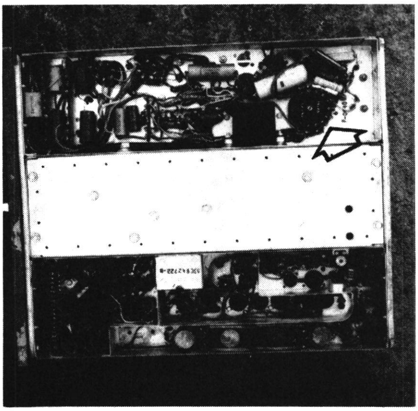


Fig. 3-8. The power-supply chassis of the Motorola T44 has plenty of room (arrow) for mounting the Triad TY-81 or TY-82 round toroidal-type transformer.

If radiation of the switching frequency or its harmonics causes interference, it can be reduced by connecting a choke in series with the input. A suitable choke coil can be obtained by winding about 50 turns of #12 wire on a ½-inch diameter air core (the number of turns per layer is unimportant), or removing this type of coil from an old car radio. In some cases a choke in conjunction with the output filter will help reduce interference.

Inverters operating in the two- to five-kHz frequency range often produce an audible squeal which can be annoying if the unit is

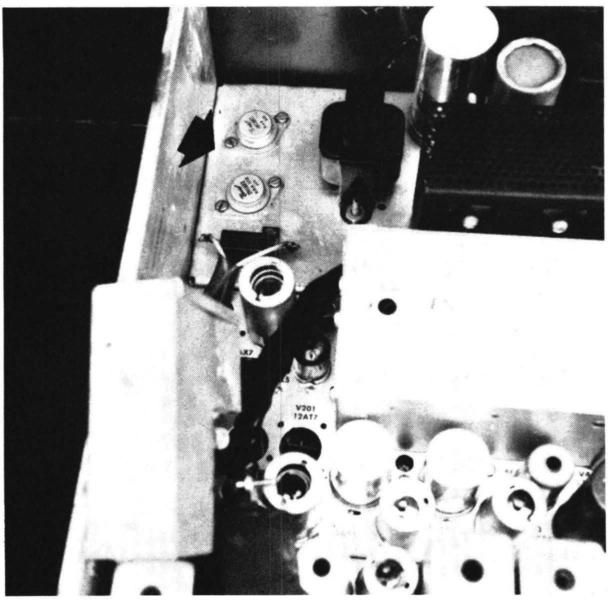


Fig. 3-9. The transistors mount near the transformer from the top of the chassis.

close to the equipment operator. This noise can be reduced by placing a thin cushion of rubber or other resilient material between the transformer and chassis.

Modification of Unit

Incorporation of a separate receiver supply involves nothing more than disconnecting one lead and reconnecting it elsewhere. This is true for the MC-306 as well as the T44. Then, in the event of T-supply failure, the unit can be returned to stock operation in no longer than it takes to resolder a lead.

The receiver high-voltage lead must be disconnected from the stock supply. In both the GE and Motorola units described, receiver B+ is routed through a push-to-talk relay. To keep the receiver operating continuously, the receiver B+ lead on the output of the relay should be moved to the B+ terminal of the added supply. This can be accomplished on the Pre-Prog MC-306 by removing the receiver lead from pin 11 of the power connector on the strip, and replacing it with a lead from the transistor supply output. The equivalent location on the T44 receiver strip is pin 1.

Mobile Monitoring of Remote Station

The control mobile unit should have the capability of monitoring both the uhf control repeater output and the remotely operated base-station signals. Many oper-

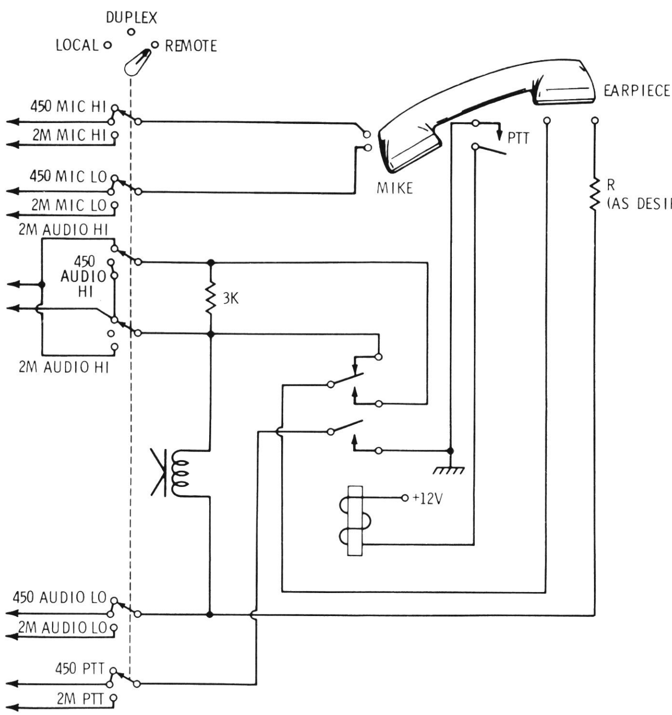


Fig. 3-10. Compatible monitor system for two-unit mobile repeater control and operation.

ators simply mount a transmitter/receiver unit for each band in the car and keep both turned on. These operators are readily recognizable by their incessant feedback squeals. A better approach is pictured in Fig. 3-10. This switching system not only offers the advantage of feedback-free operation, but it allows the use of a single handset rather than two individual mikes.

Here's how it works: The local-duplex-remote switch is placed in the desired position. (Local in this case would mean two-meter operation direct from the mobile.) If the remote equipment is activated, the operator will transmit (local position) on two meters while his speaker is shut off, but he will monitor the two-meter signals (or talkback) on the handset earphone as they are transmitted from his remote uhf transmitter. (Not quite true for duplexed uhf gear, but this is discussed later.) During his transmissions, if a stronger signal comes on the channel, he will be able to hear it and can wait until the frequency is clear before continuing. Or he can switch to the remote position and resume. When the push-to-talk switch is released, the speaker and the earphone are reconnected to the two-meter transceiver for direct monitoring.

In the remote position, the opposite case occurs. The talkback is monitored until the push-to-talk button is pressed, at which time the speaker is shut down and the earphone is connected to the local two-meter unit.

If the uhf mobile equipment is set up for duplex operation, the speaker continues to receive two-meter and uhf signals during uhf transmissions, but the two-meter signals are substantially cut in volume. During two-meter transmissions from the car, the speaker is fed with reduced-level audio from the uhf rig. Duplex simply means that the uhf transmitter operates simultaneously with the uhf receiver. This condition is a virtual necessity for operators using remotely controlled telephones.

Feedback, the chief problem with duplex operation, is minimized in the control design shown here by reducing the speaker volume in the duplex mode. Since the handset will be used during duplexing, the volume at the speaker can be greatly reduced without compromising listening ability. The 3K resistor in the schematic can be increased or decreased in value to yield just the right amount of drop in audio to stop feedback effectively.

3-7. LICENSING REMOTE FACILITIES

The distinctions between facility types become very obvious when the time comes to apply for a license. Repeaters to be operated locally (set up at an existing amateur station residence, and manned by the licensee or other amateur) will require no special license. The FCC considers a local repeater to be in the same class as a conventional amateur station, but remotely operated repeaters (unmanned, controlled by radio or wireline) are quite another matter. An amateur who intends to operate his own station by remote control will be confronted with the same licensing requirements as the prospective operator of a remotely situated repeater system.

The license you receive is not a license for your remote station so much as it is an authorization for you to exercise positive control of an unmanned facility. True, a copy of your license must be posted at the remote site; but to get the license, you must demonstrate to the FCC's evaluation team that you have the capability of adequately controlling the unmanned station, and that the system design is sound enough to assure positive control under a variety of possible unfavorable conditions.

The evaluation team cannot come out and physically inspect the facilities of all applicants, so they do the next best thing: they carefully examine your application (which is in truth more of a proposal than an application). They will issue your license if it is obvious that you "know your oats," and your submittal shows that you have a respect for the rules as well as an understanding of **their intent,** that you have a sound and workable design, that you have taken reasonable design precautions to assure automatic shutdown in the event of control malfunctions, that you (and any other licensees) will be able to maintain exclusive control, and that you will comply with the explicit provisions of Part 97.43, FCC Rules and Regulations governing amateur radio service.

Convincing the FCC examiners of your compliance in all these areas may take a bit of selling. But thousands have done it; and most of those who have agree that it was not nearly so difficult as they had originally anticipated.

First, carefully read Part 97.43, the segment of the Rules that details the basic requirements for remote control. (Part 97.43, excerpted from the Rules, is reprinted verbatim following this paragraph.) Then prepare a statement in your own words that shows, paragraph by paragraph, that you will comply with the terms of 97.43.

§97.43. *Location of Station. (a) Every amateur station shall have a fixed transmitter location. Only one fixed transmitter location will be authorized and will be designated on the license for each amateur station, except that when remote control is authorized, the location of the remote control position as well as the location of the remotely controlled transmitter shall be considered as fixed transmitter locations and will be so designated on the station license. Unless remote control of the transmitting apparatus is authorized, such apparatus shall be operated only by a duly licensed amateur radio operator present at the location of such apparatus.*

(b) Authority for operation of an amateur station with the licensed operator on duty at a specific remote control point in lieu of the remote transmitter location may be granted upon filing an application for a modified station license on FCC Form 610, provided that the following conditions are met: (1) The remote control point as well as the remotely controlled transmitter, shall be located on premises controlled by the licensee. (2) The remotely controlled transmitter shall be so installed and protected that it is inaccessible to other than duly authorized persons. (3) In addition to the requirements of §97.85 a photocopy of the amateur station license shall be posted in a conspicuous place at the location of

the remotely controlled transmitter. (4) Means shall be provided at the control point to permit the continuous monitoring of the emissions of the remotely controlled transmitter, and it shall be continuously monitored when in operation. (5) Means shall be provided at the remote control point immediately to suspend the radiation of the transmitter when there is any deviation from the terms of the station license or from the Amateur Radio Service rules. (6) In the event that operation of an amateur transmitter from a remote control point by radio is desired,

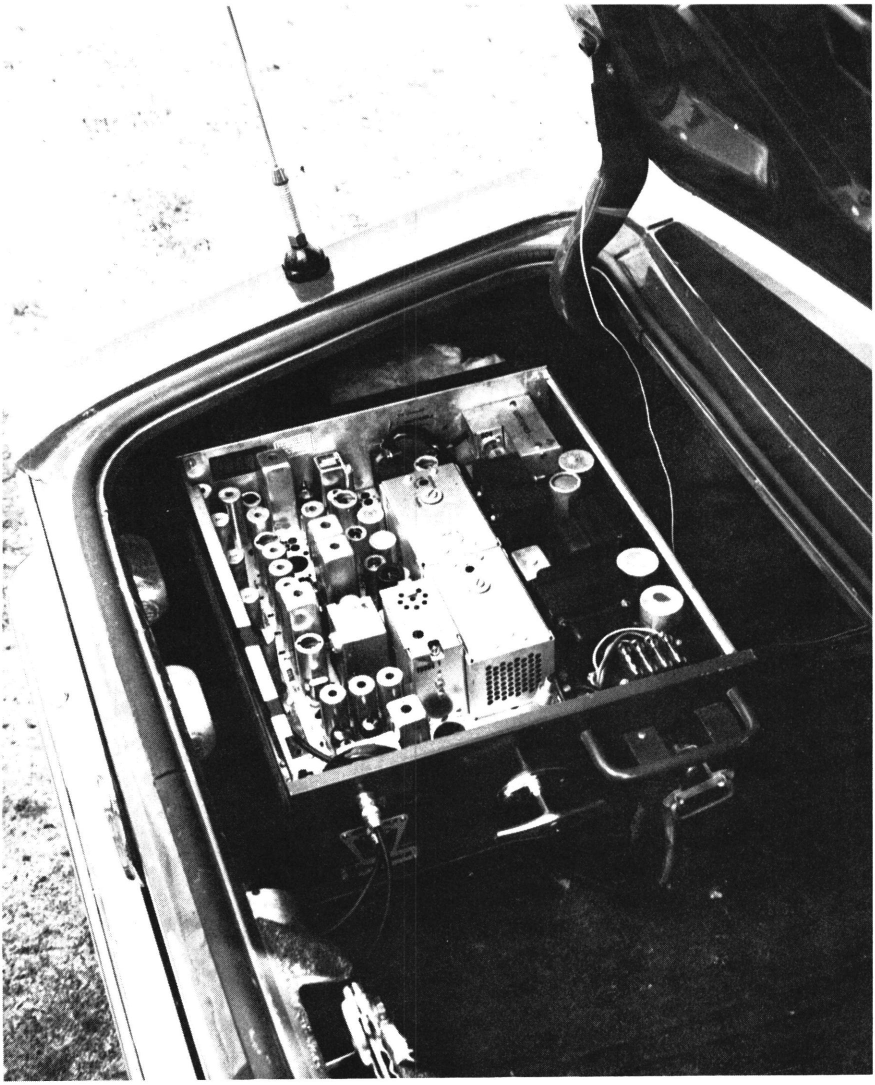


Fig. 3-11. Stock T44's and Pre-Progs have but one antenna connector on the transceiver case. To complete duplex installation, it is necessary to eliminate the antenna relay, bring coax leads from both transmitter and receiver, and terminate them in connectors as shown in the photograph.

an application for a modified station license on FCC Form 610 should be submitted with a letter requesting authority to operate in such a manner stating that the controlling transmitter at the remote control location will operate within amateur frequency bands 220 megacycles or higher and that there will be full compliance with subparagraphs (1) through (5) of this paragraph. Supplemental statements and diagrams should accompany the application and show how radio remote control will be accomplished and what means will be employed to prevent unauthorized operation of the transmitter by signals other than those from the controlling unit. There should be included complete data on control channels, relays and functions of each, directional antenna design for the transmitter and receiver in the control circuit, and means employed for turning the main transmitter on and off from the remote control location.

(c) An amateur transmitter may be operated from a remote control point in lieu of the remote transmitter location without special authorization by the Commission when there is direct mechanical control or direct electrical control by wired connections of the transmitter from a point located in the same or closely adjoining building or structure provided there is full compliance with the conditions set forth in paragraph (b)(1) through (5) of this section.

A model application for a remote license is included as indented matter on the next few pages. If you have trouble putting the right words together, use the model by copying the applicable information and making changes where your design deviates from that of the model. Your submittal

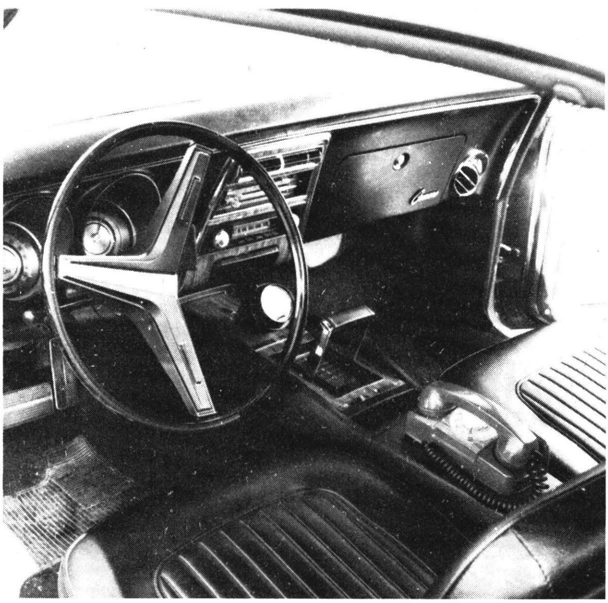


Fig. 3-12. Installation of a conventional bedroom telephone set in the car can do a great deal to enhance the overall installation, and it is particularly desirable where a phone patch is interconnected with a uhf repeater. The control head is eliminated by connecting a fixed resistor (about 1.5K) from squelch to ground inside the unit, by presetting the volume control, and by connecting the transceiver so that it comes on with the ignition. In this installation the speaker is hidden behind the dash. Lifting the handset from its position lowers the level to the speaker so that feedback is avoided.

to the FCC must of course be accompanied by your fully completed FCC Form 610.

REMOTE APPLICATION

To: FCC
From: Frederick W. Daniel (WB6SVC)
Subject: Supplemental Data in Application for a Remote Control (Radio) License

SCOPE AND PURPOSE

Authorization is requested to install, maintain, and operate (via a radio link) an amateur radio station to be situated at Sunset Peak, near Pomona, California. The station license has been issued: this request is for a modification of that license. The information contained herein is submitted as evidence of my understanding of the FCC's requirements concerning such operation; and it is further intended to show the type of equipment, techniques of control, frequencies of operation, and methods by which the FCC Rules will be adhered to in actual operation of the facility.

BASIC COMPLIANCE

In compliance with the applicable paragraphs of FCC Rules & Regulations, Part 97.43, the following conditions will be met. (The subparagraph numbers used below represent like items from FCC Rules, Part 97.43.)

(a) One fixed transmitter location will be used for control and one will be used for the remotely controlled equipment. As shown on the attached FCC Form 610, the point of control is to be:

1678 E. Mission
Pomona, California 91767

The equipment to be operated via the radio link is to be situated within a locked building at:

Communication Specialties
Commercial Radio Site
Sunset Peak,
Baldy Range,
Angeles Nat'l Forest,
Pomona, California

(b) Pursuant to the requirements outlined in the Rules, the following conditions will be met:

(1) The remote control point as well as the remotely controlled transmitter shall be located on premises over which I have control. The control transmitter is to be located on my own premises, and will be inaccessible to unauthorized persons. The remote transmitter is located in a building owned by me, and on property which I lease from the U. S. Department of Agriculture, Forest Service. The Forest Service recognizes that I am applying for a permit to operate a remote amateur facility, and has granted me unlimited access to the remote site (pursuant to their own general rules).

(2) The remotely controlled equipment is to be so installed as to be inaccessible to unauthorized persons. The building which will house the equipment will be used for no other purpose, and the door will remain locked at all times when an authorized individual is not physically at the site.

(3) The original license will be filed at an accessible spot under my jurisdiction. Photocopies of the license will be distributed as follows:

- 1 copy will be posted conspicuously in the building where the remote transmitter is deployed; it will be displayed near the place where the actual transmitter is situated.
- 1 copy will be posted conspicuously at my home (the remote control point) near the control transmitter.
- 1 copy will be kept on my person at all times I am using any amateur station.

(4) Means shall be provided at the control point to permit continuous monitoring of the emissions of the remotely controlled transmitters, and I shall monitor such signals during all periods of use.

(5) Means will be provided at the remote control point to suspend the operation of the remotely controlled transmitter when its emissions are such as to cause deviation from the terms of the station license or FCC Rules (Part 97). The manner in which such operation suspension will be achieved is described on subsequent sheets of this submittal.

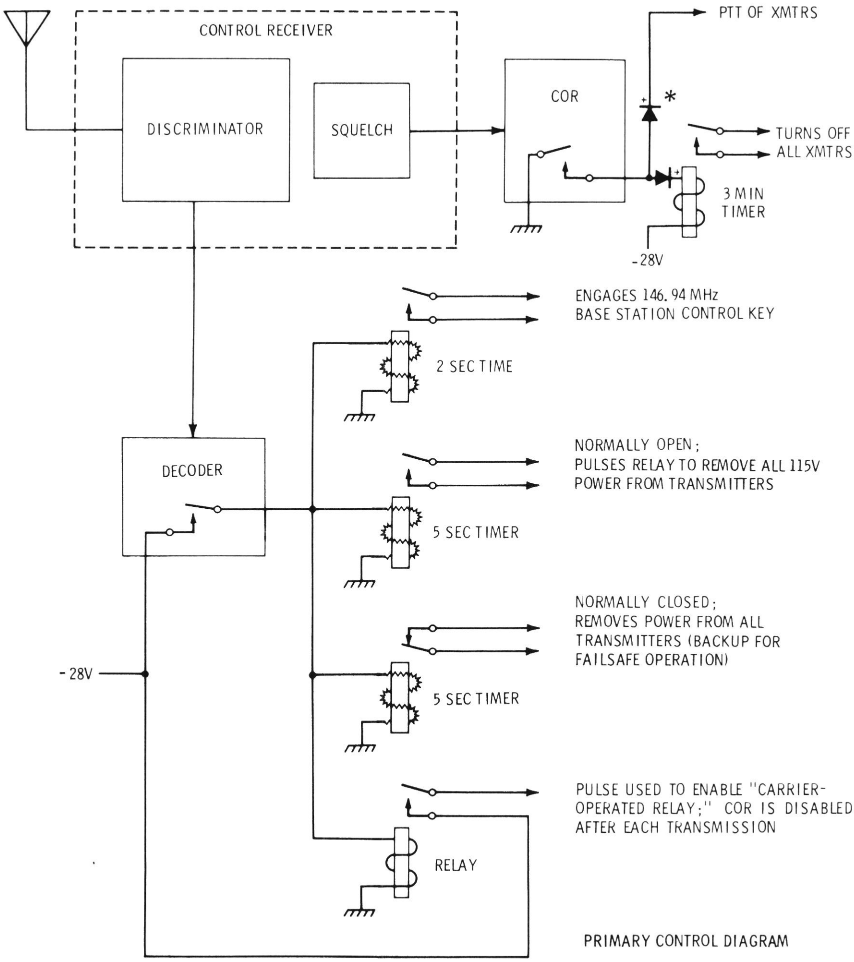
(6) In accordance with the Rules, this document is to serve as the "letter requesting authority" cited in FCC Rules, Part 97.43 (b) (6). The frequency and mode to be used for control will be:

442.00 MHz, F_3
(wideband)

I hereby certify that I will operate my remote transmitter in full compliance with all the terms and conditions of items (1) through (5) of paragraph 97.43, FCC Rules and Regulations, Amateur Radio Service, Part 97.

SUPPLEMENTAL DATA

The following paragraphs (and diagrams) are included to show how radio remote control will be accomplished and what means will be employed to prevent unauthorized operation (as by signals other than my own). Also included herein is information on control channels, relays (and their functions), antennas, etc., as well as descriptions of special



PRIMARY CONTROL DIAGRAM

* DIODES KEEP PTT AND TIMER ISOLATED FROM EACH OTHER TO PREVENT KEYING FROM VOLTAGE RESIDUALS AFTER COR IS OPENED. (POLARITY DEPENDS ON VOLTAGES.)

circuits to be used for log-keeping, identification, and other required functions.

Control

Control will be accomplished with audio-frequency tones of critical level and frequency. Decoders at the remote site will pull in relays on command, as a means for on–off function control. Design will be such that momentary power loss at the remote site will shut down all equipment. Unauthorized access is to be prevented by requiring the presence of the control tone for a short duration at the outset of each transmission. Signals not accompanied by the control tone will not trigger the relay which turns on the remote transmitter.

Control Design

The control input is to be 442.0 MHz, wideband fm. The remote transmitters will be on 448.00 MHz and 146.94 MHz, both wideband fm. The 448.00-MHz output is to be part of a control-link repeater, which will retransmit all signals on 146.94 MHz as well as coded (tone-carrying) signals on the control input.

Relays to control system interconnects, turn-on, shutdown, and various automatic functions, are to be incorporated as follows.

Repeater

Signals (from the control input) accompanied by the proper audio tone will be repeated on the control output. An electrically latched relay, energized by the tone decoder, will be held in during all periods of operation. In the event of system failure, the relay will be released and the remote system will shut down.

A 2.0-second timer will be connected to the decoder so that an additional relay can be selectively energized for applying power to the 146.94-MHz transmitter. Once energized, all tone-bearing signals on the control input will be retransmitted on 146.94 MHz; and all 146.94-MHz signals will be retransmitted on the control output. Since the control receiver, given precedence, is operational 100 percent of the time, operation of all remote equipment can be suspended at any time, regardless of whether signals are being transmitted on the control output.

Shutdown

Shutdown is accomplished in the following ways (see block diagram).

(a) All remote transmitters will shut down when any emission from the remote equipment exceeds 3.0 minutes.

(b) The remote 146.94-MHz transmittter will shut down when no signal appears on the control input for 3.0 minutes.

(c) The remote 146.94-MHz transmitter will shut down when no signal appears on the 146.94-MHz input for 3.0 minutes.

(d) All remote transmitters will shut down when a 5-second tone appears on the control input.

Antennas

Directional high-gain yagi antennas will be employed at the control point as well as the remote site. At a later date, it is my intention to deploy an omnidirectional antenna at the remote site for short periods. I would accomplish this by sending a low-frequency tone with each transmission so that antenna switchover would be accomplished at the remote site. Loss of the tone would return the directional antenna into the circuit. All shutdown signals (and absence of signals) would also cause the switchover relays to drop out and the directional antennas to again be part of the system. The nondirectional antenna function would be used solely to allow temporary access to the system from a mobile, for the purpose of communication (though not for control).

Logkeeping

When any remote transmitter is engaged, a tape recorder will also be energized. The recorder will be on continuously, recording all audio transmitted on the control output. It will be my responsibility to verbally announce the date, time, and frequency of operation at the outset of any operating period. Since the tape record will be in real time, no further time announcements will be made until the transmitter is energized after a period of shutdown. The recorder is capable of operation for 42 hours of continuous use. It is anticipated that tape changes would be required approximately once per month.

Identification

No means of automatic identification is planned. It will be my responsibility to identify the remote transmitters each 3 minutes during periods of use.

Miscellaneous

The tone encoder and decoder units are of conventional design, operating at a frequency of 1700 Hz. The units were constructed from plans which appeared in FM Magazine, July 1968. The remote transmitters are commercial units adapted for operation in the amateur band.

Certification

I certify that all statements and assertions included herein are true and valid to the best of my knowledge, and that my remote station will be operated in accordance with the plans cited herein (or as amended by the FCC). I hold two amateur licenses (two stations: W6NQS and WB6SVC) and a valid first-class commercial license with radar endorsement.

Signed ______________________

Date ______________________

Chapter 4

Building a Repeater

The one system type that is almost universally applicable to all remote applications is the uhf repeater. For this reason, many of the specifics included in the text are geared particularly to projects involving construction and setup of a control-channel repeater in the 450-MHz band, though most of the information is applicable to setup and deployment of low-band and high-band systems as well.

4-1. EQUIPMENT SETUP (REPEATER)

Space limitations prohibit listing all the detailed equipment peculiarities and individual requirements. But as your 450-MHz repeater begins to take shape you will begin to see how to apply the principles and concepts to your own unique problems in other related repeater projects.

Duplexing

Whether your repeater is a vhf "open" type or a private-use "closed" uhf system (or both), chances are the repeater itself will begin as a conventional commercial base station. The first step in converting a base station to a repeater is to get the transmitter and receiver operating independently. This means the normal transmit/receive functions of the unit must be modified to allow the receiver to function continuously, regardless of whether the transmitter itself is activated or not. And this procedure will likely be the simplest of all the subsequent tasks, provided the equipment is blessed with a little built-in capability.

Not all commercial base stations are equipped with power supplies husky enough to power the transmitter and receiver sections simultaneously. Since most **Motorola** and **GE** units in the uhf range do have this capability, they have become "standards" for repeater use. Getting the receiver to operate independently from the transmitter (on most **Motorola** and **GE** uhf units) involves no more than jumpering an internal connection and bypassing the built-in antenna relay.

The **Motorola** L44 is a 450-MHz base station which uses the same transmitter and receiver strips as the T44 mobile. To convert this unit for independent transmit/receive operation, connect individual antennas directly to the transmitter and receiver. Connect a jumper lead from terminal 1 to terminal 2 on the junction strip located in the bottom of the power-supply chassis. (The procedure is the same for the J44 and B44 units.) The last step is to disconnect the grounded 2-watt resistor from the T/R relay (B+ line), which is located in the power-supply underchassis. To convert a **GE** Pre-Prog, connect a jumper from pin 3 to 4 on TB601 of the receiver power supply and connect separate antennas to the receiver and transmitter. These simple connections will effectively "duplex" the radio when separate frequencies are used for transmit and receive; the transmitter can be energized without operationally affecting the performance of the receiver.

The basic repeater is born as soon as some means is provided for automatically triggering the transmitter when a signal appears on the input frequency. This function is most often achieved with the carrier-operated relay, the construction and interconnections of which are described in Section 2-1.

Mounting of Equipment

Regardless of the original model and type of your repeater-to-be, the equipment should be installed in an easily accessible upright cabinet. This will assure plenty of space for expansion, and it will considerably enhance the "maintainability" of the system.

Do not select a cabinet with "front-mount" rails because such cabinets hinder rear access. Use a cabinet with mounting rails extending vertically along the center of the cabinet's interior on both sides, as shown in Fig. 4-1. If your cabinet does not have this recessed mounting capability, you can probably modify it by mounting 1-inch L-bracket strips to the inside as shown. Be sure first, however, to drill (and tap) a sufficient number of holes to mount (and physically align) the receivers, transmitters, power supplies, and termination equipment you intend to use.

Most **GE** and **Motorola** units in use by amateurs are easily adapted to rack-mounting in cabinets with standard 19-inch panel widths. The mobile **GE Progress Line** is an exception (its strips are about a foot in length), but even these can be adapted with relative ease. One expedient is

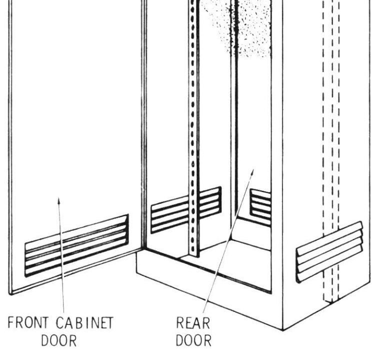


Fig. 4-1. Typical 4- or 6-foot equipment cabinet with inside mounting rails.

to mount the Progress Line strips vertically on two 19-inch rails, as shown in Fig. 4-2. This approach allows optimum use of space inside the cabinet while keeping all strips accessible enough for servicing.

The **GE** Pre-Progs and virtually all surplus **Motorola** equipment are easily mounted with short lengths of "angle iron" or standard, commercially available L-brackets. Without the brackets, the chassis just fit inside cabinet mounting rails. The simple brackets extend the chassis just enough to provide a good fit (Fig. 4-3). It is usually a wise idea to position the units in the cabinet with the idea that the transmitter might cause interference to the receiver. A power supply mounted between the two units, for example, might be just the solution to a minor desensitization problem.

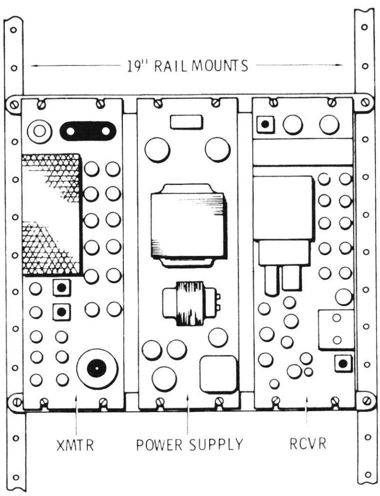


Fig. 4-2. Method for mounting unconventionally proportioned strips (such as the Progress line).

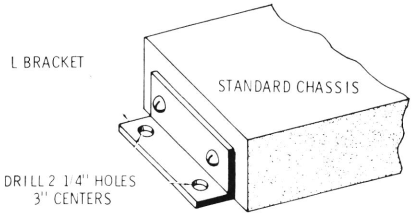


Fig. 4-3. Mounting commercial mobile chassis in a standard 19-inch enclosure.

As a rule of thumb, mount the transmitter at the top. It generates more heat than any other chassis and top-mounting it keeps this rising heat away from the other components.

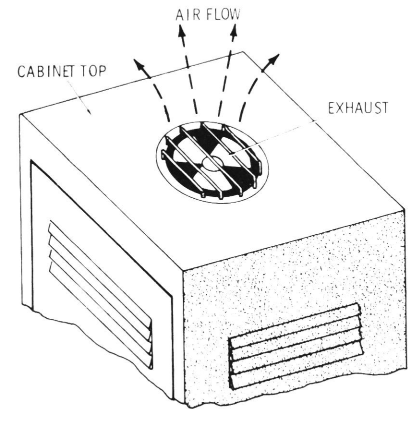
Ventilation

Due consideration to ventilation is vital if a reliable repeater is to be expected, for without an adequate exchange of air, the repeater components will wilt and die like unwatered shrubs. Remember, your repeater will be situated in some remote spot, probably without air conditioning. There will be no continuous opening and closing of doors to circulate the ambient air. At midday, particularly in the summer, the room temperature may be well above 100°F.

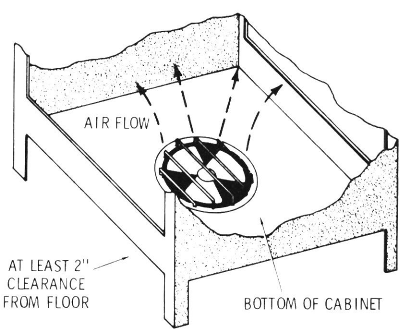
To aggravate the thermal problem, you will likely be using vacuum-tube receivers and transmitters. The filaments burn like beacons, constantly pushing the temperature upward. If you want to have a repeater that will operate without constant attention **do not** fail to build in a circulator of some kind.

Most commercial base stations incorporate blowers as integral parts of their transmitter chassis, but mobile transmitter strips are rarely so equipped. If a small blower can be attached conveniently on the transmitter to blow fresh air efficiently through the driver and final cages, adequate ventilation would be provided by energizing the blower from the push-to-talk circuitry. But if air cannot be forced directly into the final, some means should be provided for **continuously** circulating the air inside the cabinet.

The cabinet itself must have ventilation holes or louvers at the top and bottom—preferably on both access doors as well as both cabinet sides. If a fan is mounted at the bottom of the cabinet, it should be oriented to blow air upward into the cabinet. If the fan is mounted at the top, it should be so arranged as to draw air up from the bottom and exhaust it out through the louvers or a special port.



(A) Top-mounted exhaust fan.



(A) Bottom-mounted forced-air type.

Fig. 4-4. Different methods of mounting ventilating fans.

Muffin fans make effective ventilators. Again, if the muffin fan is at the bottom, it should take air into the cabinet. If it is top mounted, it should exhaust air. Fig. 4-4 shows acceptable mounting techniques. Do not make the mistake of bottom-mounting a muffin fan when the cabinet has no floor clearance. If there is not at least 2 inches between the floor and the cabinet bottom, mount the fan at the top.

Metering

The one thing virtually **all** commercial f-m units have in common is their method for tuneup and checkout. Almost without exception, they require a sensitive meter to monitor test points for each component stage. **GE** units can be checked with 0–3V dc meters; **Motorola** units are designed for monitoring with a 0–50 μA meter. **DuMont, RCA,** and **Aerotron** systems are all similar. This simplified method for checkout and test makes it easy for the amateur to incorporate a built-in test set as a functional part of a repeater system.

Fig. 4-5 shows how to set up such a monitoring system for a Motorola unit. This test set is a bit more complicated than the

GE, but it will be a bit simpler to use. The **Motorola** test set is simply a 0–50 μA meter with leads which plug into the chassis test receptacle. A selector switch allows the test points to be monitored in a logical sequence.

Motorola transmitters and receivers are equipped with identical test receptacles (standard 11-pin tube sockets). The metering lead is plugged into whichever chassis (transmitter or receiver) requires checkout. The legend in Fig. 4-5 shows the stage being monitored with each position of the selector switch.

The **GE** meter is the epitome of simplicity. The meter itself (0–3V dc) is mounted on a panel so the leads will reach all areas of the GE strips. The leads themselves should be terminated in standard pin plugs.

In all cases, the meter should be mounted so as to be easily viewed while making adjustments from the front of the cabinet. One idea is to mount the meter and whatever switching circuitry is required in the corner of an 8-inch rack panel, then position the panel between the transmitter and receiver. If you later expand your system, the rest of the panel will prove a very convenient mounting spot for timers, phone patches, control relays, and the like.

4-2. INTERCONNECTING CIRCUITRY

The fact that several audio circuits will at times be superimposed on the control repeater output signal is reason enough to expend a little extra care in the interfacing of these various circuits. Thoughtless input-to-output and output-to-input cross coupling will result in almost certain design miseries after deployment. If your system is in the design stages, take the advice of many lamenting oldtimers: keep the audio circuits of all equipment sufficiently isolated so that no level changes of one circuit affect those of another.

Audio Matching

A good idea is to maintain one common audio line of 600 ohms impedance and retain this characteristic impedance regardless of the number and type of audio interconnections anticipated. This task is not as difficult as it might seem. The trick is to provide transformer access to the 600-ohm line and to provide all audio circuits with individual cathode-follower (or emitter-follower) terminations. The block diagram of Fig. 4-6 illustrates this scheme. Fig. 4-7 is a schematic of a typical cathode follower for repeater applications.

The cathode follower is an audio "conditioner" (it has no gain and is used for matching and isolation rather than amplification). When such a circuit is used, it is better to obtain the receiver audio directly from the discriminator. There are several reasons for this: For one, the discriminator bears essentially "pure" audio that has not been processed through the receiver's emphasis circuitry — thus, the very highest achievable quality can be maintained. A second reason is that all the local volume-control circuitry is bypassed; local levels can be changed at will without disrupting the balance of

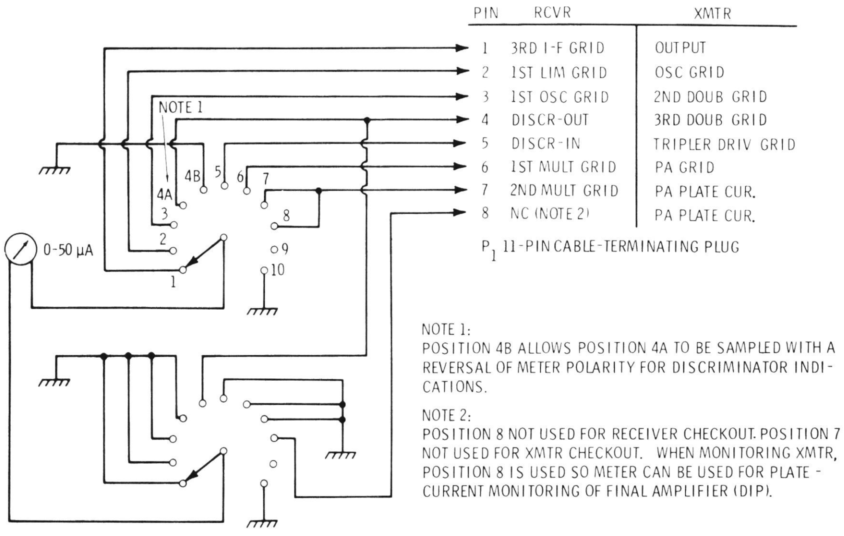


Fig. 4-5. Motorola test set.

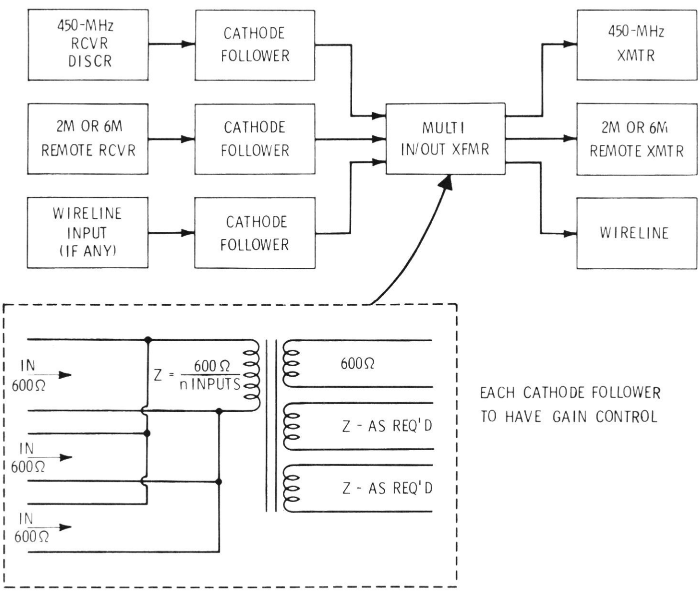


Fig. 4-6. Recommended audio interconnection scheme.

the actual "repeat" audio.

Since the discriminator receives audio before the squelch circuitry, squelch noise is con-

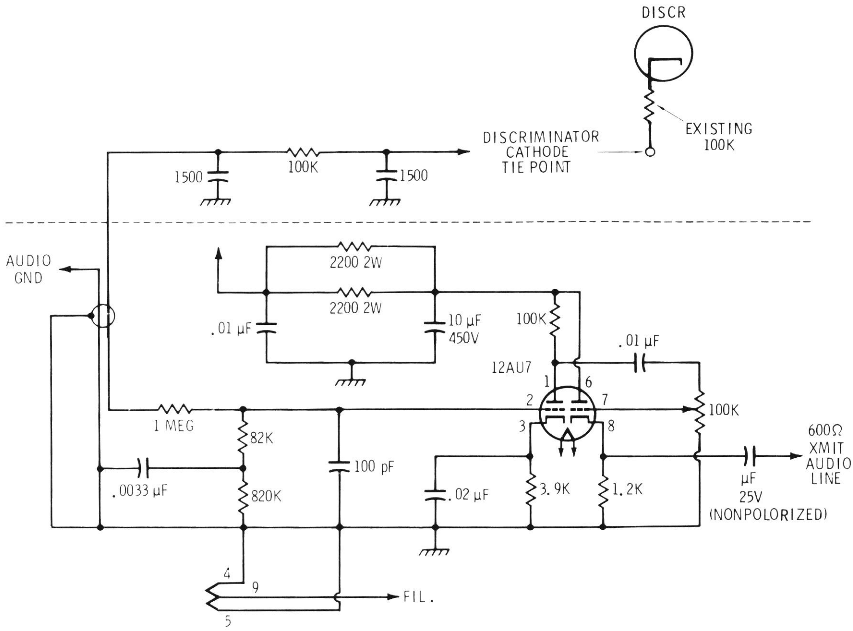


Fig. 4-7. Cathode follower of the type used by GE for Pre-Prog factory repeaters.

tinuously present. To keep the squelch noise off the 600-ohm line in the nonrepeat mode, the COR contacts can be used to short the cathode-follower output to ground in the no-signal state. An incoming signal then lifts the short circuit and the discriminator audio is processed through to the transmitter. Telephone company standards should be adhered to with respect to the level of the 600-ohm line; it should be held to within 1.0 dB of zero dBm (1 mW into a 600-ohm load).

If no remotes are planned for eventual use and a single vhf or uhf repeater is to be the only functional element of the planned system, there is, of course, no need for the audio complexity of Fig. 4-6.

A simple repeater can be connected as shown in Fig. 4-8A, when the output of the receiver is coupled directly into the transmitter. If the impedances do not match or if audio problems occur, a matching audio or compensation network should be employed, as shown in Fig. 4-8B and 4-8C.

The advantages of the common 600-ohm audio line are obvious in terms of expansion capability. This type of system is recommended over those of Fig. 4-8B because its add-on capabilities are virtually limitless.

You will find the secret of maintaining a system with consistent high-quality audio lies in your ability to keep a constant nonvarying load on the common audio line. This will require the

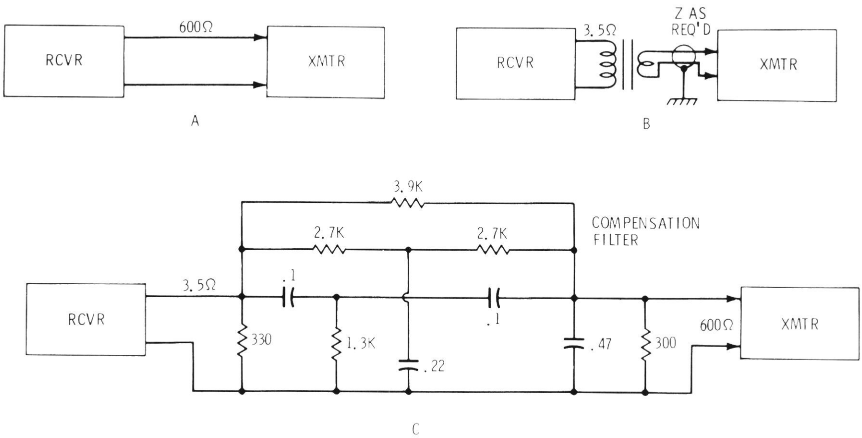


Fig. 4-8. Audio interconnections for simple repeaters.

use of resistors to simulate a load when an audio function is out of the circuit. Fig. 4-9 represents a uhf repeater incorporating a remote two-meter system as an occasional function. Note that when the control relay interconnects the audio line, the terminating resistor is removed from the circuit. In this way, the common line always sees the same load impedance.

Switching Interconnects

Every receiver to be remotely operated should be equipped with a carrier-operated relay (COR) (Section 2.1). The COR will give a relay closure with each incoming signal. The COR

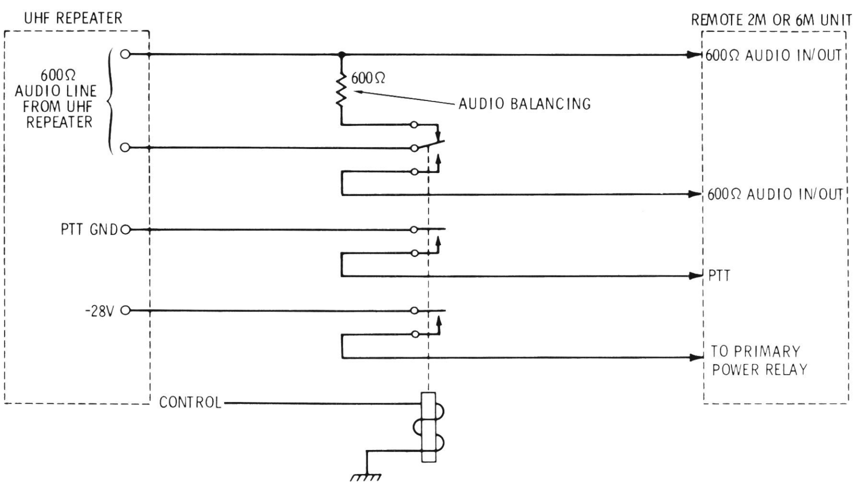


Fig. 4-9. Two unit audio and control intertie. The audio-balancing resistor maintains the audio load at a constant level.

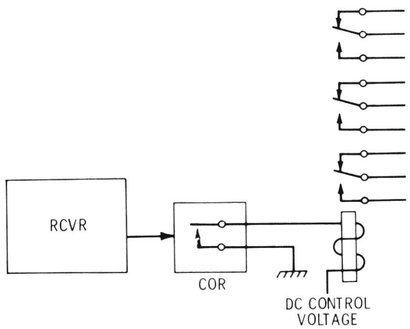


Fig. 4-10. Using COR for heavy-duty switching applications.

itself is not normally used to provide direct switching of repeater functions. Rather, it is used to energize a multicontact relay of heavy-duty construction, as shown in Fig. 4-10. The heavy-duty relay should be selected to allow a choice of either normally closed or normally open switching.

The simplified block diagram of Fig. 4-11 shows the primary switching function of a COR in a typical repeater application: that of keying the push-to-talk circuits of all transmitters to be used. As shown, individual control of all transmitters is possible even though only one COR is used.

4-3. MULTIFUNCTION CONTROL

Where CTS or **Touchtone** is used for control, the function-selection system is pretty well cut-and-dried; a decoder performs the required switching action, and the operation remains relatively simple and straightforward from the system viewpoint. But single-tone digital pulsing is

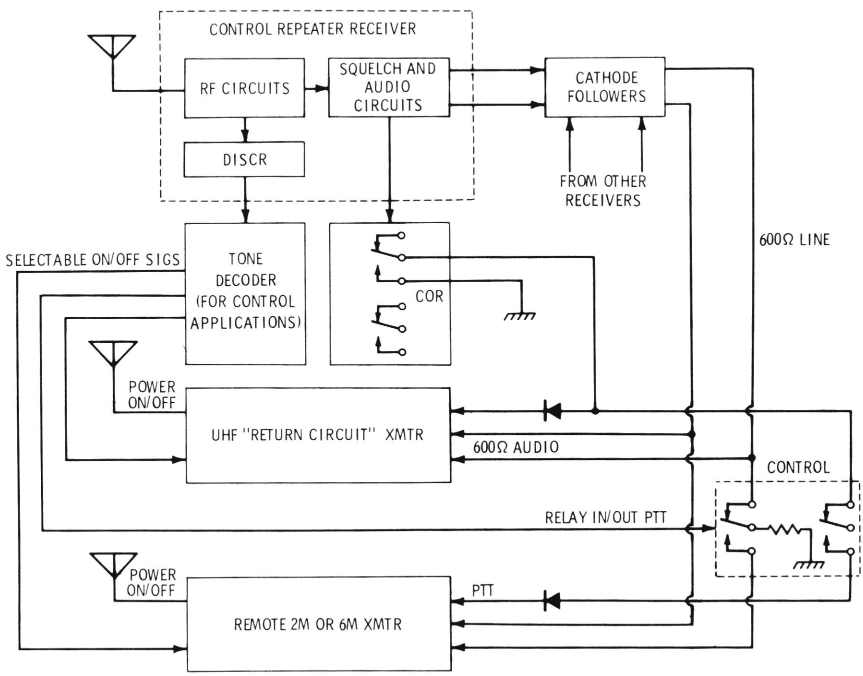


Fig. 4-11. Simplified block diagram showing switching interconnect design concept.

quite another matter, and there are any number of methods for effective and conservative function selection. It would be impossible to describe all methods for creating a remotely situated control system (or "brain"), but certain aspects of digital control are more or less universally applicable. One example is the question of whether to use solid-state components or relays for switching and function selection.

Transistor selection systems offer advantages in terms of long-range reliability and power-consumption economy, but they are limited by (1) range of effective switching applications, (2) requirement for a workable theoretical knowledge on the part of the builder, (3) complexities of troubleshooting, and (4) lack of add-on flexibility because of the cost of adding new stages.

Integrated circuits offer a very promising future for repeater control applications, though certain inherent limitations make them somewhat less than ideal at the existing state of the art. The weak link in a control chain of integrated circuits (IC's) is the vulnerable collector-to-emitter breakdown voltage point. Even the most expensive "chips" typically can handle no more than about 30 volts, and devices within the typical amateur's pocketbook range often break down at voltages no higher than 10 volts or so.

The switching limitations of IC's preclude their use in direct control of most ac loads or loads of characteristically high current or inductance. It is for this reason that the amateur who uses IC's for control will usually end up with a hybrid system employing IC's, transistors, and conventional relays. Transistors and relays can be selected for compatibility with a single power supply, of course, but the very low voltage requirement and general criticality of IC's means construction of a separate power source especially for the IC's.

While the use of mechanical devices such as relays, steppers, etc. for repeater control circuits may seem a bit on the anachronistic side in contrast to the IC concept, they do have some fairly persuasive advantages. It is true that mechanical contrivances are inherently less reliable for long-term operation, and they draw disproportionately large amounts of current as compared with their semiconductor counterparts, but in consideration of their basic ability to withstand the elements and their virtual imperviousness to voltage variations, the case for relays seems quite strong indeed.

One extremely important advantage is that virtually anyone can understand the operation of relays in a circuit by merely studying the schematic. Troubleshooting a relay system is a relatively simple task, too; when a relay doesn't pull in, the cause and effect can readily be traced.

Another advantage of a relay control system is its broad degree of built-in flexibility. Use of a **Strowger** (two-axis stepper), for example, allows no less than 100 different selectable commands using a two-digit pulsing scheme. And adding an additional function to a system not utilizing the

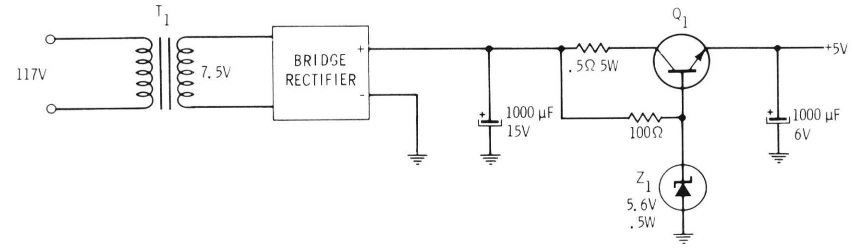


Fig. 4-12. Regulated power supply for integrated circuit.

full capability is no more bother than connecting a latching relay to the proper contact of the stepper.

But the most convincing case for relays lies in their ability to switch any kind of load (inductive or resistive, high current or low, ac or dc) under virtually **all** weather conditions.

Integrated-Circuit Control

Most remote sites are characterized by wide variations in temperature and humidity. Line voltages may vary anywhere from 95 to 125 volts. Considering the critical voltage requirements of integrated circuits, and the expense of replacement, it seems almost foolhardy to construct a power supply that cannot provide a stabilized, nonvarying output under a wide range of inputs. A second consideration is protection for the IC's in the event of inadvertent short circuits or other unforseen high-current conditions. The power supply shown in Fig. 4-12 offers a sound first step in the design or construction of an IC control system. Designed by Tom Woore (WB6BFM) to power an integrated-circuit identifier for the W6FNO repeater at Radio Ranch, the circuit provides sturdy regulation and short-proof operation.

A simple, well-proved control system utilizing integrated circuits is shown in Fig. 4-13. The circuit shown is the result of a series of design improvements and simplifications by Gil Boelke (W2EUP), one of the sharpest solid-state design men in the country. The Buffalo repeater in upper New York State has been controlled with a system of this design for the past year without failure. As a consequence, more and more repeaters are switching to similar designs. While it may not offer some of the control versatility of the mechanical devices, the IC system has all the combined attributes of compactness, ruggedness (and attendant reliability), absence of moving parts, and simplicity.

The integrated circuit control system was designed to be used with an **interrupted** single-tone input, though it is readily adaptable to a straight digital single-tone pulsing scheme. The complete circuit can be built on two average-size circuit boards, yet it contains all the necessary control elements, including tone decoder (referred to as a tone detector on the schematic), timers,

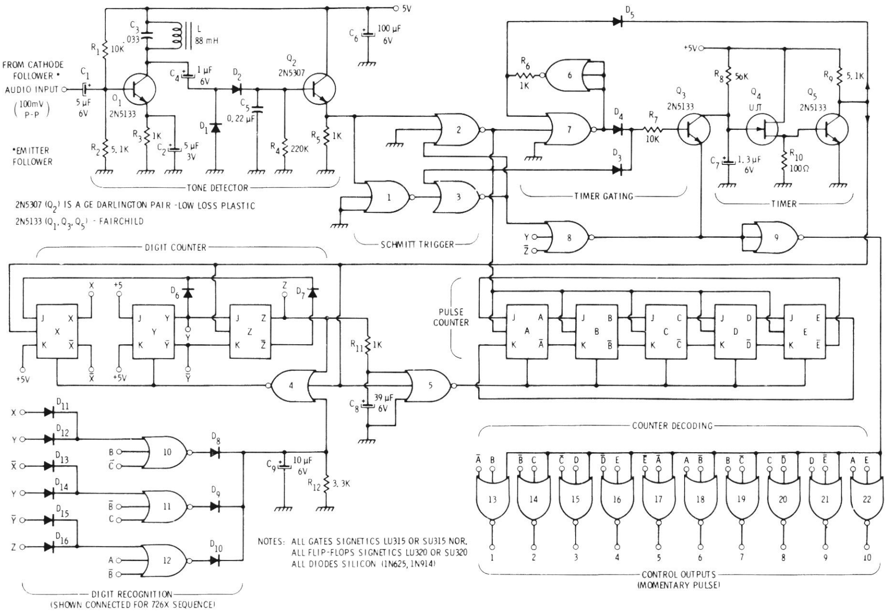


Fig. 4-13. W2EUP single-tone decoder and control logic.

PARTS LIST

Q_1	Motorola HEP 245
Z_1	1N5230, 5.6V, 0.5W
BR	Full-wave bridge, Motorola HEP 175
T_1	117 VAC Pri — 7.5 VAC Sec. 1A
Q_1, Q_3, Q_5	2N5133 Fairchild NPN transistors
Q_2	2N5307 GE Darlington Pair
Q_4	General purpose unijunction transistor
Gates 1-22	Dual three-input NOR gates, signetics LU315 or SU315
FF-A thru E, FF-X, Y, Z	J-K Flip-flops, Signetics LU320 or SU320
C_1	5-μF, 6V, electrolytic capacitor
C_2	5-μF, 3V, electrolytic capacitor
C_3	.033-μF, mylar capacitor
C_4	1-μF, 6V, electrolytic capacitor
C_5	0.22-μF, paper capacitor
C_6	100-μF, 6V, electrolytic capacitor
C_7	1.3-μF, 6V, electrolytic capacitor
C_8	39-μF, 6V, electrolytic capacitor
C_9	10-μF, 6V, electrolytic capacitor
D_1-D_{16}	1N914 or 1N625 Silicon diodes
R_1, R_7	10K, ¼-watt (or greater) resistor ±10%
R_2, R_9	5.1K, ¼-watt (or greater) resistor ±10%
R_3, R_5, R_6, R_{11}	1K, ¼-watt (or greater) resistor ±10%
R_4	220K, ¼-watt (or greater) resistor ±10%
R_8	56K, ¼-watt (or greater) resistor ±10%
R_{10}	100Ω, ¼-watt (or greater) resistor ±10%
R_{12}	3.3K, ¼-watt (or greater) resistor ±10%

digit and pulse counters, and coding networks.

As depicted here, Boelke's IC control system requires the processing of three specific digits (a prefix code) before an output can be obtained (by dialing of the fourth digit). Regardless of the inputs and input sequences, no function can be selected unless the proper prefix code is transmitted. In the circuit pictured, the prefix code for function selection consists of 7, 2, and 6—sequentially transmitted.

The output of the control system contains ten **AND** gates, any of which can be selected on the fourth digit (provided the prior three digits were 726). When pulsed, the selected output gate provides a short pulse that can be used to latch a relay, an SCR, or a transistor switching device.

The prefix can be changed by the control operator. The sequence is determined by selection of drive signals at the digit recognition gates. The pulse counter (which supplies these drive signals) contains five flip-flops; since each flip-flop has two states (set and reset, on and off, 1 and 0, etc.), there are ten possible single conditions. In operation, the first pulse changes the state of the first flip-flop from A to $\bar{A}$, but the second flip-flop (B) remains unchanged. The code, then, for the digit 1 would be $\bar{A}B$. The next pulse triggers B to the $\bar{B}$ state, leaving C unchanged; so the digit 2 would be represented by $\bar{B}C$. Thus, to change the prefix code from 726, the digit recognition gates (numbered 10, 11, and 12 on the schematic) would have to be reprogramed according to these logic equations:

1	$\bar{A}B$
2	$\bar{B}C$
3	$\bar{C}D$
4	$\bar{D}E$
5	$\bar{E}\bar{A}$
6	$A\bar{B}$
7	$B\bar{C}$
8	$C\bar{D}$
9	$D\bar{E}$
0	EA

Close examination of the table will reveal what may appear to be an inconsistency in the programing scheme. In all cases but digits 5 and 0, the following stage is of an opposite state. The schematic shows an inversion of the output of the fifth flip-flop, however. This inversion is necessary to reset the flip-flops after the first five have been set, and to set the first after the last has been reset. Unlike other counters, which contain a series of flip-flops each of which will trigger the preceding stage, this one contains flip-flops that stay in their pulsed state until actively changed by the incoming digital train. At the conclusion of each digital train, all flip-flops are reset to allow counting of the next incoming pulse series.

Mechanical Control

By far the most common and inexpensive method for multifunction control is the use of a conventional "telephone - type" stepper as the system brain. Fig. 4-14 is a diagram showing an extremely simple means for the remotely controllable selection

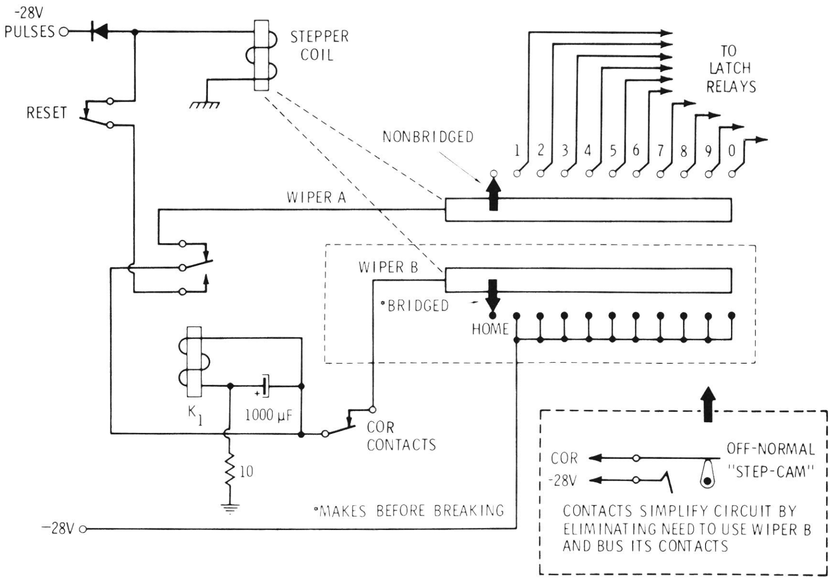


Fig. 4-14. Simple repeater "brain."

of up to 10 functions. In the plan illustrated, a negative supply voltage (−28 volts) is used for control and pulsing. The decoder, which provides a −28 volt pulse with each tone pulse transmitted, is not shown. As shown, the pulse voltage is supplied through a diode which isolates the stepper potential from the decoder. (The diode must be reversed, of course, if a positive control voltage is used.)

Many steppers have a "step cam" contact that provides a closure as soon as the stepper is moved off normal. This contact supplies control voltage to the normally closed COR contacts. When the stepper does not have this capability, it can be simulated by bussing all the contacts of one deck together and connecting that deck's wiper arm to the COR contact as shown in the sketch of Fig. 4-14. This keeps control voltage off the wipers when the stepper is at the "home" position.

Steppers also characteristically have reset contacts, which are nothing more than a normally closed set that opens momentarily with each pulse. When a continuous voltage is applied here, the switch pulses rapidly until it reaches the home position.

In the circuit illustrated in Fig. 4-14, control pulses from the decoder are fed to the stepper coil, which causes the wiper arms to step to the position corresponding to the digit transmitted at the control point. While the digits are being transmitted the COR is pulled in, thus keeping relay voltage from the reset circuit (K_1). When the digital sequence has been dialed and the control operator stops transmitting, momentarily, the COR closes, sup-

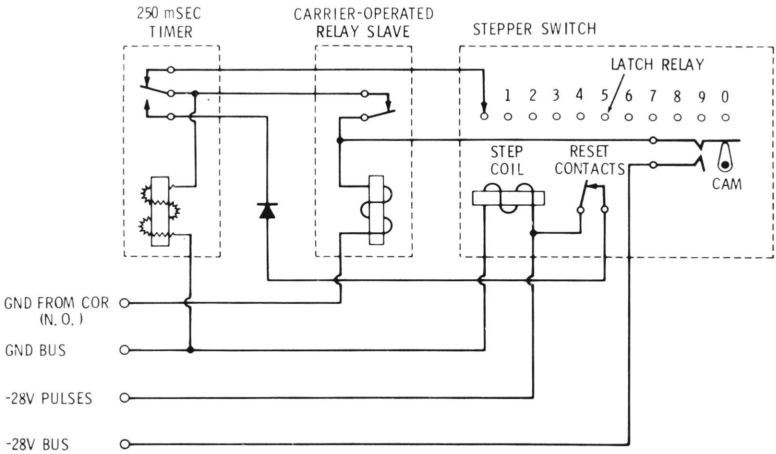


Fig. 4-15. Universal stepper circuit incorporating timer for precision pulse-period control.

plying voltage to the 1000-μF capacitor on K_1 and feeding wiper A.

The 10-ohm relay and large electrolytic on K_1 act to delay the relay's response while the control voltage pulses the contact selected by wiper A. Then, after the capacitor charges, it pulls in K_1 to remove voltage from wiper A and trigger the stepper's reset function. The bussed contacts of wiper B keep voltage on K_1 until the wiper moves off contact 1 toward home. The capacitor at K_1 holds sufficient charge to keep the reset in action and the cycle is completed.

The result of the above operation was the appearance of a voltage pulse of a hundred milliseconds or so on the selected contact of wiper A. Had a latching relay been connected at that point, a useful function would have been successfully switched.

Fig. 4-15 shows a stepper brain which uses a timer rather than a timed relay. This offers the advantage of precision operation under all voltage and temperature conditions.

Stepper Considerations

Stepper switches are usually equipped with two or more wipers for simultaneously switching all legs of the circuits being controlled. Wipers are most frequently of the nonbridging type, which leave one contact completely before coming into contact with the next (make after break). In some cases, however, it is desirable that the circuit through the switch wipers be maintained without interruption throughout the complete selection or reset process. To accomplish this, most steppers have at least one bank of bridged contacts; that is, the wiper makes contact with each step before breaking the contact of the previous step. In all cases, wipers touch only one contact when at rest.

The length of time the circuit is closed (or open) in a series of fast pulses is important. To be fully effective, a pulse to the stepper must consist of an "on" interval (coil current flowing) long enough to attract the switch's armature into a cocked position, storing potential energy in the drive spring while doing so. The "off" time interval must be adequate for the drive spring to move the armature and wiper assembly to the next bank contact position. For a series of nearly constant-speed pulses this can be expressed as "percent make" (closed-coil circuit) and "percent break" (open-coil circuit) as related to the overall span of a single pulse. At 10 pulses per second (the generally adopted standard because of compatibility with telephone dialing speed), a percent make of 80 percent and a percent break of 20 percent would represent a pulse "on" time of approximately 80 milliseconds and an "off" time of about 20 milliseconds. This is an ideal condition for most stepping devices.

Strowger Considerations

The **Strowger** two-motion stepper switch will select any desired circuit from among a possible 100 circuits in approximately two seconds. The wipers move first upward, then rotate horizontally, over two contact banks of 10 levels, with 10 contacts per level. The contact arrangement is illustrated in Fig. 4-16.

The stepping mechanism includes the wipers, the shaft on which they are mounted, and the

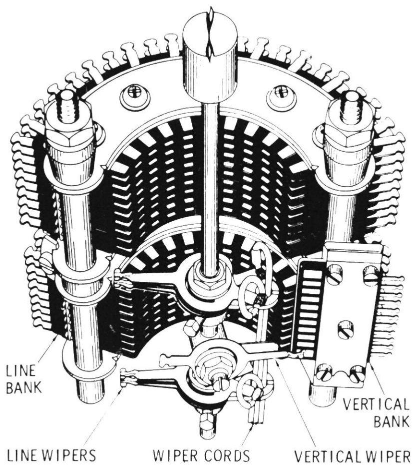


Fig. 4-16. Contact arrangement of the Strowger two-motion stepper switch.

mechanical devices which raise and rotate the shaft. The sketch of Fig. 4-17 shows two views of a typical **Strowger** and identifies the parts that comprise it. As illustrated, the contact wiper assembly is carried by the vertical and rotary motion of the shaft. The wipers are positioned on the switch shaft so that they are raised and rotated (all together) to the same relative position on each bank.

The switch is raised, rotated, and released to its normal position (up, around, and return motions) by combinations of electromagnets, armatures, pawls, ratchets, and detent mechanisms. The interacting parts are designated vertical, rotary, or release, according to the motion each imparts to the movable shaft.

The switch is operated by a series of pulses controlled by the dialed number (six pulses for the number 6, two for the digit 2, etc.). When this series of pulses

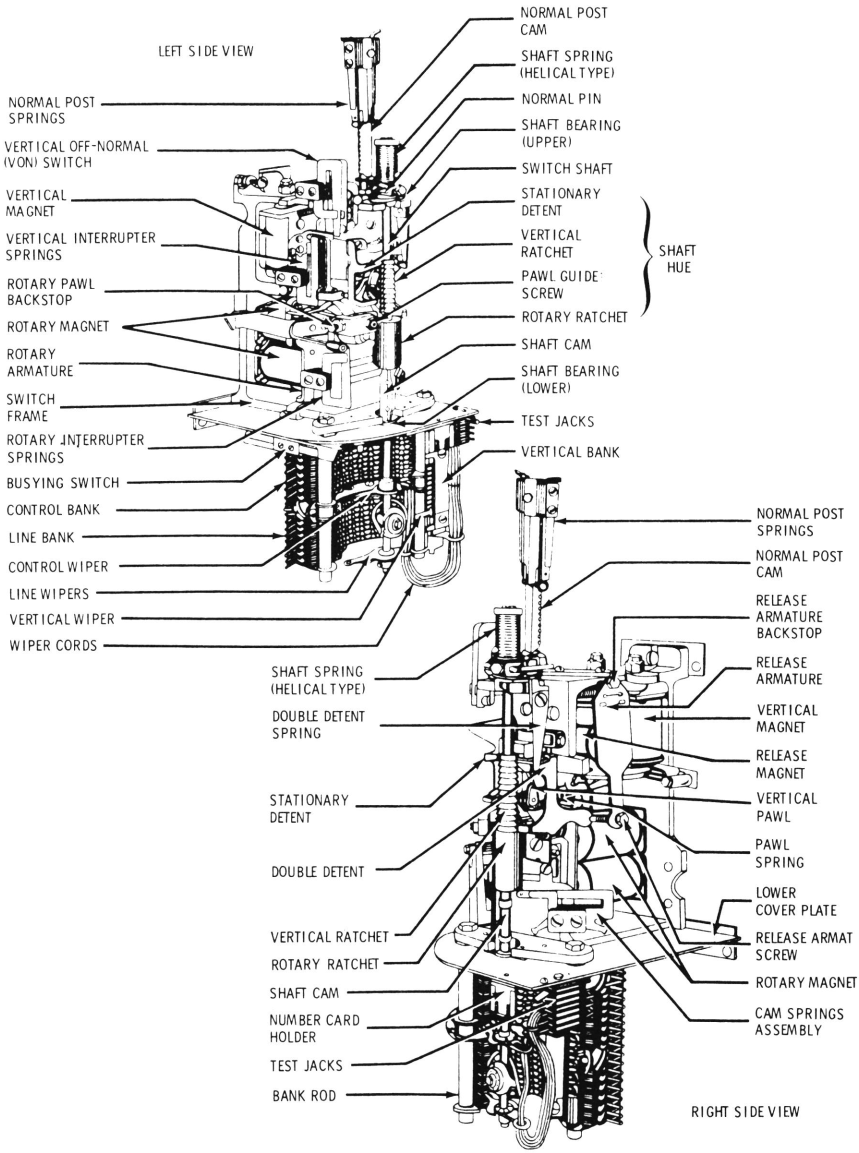
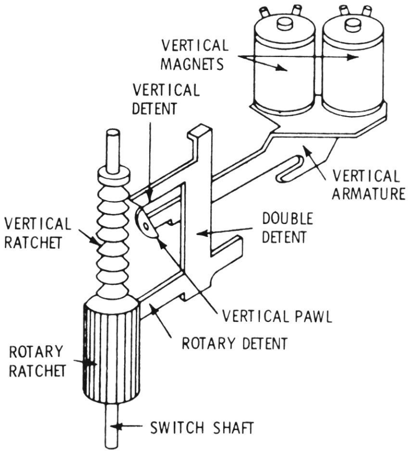
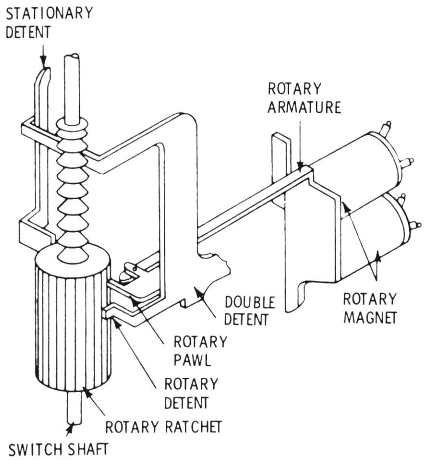


Fig. 4-17. Strowger two-motion stepping switch.

is fed to the vertical magnet, it causes the shaft and wipers to move a number of steps equal to the digit represented by the pulses. (The magnet energizes once for each pulse in the pulse train.) At each pulse, the magnet attracts the armature (shown in Fig. 4-18A), which presses the vertical pawl upward against the tooth of the vertical ratchet on the switch shaft. This pressure raises the shaft and wipers on each pulse.



(A) Vertical.



(B) Rotary.

Fig. 4-18. Stepping mechanisms.

The horizontal, or rotary, motion of the shaft and wipers is due to a pulse train fed to the rotary magnet. The rotary magnet receives these pulses automatically following the transmission of a pulse series to the vertical magnet. The rotary magnet attracts the rotary armature, which causes the rotary pawl (Fig. 4-18B) to engage a tooth on the rotary ratchet of the shaft. Each pulse of the series then rotates the shaft one step. The rotary detent holds the shaft in its selected position until the switching process is completed, at which time the release magnet is automatically energized (an internally timed function). Upon release, the detent withdraws from both the vertical and rotary ratchets and the shaft returns to its normal "home" position.

Although the **Strowger** may appear prohibitively complicated, it is one of the most reliable stepping devices ever conceived. Hundreds of thousands are still in active service in commercial telephone installations all over the world. The user need not get too involved with the workings of the **Strowger** switch, either (though operational knowledge is of course helpful). One of the attractive advantages of this stepper is its capability of "thinking for itself." The user need but provide the suitable drive voltage (unfiltered 48 volts dc is usually adequate) in the form of properly spaced pulses. The up, around, and down activities of the device all happen automatically.

Latch Relays

Regardless of the control system you adopt, your scheme will probably use low-voltage dc pulses to effect the various switching functions. Since the voltage will only be available for a few milliseconds following a command from the control point, it must be used in conjunction with devices that change state after being pulsed. Obviously, a simple relay is of itself inadequate; a conventional relay will pull in with an applied pulse, but when the pulse is gone the relay drops out. A latch relay, on the other hand, serves as a bistable multivibrator, or flip-flop; it pulls in and holds when the pulse is applied, and a second pulse is required to release it.

Latch relays can be built easily using standard relays as integral elements or they can be purchased as individual units. Off-the-shelf latch relays take several forms: the magnetic latch, the double-coil, and the ratchet are but a few. If you build your own, you will probably decide on either the double-relay electrical latch or the self-latching type.

Magnetic Latching Relays

Probably the most expensive of all the latches is the magnetic type, which typically responds positively and fully to extremely short pulses. A magnetic latching relay with a 2-ampere switching capability may be physically no larger than a small hermetically sealed crystal can. From the standpoint of miniaturization, it is a pretty attractive package.

The relay has two coils. When the "on" coil is energized by a short voltage pulse the contacts are held securely by a magnetic element. (This system provides an additional benefit to the user because of the lack of contact bounce.) It takes a new voltage pulse at the "off" coil to overcome the pull of the magnet and return the relay to the original state (also magnet-held).

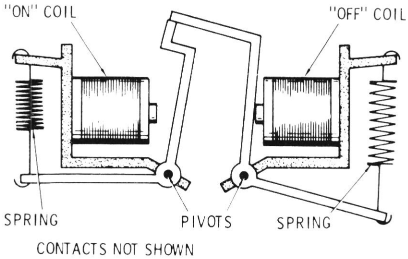
The magnetic latching relays do have disadvantages, however, over and above the high initial cost. They are generally not satisfactory for inductive loads. Also, the contacts must not be used for switching loads higher than rated. A more or less typical problem with magnetic latching relays is a sudden inability of a pulse to cause the relay to change states. In most cases this has proved to be attributable to contact "welding," where an excessive load was switched. Since these relays are hermetically sealed, malfunctions generally make them useless, and impossible to repair.

Another problem inherent with a magnetic latching relay is its inability to return to the "off" state without a positive command. This limits the "fail-safe" features of a remote system. For repeaters and remote-control applications, magnetic latching relays are not recommended.

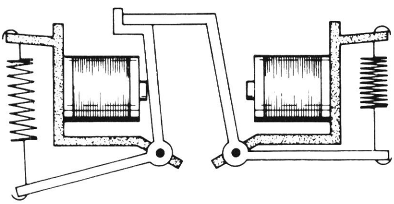
Double-Coil Latching Relays

The double-coil latching system is also often referred to as a mechanical latch. With this approach, two conventional relays are combined in such a configuration that one holds the other in the "make" state, as shown in Fig. 4-19.

This double-coil latching relay is normally of high reliability and rarely requires adjustment. It does have certain disadvantages for repeater use, however. Since it uses conventional relay elements, it requires a significantly



(A) Unlatched position (off).



(B) Latched position (on).

Fig. 4-19. Double-coil latching relay configuration.

long pulse for pull-in and draws considerably more current than the magnetic latch. The pulse length can be adjusted in the control circuit, but often the pull-in current drain poses serious problems for the remote user. For example, if a pulse is required to do nothing more than energize the latch, no problems would be likely to develop. But if the single control pulse were required to trigger several functions (as with a master shutdown command), the overall current drain could cause the pulse voltage to drop momentarily to a level below that required for pull-in. Granted, such a problem can be skirted during repeater design by having sufficient power reserve in the control-voltage source, but high-current control requirements must still be considered questionable design practice at best.

Another disadvantage is the fact that a double-coil latch stays latched until commanded to release, regardless of control malfunctions, loss of communication with the repeater, etc. Ideally, momentary power loss or temporary system shutdown should return all latched relays to their original states.

Ratchet Latch

The ratchet is similar in concept to the double-coil relay, but it incorporates a single coil. The first pulse latches the relay on, the second releases it. The prime disadvantage with this system

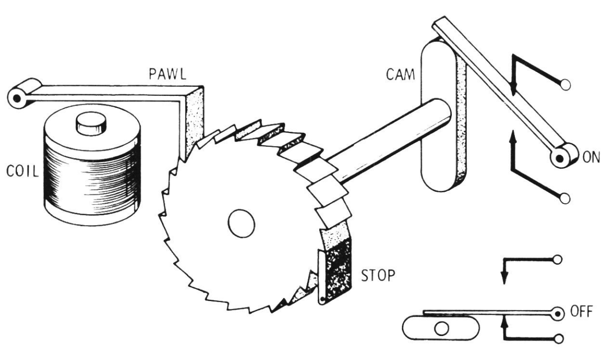


Fig. 4-20. Single-coil ratchet relay.

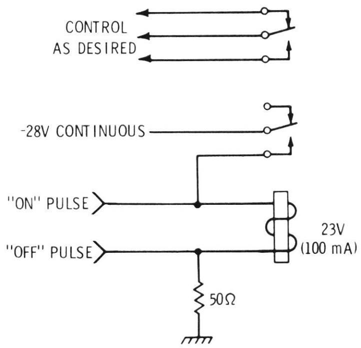


Fig. 4-21. Schematic of a self-latching electrical relay setup.

is that the control operator may wind up energizing a function he wants to shut down. Fig. 4-20 is a schematic presentation of the ratchet relay.

Electrical Latching Relays

Electrical latching relays are by far the best for remote use because they allow for a wide latitude of built-in safety features and because they can be easily built up with conventional relays. The simplest electrical type is the self-latching relay. This concept involves the use of an extra set of contacts on the relay for supplying the relay's own coil voltage.

As Fig. 4-21 shows, a simple latch can be built by connecting the relay coil in series with a resistor. The value of the resistor is so chosen that sufficient voltage is developed across the relay to keep it energized. If a 28-volt system is used, the relay coil voltage can generally be between 20 and 24 volts. The resistor itself will be fed the remaining 4 to 8 volts. The resistor should be no less than 10 watts because it will be required to dissipate a considerable amount of power on a surge basis when the relay is pulsed off. As shown, the 28-volt "on" pulse causes the relay to pull in (assuming the coil draws 100 mA and will operate from a 23-volt source). The continuous 28-volt source continues to supply coil voltage through the relay's closed contacts. In the event of a momentary power loss, the relay opens and cannot close again until pulsed on. The "off" command consists of pulsing the ground side of the relay with a pulse of the same polarity as the ungrounded side. When this occurs, no voltage is developed across the relay coil and it opens. As with a power loss, a new "on" pulse is required to engage the relay again.

When the 28-volt pulse is applied to the ground side of the relay, the resistor is required to dissipate the full load, which in the case shown is more than half an ampere, or nearly 12 watts. The 10-watt resistor will easily handle short pulses of up to 20 watts without degradation. The chief disadvantage is the tremendous current surges required of the control-voltage power supply.

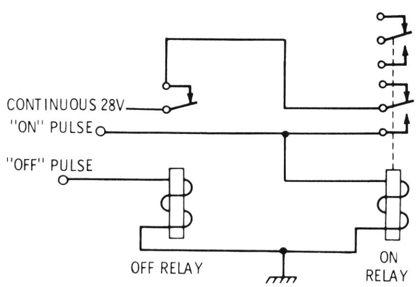


Fig. 4-22. Two-relay electrical latching system.

The optimum electrical latching relay from a design standpoint is that shown in Fig. 4-22. This approach combines the advantages of the self-latching relay but offers no taxing burdens on the power source. It utilizes two conventional relays for on–off control. The normally closed contacts of the "off" relay carry the primary supply voltage for the latch. When the off relay is pulled in or when power is lost momentarily in the circuit for any reason, all relays return to the normal state.

Control Voltage Source

Sooner or later there comes the question of whether or not to incorporate a separate power supply as a control-voltage source. From the information presented in the preceding text pages, you have probably already come to the conclusion that a low-voltage direct-current power source is a hard requirement for control of a repeater or remote station. In truth, such is not necessarily the case. There are no rules specifying the state or polarity of the voltage you use for control of your system; it can be ac or dc, negative or positive, low voltage or high. But there are a number of tradeoffs to be considered when making the final decision.

Obviously, the simplest idea would be to use the commercial 120-volt ac power right off the line. But the drawbacks include likelihood of generating hum, increasing the possibility of electrical shock, and the excessive cost of relays with 120-volt ac coils, A well-engineered system will probably not be the one in which line voltage is used for control.

The chief disadvantage of low-voltage ac for control are cost of relays and the potential of hum problems. Low voltage dc seems clearly the best choice, and offers the fallout advantage of compatibility with transistors.

But what voltage? Relays are reasonably inexpensive for both 6- and 12-volt dc applications. These lower dc voltages, however, require larger current-carrying conductors than a 28-volt control system. A 6-volt system can readily be adapted to integrated circuit elements, but this compatibility is offset by the fact that steppers with 6-volt coils are so rare as to be virtually nonexistent.

Now consider some of the arguments in favor of a 28-volt system: Conductors can be small because 28-volt current drain will be below that of all lower voltages. The military's widespread use of 28-volt dc systems has helped to create an abundance of low-cost steppers and relays on the surplus market. And since 28 volts is such a "nonstandard" standard, military surplus components operating from this supply voltage will nearly always sell for less than their 6- and 12-volt equivalents.

The 28-volt dc power supply will be less expensive to build, too. Practically any silicon rectifier will handle 28 volts; and the low current requirements of a 28-volt system contribute to its overall economy. The only remaining question is that of polarity. In most cases, it will be a

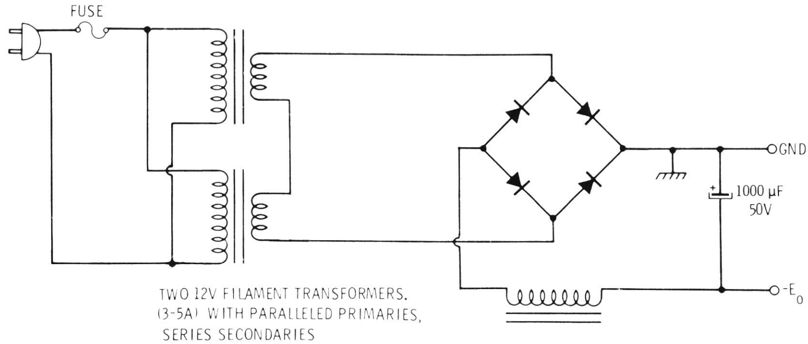


Fig. 4-23. Power-supply for 28 volts using two standard filament transformers. (The high value of filter capacitor allows short-term pulses of very high currents without taxing the voltage capability of the dc supply.)

50/50 proposition. There is, however, one advantage to a negative-voltage 28-volt system. Its additional usefulness as a bias source for the transmitters, if necessary, can be a blessing if provisions for this have not been previously incorporated. If conventional base stations are used, this advantage loses much of its meaning because commercial base station power supplies have integral bias sources.

The power-supply circuit shown in Fig. 4-23 is a negative-output type. By grounding the opposite end of the bridge (and ungrounding the other) and reversing the filter capacitor, the polarity is, of course, reversed. Care must be exercised when using diodes with negatively polarized systems; pulse "travel" will always be cathode-to-anode, as depicted in the sketch of Fig. 4-24.

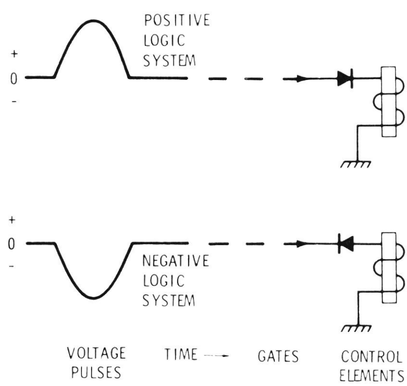


Fig. 4-24. Positioning of diode gate for control with polarized pulses.

The circuits used throughout this book are based on a control system of negative polarity. The same schematics can be adapted to a positive control-voltage system by the expedient of inverting the diodes.

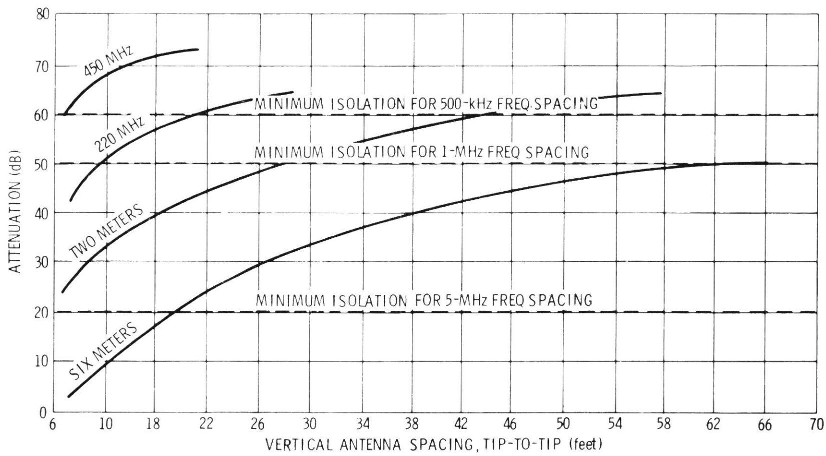
4-4. DESENSITIZATION

Desensitization becomes of greater concern as the frequency of repeater operation decreases. Where a 450-MHz repeater may encounter no measurable desensitization at all, a two-meter or six-meter repeater at the same site may be so plagued with it that useful operation at reasonable ranges is made totally impossible.

Desensitization is without doubt the most common single source of problems with repeaters. It is a phenomenon whereby a repeater receiver suddenly loses sensitivity when the repeater transmitter is energized. Like any other source of electromagnetic interference, desensitization can nearly always be significantly reduced. The likelihood of desensitization problems can be minimized at the outset through sound engineering and design practices.

Desensitization Characteristics

In a typical case of repeater desensitization, the transmitted signal causes the limiter current of the receiver to increase. Effectively then, the incoming signal is forced to compete with the repeater transmitter for control



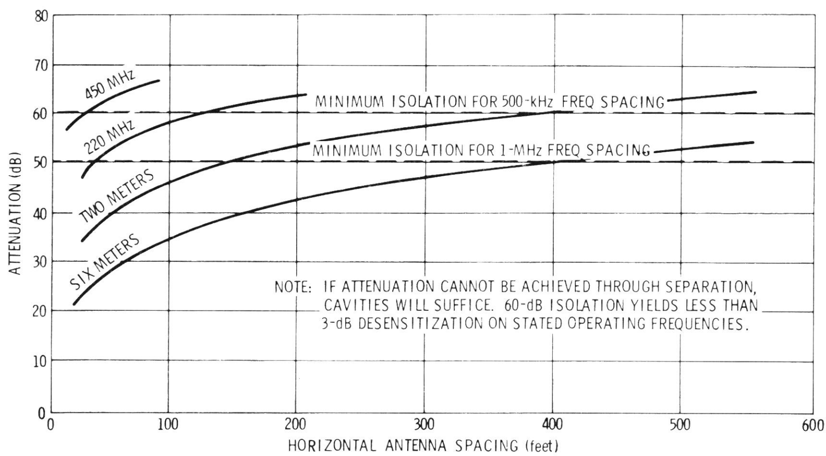
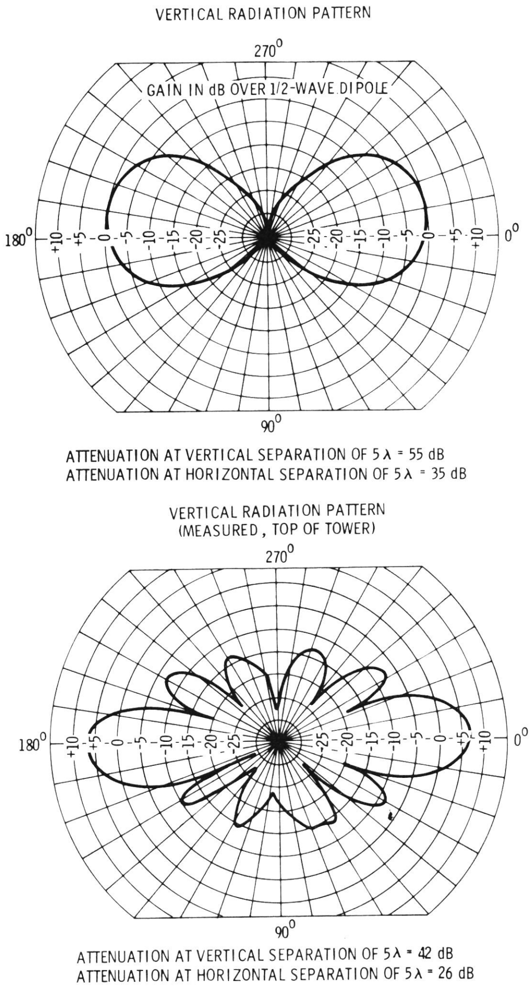


Fig. 4-25. Isolation data, vertical and horizontal separation.



(A) Unity-gain groundplane.

(B) 5.8-dB gain Prodelin *OMNI-6*.

Fig. 4-26. Vertical radiation characteristic for typical omnidirectional antennas.

of the receiver. The transmitted signal will not have the characteristics of a signal, however, because it does not generally quiet the squelch. So here is what happens when a weak repeater input signal appears: The weak signal is picked up by the sensitive receiver, whose carrier-operated relay pulls in to turn on the transmitter. As the transmitter is energized, the receiver limiter current rises appreciably, and the receiver is no longer as sensitive as it was. The sudden drop in sensitivity might render the input signal totally uncopyable, and the receiver appears to be receiving an excessive amount of noise. The noise amplifier then tightens the squelch, shutting down the receiver. When the squelch closes, the carrier-operated relay opens to release the transmitter push-to-talk, and the transmitter shuts down. Once the transmit signal is gone, the receiver is again sensitive, and the weak signal is again apparent. So the cycle repeats continuously as long as the weak input is in the very-weak-signal range.

Antenna Placement

One of the most effective methods for beating the desensitization problem is careful placement of transmit and receive antennas. Attenuation of the unwanted transmit signal is best achieved by separating the two antennas from one another to the greatest extent possible. Since the radiation angles of the two antennas are ostensibly outward, maximum isolation is achieved by vertical separation. The curves of Fig. 4-25 show the attenuation in decibels that can be expected on the three primary amateur bands by separation in both horizontal and vertical planes. In all cases, the antennas used for the calculations were unity-gain vertical antennas with omnidirectional radiation characteristics. Omnidirectional "gain" antennas offer even better separation possibilities than groundplanes and coaxial verticals when the separation is not to be in the exact vertical plane, because of the considerably attenuated radiation above the horizon. Fig. 4-26 shows typical vertical radiation patterns for a groundplane and a 5.8-dB gain collinear antenna. Note that the collinear antenna obtains its gain by virtue of its reduced vertical radiation; the doughnut-shaped radiation pattern of the groundplane is flattened with the gain antenna to yield a maximum signal at a plane perpendicular to the axis of the antenna. The "absolute" vertical isolation of groundplanes is typically better, however, than that of the gain antennas. (It may be better to separate gain antennas by moving one slightly off the axis of the other—horizontally or vertically — based on your own empirical measurements.) The intense output of the gain antenna at ninety degrees makes horizontal separation a nearly hopeless arrangement for single-site deployment, although excellent results can be obtained by situating one of the two antennas at a horizontal distance, then up a few degrees above the other's prime radiation pattern.

Where efforts to reduce desensitization to a nonharmful level fail, more drastic measures can be taken. Since these advanced measures require considerable time and effort, it is usually wise to check out all the "standard" techniques first. For example, it would be foolish to concentrate on minimizing desensitization at the antennas when the problem might be attributable to rf getting directly into the receiver circuits from "the inside."

To determine the source of the problem, connect a sensitive meter to the receiver first-limiter test point and take a reading without keying the transmitter. Then key the transmitter and note the difference in the meter indication. Next, disconnect the antenna from the transmitter and attach a good resistive dummy load (with low VSWR) to the transmitter. If the problem is as bad (or worse), you can forget about antenna placement, because the odds are now in favor of trouble with the receiver circuitry.

You can double-check this by reconnecting the transmitter to an external antenna and connecting the dummy load to the receiver terminals. (This minimizes the chances of stray radiation entering the receiver at this point.) Transmit again and watch the limiter monitor. If the reading has shown no significant decrease in value, it is time to do some shielding (or resurveying of various operational frequencies).

The need for shielding of repeater components may be so slight in the uhf range as to be insignificant, but at the lower frequencies it becomes unavoidable. There are two very important reasons why shielding requirements change with frequency. One is the fact that transmitters and receivers of a uhf repeater can be physically isolated by easily more than a wavelength in the same cabinet. (To offer a one wavelength separation on six meters, the cabinet would have to be more than 20 feet tall!) The second reason is frequency isolation. Where 450-MHz repeater transmit and receive frequencies can be separated by 10 MHz with ease, six- and two-meter repeater frequencies are usually spaced by no more than 600 kHz.

It is beyond the scope of this handbook to describe the various shielding techniques. Suffice it to say that stray radiation from the transmitter must be prevented with the same zeal the receiver is protected from ambient rf. Such shielding can be adequately effected by enclosing the transmitter and receiver in "radiation-resistant" screens. Most manufacturers of commercial f-m gear make shielding kits to fully enclose their units when used in repeater service. These kits are usually inexpensive and allow a neat tight fit over the chassis for which they were designed. If shielding is not the answer, and the limiter reading of the receiver indicates an improvement when either the transmitting or the receiving antenna is isolated, the problems must be countered from another tack.

Feedback Phasing

The use of receiver cavities is one effective method for reducing desensitization problems; but cavities of themselves are limited in their attenuation of unwanted frequencies. Often the transmit frequency is too close to the receive frequency to be adequately coped with by a single cavity. In such cases one can resort to a little trickery. Van R. Fields (W2OQI) successfully "fooled" a repeater receiver into "thinking" there was no transmit signal present by designing a circuit that effectively canceled the transmit signal before it was processed by the receiver rf circuits. In his repeater system, the transmit and receive antennas were separated vertically by several wavelengths. A portion of

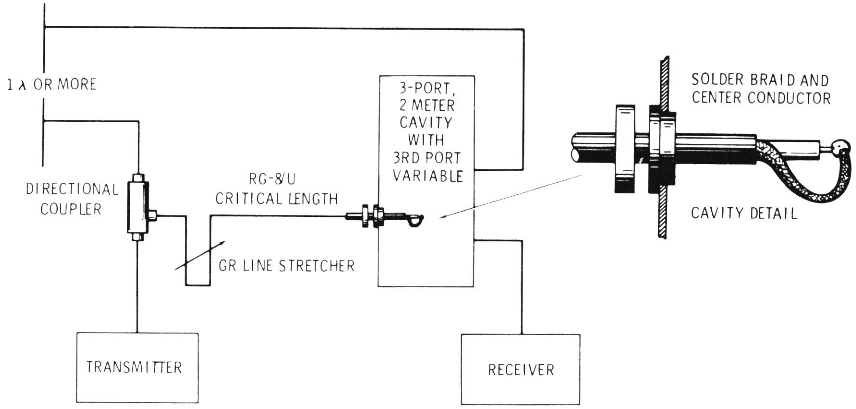


Fig. 4-27. Minimizing desensitization through feedback phasing.

his transmitted signal, emanating from the lower antenna, was being "picked up" by the upper (receiving) antenna. So he came up with the plan shown in Fig. 4-27.

The idea behind this scheme is to introduce the same transmit signal directly into the receiver at the same amplitude but **180 degrees out of phase** with the antenna-supplied signal. He did this by sampling the transmitted signal with a directional coupler, adjusting its phase with a line stretcher, and adjusting the critical length to the cavity. The cavity's loop was made variable so that attenuation without phase shift could be achieved.

To adjust, watch first-limiter current on a sensitive meter and turn adjustable cavity loop to about 45 degrees. Next, adjust the line stretcher. A dip should be noted on the meter at some point. If the dip comes at the end of the adjustment (and it always seems to), add a small section of coaxial cable. It pays to have several short random lengths of coax available (or you can cut each one a nanosecond longer than the last).

Once you have a dip, adjust the cavity loop for minimum limiter current. Once it is operating, the line stretcher can be replaced with a piece of coax of the proper length. Trimming can be accomplished by adding connectors or adapters.

The W2OQI approach represents a satisfactory and relatively simple solution to the problem of receiver desensitization, but it, too, has its limitations. Since effective cancellation depends on the critical phase separation, high winds or other unstable conditions at the site would be disastrous. It is necessary to keep the two antennas rigid so they will not move with the breezes. Also, the system must be moisture proof. If the VSWR shifts on a damp night, the phasing is out and so is the repeater.

Hybrid Loop Diplexing

Of all the methods for defeating desensitization, none quite compares with the **diplexing** concept, whereby one antenna is used for the simultaneous operations of transmit **and** receive. Construction of a diplexer is complicated by the requirement for several cavities and by the close tolerances that must be adhered to in fabricating the various critical elements. But the result is what counts, after all; and a good diplexer can give an overall insertion loss of less than 1 dB. Adding to the diplexer's appeal is the renewed purchasing power of the repeater's "antenna fund." Where two antennas might have been planned, a diplexer needs but one. So the repeater owner has the pleasant task of choosing to buy a better antenna than originally planned or to save the cash for other eventualities.

The diplexer of hybrid loops and cavities described herein was first publicized in the Toronto FM Communications Association Bulletin, of Canada, and later in FM Magazine. The designer, Gil Boelke (W2EUP) has earned the reputation of being not only a gifted engineer but a prolific writer as well. Any changes to Gil's wording of the diplexer's theory and operation would be an injustice; for this reason, it is presented verbatim (except for figure numbers):

"As Fig. 4-28 shows, a hybrid loop is a 1.5-wavelength section of low-loss coaxial cable with ports at strategic places to allow access and termination of the rf signals.

"At the pass frequency (f_1) the cavity is series-resonant, providing an effective short circuit at the cavity port (B). Counterclockwise-traveling rf power thus meets a short circuit after traveling one-quarter wavelength. The input end of this quarter-wave section then looks like an open circuit at this frequency.

"Power flow from port A is clockwise, then, since the counterclockwise path looks like an open circuit. The characteristic impedance of the input line is continued clockwise with negligible disturbance at port A.

"Assume for the moment that port C is unterminated and does

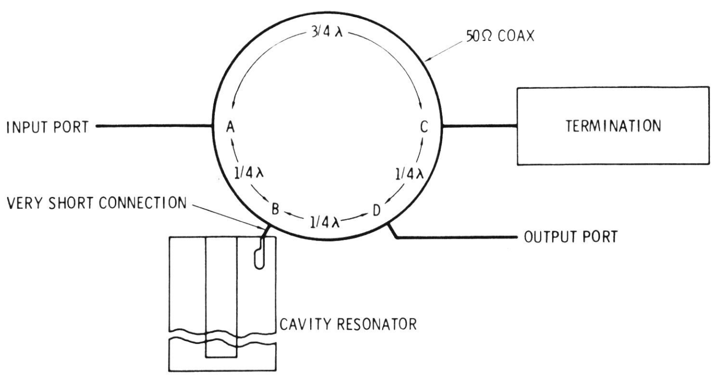


Fig. 4-28. Hybrid loop dimensions and terminations.

not have any effect on rf power traveling clockwise past it. Clockwise-moving power from the input then continues past port C to port D. The coax from port D to B is one-quarter wavelength and shorted by the cavity at B. Therefore, an open circuit appears to the left of port D, and power flow continues out of port D to the load at f_1. The power flow path from port A to port D is achieved without setting up a VSWR on the line at any point and, if the cavity loss is low, without appreciable attenuation.

"At the reject frequency (f_2) the cavity is no longer series-resonant, but it is detuned and presents a nearly pure reactance at port B. Radio-frequency power now flows past port B toward the output port. In so doing it traverses one-half wavelength of coax, with a resulting phase shift of 180 degrees.

"Note that the phase difference between these two waves is 360–180, or 180 degrees. If the power contributions are equal from opposite sides of the output port, power at f_2 is completely canceled.

"In practice, power passing port B is distributed by the cavity reactance. If port C is terminated in an equal reactance of the same sign as that of the off-resonance cavity at port B, the output contributions are again equalized and f_2 is canceled at the output. A useful analogy is to compare the loop with a bridge circuit. Anything seen at port B must be seen at port C to balance the output at port D.

"At f_1, in practice, port C is not open, but rather terminated in a reactance equal to the cavity reactance at f_2. This disturbs the wave traveling to port D, setting up a VSWR in the coax back toward the input port. The cavity is then detuned from exact series-resonance enough to produce an equal VSWR in the other leg of coax to the input termination, port A. The reactances appearing on opposite sides of port A are equal and opposite, so they cancel at the input. This adjustment in turn has an effect on the balance of the loop at f_2, and reactance at port C must be retrimmed.

"In the adjustment procedure the output power is maximized at f_1 by tuning the cavity, and the output power is minimized by adjusting the impedance at port C at f_2. Alternate adjustments will eventually result in a null at f_2 and a peak at f_1 if the cavity **Q** is high enough for the frequency spacing and the coupling is adjusted properly. If the insertion loss at f_1 is too high, it can be reduced by increasing the coupling in the cavity, and repeating the adjustment procedure. Too much coupling may prevent convergence of adjustment, and reduces the notch bandwidth.

"The value of impedance at port C depends upon the impedance of the cavity at f_2. The cavity, when coupled with an inductive coupling loop, varies roughly as in Fig. 4-29.

"A parallel-resonant point occurs at a frequency (f_3), slightly below that of f_1. This frequency may be varied by changing the coupling or inductance of the link. It is possible, when f_2 is lower than f_1, to place f_3 at f_1. At

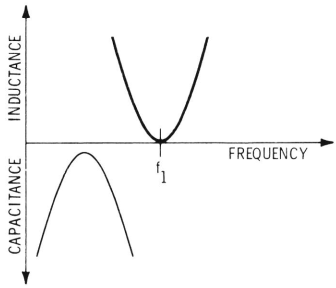


Fig. 4-29. Cavity characteristics with inductively coupled input.

this point it is possible to eliminate port C entirely, since the necessary impedance is near infinity.

"For f_2 above f_1, the reactance becomes inductive, and it becomes capacitive only below f_3. If a parallel-resonant tank is placed at port C, one sweep of the tuning capacitor wil lcause a swing from inductive, through infinity, to capacitive reactance. This technique is very convenient when the required value is inductive, because it allows variation of the inductive reactance with a variable C.

"In some cases it may be necessary to use some resistance at port C to achieve balance. This case occurs when there is some loss in the path past port B. A lossy cavity could cause it. With low-**Q** cavities, poorly cut loops, or close frequency spacing, this technique allows the system to balance at f_2, maintaining the full rejection of the cavity/loop combination, although compromising performance by resulting in a slightly higher insertion loss.

"The loop itself can be checked out by leaving ports B and C open, pumping power into the loop at port A. Very little power should come out at port D if it is cut properly. Remember that "end effects" on the coax joints can have a considerable effect upon the apparent electrical length of the lines. Shorting out either port B or port C should produce full output with little loss and a low-VSWR at the input. These checks should be made at some frequency between f_1 and f_2 preferably.

"There should be a negligible length of coax or lead lengths at ports B and C, especially when checking the loop. Port B should be mounted right at the cavity without unnecessary lead length. Port C is not as critical in this regard to the adjustable impedance.

"Two other important points: With rejections in the neighborhood of 50 to 60 dB in a cavity, lack of shielding at any point in the system can negate the effect of the cavity and loop system. Shield everything completely except the antenna itself. Also, when testing the cavity/loop, the average transmitter used as a signal source may have enough spurious radiation or even ordinary transmitter noise to limit the rejection as read on an rf indicator. It may be necessary to filter the transmitter output with another cavity to make final adjustments!

"Fig. 4-30 shows construction details for a two-meter cavity with sufficient **Q** to be used with the hybrid rings. Four each of the cavities and rings are required to produce a system by which a single antenna can be used for both receiving and transmitting simultaneously. Fig. 4-31 illustrates the

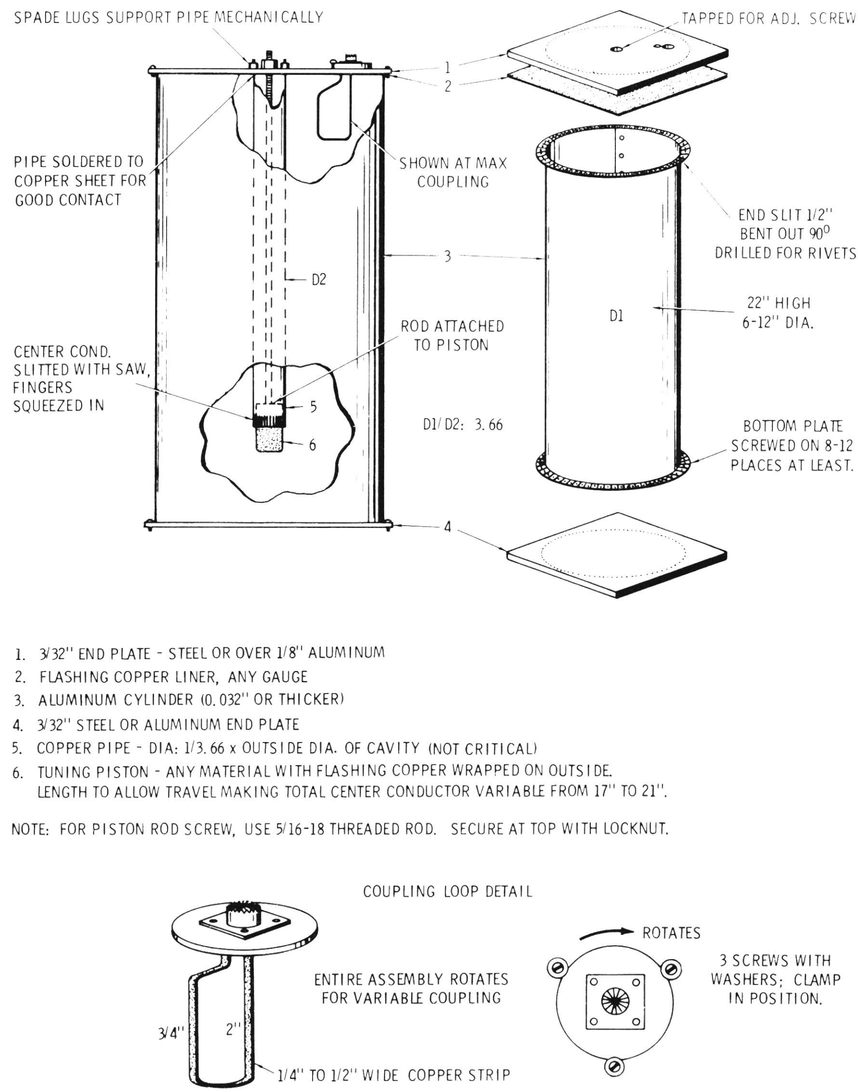


Fig. 4-30. Design details of the 144- to 148-MHz cavity.

interconnection of the elements for a 146.34-to-146.94 MHz repeater.

"A well designed preamplifier, such as a cascode FET type, can be placed at point B without getting overloaded. This placement is desirable because it reduces the diplexer loss on the receiver side to half. Similarly, it may be possible to install a power amplifier that isn't too noisy at point A, reducing the transmitter power loss in the diplexer. Experiment will tell which, if either, alternative connection is pos-

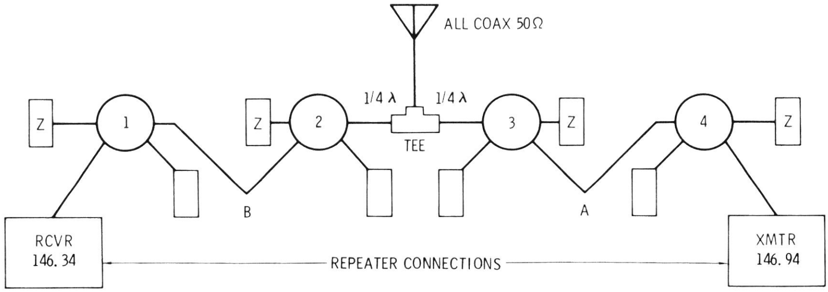


Fig. 4-31. Complete interconnection of loops and cavities for diplexing with transmit frequency of 146.94 MHz and receive frequency of 146.34 MHz.

sible for the particular system with which it is to be used.

"The terminations (**Z**) can be coax stubs or tuned circuits. I prefer the tuned circuits because they permit the attainment of a perfect null, whereas stubs produce a finite dip. Stubs should be shorted, because open stubs may radiate unless the ends are shielded. I found that a parallel-resonant circuit worked best on the transmitter cavities, and that a 3K shunt resistor across the tuned circuit produced a null in the 70- to 80-dB range. On the receive side, I found that a series-resonant circuit worked better. Again, the tuned circuit needed some loss to make a perfect null. However, an alternative method was used, which is equally applicable in either the receive or the transmit cavities.

"By varying the LC ratio of these tuned circuits, the resistive portion of the resonant circuits can be varied. Thus, instead of physically inserting a resistor, I raised the effective **Q** of these circuits until they produced the appropriate amount of loss. Tuning is simply a matter of dipping the capacitor (piston type for smooth accurate adjustment), noting the amount of rejection, then squeezing or spreading the coil and redipping. The inductance value is readjusted until the signal disappears in the noise. Rejection is limited only by the stability of the adjustment and the bandwidth required of the notch.

"Notch bandwidth and insertion loss are the only limiting factors for frequency spacing. I was able to get 60-dB rejection and 1-dB loss at 300-kHz separation. However, the notch width is small, and rejection degrades rapidly with deviations from the center of the notch. The 60-dB figure only represents the rejection level easy to attain in a quick adjustment. It should be emphasized that the notch depth is always unlimited except by the fact that it becomes more and more critical to adjust as it gets deeper, and obviously harder to hold there.

"My insertion loss measurements are not as accurate as I would like and I hesitate to quote them, but the rejections are reasonably accurate. Here are some figures: Pass 146.34, reject 146-.94: Insertion loss less than 1 dB; rejections: at 146.940, 70 dB; at 146.928 and 146.952, 50 dB. Pass

146.94, reject 146.34: Insertion loss 0.6 dB, rejection at 146.34, over 80 dB (saw 100!); at 146.328 and 146.352; 50 dB.

"Miscellaneous facts: Low cavity **Q** results in high insertion loss for a given notch bandwidth. Rejection notch still unlimited theoretically; depends upon stability and accuracy of adjustment. Use low-loss coax for loop. I tried small **Teflon** coax and got very poor results. Solid shield better in system. Need double-shielded

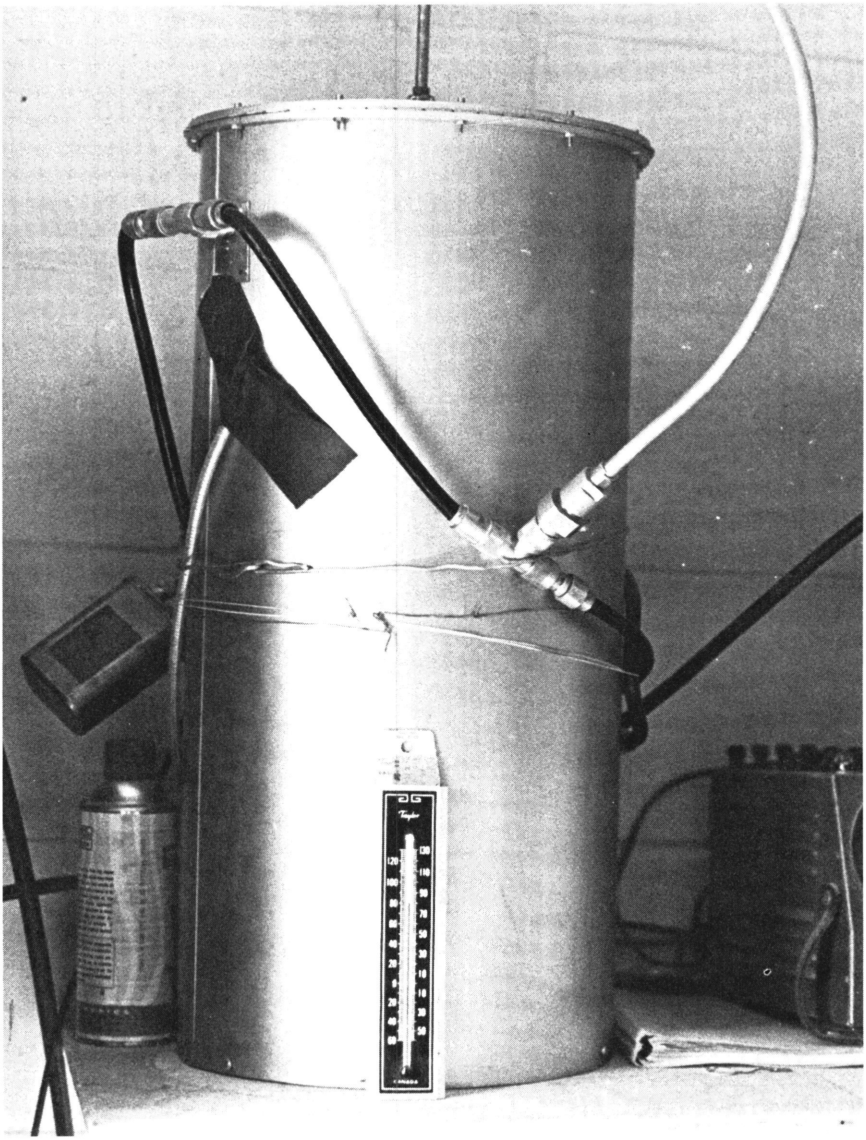


Fig. 4-32. This receiver cavity, in use by Ontario's VE3RPT repeater, uses Boelke's design.

coax at receiver output and transmitter input lines. Double-shielded cables also make good loops. Clamp loops down to prevent movement. Cavity coupling loops must be wide straps, not wire.

"For test purposes, a receiver makes the best rf indicator, with a good calibrated attenuator-type signal generator. Theoretically, the VSWR at the input of these cavity/loops at the frequency to which it is tuned is unity for a resistive load. In practice, it might be desirable to add a variable matching network to the system on each side because a cavity/loop tuned for best rejection may not exhibit a good VSWR at the pass frequency.

"With careful design and construction it is possible to combine all the best attributes, so that a single high-gain antenna and a lone run of low-loss coax will give results comparable to two such installations spaced a great distance apart."

As more and more equipment gets placed into service at a remote site, the chances of interference increase more than proportionately. Consider the possible signal sources: In the standby mode, there are local and i-f oscillators of nearby receivers and their respective harmonics, there are harmonics of transmit signals from other units in the area. And in the repeat mode, there are all these problems **in addition to** the signals caused by "mixing" of the transmit signal (or one of its submultiples) with one of the other stray signals. The list of possible sources sometimes seems endless.

Two-Site Deployment

One of the most effective methods for defeating desensitization is the passive method of using two separate remote locations—one for the transmitter and one for the receiver. If the two sites are close enough to allow economical interconnection of the

Fig. 4-33. Site layout for on-channel repeater. On-channel capability exists when the transmitting and receiving antennas are poorly situated with respect to each other, though both are adequately positioned for coverage in the general area of use. The Radio Ranch repeater antennas are separated by a mountain of rock rendering the receiver immune to low-power signals from the transmitter.

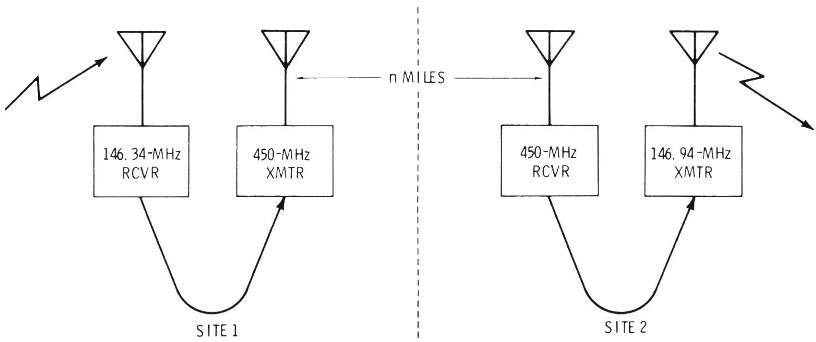


Fig. 4-34. Two-site deployment of repeater using uhf radio link.

two sites with a wire line, but far enough apart to rule out possible desensitization, an ideal set of circumstances exists. (See also Wireline Control, Section 2. 3.) Where the two sites are well-situated with respect to the repeater users, but poorly situated to each other, the operational possibilities become even more interesting, opening the door to such awesome systems as the "on-channel" repeater, which retransmits on the same channel as it receives because of the receiver's insensitivity to the transmitter.

Though seldom used in this service, the author's Radio Ranch facility possesses the unique "on-channel" capability when the repeater transmitter is set for operation at low output power levels. The layout sketch of Fig. 4-33 shows how it is achieved.

The best thing about on-channel repeaters is, of course, the fact that user mobiles need not purchase special crystals to enjoy the benefits of repeater operation. The only disadvantage is that each user will have a "heterodyne belt" where his signals will compete with those of the repeater transmitter. The characteristic "capture" nature of f-m will tend to minimize this belt of unusability, however, so that the repeater will not hinder communications.

Where on-channel repetition is not desired, two-site deployment offers the capability of extremely close spacing between input and output channels. Two-meter f-m channels are spaced at 60-kHz intervals (from 146.04 MHz at the lower end extending to the top of the band); a great many two-site repeaters in operation throughout the United States are set up to retransmit the received signal on the adjacent channel.

Where the distance between receiver and transmitter sites is too great to economically employ a wire-line link, a separate set of radio channels (in the uhf region) can be used. Fig. 4-34 illustrates this concept, which has also become a common practice by American repeater owners. The important criterion here is that the two sites be line-of-sight with each other so that the

W9CR

uhf link can be made to operate with minimum transmitter power and uncritical receiver sensitivity. Where the distance is such that peak performance must be obtained from the uhf link, the system's reliability is compromised because of its dependence not so much on the uhf link itself but on **performance** of the link.

4-5. OPTIMIZING THE SYSTEM

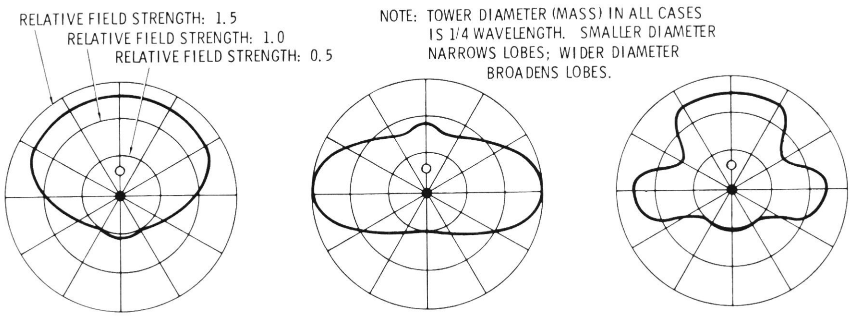
When it comes to making all the little adjustments and modifications to make your system work better for its intended application, you would do well to "follow the pros." The commercial boys—our f-m counterparts in the bands adjacent to our own uhf and vhf amateur spectra—have done a great deal of the pioneering work necessary to get peak performance efficiency from a given remote emplacement.

Antenna Orientation for Gain/Directivity

It often happens, once a repeater is installed and operating, that one or two areas of anticipated coverage just do not quite "pan out." If the questionable areas are borderline (or near-borderline) cases, signal levels to and from such areas can generally be improved through antenna orientation—particularly in the uhf range, where resituation of antennas will pose no great mechanical problems.

A little known (but very useful) fact is that directional coverage can be effected with omnidirectional antennas to almost any degree required. This can be achieved **without modifying the antenna** by merely using the antenna mounting structure in such a way as to affect the radiation pattern. When an omnidirectional antenna (including the "gain" types) is mounted atop a tower, its horizontal radiation pattern is fairly uniform—ideally, it is roughly circular for constant gain in every direction. However, when an omnidirectional antenna is mounted **adjacent to a mast or tower, the supporting structure itself becomes a critical part of the overall antenna system.** Now—if you learn two simple rules, you will be able to position your antennas on their mast to give added gain in the directions required: The first rule is that for each **quarter-wavelength** you space the antenna radiator from the tower (or mast), you will get one major radiation lobe. The second rule is: the larger the mass of the supporting structure is, the wider will be the lobes.

In the pattern of Fig. 4-35, the central dot represents the tower or mast as seen from the top. The small circle immediately above the center is the antenna. If the antenna were mounted atop the mast (rather than adjacent to it) the pattern (for a relative field strength of 1.0) would resemble that of the circular reference pattern, noted by dashed lines on the sketch. But when the antenna is mounted on the face of the face of the tower as shown, and spaced one-quarter wavelength away, the pattern for the same relative field strength takes on an almost cardioid characteristic, as indicated by the



(A) ¼-wavelength spacing (one lobe, forward). (B) ½-wavelength spacing (two side lobes). (C) ¾-wavelength spacing (cloverleaf lobes.)

Fig. 4-35. Directional patterns achieved by spacing of omnidirectional antenna from metal tower or mast.

asymmetric heavy line imposed on the concentric circles.

As Fig. 4-35B shows, half-wavelength spacing will yield a pattern that favors two areas spread 180 degrees apart, while sacrificing frontal performance to some extent. Unless the frequency of operation is particularly high, it becomes unfeasible from the standpoint of physical stability to mount antennas more than a few quarter-wavelengths from the tower; but this approach would likely not be helpful anyway, since as the spacing increases, the pattern begins to return to the circular configuration depicted by the broken lines in the sketches.

Antenna Inversion to Lower Radiation Angle

Another antenna trick, which is particularly applicable to groundplanes, involves inversion of one of the two antennas. Groundplanes characteristically have a very high radiation angle, which sometimes results in unfavorable coverage in certain areas. Inverting the antenna essentially inverts the radiation pattern to concentrate the pattern in the plane desired.

Where two groundplanes (one for transmit, one for receive) are deployed on a single tower and separated vertically, this approach can be very beneficial. The lower antenna—**NOT** the upper—can be turned upside down to yield better isolation between antennas and lower angle of radiation without affecting the antenna's vertical polarization and without compromising performance.

The transmitting antenna, which should be the lower of the two antennas, is the one to reverse. But this reversal should only be done when no physical obstructions (other than the tower or mast) are within two wavelengths of the antenna, and when the inverted antenna is no less than four wavelengths above the ground. Fig. 4-36 shows typical vertical radiation patterns

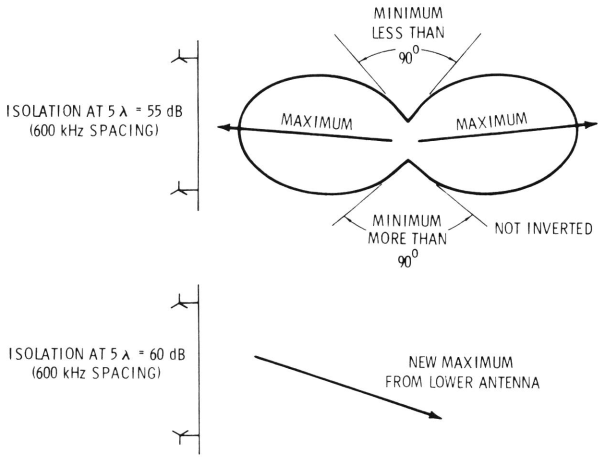


Fig. 4-36. Modification of isolation and radiation characteristics after inversion of lower groundplane.

of a groundplane and the isolation in decibels to be expected before and after inversion.

The antenna inversion technique can be used with any omnidirectional antenna, though its value is questionable with gain antennas, where the radiation angle is essentially 90 degrees and radiation in the vertical plane is about equal, up or down. When an antenna characteristically radiates high, however, and where a null in the pattern tends to exist immediately below the antenna, the inversion can prove highly beneficial.

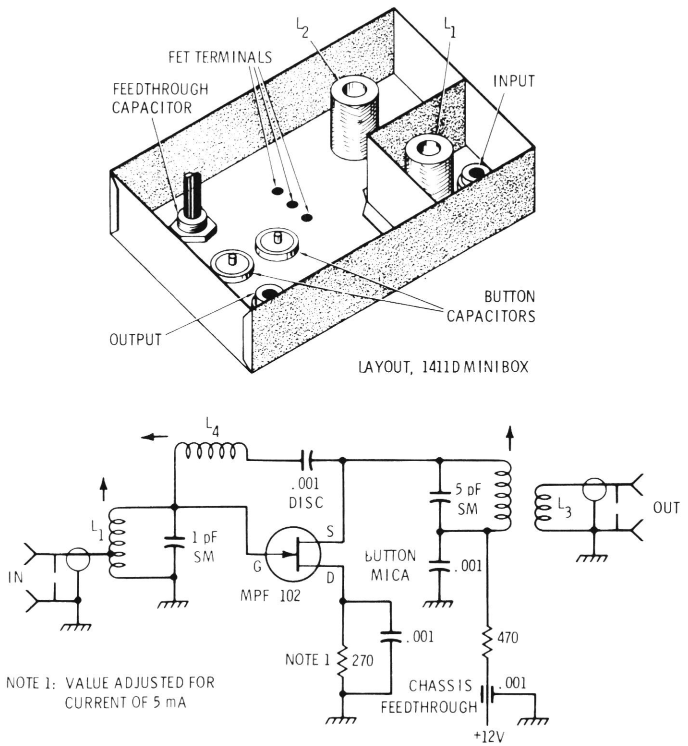
Inversion of the antenna brings about one other consideration—waterproofing. The new installation must be made so that no water or moisture sediment is allowed to seep down into the antenna joint. Ordinary beeswax provides an almost completely inert substance that is ideally suited to this application. Since the coaxial cable will be extending from the top of the antenna rather than the bottom, rain and moisture will have a tendency to collect near the termination. A tightly packed mound of beeswax or silicone compound at this point of entry will shed the water and result in a consistent VSWR.

The beeswax never solidifies completely, so it is important to immobilize the transmission line as it exits from the antenna terminal point (somewhere near the base). Otherwise, movement of the coax will create a water-carrying funnel-type aperture which will eventually be sure to result in loading problems.

Improving Receiver Performance

Where desensitization proves no great problem, the operation of a repeater can usually be enhanced by the installation of an rf preamplifier on the receiver. Individual circumstances notwithstanding, repeaters generally **are heard** better than they **hear.** In many cases, this inequality is attributable more to the pains that have been taken in "super-tweaking" the repeater transmitter than to inherent deficiencies in the repeater receiver. But a little extra time spent with the remote receiver will often pay off in valuable range extension.

There is, of course, a limit to the useful sensitivity of a receiver. When the receiver is already exhibiting a value of 0.3 μV (for 20-dB of quieting) during the repeat mode, there is little hope for improvement. Rf preamplification at this point would almost certainly result in sensitivity to the repeater's own transmit signal, or perhaps the relaying of signals which should be considered as no more than noise. An additional problem is the tendency of a preamplifier to sat-



NOTE 1: VALUE ADJUSTED FOR CURRENT OF 5 mA

- L_1 - 4T #16, SPACED 3/8 IN. TAP 1-1/2 T FROM GROUND END.
  L_2 - 4T #22, SPACED 3/8 IN.
  L_3 - 1T #22 AROUND "COLD" END OF L_2
  L_4 - 9T #22, CLOSE WOUND

- ALL COILS 1/4" SLUG-TUNED FORM
  WHITE SLUG FOR L_1 & L_2, BRASS FOR L_4

Fig. 4-37. FET preamplifier for two meters.

urate when excessively strong signals are in the vicinity of the repeater. Such a condition can make a preamp useless in situations where a number of repeaters are deployed at the same location. (A saturated condition results when the preamplifier is made to conduct heavily in the presence of strong signals so that it is insensitive to the presence of weaker signals on the frequency for which it is designed to operate.) But for the majority of receivers, in the 0.8 μV to 1.5 μV class during repeat, the rf preamplifier can be the perfect complement.

150-MHz Preamplifier

Fig. 4-37 is a schematic diagram of a soundly engineered FET rf preamplifier submitted by Court Broad (VE3EW), of Canada. His circuit, which appeared in the Toronto FM Communications Association Bulletin*, has been duplicated and used with success by a great many two-meter f-m operators and repeater builders in the U.S. and Canada. The design emphasizes simplicity in that it uses but one semiconductor to yield a compact unit capable of adding some 6 dB to a receiver's usable sensitivity.

When attaching a preamplifier to a receiver, it is a good idea to exercise restraint. Do not try to get more sensitivity than your system is capable of handling. The danger signs are excessive first-limiter current, evidence of oscillation, and undue susceptibility to interference.

The preamp uses a **Motorola** MPF-102 FET in a common-source amplifier configuration. For best noise performance neutralization is needed. This is easily accomplished by feeding an out-of-phase signal from the preamp output back to its input. L_1 is used to accomplish this.

Anyone familiar with vhf construction techniques should have no trouble in duplicating the performance of this unit. Court Broad claims no originality, since variations of the circuit generally have been published before. The component types and values, however, may be peculiar to this unit. The preamp is built in a Hammond 1411D chassis box. This facilitates complete shielding of the unit and allows flexibility of installation in either base or mobile equipment.

A good vhf signal generator is required for optimum adjustment of the preamp; however, a rough tuneup can be made using on-the-air signals. First, peak the repeater receiver for optimum performance; then insert the preamp ahead of the receiver. Make sure that the length of coax is the same in the final installation as the one used for tuneup. Set the generator for a nonsaturating signal at the first limiter. Adjust L_1 and L_2 for maximum indication, reducing the generator output as the preamp is tuned to resonance.

Next, connect the signal generator to the output of the preamp and connect the input of the preamp to the input of the receiver. Increase the signal generator output until a reading is obtained at the first limiter as before. Adjust neutralization coil

*Box 943, Toronto 5, Ontario, Canada

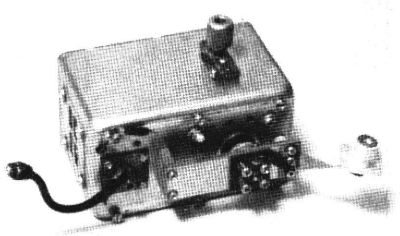
L_4 for minimum signal feedthrough. This adjustment must be made with the preamp connected to its power source. Reinstall the preamplifier correctly and readjust L_1 and L_2. Repeat this procedure several times to be sure of the correct setting, because the adjustments do have a tendency to interact slightly.

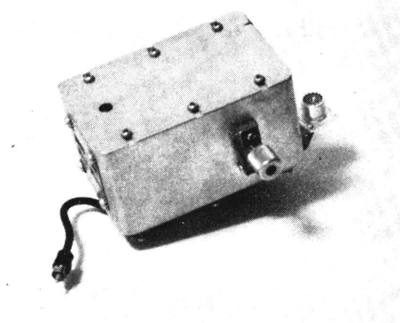
This preamp has a measured noise figure well under 2 dB; this figure results in man-made noise being the only limiting factor in the receiver's ability to hear weak signals. The bandwidth of the preamp is approximately two megahertz (the design center is 147.00 MHz).

450-MHz RF Preamplifier

As a rule, rf preamplifiers for the 450-MHz region require somewhat more critical layout than those for the vhf bands. And, of course, the semiconductors for the uhf range are a bit more expensive. Amateur ingenuity being what it is, however, someone always seems to come up with something simple, quick, and effective.

Such is the uhf preamp whose circuit is shown in Fig. 4-38.





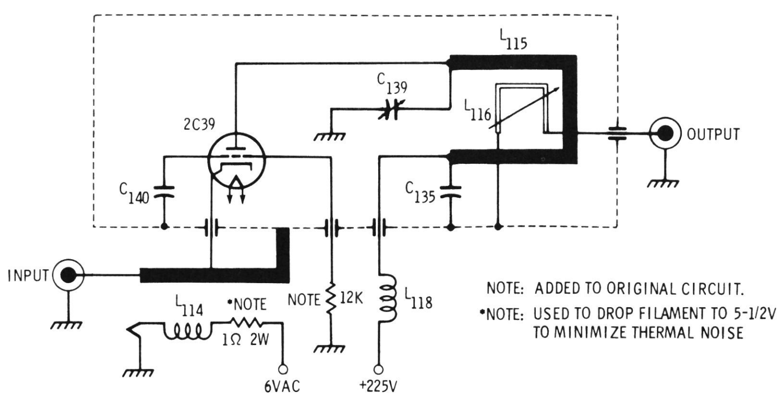


Fig. 4-38. Saturation-proof 450-MHz amplifier constructed from final cage of Pre-Prog transmitter strip. The RCA phono plug on the coaxial lead plugs directly into the receiver antenna receptacle.

Adapted from a **Motorola** idea by Don Milbury (W6YAN), this unique device is the complete final cage and associated circuitry from a **Motorola T44** or **GE Pre-Prog** transmitter. Its most interesting (and most attractive) feature is the fact that it is virtually impossible to saturate this remarkable amplifier. The unit retains its high sensitivity regardless of ambient rf. This makes the unit particularly desirable for applications where a preponderance of repeaters exist, as in commercial two-way or broadcast installations. Another nice feature is that no modification is required of the final cage to produce the uhf preamp. It uses the same tube, the same components, the same everything.

To be sure, this preamp's dependence on the vacuum tube is more than excused by its availability, ease of construction, and overall performance. The finished preamp is said to have an effective signal gain in the neighborhood of 20 dB. There are only two significant points of concern: first, the plate voltage should be limited to around 200 volts to minimize thermal noise pickup; and second, you can expect some mechanical difficulty in moving the T44 transmitter's final cage to another chassis.

4-6. LOGGING AND IDENTIFICATION

The biggest single source of headaches for remote operators is the FCC requirement for logging, a rule which no one has to date been successful in compromising (although a great many have tried).

The FCC's Attitude

The FCC holds that logging is a requirement that must be met, regardless of the burden it places on the user. The FCC states that amateurs must adhere to the letter of the law until the law is changed. Proposals to change laws pertaining to logging are being considered, but the wheels turn slowly. And until definite official reversals are made, the log of a repeater must show the stations being called, the date and time of each transmission, and the call of the station using the repeater.

The one (and apparently the only) aspect of the Rules relaxed by the Commission has been the requirement for all operators to sign the station log. Repeater logs are now acceptable in the form of magnetic tape recordings.

The fact that a repeater must log all activity on a given frequency gives rise to another question: Must individuals operating on the frequency keep separate logs if the repeater has the capability of furnishing a master record? Or: Can the repeater log be used as a central logging system for the community to relieve user stations from a responsibility that essentially duplicates the repeater record?

Redundant though it may seem, each amateur must keep his own station log, even if he transmits on no frequency other than that of the repeater input. This is unfortunate, of course, but it is in no way illogical. For example, if you spent all your operating time talking with one individual, would you expect his log to save you from your own logkeeping requirement? By the same reasoning, if all operating stations keep logs, why should a repeater, which would provide a redundant record if all stations logged as required.

The FCC has made it the responsibility of each amateur to maintain an accurate log of his station's operating time. Regardless of the logs of other stations, your own must be up-to-date, independent, and accurate.

The Commission has been lenient in its enforcement of the logging regulation for repeaters, but it has not been lax in its definition of the requirement. The truth to tell, virtually every operating repeater would be put out of commission if the FCC were to crack down on violations.

Automatic Logging

Accurate logging poses some pretty complex engineering problems for repeater owners, and some of them are all but insurmountable. Making a tape record of the station activities is no threat in itself, of course, because this simple task can readily be achieved with a COR-driven recording device. But an accurate record of date and time to accompany the tape record is something else again.

An obvious solution to the problem would be to prerecord the time data on tape, then allow the recorder to operate continuously, superimposing the receiver's input onto the taped time data. Once or twice a day, then, one of the repeater users could announce the date. The trouble with this approach is the impracticably short tape longevity; a continuously running tape would hardly last more than a day, regardless of the recording speed, which can be reduced considerably by filing the capstan or replacing it with a smaller diameter cylinder.

Automatic Logging/Identifying

A more desirable approach to the logging requirement involves the use of two tape transports. One transport, a very slow-speed unit, records all activity on a carrier-operated basis. The second continuously plays back prerecorded time data from a 12-hour continuous loop.

One of the nice features of the two-unit approach is that a secondary repeater burden (that of identifying at periodic intervals) is automatically relieved when taped time announcements are accompanied by voice self-identifications. A block diagram of this system arrangement is shown in Fig. 4-39.

The two-unit identification and logging system has one slight drawback: Where does one get a tape playback system capable of accepting a 12-hour continuous loop? An alternative method would be to incorporate a one-hour continuous loop with prerecorded identification of station and time data. Of course, this time data would be as meaningless as a clock with no hour hand, and would require a bit of help

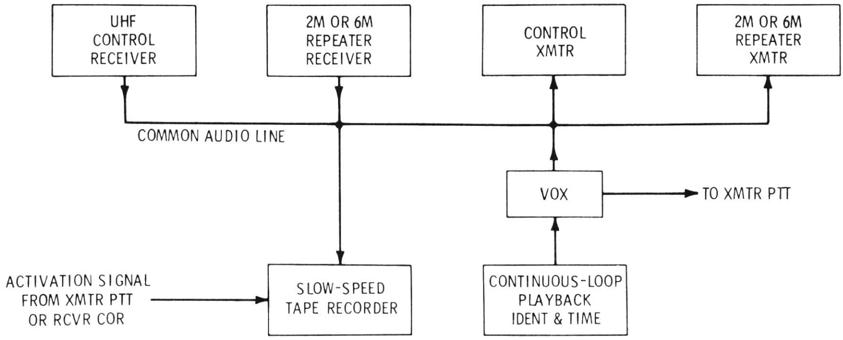


Fig. 4-39. Logging/identification tape units in typical remote system.

from the users. The time data might be no more than the words "plus three," "plus thirty," "minus ten," etc., indicating the minutes after or before the hour. Users themselves would be expected to announce the basic hour at some time during their sequence of transmissions.

Audio from the playback unit should be coupled into the audio line at a low enough level that user stations could be heard distinctly through the periodic announcements. Also, the operation should be engineered so that once an identification announcement has been started, the transmitter stays on the air until the message is completed. The easiest means for achieving this capability is through the use of a voice-operated switching system, or VOX, such as the type employed on many single-sideband transmitters. This function is illustrated in the block diagram of Fig. 4-39.

It may well be that these logging methods are unsatisfactory for your particular application. If so, and you cannot come up with a satisfactory automatic method, you must be responsible for manually logging your own repeater activity. Many amateurs who operate repeaters are expecting the FCC to relax the logging requirements, and are "temporarily" keeping their logs up to date "by hand" with the help of a few repeater "trustees" who are appointed as monitors and recorders for specific periods during each day. These groups have their own procedures for identification independent from the logging procedure.

Automatic Identification Methods

The Code Wheel—The code wheel has become one popular method for automatic repeater identification. The code wheel is a member of the "industrial timer" family, incorporating the electric timer motor, and often the switch assembly and gear arrangement. It differs in that the switch portion activates a serrated wheel that revolves once at the termination of each timed period. As Fig. 4-40 shows, the serrated wheel is used to key a tone oscillator in Morse code so that the identification is in the form of modulated cw.

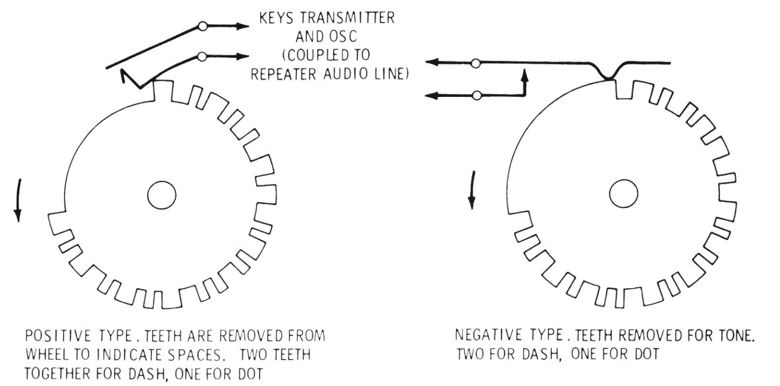


Fig. 4-40. Code wheels for repeater identification. Most code wheels start according to timed period, then stop at the end of the single cycle.

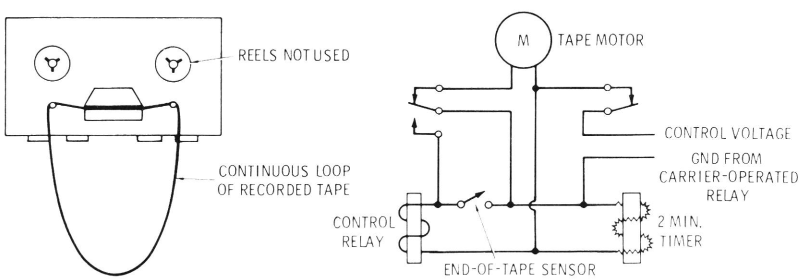


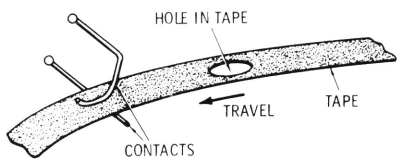
Fig. 4-41. Automatic timed identification unit using tape transport.

Tape Unit—A reasonably sophisticated voice identification unit can be built up if you have an old tape transport and a little ingenuity. Record the desired identification message on the tape, then use only that recorded piece to form a continuous loop. The circuit in Fig. 4-41 shows the interconnection for such an arrangement.

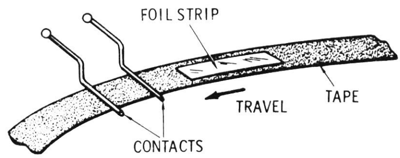
Here is how it works: Each time the repeater is keyed, the COR supplies a ground signal to complete the electrical circuit of the timed identifier. The ground signal energizes the two-minute timer and starts the tape transport. (The relay, timer, and tape transport are shown to operate from the same supply voltage; if such is not the case, extra relays can be used for keying.)

When the tape has played through one time, the end-of-tape sensor closes momentarily to energize the control relay (which latches because of the voltage supplied through its contacts). The control relay opens the circuit to the transport and keeps the unit from operating until either (1) the carrier drops, or (2) the timer energizes.

If the carrier occupies the input channel for longer than the timer's period, the timer pulls in, removing voltage from its own



(A) Hole in tape allows contacts to touch; tape momentum causes switch to open again.



(B) Strip makes contact between two pins resting on tape.

Fig. 4-42. Fabrication of end-of-tape sensor for voice-identification unit.

coil as well as the coil of the control relay. Continued presence of the carrier, of course, allows the timer to begin its cycle again. But removal of coil voltage from the control relay released its contacts and completed the circuit to the transport again, which was allowed to cycle once to repeat the operation. The feature of this circuit is that each new carrier causes instant identification, and a continuous carrier causes timed identifications.

The key to this approach is the momentary-make end-of-tape sensor, which keeps the identification message from being transmitted more than once after each activation.

You may have to figure some unique scheme for initiating this shutoff function at the end of each playback period. If the transport has a built-in tape-sensing switch, the problem is simplified, of course. But in most cases you probably will not be that lucky, so you will have to synthesize the function.

Fig. 4-42 shows two methods for creating your own end-of-tape sensor. In each case the sensor makes but a momentary closure because the tape's momentum, by design, carries the tape a bit beyond the sensing switch.

Solid-State Identifier with IC's

The epitome in identification units is the solid-state system, comprised of diode logic, integrated circuit pulsing — the works. If your repeater control is all semiconductor up to this point and you do not want to "spoil" it by introducing mechanical contrivances, the beautifully complex-but-simple circuit board approach is your alternative.

Consider the identifier shown in the diagram of Fig. 4-43, whose design was conceived and refined by Tom Woore (WB6BFM), a young graduate engineer of Pomona, California. Tom constructed the device for use in the W6FNO repeater at Radio Ranch, which serves the greater Los Angeles area. While other amateurs have designed and built transistorized identifiers, Tom Woore's is the first on record to consist entirely of integrated circuitry.

The Woore identifier system, comprising two small circuit boards, contains all the timing and identification circuitry required to key an external tone oscillator. At some sacrifice in proportions, the tone oscillator itself could be incorporated into the identifier.

The logic portion, shown in the schematic of Fig. 4-44, is a

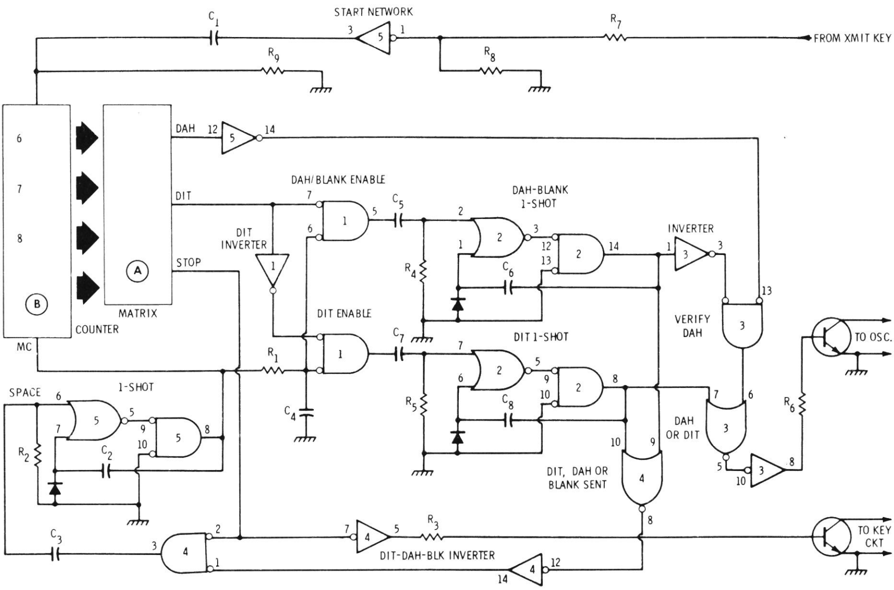


Fig. 4-43. System diagram of digital integrated-circuit repeater identification unit.

PARTS LIST

R_1, R_7	3.3K
R_2, R_3, R_4, R_5, R_6, R_9	10K
R_8	6.6K
C_1, C_3, C_4, C_5, C_7	.05 μF
C_2, C_8	10 μF
C_6	30 μF
Diodes (including matrix diodes), 20 to 100	
1, 2, 3, 4, 5 (within symbols above)	HEP 570 (Motorola)
6, 7, 8 (within symbols above)	HEP 572 (Motorola)
Transistors	2N3415 (GE)

All resistors: one-quarter watt or greater capability.

All capacitors: 6 volts or greater, working capability.

Numbers outside symbols refer to pin contacts on IC's. Grounds not shown.

Ground contacts are as follows:

IC NUMBER	GROUND PINS
1	12
2	12, 10
3	2, 9
4	13, 6
5	10, 13, 2

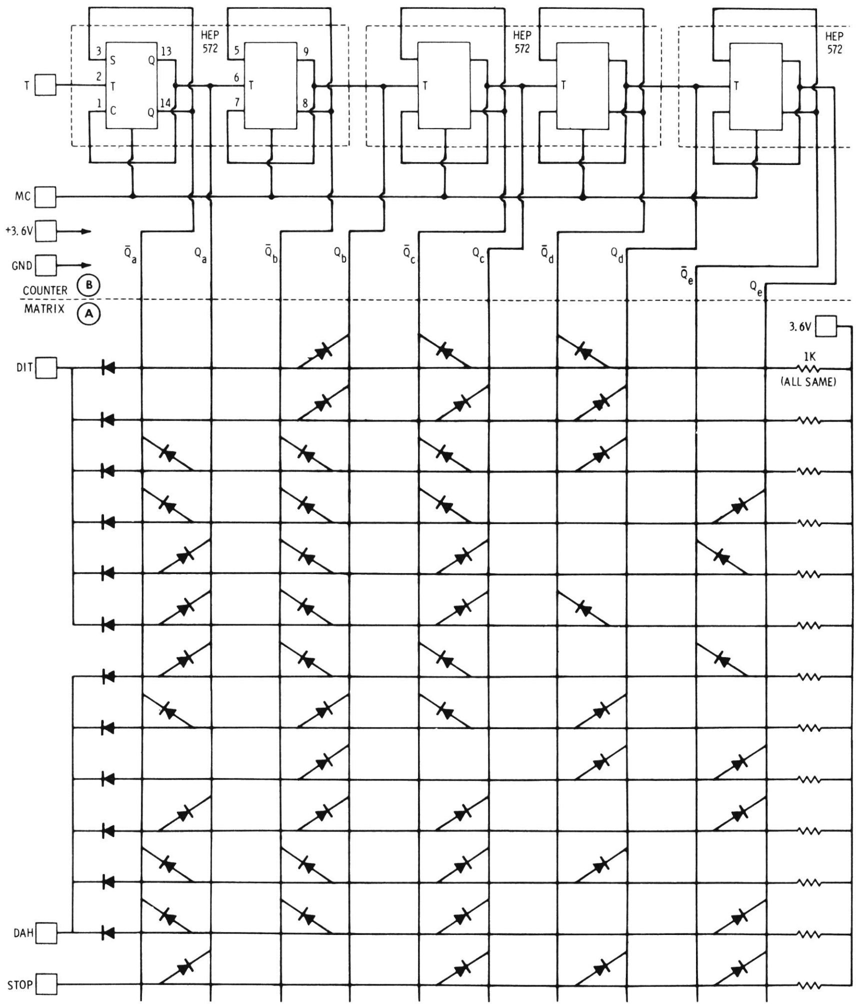


Fig. 4-44. Counter and matrix connections (A and B of Fig. 4-43).

straightforward diode matrix arrangement such as the type found in conventional pulse decoding systems. It is fashioned from integrated-circuit chips (modules) by shorting out selected diodes in a matrix cube. The cube contains a large matrix of diodes, some of which will not be used. The diodes that are not used are shorted by applying a voltage across them that exceeds their rated PIV. The diodes to be "zapped" are selected according to the identification signal to be generated.

The solid-state identifier is no project for a novice. And unless the builder has a pretty keen mind for Boolean algebra, he'll find himself in a gigantic network of diodes. There are only 41 diodes in the W6FNO identifier, but without a complicated reduction and cancellation process the number could easily have passed 200.

One last point on the identifier: The diode "cube" is certainly no necessity. With a little (more truthfully, a lot) extra trouble, individual diodes can be wired up on a board to serve as the matrix. The cubes are relatively new in the industry, and their cost is all but breathtaking. When you stop to think about how worthless the cube would be if you zapped one of the wrong diodes, the hand-wiring idea may be even more attractive.

The counter portion of the identifier system is shown with the logic in the diagram of Fig. 4-44. The complete parts list for Fig. 4-43 is shown.

Chapter 5

Remote Applications And Functions

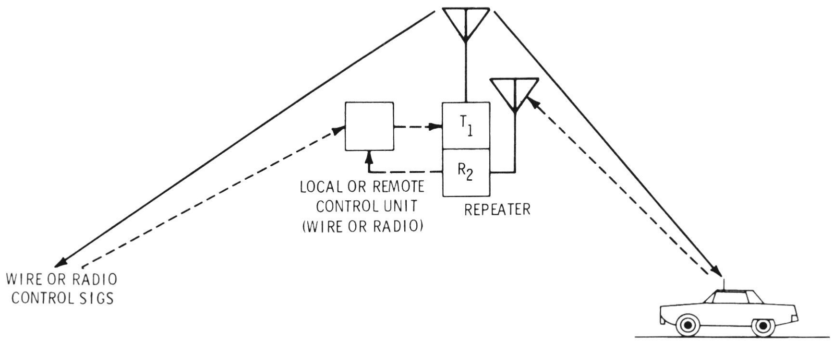
The functional variations of active remote stations tend to be dependent on a number of individual (sometimes unique) requirements, with the result that nearly every remote station includes features or functions not even considered by the other remote operators. The general (and understandable) secrecy that typically enshrouds a "remote" project contributes to the multitude of routes available leading to the same end.

But purposes, too, vary. One station might be put into service for the express objective of relaying all signals on a given frequency. Another may be established to serve as a "super intercom" for a small group of uhf isolationists. A remote station can be used to give the ego-involved mobileer his own private supersignal that is unjammable, unmatched, and never ignored—or it can provide its builders with the multifaceted capability of remote base station operation, private-channel repeater, open-repeater control, and mobile telephone.

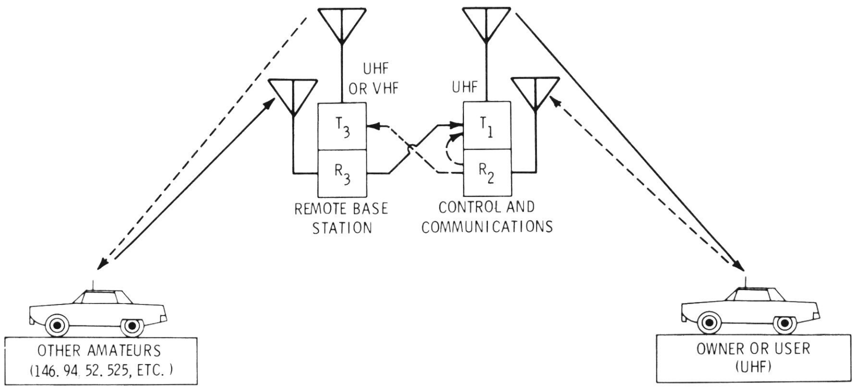
5-1. TAILORING THE SYSTEM

With the wide array of remote-station types and aims comes a broad range of achievable remote functions which vary in importance according to the scope of each installation. A few of these functions and applications are described in this section. It is acknowledged that the circuits and techniques presented herein represent but one or two methods for achieving a desired result. Equally important, where many methods may be applicable for solving a given problem, one repeater application (or function) may be employed to solve a number of different and unrelated problems. The back-to-back repeater, as an example, described herein as a means for expanding telephone capability, can be just as effectively used as the basis for a system by which two distant open repeaters might be interlinked.

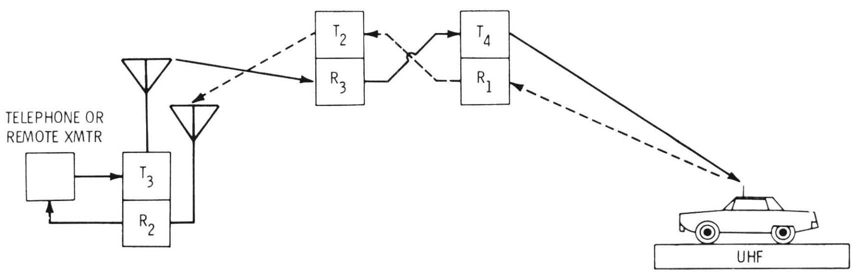
To get the maximum benefit from the applications cited, it is essential to view not so much



(A) Conventional repeater.



(B) Remote base station. (with uhf intercom repeater).



(C) Back-to-back repeater.

Fig. 5-1. Three of the most common types of remotely operated radio systems.

the discrete circuitry, but the theme, or overall approach; for repeaters and remotes represent a welcome departure from the build-it-on-a-chassis-in-a-night tradition of amateur radio and provide the impetus for a brilliant step toward the "system" concept, whereby existing "black boxes" are arranged and interconnected to function as a unique and wonderful network.

Fig. 5-1 shows the few basic skeleton systems that may be used for remote applications. Of these, the nucleus system in most amateur applications is the uhf "intercom" repeater, which is used in various combinations to produce such outgrowths as the uhf-controlled vhf repeater, the remote-controlled base station, and the useful and impressive automatic telephone repeater, or "autopatch."

5-2. THE AUTOPATCH

The term **autopatch** is one coined by the f-m amateur remote operator to describe a remotely controllable, fully automatic duplex telephone patching device. An autopatch can be employed as a lone function or it can be but one of a number of functions in any of the existing repeater types, so long as system compatibility is maintained in each application. Depending on the complexity which can be tolerated in a system, the autopatch can be designed and constructed to give a capability of "answer only," "call and answer," or "call only."

Frequency of Operation

It is unlikely that you will use two meters to access your remote telephone, because the principal requirement for any remote system is that control be effected from 220 MHz or above. Even if you could logically rationalize the legality of phone control on two meters, it would be an unfavorable band for operation; there is little privacy there, so your phone's usefulness would be impaired by inhibition, at least. Also, the two-meter region is heavily populated, so you would be subject to interference as well as possible phone use by unauthorized amateurs.

A phone system does not lend itself particularly well to incorporation in a two-meter repeater system, either (although some two-meter repeaters **do** include such capability). What happens to the repeater when someone wants to use the phone? What happens to the repeater when phone calls start pouring in? You cannot just tie up the repeater so one man can make exclusive use of the autopatch; it would not be practical. Telephones seem to belong where activity is minimum and control is sanctioned.

Complete Call-and-Answer Capability

If the telephone system is already converted to **Touchtone**, and your control system uses **Touchtone** signaling, interconnection of the patch is a simple matter. If not, close attention must be paid to setup of telephone dials on the control units. Remember, the dial's pulsing contacts are normally closed. The encoder in the control transmitter must generate tone pulses only when the dial contacts are open. Section 2-2 (specifically, the subsection entitled "Encoder Pulsing Considerations") includes the information necessary to set up the control stations and the remote decoder.

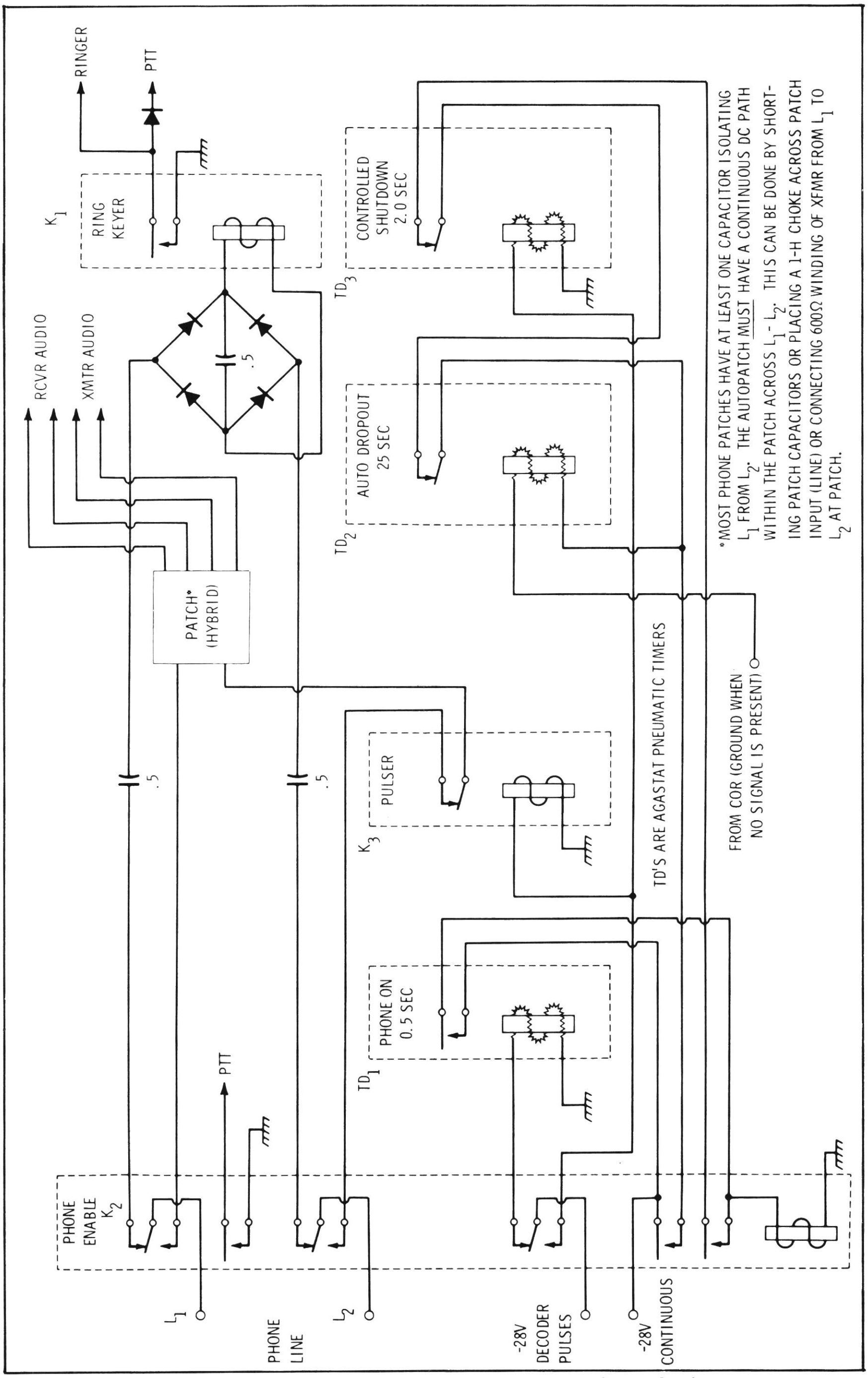


Fig. 5-2. Autopatch circuit showing inputs, outputs, and transfer functions.

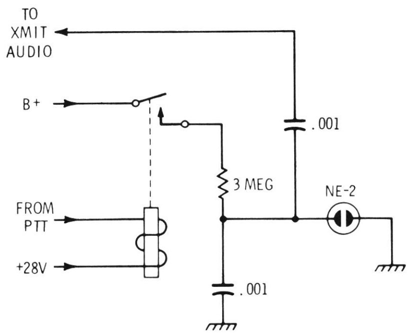


Fig. 5-3. Relaxation oscillator for effecting telephone ringback.

Fig. 5-2 shows the complete schematic for the uhf autopatch. Here is how it works: When the telephone rings, the ac "ring" voltage is rectified (after isolation from the line through capacitors) to drive a sensitive plate relay (K_1) that triggers the transmitter push-to-talk as well as a special ring oscillator. (The ring indicator need be nothing more than a simple relaxation oscillator as shown in Fig. 5-3.) The plate relay keys the push-to-talk through a diode so the "ring" oscillator will not be triggered when the transmitter is keyed through the normal carrier-operated function.

To place a call or respond to a phone ring, you simply transmit a continuous tone for 0.5 second. This is achieved with the phone dial at the control point by bringing the digit "1" to the finger stop (which keys the mobile transmitter and causes the hilltop COR to turn on the repeater transmitter) and turning the dial counterclockwise just far enough to open the dial's normally closed contacts. While the contacts are open, a continuous tone will be generated. At the end of the half-second period, the phone will be engaged by the timer (TD_1) and the dial can be released.

When the phone comes on, the telephone-enable relay (K_2) is energized and latched; the phone lines are disconnected from the rectifier and fed directly into the phone patch. The decoder relay is coupled to the phone pulser relay (K_3) so that additional dialing will pulse the phone line exactly as a local dial would.

As long as you periodically transmit a signal, the telephone will stay on. Presence of your carrier keeps a ground signal from engaging the autodropout timer. If you drop carrier, the timer is started. The shutdown timer allows the phone patch to stay on for 25 seconds without the presence of a carrier. If no carrier appears by then, the timer pulls in and shuts the whole system off.

The last timer in the circuit (TD_3) allows the phone to be shut down by operator command. A 1.5-second tone pulls the timer in and interrupts the latching voltage on the telephone-enable relay. Thus, the system includes a positive shutdown capability.

When selecting the phone patch to incorporate into your remote system, be sure to use a hybrid type. Hybrid patches are important because they allow a very definite and positive audio null and prevent feedback.

There are many manufactured hybrid types available and a great number of published circuits for their construction. If you are sure you have good audio

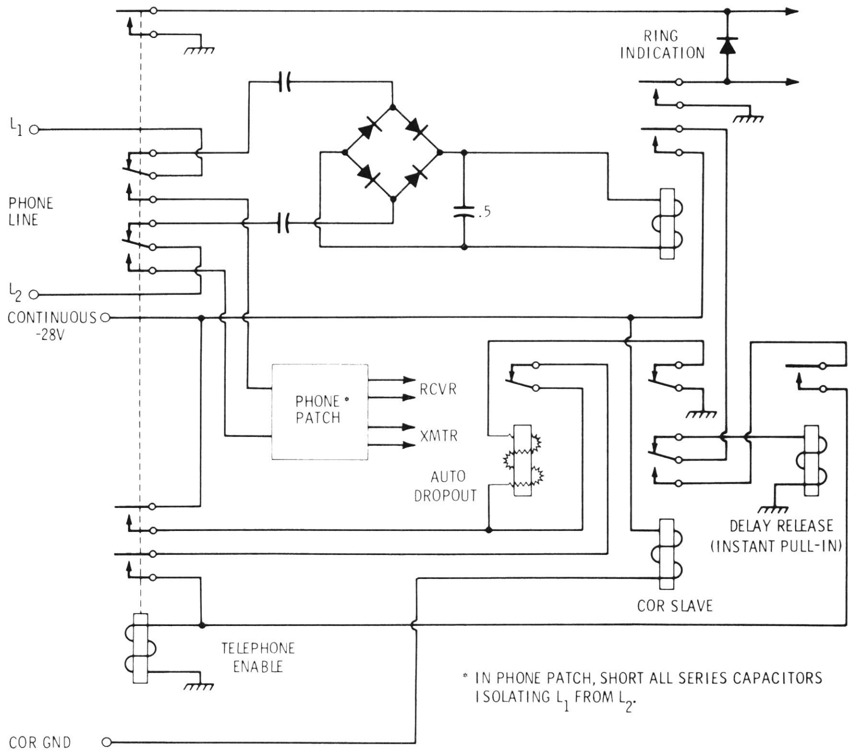


Fig. 5-4. Autopatch with answer-only capability.

transformers, go ahead and build your own. If you are not sure, you will probably be better off buying a commercially made unit.

The **Waters** universal hybrid coupler* is uniquely suited for autopatch operation. Not only does it possess a remarkable degree of input-output isolation, but it incorporates an integral compressor and audio preamplifier.

Compreamp

The Compreamp serves to keep line gain at a constant level regardless of variations on individual calls. Such an advantage can be appreciated by remote operators who do not live close enough to the installation to make repeated level adjustments.

Answer-Only Capability

The autopatch of a uhf repeater can be simplified if no calls are to be initiated from the control point. An **Answer-only** capability requires no tone decoding to activate the remote telephone system. In application, the ring-and-key rectifier causes the uhf repeater transmitter to signal the presence of an incoming call. Automatic (but controlled) answering is accomplished when a control operator transmits a sig-

*Waters Manufacturing Co., Wayland, Mass. 01778

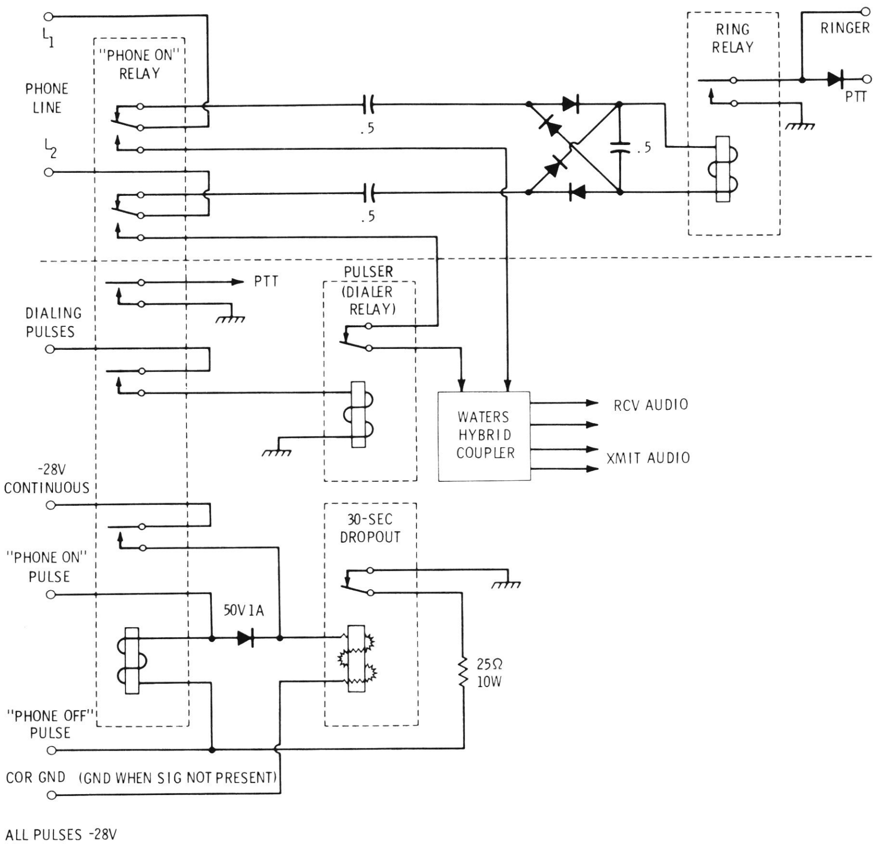


Fig. 5-5. Autopatch accessible by existing control circuitry.

nal on the repeater input at the proper moment. If he does not transmit at the right time, the answer function cannot be achieved, and the phone will continue to ring. After the interconnect takes place, hangup is accomplished solely by removal of the carrier from the repeater input.

The answer-only circuit is shown in Fig. 5-4. From the diagram, you will note the circuit is actually quite similar to that of Fig. 5-2, the prime differences being absence of tone-activated timers and incorporation of the controlled answering mechanism.

The "controlled-access" concept of the answer-only autopatch is a useful necessity. Without such an arrangement, the phone would have to be answered by no control signal other than presence of a carrier. The obvious drawback in such an approach is that a control operator, who might be transmitting when the call comes in, would find himself inadvertently and unknowingly conversing with the landline caller!

The COR slave relay, the ring keyer, and the access control timer combine to make up a system which precludes the eventuality of inadvertent telephone interconnection. To activate the autopatch, the control operator must begin his transmission after the ring indication has started, but before it is completed. If his carrier already occupies the channel, the remote telephone rings harmlessly. The duplexed control station will hear the ring even while transmitting so the control operator can drop his carrier momentarily when he hears the ring indication, then press his push-to-talk button during the succeeding ring.

Compatible Autopatch

Where the remote system is designed for specific applications other than automatic telephone use, certain provisions must be incorporated in the control circuitry to assure compatibility. The interconnection of the telephone, for example, should automatically shut down the remote transmitters (other than the control repeater output) to avoid the possibility of a phone conversation being repeated onto an active f-m channel.

The circuit shown in Fig. 5-5 shows how an autopatch might be incorporated into a system with multifunction stepper control. In this version, the telephone can be accessed by dialing a specific number for telephone turn-on. When the telephone comes on, control voltage is removed from the stepper so that dialing can be accomplished. The telephone-enable relay also pulls in to supply shutdown voltage for all functions which should be shut down during phone use.

5-3. BACK-TO-BACK REPEATERS

The back-to-back repeater is a versatile relay system which provides an interesting extension of an ordinary repeater's capability. Essentially, this system consists of two uhf repeaters cross-connected as shown in Fig. 5-6. This system is generally used in conjunction with a third repeater situated at a location that prevents direct access by user mobiles.

Sound complicated? Perhaps it is, but not nearly so much as it might at first seem. And in application, the added complexity is recompensed by the system's enhanced usefulness over a conventional repeater setup. As an example, consider a typical application of a back-to-back system—providing telephone/repeater interconnection in outlying exchange areas.

First, examine a few very common problems. Suppose your remote system is located 30 or 40 miles from the area in which 90 percent of your calls will be placed. Without a back-to-back system, these calls will be toll-charged. Or perhaps your repeater is situated in a spot so isolated from civilization that no phone service is available at the site at all. It makes no real difference; you can still have your amateur mobile telephone by employing the back-to-back repeater.

The back-to-back repeater acts as a relay for your signals and

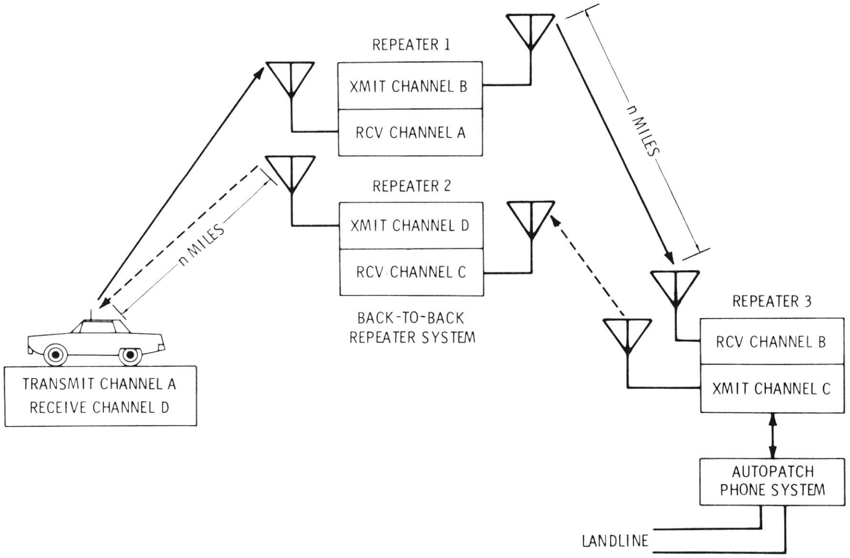


Fig. 5-6. Complete layout of back-to-back repeater system with autopatch.

lets you put your phone anywhere within range of the repeater by simply adding a third repeater at any site in the desired telephone exchange area.

One of the chief advantages of this approach is that any number of telephones and exchanges can be incorporated into a system by the simple expedient of installing a repeater at each phone to be used. Use of tone-selective circuitry at the different phone sites allows complete choice of access by the user.

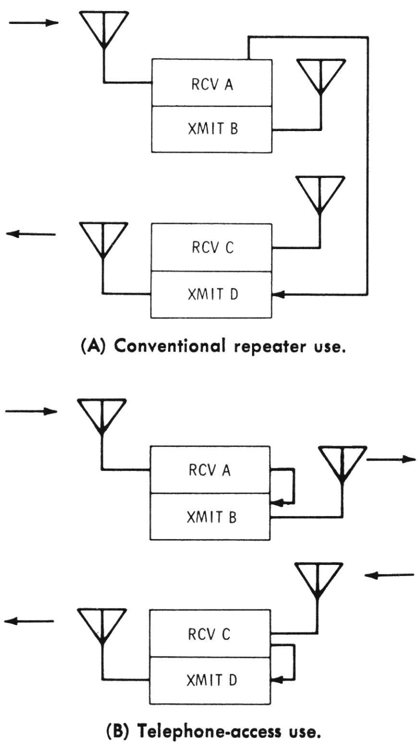
In the system diagramed in Fig. 5-6, channel A is the control link. Channel B and C comprise the relay link, and channel D is the return circuit.

Since mobiles access only the control-link receiver, the back-to-back portion of the system is the only system element that must be located at a vantage spot. And since this position need be nothing more than a passive relay, elaborate control circuitry here is not required. The control circuits (which can be those described in Section 5-2, The Autopatch) are to be part of repeater 3, the location of which is presumably more accessible and convenient than the remote site.

There are many methods for interconnecting the back-to-back system, but simplicity should be the principal criterion. The concepts employed by Donald L. Milbury (W6YAN) in his system are recommended here because of the virtual absence of complexity at the remote site.

Don Milbury's back-to-back repeater is situated on Radio Ranch, a 3000-foot peak some 30 miles from Los Angeles. He uses his system to access a telephone at a private residence located in one of the Los Angeles central telephone exchange areas.

When his telephone system is not being used, the hilltop equipment serves as a conventional repeater (Fig. 5-7A). On command, the system becomes a telephone relay (Fig. 5-7B). Fig. 5-8 shows the switching required at the remote site to effect the changeover without the employment of special decoding devices. His secret lies in the use of a carrier-operated relay (COR) on receiver C to perform the switchover.



(A) Conventional repeater use.

(B) Telephone-access use.

Fig. 5-7. Two modes of operation for remote equipment.

The system he uses is admittedly not designed for use in an area where an abundance of 450-MHz signals crowd the band. But in inactive areas, it is quite adequate. As shown, receiver C stands ready at all times to effect the interconnect. Presence of a signal indicates that transmitter C at the phone site has been energized (as by an incoming call, from local command, or from a "telephone-access" command from the control point). When a signal appears at receiver C, the COR pulls in and the back-to-back system is operational. A timer at the phone site shuts down transmitter C when no signal is received on receiver B for a certain prespecified period (usually 45 seconds to 1.0 minute).

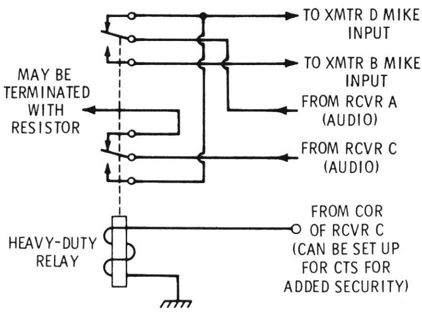


Fig. 5-8. Decoderless control of phone tie-in at remote site.

5-4. FREQUENCY NETTING BY REMOTE CONTROL

If you are anything at all like your fellow remoters, you will go through the "automate" phase in the early days of your remote system's operation. You will be so taken with your capability of controlling from a distance that you will entertain thoughts of dialing tower lights on and off, rotating beams, turning on (and off) heaters and air conditioners at the remote site, and possibly a dozen or two other such notions. Often these ideas can be real gems; that is how Bob Mueller (K6ASK) dreamed up the method for zeroing a number of user mobiles to the repeater discriminator—and all by remote control.

His problem was fairly typical of remoters: The K6VBT repeater which he uses is situated in an isolated area some 25 miles from civilization. It runs reliably, so few trips to the repeater site are required. He noticed, over a period of time, that the operating frequency of the user mobiles would vary by as much as 5 kHz. With the site so far away, and new stations coming on with reasonable regularity, how could he be sure which of the stations could serve as a repeater frequency standard?

The solution was installation at the repeater of an oscillator that could be turned on by remote control. This oscillator, crystal-controlled on the repeater discriminator frequency, is coupled, on command, into the low i-f of the repeater receiver so that it (the receiver) "thinks" it sees a weak "on-frequency" signal. With the oscillator dialed on, mobile operators with duplexed units need only zero their transmitters while monitoring the heterodyne on the output for a zero beat.

The crystal oscillator for the K6VBT remote was 290 kHz to match its **GE Progress Line** discriminator. Commercial oscillator circuits can be purchased for about $5 postpaid*, or they can

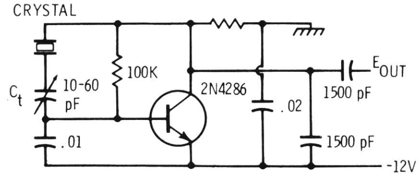


Fig. 5-9. Stable crystal oscillator for remote zeroing.

be constructed with very little effort. Fig. 5-9 shows a stable transistor oscillator which operates from a 12-volt dc source (this is essentially the same circuit as the commercially built unit).

Installation

When you install the oscillator, disconnect the repeater receive antenna during setup. Then, with the oscillator in the circuit, tune trimmer (C_t) for zero on the discriminator, and reconnect the antenna.

If certain precautions are not taken to maintain control of your repeater, you will likely experience the sad fate of being jammed out of your own repeater. When dialed on, the oscillator feeds the receiver a legitimate signal. And if your signal is weaker than the oscillator's, you have lost control. This problem can be precluded by installation of a timer to turn off the oscillator automatically after a predetermined period (30 seconds or so).

Fig. 5-10 shows how this can be accomplished using a single pulse for control without a latching relay. When the function is dialed on, a −28 volt pulse pulls in the relay, which stays closed

*Sentry Manufacturing Company, Model F60-112.

because its own contacts supply coil voltage. The timer begins the timing sequence the instant the relay pulls in.

The normally closed timer contacts supply the control voltage for the oscillator as well as the constant relay voltage. At the end of the timed period, the timer contacts open, releasing the relay and removing control voltage from the oscillator. If you use the oscillator circuit of Fig. 5-9 and a −28 volt source, be sure to incorporate a means for dropping the voltage to around 12 volts. The diodes (D_1 and D_2 in Fig. 5-10) may not be required

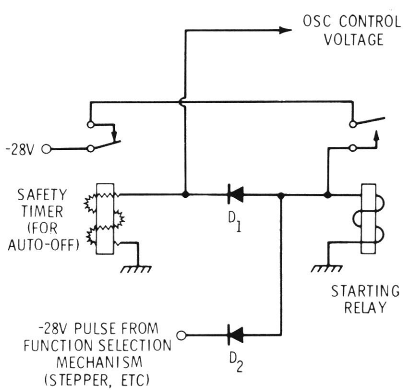


Fig. 5-10. Control circuit for dial-on oscillator.

in your own control scheme, but it is good engineering practice to incorporate them. Diode D_1 prevents the trigger pulse from working too hard; it is arranged so that presence of a negative pulse keys only the relay. Remote owners who do not use diodes in circuits such as this sometimes find themselves with unreliable control systems. When a pulse is required to perform a number of functions, the excessive current can cause the pulse voltage to drop to such a level that many functions may go untriggered. Diode D_2 offers nothing more than isolation; it prevents the constant relay-coil voltage from appearing at the control wiper arm or the pulse source.

5-5. REMOTE SWITCHING OF REPEATER OUTPUT POWER

Remotes and repeaters traditionally run low power. Usually, low power is all that is required; the remote transmitter is situated on a tall building or at a mountaintop location, so blanket coverage is obtained by elevation—and extra power does not buy more than devastating electric bills. Most owners of repeaters and remote base stations will agree, however, that an occasional power increase can be a highly desirable function.

Suppose, for instance, that a repeater user is operating a mobile in a fringe area. It would not be too difficult for him to increase his mobile power temporarily to get into the repeater. But what benefit would he gain if he were unable to hear the repeater output?

Or suppose that an operator is conversing with another station through the repeater, but other stations are talking "direct" on the repeater's output channel. As likely as not, the repeater could "get through" without disturbing the other communicants if the output power level were increased for a few minutes.

It is neither economical nor legal to run high power continuously without a specific **need.** But boosting transmit power **as required** is in keeping with the FCC regulation which states, in essence, that transmitter power should be limited to no more than that required to maintain communications. Further, your ability to decrease repeater power will be respected by other operators on the output channel. They will realize that your high-power capability could be exercised on a continuous basis, but out of consideration for other f-m operators, your repeater or remote station normally runs the lowest practicable power level.

A typical benefit of the multi-power-level capability is the reduction of design compromises during initial construction and installation of the remote equipment. An owner who knows he will be able to increase his repeater or remote output power on command will be less likely to install a system that runs even moderately high power on a continuous basis.

Power-level changing can be accomplished in many ways, from the simple expedient of circuit switching in the power supply (effecting a voltage change on the final) to automatically "patching in" an add-on power amplifier (the most impressive approach).

There are a number of vital elements to consider when designing a system for control of an add-on amplifier. One of the most important of these is comparing the normal output power of the remote transmitter with the input-power requirements of the add-on amplifier.

When the normal transmitter output exceeds the drive requirements of the amplifier, a means must be provided for reducing it. This can be done in several ways; the easiest method is to back off on the loading of the basic transmitter so that its normal output will automatically match the drive-power requirement. But this is compromising the capability of the repeater transmitter.

Another method is to use a resistive network as an artificial load at the time of power transfer. But this approach is inferior because the characteristics of the resistors are difficult to match exactly with those of the antenna, and the result will be an off-resonance condition in one position or the other. In addition, any variation in the power-amplifier grid tuning will greatly affect the input load impedance. Since the transmitter will be operating at its maximum output, even a slight off-resonance condition will wipe out the transmitter final amplifier in short order.

The most satisfactory solution is to use a clamp in the screen circuit of the final such as that shown in Fig. 5-11. When the grid of the clamp tube (6BF5) is not grounded, transmitter output is limited to a fraction of its full capability. By inserting a variable resistance between the clamp tube grid and ground, the output can be safely adjusted to any level desired. The clamp will be preset, then, so that when the add-on amplifier is switched on,

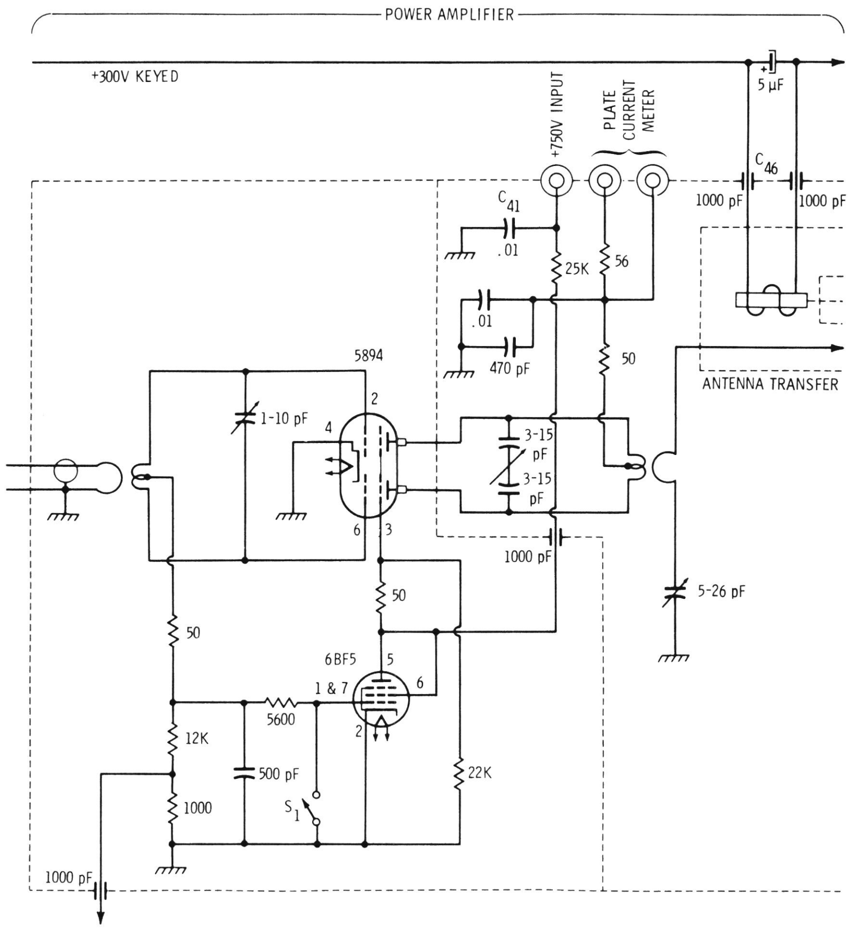


Fig. 5-11. Clamping circuit installed in a typical final amplifier.

the clamp is also energized, and the transmitter output automatically drops to the exact output necessary to properly drive the add-on amplifier.

If the power amplifier is a commercially built unit with its own integral power supply, the turn-on/turn-off problems are simplified. For a remotely operated base station, here are the functions which must be performed: On "amplifier turn-on" command, the basic receiver and transmitter must remain in service until the amplifier filaments are warmed sufficiently for power transfer to take place. After warmup, the receiver must remain connected to the antenna until the push-to-talk circuit is energized. During transmit, the output signal must be fed into the add-on unit, and the add-on unit must be connected to the antenna. And, of course, the clamp circuit must

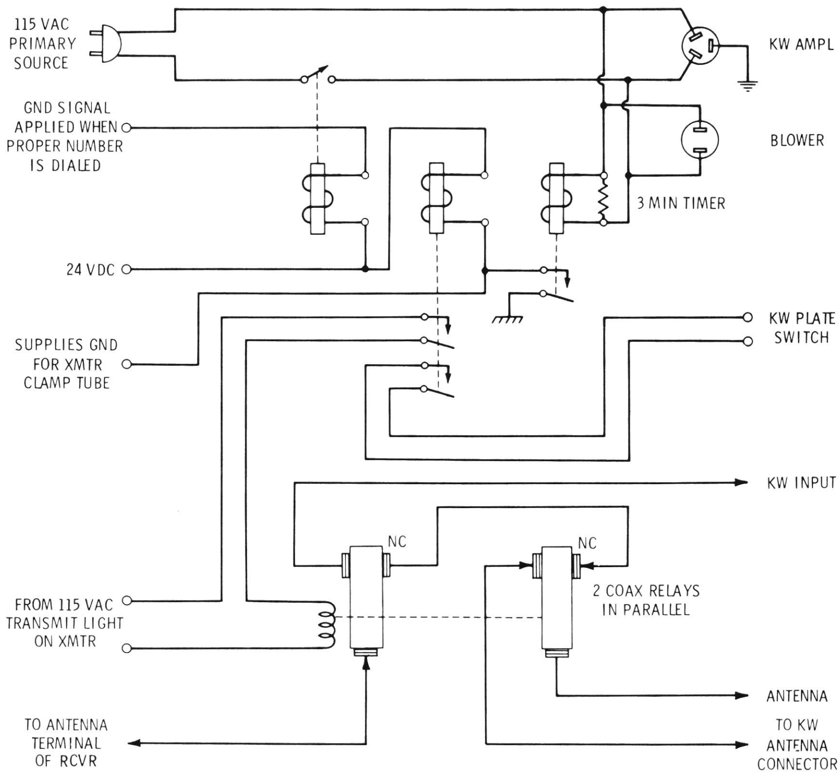


Fig. 5-12. Circuit for remotely transferring to a kilowatt class-C amplifier.

be energized so that the transmitter output now meets the input requirement of the amplifier.

Fig. 5-12 shows how these functions are performed on the author's remotely controlled two-meter base station. The add-on amplifier is a **Johnson Thunderbolt** kilowatt, operating class C. The base station is a 30-watt (output) **DuMont** f-m transmitter/receiver combination. As shown, the **Thunderbolt** primary power switch is left in the on position, and the plate switch is turned off. The normally open contacts of a 28-volt relay are placed in series with the ac input to effect filament switching. The contacts of a timer-driven 28-volt relay short the plate-supply switch after warmup. The balance of switching takes place on a push-to-talk basis. Turnoff of the amplifier is achieved by simply removing the ground signal from the key switching relays.

Another method of power control can be effected in the power supply circuit of the basic transmitter by switching from full-wave rectification to a bridge circuit. Doubling of the voltage on the final doubles the plate current—and the result is a power increase by a factor of 4.

Fig. 5-13 shows how to accomplish this function. As

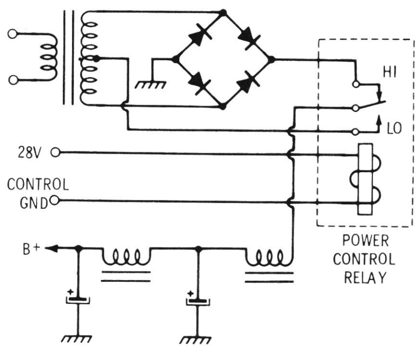


Fig. 5-13. Power-supply switching.

shown, plate voltage is switched at the unfiltered output so the filtering is connected to whichever voltage source is selected. The transformer centertap of a bridge circuit yields a fully rectified dc voltage equal to half the bridge output. Thus, a switchable relay in the circuit allows selection of either high or low power.

If both power-shift systems are used (power-supply switching and power-amplifier add-on), a means must be provided for returning the transmitter to its normal level before the amplifier is used. Diodes do this job nicely. If low power is the normal level, the high-power function (with voltage switching) is a temporary function. A diode should be connected from the amplifier add-on command signal source to the power-supply switching relay so that the "normal-power" function is enabled each time the amplifier is energized. (See Passive Functional Control, Section 2-4.)

5-6. SYSTEM STATUS MONITORING

Probably the least touted of all remote-control functions is **telemetering**—receiving one-way signals from the remote/repeater site which indicate the status of selected repeater subsystems. The term **telemetering** was coined in the early days of instrumented meteorological research to identify a very useful method for making (by remote radio control) precise meter readings of key system parameters aboard a rocket-type "sounding" vehicle (rocketsonde).

Telemetering, or remote status monitoring, is actually a relatively simple process in principle. In military and aerospace applications, it is achieved with closely calibrated transducers which convert various "value" ranges of voltage, current, temperature, pressure, etc. to dc voltage analogs of a standard range (usually 0 to 2 volts). This means that a critical plate-current range of, for example, 100 to 150 mA would be indicated by a 0- to 2-volt signal **whose scale is proportional to that of the monitored parameter.**

Obviously, since dc voltages cannot be transmitted directly through space by radio waves, another conversion process is required. One very common method for relaying dc analogs is to convert the 0- to 2-volt dc signal into an audio-frequency tone with a proportionate range (say, 600 Hz to 1 kHz).

The overall business of status monitoring may not be as complicated as it first sounds. The tone-analog circuitry, for instance, need not be duplicated for each monitored parameter; it will become a meter, so to speak,

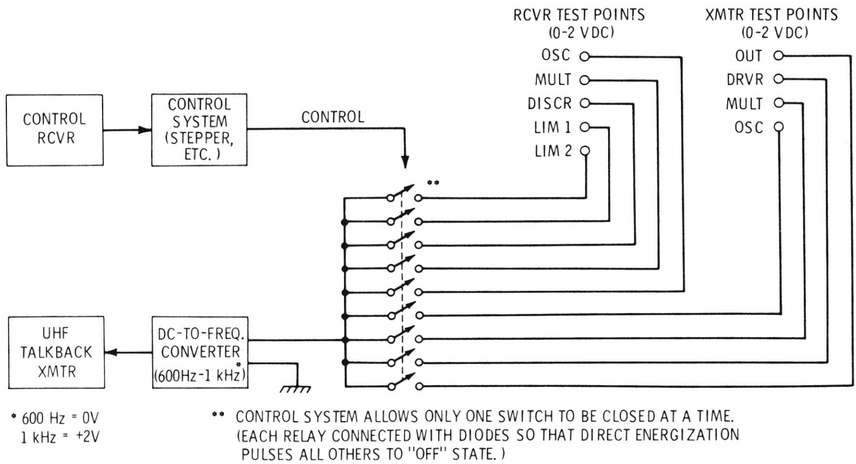


Fig. 5-14. Block diagram of status monitoring system, remote site.

which can be used to measure the dc outputs of any selected function by command from the remote-control point.

The most difficult task in designing a status-monitoring system is that of transducing, or converting the various parameter values to a 0- to 2-volt dc range that is analogous to the range of the monitored parameter. Fortunately, this task is already accomplished for the amateur who intends to monitor most repeater functions by remote control.

Commercial f-m units typically have an abundance of built-in test points capable of being monitored with a 0- to 2-volt dc meter. These test points can be used to drive the tone-analog device directly, as selected by command from the control point. The block diagram of Fig. 5-14 shows the signal-producing process. From this diagram, it should be

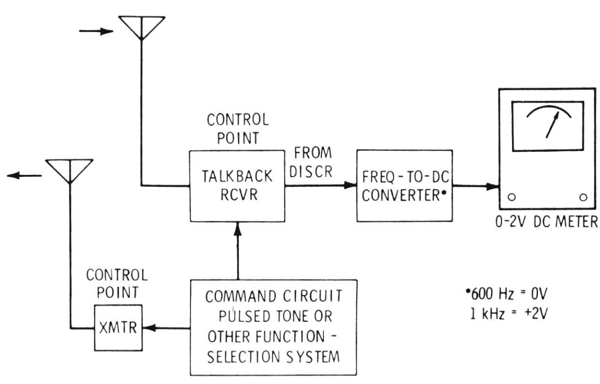


Fig. 5-15. Control-point parameter selection and signal decoding process.

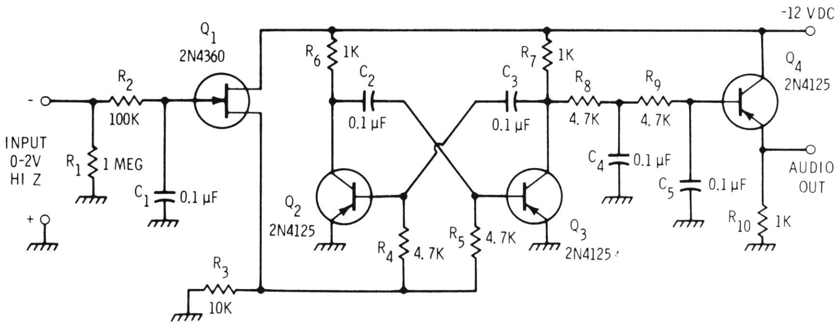


Fig. 5-16. Diagram of dc-to-frequency converter for remote status monitoring (Designed by Paul Hudson, VE3CWA, especially for this handbook.)

PARTS LIST

Q_1	**(Fairchild)**
Q_2, Q_3, Q_4	**2N4125 PNP transistor (Motorola)**
C_1 thru C_5	**0.1-μF paper or *Mylar* capacitor**
R_1	**1-megohm resistor**
R_2	**100K resistor**
R_3	**10K resistor**
R_4, R_5, R_8, R_9	**4.7K resistors**
R_6, R_7 R_{10}	**1K resistors**

2N4360 P-channel FET

Note: All resistors $\pm 10\%$ or better, ¼-watt or more.

Comments:

1. **Frequency of operation about 1200 Hz.**
2. **Rate of change is about 100-Hz per volt.**
3. **Output impedance is low (600 ohms).**
4. **Output level is about 0.5 volt p-p.**
5. **— 12 volt supply should be regulated.**
6. **Input impedance is 1 megohm.**

Operation:

Q_1, P-channel FET provides high input impedance and a five- to six-volt negative offset at its source. This voltage controls the frequency of a stable multivibrator for Q_2, Q_3. R_8, R_9, C_4, C_5 form a low-pass integrating filter to shape the output waveform to something approximating a sine wave. Q_4 is an emitter follower providing a low output impedance.

obvious that the control operator can access any function at will for measurement, and the result will be a transmitted tone corresponding in frequency to the value of the parameter. At the control site, the operator can "reduce" the data to direct meter reading by simply converting the tone back into a dc analog of the tone. This process is illustrated in Fig. 5-15.

The system for monitoring repeater functions by remote control is not merely a sophisticated toy. Apart from allowing the control operator to know what is happening at the remote site, it opens up an entirely new area for him to explore—new capabilities to exploit. In the latter category are such exciting concepts as vfo control, ssb and a-m tuning, precision control, and monitoring of highly directional beam antennas. The list becomes almost limitless.

The schematic of Fig. 5-16 shows a dc-to-frequency converter with a conversion-error

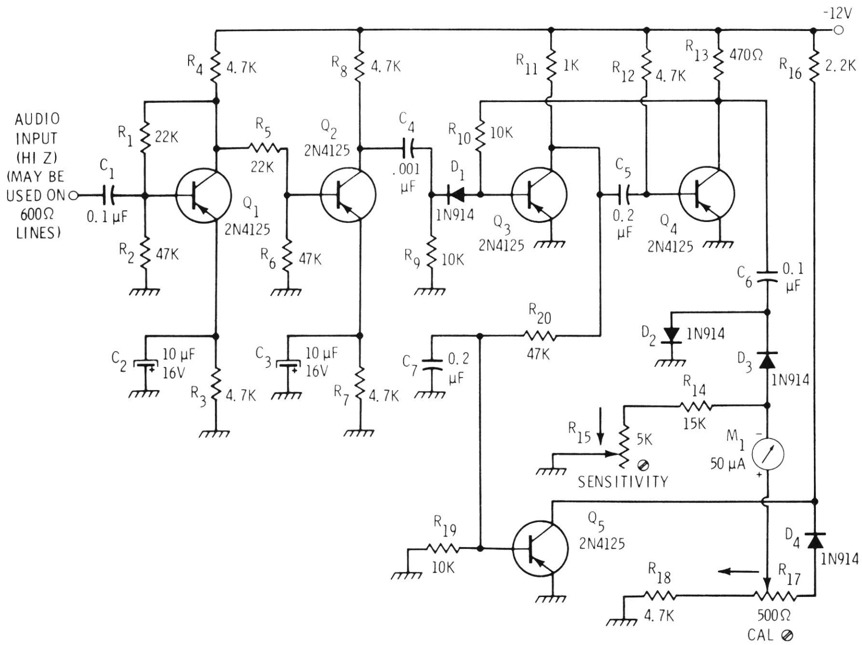


Fig. 5-17. Frequency-to-dc converter (tone converter) for changing audio signals to meter readings. (Circuit designed by Paul Hudson for this handbook.)

tolerance of better than 2 percent (more accurate than the average panel meter). The values of all components should be held as closely as possible to those depicted in the schematic. Close-tolerance resistors and capacitors should be used for **all** components to assure ultimate accuracy.

The overall accuracy depends not just on one element, but on a number of them: the dc-to-frequency converter, the transmitter itself, the receiver, the frequency-to-dc converter, and, of course, the panel meter at the control point. (It should be noted that any type of readout device could be used, depending on the sophistication of the system. Typical displays to replace the meter include strip-chart oscillographs, direct-readout Nixie tubes, and even zener-driven go/no-go indicators.) Mathematically, the overall system error will be the equivalent of the square root of the sum of all the errors squared, or:

$$\sqrt{e_1^2 + e_2^2 + e_3^2 + \ldots e_n^2}$$

The individual system errors referred to in the equation are the tolerance errors of the various components of the system, and the resulting error will generally be in the neighborhood of 3 to 4 percent.

Fig. 5-17 is a schematic for the tone converter (frequency-to-dc) to be used at the control point. The output of this device drives a

PARTS LIST

Q_1, Q_2, Q_3, Q_4, Q_5	2N4125 PNP transistors
D_1, D_2, D_3, D_4	1N914 silicon diodes
C_1, C_6	0.1-μF paper or *Mylar* capacitors
C_2, C_3	10-μF 16V electrolytic capacitors
C_4	0.001-μF ceramic capacitor
C_5, C_7	0.2-μF paper or *Mylar* capacitors
R_1, R_5	22K resistors
R_2, R_6, R_{20}	47K resistors
R_3, R_4, R_7, R_8, R_{12}, R_{18}	4.7K resistors
R_9, R_{10}, R_{19}	10K resistors
R_{11}	1K resistor
R_{13}	470-ohm resistor
R_{14}	15K resistor
R_{15}	5K linear potentiometer, screwdriver-adjust
R_{16}	2.2K resistor
R_{17}	500-ohm linear potentiometer, screwdriver-adjust
M_1	500-μA meter

Note: All resistors $\pm 10\%$ or better and ¼-watt or greater.

NOTE: R_{14}, R_{18} selected if necessary.

OPERATION:

Q_1, Q_2 are limiting amplifiers providing a high input impedance and allow input voltages from 0.25V p-p to 5V p-p audio. C_4, R_9 differentiates the waveform at Q_2 collector and through D_1 triggers monostable multivibrator Q_3, Q_4. This device provides constant pulse amplitude and width so that only the *rate* or frequency changes. D_2, D_3 rectify this pulse and drive M_1 with a negative voltage. R_{16}, R_{17}, and R_{18} provide the necessary offset to have the meter read zero with a zero dc input. R_{19} and D_4 clamp the meter to ensure that the meter does not go off scale if tone is removed.

0- to 2-volt dc meter directly (or other display device). Again, accuracy of components and care in construction is of paramount importance if reliable readings are to be expected.

Chapter 6

What Repeater Owners Should Know

Open repeaters have a way of being notoriously unpopular or phenomenally successful—there aren't many in-betweens. As it happens, new repeaters are often looked on by local amateurs with suspicion and distrust. Nearly every new repeater installation tends to leave in its wake two groups of active channel users, records show: One group consists of the helpers, contributors, the followers; the other, the dissenters. The dissenters precede the actual installation with the "who-needs it" attitude, and make every attempt to discourage eventual deployment. Their reasons vary. Perhaps the repeater will rob a few of them of having the strongest signals on the air. Perhaps some of them feel their sacred channel will become too active. Maybe some of the dissenters are dissenters without even knowing exactly why. But dissenters there will surely be. And the followers, always with the softer voice, continue to make final preparations for the repeater, lending the opposition only cursory attention.

Then, when the repeater is finally placed in service, the moment of truth arrives, The dissenters will be looking for ways to say "I told you so." They will exaggerate every conflict between the repeater and the normal "pre-repeater" channel activity. And this is the time when the repeater owner must hold steadfast to the commitments he has made to operate an open repeater—or face failure.

If you own an open repeater, you must, for all practical purposes, relinquish all personal rights to it from the moment of installation. The repeater can no longer be "yours." It MUST become the property of all who wish to use it. The fastest cause for a repeater's doom is an owner who mothers his "child"—who actively monitors the output and dominates its operation.

The dissenters may put forth a concentrated effort to destroy the effectiveness of a repeater. They will make comments, transmit annoying and sometimes meaningless signals on the input frequency, and they will complain.

The temptation may be great to yield to the demands of the dissenters and shut down the repeater. But a repeater shut down is worse by far than no repeater at all, because those who DO use it will be forced to go to some lengths to regain a means of communication. They must replace either transmit or receive crystals (or perhaps both) to return to a simplex mode. And once they have had to do this, they may be reluctant to depend on the repeater later.

The best way to insure the success of a repeater is to get the machine operating reliably, then forget it. Monitor it, but monitor it **passively.** Ignore the comments, the barbs, the spurious input signals. **The repeater must stay on the air at all costs!** Sooner or later (and it may seem like forever) the uncooperative element will become bored or passivated. At this point, the repeater, if it has not been shut down, will have successfully passed the first and most crucial test.

The second test, if passed successfully, will draw the new people to the repeater. The test is endurance, and the new people will be those who watch the operation critically and cautiously—perhaps even pessimistically at first. These individuals are those who do not intend to put out good money for new crystals until they have become convinced, beyond any reasonable doubt, that their money will not have been wasted.

This second test calls for patience and understanding on the part of the owner, because it may take as much as several months before the repeater is accepted as "part of the scenery." The "watchers" must be shown, without coercion, what the repeater can do, and they must be assured and reassured of its dependability, reliability, accessibility, and general freedom from attached strings.

The worst possible thing that can happen to a repeater during this period is to have a possessive owner, who makes the repeater an intermittent entity. A nightly shutdown is sufficient excuse to discourage those who might otherwise want to use a repeater. Discounting such aspects as coverage and performance, the most nearly perfect repeater is one which is most nearly eternal in operation. Ideally, the repeater should be accessible one-hundred percent of the time, night and day, rain and shine, winter and summer, year in and year out. But if this cannot be arranged, the next best thing is **regular hours.** The repeater cannot be a success if it is turned on and off according to the whims of the owner. Soon after the repeater is installed, a schedule of operating time should be initiated, and this schedule must be adhered to religiously for the life of the repeater.

The W6FNO Radio Ranch repeater in Southern California faced more than the usual amount of opposition when it was first installed for several reasons. First, it was to be a talkback repeater, or one whose input (rather than output) frequency was a national, highly active f-m channel. (This is an unsatisfactory type for those who build a repeater for the capability of dumping powerhouse signals on existing active channels.) Second, the output frequency was to be 146.70 MHz, the channel generally set aside across the nation for radioteletype use.

The fact that radioteletype transmissions on 146.70 MHz were so rare as to be virtually nonexistent was immaterial. Those who held to the belief that RTTY's sovereignty should be protected and respected were determined that the repeater should fail. As a consequence, many prospective repeater users adopted a skeptical wait-and-see attitude. The repeater would simply have to prove itself.

In its early days, the repeater had but a quiet handful of brave users. But it had an equally sized (but more vociferous) group of dissenters. A few members of a radioteletype group (which had been operating for years on a frequency other than 146.70) resolved to devote a nightly period to transmitting RTTY on the active f-m channel (which was the repeater input). If the repeater could operate on an RTTY frequency, why not have RTTY on the f-m channel?

It was months before the irresistible force gave way to the immovable object, but finally the RTTY periods became fewer and fewer. The repeater was never shut down. And the repeater users rarely discussed the conflict or the outcome. Eventually, the problem resolved itself by the apathy of the instigators.

Those curious onlookers who watched the goings-on with bewilderment noted that the repeater was always there—come good times or bad. Slowly, cautiously, **and with practically no fanfare,** the repeater came into its own.

The moral is of course the Big Rule. When the repeater is airborne, forget it. Let come what may, do not touch the repeater. Don't talk about it when there is dissent; just close your eyes and ears, and keep your hands off the switch. Leave it on, and leave it alone!

Appendix I

American Repeaters (Open)

Listings in this directory are alphabetical by state and area of coverage. This concept (as opposed to a listing by actual repeater location) allows mobile operators to determine with ease the repeaters available for use along any cross-country route.

LOCATION	IN (MHz)	OUT (MHz)
ALABAMA		
W4RFR (wideband)	146.34	146.94
W4VO (Northeast Alabama, Northwest Georgia)	146.34	146.94
ARIZONA		
Prescott area		
W7AJU (wideband)	146.34	146.94
Phoenix area and regions adjacent thereto		
WA7CEM (wideband)	146.34	146.94
ARKANSAS		
WA5VNQ (Fayetteville; narrowband)	50.50	50.40
W5DI (Little Rock and vicinity; narrowband)	146.30	145.50
CALIFORNIA		
Los Angeles area		
W6FNO (Radio Ranch)	146.82	146.70
Wideband. Transmissions limited by timer to one minute each. Covers San Fernando Valley, San Gabriel Valley, Pomona Valley, Paradise Valley, most of Los Angeles County, Orange County, parts of Riverside County, and southern third of San Bernardino County. Elevation 3000 ft. Separate receiver and transmit sites. 35W out. User must whistle (1750 Hz) to activate repeater initially; carrier-operated unless input channel vacated for three minutes.		
WA6VFO	146.52	147.18
WA6MPV	145.12	146.90
WB6GUA (intermittent)	146.44	146.94

San Diego area		
WB6DSL	146.34	146.94
Extended Southern California area		
WB6WYM (Twin Peaks)	50.75	52.525
Narrowband. Transmissions limited by timer to three minutes. Covers Lucerne Valley and all of Southern California with the exception of areas shielded by Mt. Baldy, such as San Fernando Valley and some parts of Los Angeles. Elevation: 6000 ft. 100W out. Input deviation: 3 kHz; output deviation: 15 kHz.		
San Bernardino County		
WA6TTL (Silver Peak)	146.34	146.94
Eastern High Sierra Amateur Radio Society: T. Downey, President. Provides wideband coverage over Owens Valley, Bishop, Greater San Bernardino County. Elevation: 10,880 ft. Can link with Las Vegas and Los Angeles through WB6UGT, WB6SLR, and W6FHF.		
Northern California		
WB6AAE (Grizzly Peak)	146.20	146.80
WB6TSO (Central coastal region)	146.20	146.80
W6NCG (Meadow Lakes)	146.85	147.71
WA6YCZ (Mt. Umunhum)	146.85	147.71
W6DOO (Mt. Allison)	146.85	147.71
W6AQU (Mt. Toro)	146.85	147.71
W6AEX (Mt. Vaca)	146.20	146.85
W6CX (Walnut Creek)	147.80	146.94
K6JIM (Central Valley)	146.00	147.70
WB6QEO (Alabama and vicinity)	51.20	51.00
WB6QVV (Placer County)	51.20	51.00
WB6LJR (Santa Clara and vicinity)	51.624	51.024
No call (Solano County)	51.624	51.024
WB6NDJ (Alameda and vicinity)	51.70	51.075
CANADA		
British Columbia		
VE7CAP (Kimberly)*	146.46	147.33
VE7BTU (Nelson)*	146.46	147.33
VE7MQ (Vancouver to Seattle)**	146.34	146.58
VE7APU (Vancouver to Seattle)**	146.33	146.58
Quebec		
VE2MT (Mt. Royal, Montreal)	146.46	146.94

*Info supplied by East Kootenay ARC
**Univ. of British Columbia repeater; precedence given to 146.34 input.

VE2RM (Mt. Rigeau; covers Montreal and western portions of province)	146.40	147.18
VETA (Mt. Orford Northern Vermont)	146.52	147.50
VE2XW (Mt. St. Croix and vicinity)		
VE2CRA (Ottawa)	146.46	146.94
VE2CTR (Trois Rivieres)	146.46	146.94
VE2FZ (Sherbrooke)	146.46	146.94
VE2JE (Eastern Montreal)	146.52	147.50
VE2JE (Drummondville)	146.46	146.94
VE2VD (Southern Quebec)	146.46	146.94
Ontario		
VE3NPS (Niagara Falls)	146.22	147.24
VE3RPT (Toronto and extended area)	146.46	146.94
Has secondary output on:		147.06
VE3SIX (St. Catherine)	146.22	147.24
VE3SSM (Sault Sainte Marie, with coverage into Northern Wisconsin)	146.34	146.94
Manitoba		
VE4XK (Winnipeg and extended area in southern region of province)	146.46	147.33
Saskatchewan		
No repeaters reported		
Alberta		
No repeaters reported		
Newfoundland		
VO1GT (Covers all of Cape)	146.46	146.94

COLORADO

Colorado Springs		
No call given (Cheyenne Mountain)	146.34	146.94
Northern Colorado		
No call given (Denver)	146.34	146.94
No call given (Denver)	146.88	146.94
Western Colorado		
WØPXZ (Grand Junction)	145.32	146.94
Repeater controlled from Grand Junction, deployed at Grand Mesa at a height of 11,000 ft. (Highest repeater in the U.S.) Provides coverage over western parts of state and into eastern border of Utah.		
No call given (Grand Valley) Used as local backup for Grand Junction repeater, controlled by WØPXZ	145.32	146.94
Pueblo		
WAØSNO (Extended coverage of central portion of state)	146.34	146.94

CONNECTICUT		
No call yet (Avon Mountain)	146.28	146.94
W1BNF (narrowband)	146.37	146.98
Covers Southern Massachusetts and Eastern Long Island, N. Y., plus much of Connecticut		
WA1JTB (Bridgeport)		
Covers Southwestern Connecticut. Narrowband.	146.31	146.88
W1VVK (Avon)	146.34	146.94
Coverage south to Newhaven and East Long Island, N. Y., north to Greenfield; serves as double repeater (prime/talkback)	146.94	52.92
K1TKJ (Bantam)	146.88	52.98
With secondary repeater:	53.10	146.31
FLORIDA		
Northern Florida		
No call given (Stark)		
This repeater is narrowband	146.34	146.94
Central Florida		
WB4HAE (Tampa, narrowband)	146.34	146.76
WB4GLK (Okeechobee)	146.34	146.94
Repeater covers central as well as eastern central portion of state; narrowband; repeater functions as double-output, crossed-input system.	146.94	146.76
Northwestern Florida		
W4UC *(Pensacola and vicinity; wideband)	146.34	146.76
WA4EVU (Fort Walton Beach; wideband)	146.34	146.76
GEORGIA		
Northwest Georgia		
W4VO (Rome; Mt. Alto)	146.34	146.94
Northwest Georgia Amateur Repeater Assn., A. Mitchell, K4OAG, Pres. Member ALRA Whistle-on system. 65 miles is approximate radius of coverage. Alabama area is shaded.		
HAWAII		
Diamond Head		
KH6EQF (narrowband)	52.525	53.52
KH6EQF (wideband)	146.20	146.80
KH6EQF (a-m input f-m output)	147.00	146.80
ILLINOIS		
Northern Illinois		
W9YRB (Aurora)	146.40	147.81

*Five Flags ARS, Inc.; P. Eaton WA4AYX provided information.

Central Illinois		
WA9GCK (Bloomington)	146.34	146.94
WA9EAM (Petersburg)	146.34	146.94
Chicago area and vicinity		
W9ZND (Upper Chicago)	146.46	146.88
WA9EAE (Downtown)	146.46	146.64
WA9EAE (Lower Chicago)	146.46	146.88
WA9ORC	146.34	146.76
WA9ORC	52.76	52.525
W9NGI (SRO CFAR)	147.45	147.75
INDIANA		
South Bend area		
WA9GOP	146.46	146.88
No call given	146.94	52.525
KANSAS		
Northeast Kansas		
WAØSNP (Topeka; wideband)	146.34	146.94
WAØOFH (Kansas City; wideband)	146.34	146.94
Under same call: (narrowband)	52.70	52.525
Central Kansas		
No call given (Wideband; coverage from Canton extends to McPherson, Kansas)	146.34	146.94
WAØCJQ (Salina)	146.34	146.94
Southeast Kansas		
WØDKU (Wichita)	146.34	146.94
Covers southeastern and south central portion of state. Input continuously monitored. If output is not operational, a request on the input frequency will bring activation. Narrowband.		
KENTUCKY		
W4MOP (Louisville)	146.34	146.94
K4UCS (Owensboro)	136.34	146.94
LOUISIANA		
New Orleans		
W5UK (wideband)	146.34	146.94
Galliano		
W5MCC	146.34	146.94
MARYLAND		
Baltimore and extended ranges surrounding		
W3DZD (Harmans)	146.34	146.76
WA3DZD	52.525	146.82
No call given	146.22	52.525
MASSACHUSETTS		
W1ELU (Wachusett)	146.22	146.82
No call given (Lenox)	146.25	146.94
(Same system, but directional east-west,	146.25	146.94

activated by tone burst or whistle)		
W1VAK (New Bedford)	146.34	146.94
W1ALE (Concord, N. H.)	146.46	52.525
Covers northeastern portion of Massachuetts; timed for periodic duty cycles.		
W1DRP (Wooster; Boston)	146.34	146.94
Secondary output on:		52.525
No call given (North Adams)	146.34	146.94
MICHIGAN		
Detroit		
K8PZL (Wideband; not open to base stations)	146.34	146.76
Great Lakes Repeater Assn.; Member ALRA		
Pontiac-Rochester		
No call given	146.46	146.94
Kalamazoo		
K8TIW	146.34	146.94
MINNESOTA		
WØPZT (Hennepin County)	146.54	146.85
MISSISSIPPI		
WA5UEG (Bay Saint Louis; wideband)	146.34	146.94
MISSOURI		
Kansas City Area		
WAØOFH (KC, Mo. and Kans.)	146.34	146.94
WAØOFH (KC, Mo. and Kans.)	52.70	52.525
KØOKI	52.88	52.525
WAØAMR (KC, Mo. and east)	146.34	146.94
KØFRA (Occasionally active)	52.70	52.525
St. Louis		
WAØCJW	146.34	146.94
MONTANA		
Butte; Anaconda		
No call assigned yet	146.34	146.94
NEBRASKA		
Omaha		
No call given	146.34	146.94
NEVADA		
Las Vegas		
W7DDB	146.34	146.94
W7DDB (intermittent)	146.94	147.84
Reno		
K7UGT	146.34	146.94
NEW HAMPSHIRE		
W1ALE (Concord)	146.34	146.94
Covers Southern New Hampshire, Southeast Vermont, Northeast Massachusetts. Timed for periodic duty cycles. Both listed repeaters located at same site.	146.46	52.525

K1MNS (Derry) Whistle on. Coverage is same as that listed for W1ALE. Wideband. (New Hampshire FM Assn.)	146.25	146.76
No call yet (Mt. Snow, Vermont) Covers South Vermont, Southwest New Hampshire, Northwest Massachusetts, and Albany, New York. Operated by North-eastern FM Assn.	146.31	146.88
NEW JERSEY		
Call not given (Fords, N. J.) Provides coverage throughout northern area of state.	146.28	146.76
Call not given (Brunswick) Provides coverage throughout state.	146.34	146.94
NEW MEXICO		
WA5KUI (Alamagordo)	146.34	146.94
WA5JDZ (Albuquerque)	146.34	146.94
K5CQH (Albuquerque)	146.46	147.06
WA5DMQ (Roswell)	145.50	146.50
W5PDO (Los Alamos)	146.34	146.94
No call given (Caprock)	146.34	146.94
NEW YORK		
Long Island		
W2GHR (Mt. Beacon, N. Y.) TELETYPE ONLY	52.96	146.70
W1BNF (Connecticut; narrowband)	146.37	146.98
Northern New York		
No call yet (Whiteface Mountain)	146.22	146.76
W2CVT (Mt Beacon)	146.34	146.94
(secondary output)	146.37	146.94
Albany		
W2CVT (Activated by request)	146.94	146.76
W2GHR (TELETYPE ONLY)	52.96	146.70
W1JTB	146.31	146.94
East New York		
K2AE (Schenectady) Operates from approximately 7 a.m. until 11 p.m. daily, under the auspices of the Schenectady Amateur Repeater Club.	146.46	146.94
WB2NNZ (East Central N. Y.) Operated by the TELCO club.	146.34	146.94
W1KOO (Mt. Mansfield, Vt.) Operated by the Burlington, Vermont Amateur Radio Club.	146.37	146.94
W1ABI (Killington, Vermont) Whistle on. Operated by the Northeast Vermont FM Repeater Assn. Member ALRA.	146.34	146.94

Central New York		
K2GVI (Utica-Rome)	146.34	146.94
K2AE (Schenectady)		
Operated by the Schenectady Amateur Repeater Club. Operates from 7 a.m. to 11 p.m. daily.		
WB2NNZ (Troy)	146.34	146.94
Also covers eastern part of state. TELCO club.		
W2DEG (Grafton)	146.22	146.76
W1ABI (Killington; whistle on)	146.34	146.94
WA2VNU (cross-connected system)	146.34	52.72
WA2VNU	52.80	146.76
Syracuse		
W2YRL	146.46	146.94
Buffalo		
K2GUG	146.34	146.94

NORTH CAROLINA

North Central area		
WA4FYS (Burlington)	52.76	52.525
Secondary output		146.98
Western area		
W4WID (Lenoir)	52.76	52.525
W4DCD (N. Wilkesboro)	52.525	146.90
W4DCD (Secondary of cross-connected system)	52.78	52.525

OHIO

Delaware County		
W8AIC	146.34	146.94
Secondary output		146.76
System is a wideband type and may be actuated with a whistle on the input. Replaces W8LGL.		
W8QLS	145.62	146.97
Civil Defense repeater. G. Cryder (W8LGL) operates.		
Toledo		
Call unknown (wideband)	146.34	146.94
Youngstown		
W8IOO	146.34	146.94
Cleveland		
No call given	146.34	146.94
Other areas of state		
No call given (Lorain)	146.34	146.94
W8THC (Newcomerstown)	146.34	146.94
No call yet (Pittsburgh)	146.34	146.94

OKLAHOMA		
Central/Eastern Oklahoma		
WA5LVT (Tulsa)	146.34	146.94
Dual repeater system interconnected for cross-linking. System includes automatic phone patch with Touchtone signaling. Provides greatly extended coverage over much of state. Operated by Tulsa Repeater Assn; Pat Devlin (WA5BPS) is trustee. Member ALRA.	52.68	52.525
Oklahoma City		
No call assigned yet	146.34	146.94
Bartlesville		
WA5LDB	146.34	146.94
OREGON		
K7TBL (Eugene)	146.34	146.94
WA7ANG (Extended coverage over Portland and neighboring cities)	146.76	146.58
No call given (Newport)	146.76	146.94
No call given (Dalles area, from Mt. Livington)	53.46	52.92
No call given (Pendleton area)	146.34	146.76
No call given (La Grande area)	146.34	146.76
PENNSYLVANIA		
Philadelphia		
WA3IPP	146.34	146.76
WA3IGS Cross-connected system	52.80	146.94
	146.94	52.72
Pittsburgh		
K3UQD	146.34	146.94
Alternate system	146.34	146.76
Other areas:		
K3PQZ (York)	146.34	146.76
WA3ICC (Harrisburg)	146.34	146.76
No call given (State College)	146.34	146.76
No call given (Sayreville)	146.40	146.46
RHODE ISLAND		
Providence		
W1CDO	146.34	146.94
Secondary output		52.525
SOUTH CAROLINA		
Call not given (Central portion of state)	52.76	52.525
Call not given (Central portion of state)	146.34	146.94
TENNESSEE		
Memphis		
WA4HBY	146.34	146.94

Nashville		
No call given (Double repeater system)	146.22	146.94
No call given	146.94	146.20
Chattanooga		
No call given	146.34	146.94
Shelbyville		
W4IWV	146.34	146.94
TEXAS		
Fort Worth and vicinity		
No call given	53.05	53.15
W5OZW	146.34	146.94
W5YUO	146.16	146.76
Dallas		
No call given	146.22	146.82
No call given	52.85	52.95
Houston		
WA5QLA	146.28	146.88
Austin		
No call given	146.34	146.94
San Antonio		
No call given	146.34	146.94
Other areas		
WA5LDL (Tyler)	146.34	146.94
No call given (Port Arthur)	146.34	146.94
UTAH		
East border		
WØPXZ	145.32	146.94
Provides coverage from 11,000-ft site at Grand Mesa, Colorado.		
Salt Lake City		
No call given; provides coverage over Northern Utah; wideband.	146.34	146.94
VERMONT		
Central Vermont		
W1ABI (Killington)	146.28	146.94
Northeast FM Repeater Assn.		
Southern Vermont		
No call assigned yet (Mt. Snow)	146.31	146.88
Provides coverage over southwestern parts of state.		
W1ALE (Concord, N. H.)	146.34	146.94
Provides coverage over south and southeast portions of state, overlapping with other states. Repeater timed for periodic duty cycle.		
Alternate system:	146.46	52.525
K1MNS (Derry)	146.25	146.76

Southeast and south parts of state.		
Northern Vermont		
VE2TA (Quebec repeater)	146.52	147.50
W1KOO (Mt. Mansfield)	146.34	146.94
2400-Hz tone-burst entry. Covers northern portions of Vermont and northeastern regions of New York. Operated by Burlington Amateur Repeater Club.		
No call assigned yet (Northern Vermont)	146.22	146.82
No call assigned yet (Northwestern Vermont)	146.22	146.76
VIRGINIA		
Lynchburg		
WB4HCX (Lynchburg ARC; GE employees)	146.34	146.94
Repeater operates wideband input, narrowband output.		
W4GCE	146.22	147.42
Other areas		
K8SXO (Ridgeley)	146.76	52.525
Cross-connected double repeater:	52.525	146.76
W4DXC (Richmond)	52.72	52.640
WASHINGTON (STATE)		
Northern Washington		
VE7MQ (British Columbia repeater)	146.34	146.58
Provides extended coverage in northwest parts of state.		
VE7APU (British Columbia)	147.33	146.58
Provides coverage in northwest, Seattle to Vancouver		
No call given (Seattle)*	146.34	146.58
No call given (Seattle)*	146.76	146.58
*Seattle repeaters interlinked with precedence to 146.34 input.		
W7AJF (Upper state)	146.58	146.76
Eastern Washington		
W7AAG (Spokane)	146.34	146.76
Other areas		
W7DAQ (Longview)	146.76	43.290
Intermittent operation. Precedence given to 146.76 input; double repeater.	53.290	146.76
No call given (Richland)	52.525	53.290
No call given (Yakima)	145.26	147.21
WASHINGTON D.C.		
W3JCN	146.34	146.76
WISCONSIN		
W9ROM (Milwaukee)	146.34	146.94
WYOMING		
WA7EGK (Laramie; Cheyenne)	146.34	146.94

Appendix II

Most FM'ers are aware of the fact that a petition submitted by the Buffalo Amateur Repeater Society is now under consideration by the FCC. The Buffalo petition represents a long-needed change in FCC rulemaking philosophy. Current indications are, however, that certain portions of this petition will be denied. For this reason, the editorial staff of FM Magazine has committed itself to the drafting of a completely new petition based on: (1) urgent needs of repeater owners, (2) current operating and control practices, and (3) sensible and reasonable methods for logging and monitoring.

A conflict of FCC requirements with regard to repeater identification prompted me to query Mr. James Barr, chief of the FCC's Special Radio Services Bureau. I was also troubled by the virtually impossible "time" logging requirements, the varying interpretations of fixed control, and a multitude of other problems, not the least of which is the noticeable absence of repeater references in FCC Rules and Regulations. Here, in part, is the letter to Mr. Barr:

James E. Barr, Chief, Safety & Special Radio Service Bureau Federal Communications Commission Washington, D. C. 20554

19 Oct. 1968

Dear Mr. Barr;

A year ago there were less than one thousand FM amateur radio operators. Today, there are more than *ten* thousand. The vague areas in the Rules (Part 97) pertaining to remote control and repeater operation were unimportant a few months back; today they are being read, reread, analyzed, and dissected by thousands who either: (1) intend to remotely control amateur equipment, (2) do *now* remotely control amateur equipment, (3) intend to own or operate through a repeater, or (4) do *now* own or operate a repeater.

Occasionally, an amateur writes the FCC to interpret a particular passage in the Rules. More frequently, amateurs write FM Magazine to get the editor's opinion. As editor, when I receive queries, I try to be as liberal as possible in my interpretation while staying within the intent of the ruling in question. The FCC's responses, however, are often as puzzling as the Rules themselves.

A few weeks ago, I questioned the FCC about a "three-minute-identification" ruling handed down by an FCC representative. The mandate . . . is a requirement to identify a repeater at three-minute intervals. Close examination of the referenced Rule (Part

97) is at variance with the FCC man's statement. My query about this inconsistency has not yet been answered, but I look forward to a clarification in response to this letter . . .

More recently, another amateur questioned the FCC about remote control. The response, from your office, states that the call signs of all stations using a remote must be logged, and that user stations needed not log the data . . .

Clearly, a definite and growing need exists for a complete definition of the Rules, as I think you'll agree. For this reason, I would like to describe typical remotes and repeaters and show how they are used. Then, I would like to itemize certain of the Rules and show my interpretation. Finally, I would like to question you as to how you would interpret certain listed regulations that are ambiguous.

The reasons for all this are manifold. First, I am writing, under contract to Editors & Engineers, Ltd. (Howard W. Sams, Inc.), a complete treatise on repeaters and remotes entitled "The Radio Amateur's FM Repeater Handbook." Also, as author of this handbook and editor of FM Magazine, I would like to express interpretations of the Rules according to the educated viewpoints of FCC representatives, and publish these opinions . . .

Second, I would like to get a "fix" on the aspects of the Rules where the FCC's interpretation differs from the adopted interpretation (as in the 3-minute ID case), so that a petition can be put into motion to change these areas of the Rules.

Let me describe the operation of a typical remote installation. One UHF repeater (usually operating in the 450 MHz band) is placed in service at a hilltop location. On command from the licensee, a remotely situated base station (usually 50 MHz or 150 MHz) is interconnected with the UHF repeater so that all incoming repeater signals are relayed by the remote base station (and vice versa). Although the remote installation may be licensed to but one individual, there are usually between five and twenty users of the remote operating on the control frequency so as to communicate through the remote base station.

Referring again now, my fourth paragraph, you will see wherein the confusion lies. "User stations" in FCC's eyes are not "user stations" in the eyes of the repeater operators. These individuals consider "user stations" to be UHF repeater users who have the capability of accessing the base station at will. The FCC's definition appears to include all stations *heard* by the base station.

The next point I wish to bring up has more impact and overall significance to remote operation than any other: Frequently in the Rules and in FCC letters are references to control "from the fixed authorized control site." Many amateurs have been afraid to control their equipment from mobile or portable control installations because of the emphasis on "fixed." On the back of an amateur license, however, it states that the control point is "considered . . . fixed," though "operated fixed, portable, or mobile." An FCC statement concurring with this interpretation would be welcomed by all remote operators.

As an added safety measure—and to minimize the congestion on already crowded bands—some repeater owners have installed methods for "subcontrol," which are not covered in the Rules. Let me give an example.

I operate a licensed two-meter remotely controlled repeater at Radio Ranch that is capable of being used at any time the unit is subject to control by the licensee . . . which is virtually a 24-hour-a-day proposition. Some of my associates felt that a continuously operating repeater was not a good thing because: (1) some people would use the input channel to communicate directly, without the need for a repeater, so the repeater would be operating without being used; and (2) some amateurs would transmit on the input channel without an awareness of a repeater, causing the repeater to interfere with possible activity on the output channel.

To preclude these possibilities, I installed a mechanism whereby the entire repeater would shut down automatically two minutes after the last carrier disappears from the input channel. But to regain the usefulness of the system, I also installed a broad decoder at the receiver so that it could be turned back on again by any operator on the channel with the ability to utter a short whistle.

I refer to this as "subcontrol" because it in no way affects my own control, which is ready to turn the repeater on or off regardless of the subcontrol status.

. . . I am apprised that the Buffalo Amateur Repeater Association has submitted a petition to you dealing with operation of repeaters in general. This letter should in no way influence your decision on that. What I am asking for is a fair and liberal interpretation of the existing Rules so amateurs will need not fear using a little initiative in their projects.

I think you'll agree that the "subcontrol" concept is in the best interest of amateur radio; that the "fixed" requirement can be interpreted more broadly; and that three-minute identification for repeaters is only necessary in explicit compliance with Part 97.87 (a) (i) (ii) and (iii).

. . . Most of us who own and maintain repeaters are sympathetic with the FCC on (logging). We realize that the Rules were written before the advent of repeaters, and therefore that the FCC has no choice in the matter. Speaking for all FM'ers, however, I ask your indulgence with respect to logging. Be particularly liberal here, and remember that amateur radio will not best be served by strict enforcement of outdated Rules. The need now is for *reasonable* and *just* interpretation of excessively stringent requirements. The Rules were set down when amateur radio was in its infancy. The FCC has always been an agency that relied heavily on "intent" rather than the "letter" of the law. The logging intent, as I understand it, was to provide legal evidence of a person's activity in the event of eventual questions regarding that station's operation. This intent could be served by the following:

1. Log the time at which the repeater is activated.
2. Log the time that it is shut down (for repair or other reason).
3. Log all changes in power, radiation characteristic, etc.

Mr. Barr, you will acknowledge, I'm sure, the fact that the FCC does have the power to delineate policies at variance with the Rules. As an example, I make reference to the stated requirement in the Rules (Part 97.-103b) where a log must show the signatures of all amateurs who key the transmitter. The FCC, recognizing the impossibility of this, made a prima facie exception to the Rules in this regard. I call upon you now to make another exception. I ask you to consider a repeater in the same permissive light you consider a mobile, which (Part 97.103a) requires a log entry only (1) at the time of initiating mobile operation and (2) at the time of completion of mobile operation. . .
Very sincerely yours,
Ken W. Sessions, Jr.
K6MVH
Editor, FM Magazine

And here is Mr. Barr's response:

Dear Mr. Sessions:
I have asked Mr. Everett Henry, Chief of the Amateur and Citizens Division, to look into the various problems raised in your October 19 letter, and a further response will be made. It occurs to me, however, that your principal concern is basically the fact that present Rules may not be compatible with current conditions and practices. This seems to me to call for a change in the Rules, rather than for a strained interpretation. You may want to try your hand at redrafting the troublesome Rules and submitting a formal request for amendment. See Sections 1.401 through 1.427 regarding procedure.

Sincerely yours,
James E. Barr

A few weeks later, this letter came:

FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554
October 30, 1968

In reply refer to:
7501

Mr. Ken W. Sessions, Jr.
Editor, FM Magazine
4861 Ramona Place
Ontario, California 91762

Dear Mr. Sessions:

The Amateur Radio Service rules do not specifically provide for the operation of repeaters. Repeaters which are now in operation are authorized under the provisions of Section 97.43, and licensees are expected to fully comply with all the requirements pertinent to remote control by radio if they are so authorized.

Section 97.43 is specific in requiring, among other things, that the authorized remote control point be located on premises controlled by the licensee, and that control by radio shall be on frequencies above 220 Mc/s. No exceptions to these requirements have been made, nor have exceptions been made with respect to the requirement that the licensee monitor the station's transmissions from the control point at all times the station is in operation. The Commission has consistently held that the authorized remote control point must be at a fixed location specified on the station license. The language used in the conditions of grant printed on the reverse side of an amateur license in no manner changes the foregoing.

The transmitters used to meet the requirements of Section 97.-43(b) (6) must operate on amateur frequencies above 220 Mc/s. However, this requirement does not preclude the use of "sub-control" signals transmitted on the repeater input frequency for the purpose of triggering the repeater. Such sub-control, if used, must be in addition to the required control circuits on 220 Mc/s or higher.

The logging requirements of 97.103 are applicable to repeater stations. However, in recognition of practical problems engendered by the requirements of Section 97.103(b), the Commission has informally permitted the requirements of that section to be met by entering a statement in the log that the station is operating as a repeater.

Section 97.87(a) (1) (ii), which was in effect on August 25, 1967, provided for station identification at the beginning and end of a series of transmissions, each transmission of which was less than three minutes duration. In view of the nature of repeater operations and licensees' responsibility for identification under that paragraph of the rules, the Commission decided that licensees could, if they so chose, use automatic identification at three minute intervals in lieu of the foregoing requirements. This was consistent with the overall requirements for station identification in effect August 25, 1967, the date of the Commission's renewal of your operator and station licenses. Since this permission is, in effect, a blanket waiver of permitting identification in a manner different from that required by the rule, it is the Commission's prerogative to impose conditions in the waiver which, in its judgment, are desirable.

It appears that the typical installation described in your letter may not comply with the rules. However, this conclusion may result from different connotations being placed on the terms base station, repeater, and control. You refer to the operation of your repeater subject to control from the licensee. The repeater may be operated under the call sign K6MVH only when you, the licensee, are present at the control point. When Mrs. Sessions is in control of the station, during your absence from the control point, the station must be identified by her call, WA6SPT.

Your responsibilities to your readers as an editor and an author are, of course, recognized. However, interpretation of the Commission's rules is the responsibility of the Commission, and the intent of the rules may not always be obvious to the reader, since rules are written to meet both the administrative and regulatory responsibilities of the Commission.

I'm sure you realize that the Commission cannot delegate its regulatory responsibilities. Accordingly, it would seem prudent to obtain the Commission's views on questions concerning the meaning of the rules prior to publishing interpretations.

The Buffalo Amateur Repeater Association and other groups have filed petitions proposing amendment of the amateur rules to provide for repeater operation. These petitions are being considered at the present time, and a Notice of Proposed Rule Making will be issued in the reasonably near future. During the pendency of these petitions, the Commission will adhere to its present rules and the above-mentioned exceptions permitted repeater stations to avoid any action prejudicial to the disposition of the petitions.

You may submit comments on the Buffalo and other petitions if you so desire. Copies of these petitions may be obtained through Cooper-Trent, 1130 19th Street, N. W., Washington, D. C. 20036, who has the official contract for the reproduction of Commission documents.

The procedure for submitting a formal request for rule amendment are in Section 1.401 and 1.427 of the Commission's Rules. These sections are included in Volume I which may be obtained from the Superintendent of Documents, Government Printing Office.

Sincerely yours,
E. G. Henry
for James E. Barr
Chief, Safety and Special
Radio Services Bureau

Enclosures - 2

cc: Mr. M. Van Den Branden
2005 Hollywood Street,
Grosse Pointe, Michigan

Appendix III
Proposed Rules

PROPOSED RULES

The FCC Rules have a section devoted to definitions. The first order of business would be to include an accurate definition of the term repeater. (Present Rules make no mention of repeaters.)

Definition:

> *Amateur Repeater: An automatic relay station which retransmits information from one amateur frequency onto another, and which is operated in accordance with the class of license held by the authorized licensee. (Unless otherwise noted, all Rules pertaining to amateur stations shall also apply to amateur repeaters.)*

In order to demonstrate to the FCC a willingness on the part of repeater owners to provide communications capability without adding to the congestion, FM Magazine will propose that repeater outputs be legal only on frequencies above 51 MHz (where duplex is condoned and AØ emissions are permitted). Also, FM will propose that a relaxed form of "subcontrol" be authorized, so that the repeater shuts down when not being used and can be reenergized by a simple "repeater input" control scheme, such as a whistle-on decoder or the equivalent. And since the FCC obviously will not sanction unmonitored repeaters, FM will further propose that partial control (for off commands) be designated to other amateurs than the licensee. In this way each repeater may have as many "authorized monitors" as necessary to assure continuous compliance with the Rules, while the licensee himself can be freed from the burden. A "monitor" will have the capability of commanding the system to shut down but not to turn it on again:

> *Means shall be provided for* ***automatic*** *timed shutdown of the repeater when it is not in use. A means for reactivating the repeater from the frequency of use may be included provided that such control can be overridden by a turn-off command from an authorized monitor or the licensee, and provided that such turn-off is irreversible except by direct command of (1) an authorized amateur at the repeater site or (2) remotely transmitted control signals (by wire or radio, as authorized) from the fixed control point.*

In recognition of the fact that a repeater is not an ordinary amateur station, FM proposes a method of licensing all repeaters, whether controlled locally or by remote. This proposed entry will be proposed as a change to FCC Rules, Part 97.43(d):

97.43(d)
An amateur station (including a remotely operated amateur station) may be operated as a permanent repeater provided that the FCC Form 610 is accompanied by sufficient information to show compliance with paragraph (b) (1) through (5) of this section (as applicable) and that supplementary information is submitted therewith which shows: (1) frequency and type(s) of emission to be received and retransmitted by the repeater, (2) frequency and type of emission to be employed by the transmitter, provided that no repeater shall transmit on any frequency below 51.00 MHz, (3) type of activation or method of access (continuous carrier, carrier-operated, tone activated, etc.), (4) method for automatically shutting down the repeater when it is not in use, remotely controlled or operated from an authorized amateur station, and (5) names, addresses, and signatures of all amateurs who will accept responsibility for monitoring the repeater output, provided each has the capability of immediately suspending repeater operation should the emissions deviate from the terms and conditions of the FCC Rules and Regulations (although in no case will multiple shutdown authority be construed as a Rule which relieves the authorized licensee from this responsibility).

The existing logging requirements are truly inapplicable to repeaters, although still a requirement. FM believes the intent of the ruling can be satisfied without detailed logging of time and date of each transmission. The tentative proposal is as follows:

97.104 Repeater log requirements. (a) Each licensee of an authorized repeater station shall be responsible for maintaining, at the transmitter site, an accurate log of repeater operation, which shall include the following:

1. *The date and time the repeater is placed in service.*
2. *The date and time the repeater is shut down by by the licensee or is inaccessible for any reason by the amateurs who operate on its input frequency.*
3. *The input power to the repeater transmitter's final amplifier. (This must be entered after each period of shutdown.)*
4. *The frequency being repeated and the frequency of transmission. (This information need be entered only once unless there is a change in input or output frequency.)*

5. *The type of emission used. (This need be entered but once unless there is a change in emission type.)*
6. *The method of activation; e.g., carrier-operated tone-operated, continuous-transmit, etc. (This need be logged but once unless there is a change in activation method.) Where tone-operated, the access tone frequency must be shown in the repeater log.*

(b) The repeater must at all times be monitored by an authorized amateur with the capability of suspending operation in the event the emissions are not in compliance with the Rules. (Authorized monitors are to be listed in accordance to paragraph 97.94-(d) (6). Each authorized monitor must show on his own station log the period for which he accepts repeater-monitoring responsibility. This information will consist of: (1) date and time monitoring duty is assumed, (2) name and call of previous monitor, (3) date and time at which monitoring responsibility is relinquished provided that it will only be relinquished to an authorized monitor in accordance with paragraph 97.94(d) (6), and name and call of amateur to whom monitoring authority is released. In the event that no monitor is available, the repeater shall be shut down by the last appointed monitor pursuant to the terms and conditions of 97.43(b)(4), and an entry made in that monitor's log to show date and time of shutdown. The shutdown shall be of such finality that resumption of service can be accomplished only by in-person attendance of an authorized amateur at the repeater site or, in the event of remote control, a command signal from the authorized control licensee.

Repeaters, like amateur stations, should be identified periodically, but the identification need not be of the same nature as a conventional amateur station. So, to add paragraph (v) to Part 97.87, FM proposes the following modification:

(iv) Continuation from para. iv. . . . . at least once every ten minutes during any single transmission of more than ten minutes duration, except that:

(v) in the case of a repeater, the repeater may be identified automatically each time the repeater is keyed and at intervals of two minutes thereafter until cessation of transmission or each two minutes of on-the-air repeater time.

As the last entry is 97.87 (b), immediately preceding 97.87 (c), FM proposes:

Where a repeater identification is to be made automatically, such identification shall be in compliance with paragraph 97.87(a)(1)(v), and may consist of a recorded or syntheti-

cally generated sequence (voice or Morse code) containing not less than the assigned call letters of the repeater.

Well, there it is so far. Since rule-making is a serious business and one of lasting significance, every single repeater owner should look over these proposed changes, and make deletions, additions, or corrections, as applicable. By hashing and rehashing, the FM repeater communities will come to terms with the problem of rulemaking—and the result will be a sound and workable set of constraints that are not too binding nor too lax for effective implementation.

Index