A historical view of VHF Coordination

Bryan Fields, W9CR[1]

Introduction

Amateur radio has a long history of VHF operation, and pioneered the use of repeater systems in the VHF bands. Current amateur operations on the two-meter band find their roots in historical two-way radio systems utilized by public safety and commercial communications. Commercial use rapidly expanded in post WWII America, led by many amateurs who were pioneers in the commercial space. The current amateur bands and allocation standards in use today are direct descendents of these first commercial users. In many ways, amateurs have driven new technological discoveries but commercial users allowed amateurs to achieve critical mass via cheap surplus equipment regulated out of commercial use.

The First One/Two-Way Radio

Before there was Two-Way Radio there was One-Way Radio. One-Way Radio was broadcast to all cars, and when a car would hear a message, a police call box was used to respond. It was in essence an audio pager service, operating over standard AM broadcast radio. This use was not permitted by the Federal Radio Commission ("FRC")[2] who much like its successor, the Federal Communications Commision ("FCC"), did not leave room for experimentation or novel ideas. Detroit was the first police department to use One-Way Radio in the 1920s and worked within FRC regulations through running its own entertainment broadcasting station, KOP[3]. Between announcements of missing cars and police business, music was played for the benefit of the general public. This latter part enabled the police department to hold the broadcast license.

The FRC took notice of this and licensed an experimental dedicated police transmitter above the AM band at 1650 kHz[4]. This started regular operations in April 1928 using

---

[1] bfields@fasma.org

[2] The FRC was formed in 1927, the FCC took over in 1934 (Regulation of Wireless Communications Systems pg. 25)

[3] *Milestones: One-Way Police Radio Communication*

[4] Van Wagenen, Juliet. "The First Police Radio Stopped Bootleggers in Their Tracks." StateTech , 9 June 2017, Accessed 22 May 2022.

modified broadcast radios as receivers[5] and was used until the deployment of AM two-way radio in the mid 1930s. Bayonne, NJ was the site of the first deployment of true Two-Way Radio which revolutionized police communications. These early systems utilized AM at HF frequencies (8.6 Meters/31 MHz)[6], which had a number of drawbacks, perhaps the worst being car ignition interference. The size of these systems in terms of receiver and transmitter was substantial and power requirements would rapidly drain a car battery if left on without the engine running. Duplex communication was not possible, for a number of reasons from frequency to squelch circuits of the day performing poorly with AM signals.

As the 1920s gave way to the 1930s it was not uncommon for each local police department to have its own One-, if not, Two-Way Radio system. Most remarkable was the homebrew nature of these systems; many of the radios receivers used were modified broadcast band superheterodyne units operating anywhere from the 1,600 kHz to 3 MHz range. Bosch was the first company to produce a radio for police communications, soon followed by Sparton, RCA, GE, F.M. Link and Galvin Manufacturing under the Motorola brand. All of these radios shared the same basic designs: amplitude modulation, free-running variable-frequency oscillators (VFOs), operating in the MF or HF frequency bands, and limited effective range[7]. AM and MF/HF did not scale as more and more departments signed up and certainly did not provide a working return talk path. State level departments were especially hard hit as the range was woefully inadequate to cover more than a county.

The Birth of VHF FM Two-Way Radio

Frequency Modulation (FM) was not novel nor “discovered” by Armstrong as many believe, but rather the development of Wide-Band FM was his contribution along with many practical circuits for its use. Wide-Band FM, where the deviation swings a much wider amount around it’s carrier frequency[8] was found to be greatly resistant to static and other man-made interference. While Armstrong battled RCA and moved for FM broadcasting on the UHF spectrum (50 MHz), many took notice of the benefits FM could have for Two-Way Radio.

FM of the day was rather simple. Deviation was anywhere from 15 to 45 kHz, there was no splatter filter, modulation frequency was 0 to 5,000 Hz, limited by the microphone[9],

[5] “AM_expanded_band in the United_States.” Wikipedia, Accessed 22 May 2022.
[6] “Police Use Two-Way Radios in American Cities.” Popular Mechanics, Dec. 1933, pp. 808–808.
[7] Noble, Daniel E. “The History of Land-Mobile Radio Communications.” Proceedings of the IRE, May 1962.
[8] ”Frequency Modulation: Modulation Index.” Wikipedia
[9] Karthikeyan, A. “Carbon Microphones.”

and receivers were as basic. What radically improved performance was the advent of the quartz crystal oscillator. Starting in the 1930s Bell Labs developed manufacturing processes to mass produce quartz oscillators[10]. These were still natural crystals, as synthetic quartz was still decades away, but now a radio could be held to 0.05% (500 ppm) stability, enabling operation on the "UHF" spectrum above 30 MHz.

> The reasons to move above to modern day VHF FM were many, but chief among them:
>
> - Practical antenna sizes for vehicles, a ¼ wave antenna whip was 7' or 2m
> - Lower natural noise than the MF/HF bands
> - Greatly reduced ignition pulse noise from engines
> - No long wave propagation and resulting interference
> - More channels for more users
> - Privacy from users monitoring with broadcast receivers
> - Vacuum tube receivers could be operated with very high gain, even as they aged
> - Transmitters gained 3+ dB power output as they no longer needed to be linear
> - Receiver audio volume was consistent, even with weak signals
> - *Capture effect allowed reuse of frequencies between different areas*

In 1937 the newly formed FCC established rules for the frequency bands above 30 MHz[11]. As part of this channels were assigned for Two-Way radio spaced every 60 kHz. This would be updated in 1939 to 40 kHz for 25-50 MHz, 60 kHz for 148-162 MHz, and 100 kHz for 450-470 MHz.

The first state-wide VHF FM Two-Way radio system was installed for the Connecticut State Police in 1939 by Fred M. Link & Daniel Noble[12]. This was a novel design, not only for its coverage or choice of FM but general engineering practices which set the standards for VHF Two-Way Radio in the decades to come. The system consisted of a remote base transmitter on 39.400 MHz and mobile units on 39.180 MHz. The base receiver was situated on high ground, and linked back via a 4 wire phone link to the local state police office. The frequency split was not for a repeater operation but rather allowed different state police regions to use the same frequency leveraging the capture effect of FM and ensure the cars in their region would receive the strongest transmitter. This was the reason for the split frequency operation; adjacent base stations did not compete with mobile transmitters. Car-to-car communication was enabled via an additional crystal in the mobile allowing the transmitter to talk on the base frequency.

[10] Murphy, Richard. "Canadian Inventions – The Quartz Clock."
[11] FCC Order No. 19, October 13, 1937
[12] Fors, Geoffrey C. "*General Electric FM MOBILE RADIO HISTORY: Part One, 1940 - 1965*," Feb. 2022.

This Connecticut system proved the superiority of VHF FM Two-Way Radio for land mobile use.

This “simplex” base station was standard for VHF dispatch well into the late 1970s. The split of 200-400 kHz between frequencies (or spread of all if greater than two channels) was due to radio circuits not having the wide bandwidth we know today. Until the 1990s crystal controlled two-way radio had fixed tuned receiver and transmitter circuits, 400-500 kHz was typical even in solid state radios; tube transmitters were 250 kHz at best. Receivers were primitive in this system, IF filters were 50 kHz wide at 6dB, squelch was basic, and frequency spacing (channel raster) was empirically based on this performance.

The FCC designated such simplex use as a “Base Station”, which was significantly different from a “Mobile Relay Station”. The Mobile Relay Station class is what we would term as a repeater, and the use of such was held as a non-efficient use of spectrum in the 150 MHz bands. Even police/public safety use was a special application and waiver requirement from the FCC. Commercial use was summarily dismissed even if a case could be made.[13]

Early Amateur Operations on VHF

Amateur radio operations prior to WWII on VHF (or at the time when UHF was anything above 30 MHz) was on the 5 meter band (56-62 MHz), but with CW only. AM was a complex mode at the time and even on the HF bands the use of AM was not widespread. In 1934 Amateurs received rights to all bands above 110 MHz, and 112-120 (2-½ Meters), and 224-240 MHz (1-¼ Meters). These bands were proposed by the ARRL due to the harmonic relationship from 5 meters. Of note these frequencies do not match the eventual FCC rules for these bands, as frequency tolerance of the day was poor and bands were defined via wavelength rather than frequency[14]. It was common for a station calling CQ to call for minutes, giving the other station time to tune the entire band. Constant adjustment of frequency was needed during reception and heating and cooling of transmitters would cause wide frequency shifts, 200-800 kHz was normal.

By 1938 the FCC had imposed new regulations on amateurs at 5 meters, crystal control transmitters became the norm improving stability. 112-116 and 224-236 MHz were

[13] Regulation of Wireless Communications Systems pg. 50
[14] Kaufhold, Kevin. *ON THE ULTRA HIGHS: A History of Amateur Radio VHF Activities*. pg. 67

expressly defined for amateur use in this same action[15]. AM was becoming more popular on 5 meters, but CW was still supreme. Channels as we know now were not a concept in amateur operations at this time.

World War II

Amateur operation was prohibited from December 8, 1941[16] until the end of the war. This was not unexpected, as the FCC had prohibited communications with foriegn hams from June 1940.[17] With the limited exception of W1AW, amateur radio operations ceased. Domestic Two-Way was not affected, but no new systems were installed during the war. Unless a clear civil defensive use could be shown, no new systems were permitted.

During this time, 2-½ meters was used by the War Emergency Radio Service, WERS[18], and many amateurs took part in weekly nets using these frequencies. Commercial radios were produced, but many amateurs were encouraged to build their own as well, as wartime restrictions on supply made it necessary to scavenge equipment. These radio sets used VFO based transmitters, as crystals were in short supply due to the war.

During the war, FM radio for battlefield communication quickly proved its use. The Signal Corps fielded many radio sets on VHF, all crystal controlled and mostly FM. These rugged sets permitted quick and clear voice communications amongst the US and its allies during the war. Importantly for amateurs, tens-of-thousands worth of radio sets were available as surplus after the war.

Following the war amateurs received quick permission to operate on 235 MHz; followed by 112 MHz August 21, 1945. The next month the US participated in the Third Inter-American Radio Conference held in Rio de Janeiro September 1945[19]. This conference established the modern VHF band plans for Broadcast, Two-Way, Aviation, Amateur and other services. Coming out of this conference, radio amateurs gained 144-148 MHz, 220-225 MHz and many of the present day microwave bands.

---

[15] Kaufhold, Kevin. *ON THE ULTRA HIGHS: A History of Amateur Radio VHF Activities*. pg. 74
[16] "WAR COMES! / FCC Order #87, December 8, 1941" QST, Jan 1942
[17] "Foreign Amateur Communications Banned." FCC Order #72, June, 1940
[18] "War Emergency Radio Service." Wikipedia
[19] I cannot find the records from this meeting. The national archives doesn't have a copy, nor does the ITU secretary as it was not an ITU meeting. If anyone can help on this it would be greatly appreciated.

Growth of Two-Way FM

Commercial Two-Way FM use began in earnest during the postwar boom. Motorola and GE both leapt into the FM two-way radio business (along with others), and the growth of licensees went from a few thousand in 1940 to 86,000 in 1948, 695,000 in 1958, and 1,390,000 by 1963[20]. This growth of users quickly showed the deficiencies of the early radios in use. Selectivity was poor, 50 kHz or more at -6 dB and 200-300 kHz at -60 dB, albeit helped by the small tuning range of the equipment. Transmitters were just as bad, there was little testing for spectral purity, frequency stability and deviation was 18-45 kHz with no limiter, splatter filter, or low pass audio filter. These problems did not manifest when there were a few dozen users in an area, but came to a head in the post war growth period. Input modulation (microphone) did not consider the use of a low-pass filter to restrict frequencies above 3,000 Hz as the standard carbon microphones of the day were unable to respond at such a high frequency.

The FCC rules established the following channel sizes[21]:

- 25 - 50 MHz: 40 kHz
- 148-158 MHz: 60 kHz
- 450-470 MHz: 100 kHz

These may seem wide, but considering the original rules from 1943 for FM:[22]

> Frequency modulation may be used in the emergency radio services on frequencies within the 30,000 to 40,000 kilocycles band provided:
>
> - (a) Tolerance. The carrier frequency shall be maintained within a tolerance of .01 percent of the assigned frequency. (See §§ 2.11 (b) (c) and 2.12of this chapter)
> - (b) Modulation limits. The total frequency swing arising from modulation shall not exceed 75 percent of the frequency separation band width. [Order, Sec., Sept. 16, 1941; 6 F.R. 4800]

This limit of .01% at 39 MHz is 3,900 Hz. Given the 15 kHz wide FM with 5 kHz wide signal, it is possible it could extend a bit outside of that range if the frequency was off. At 158 MHz this “stability” could be as much as +/-15 kHz from the carrier frequency so 60 kHz channels were chosen as an easy way to contain the entire signal.

---

[20] Noble, Daniel E. “The History of Land-Mobile Radio Communications.” pg. 1410
[21] FCC Industrial Radio Services, 47 C.F.R. § 11 (1953) §11.104, §11.254
[22] FCC Emergency Radio Services, 47 C.F.R. § 10 (1943)

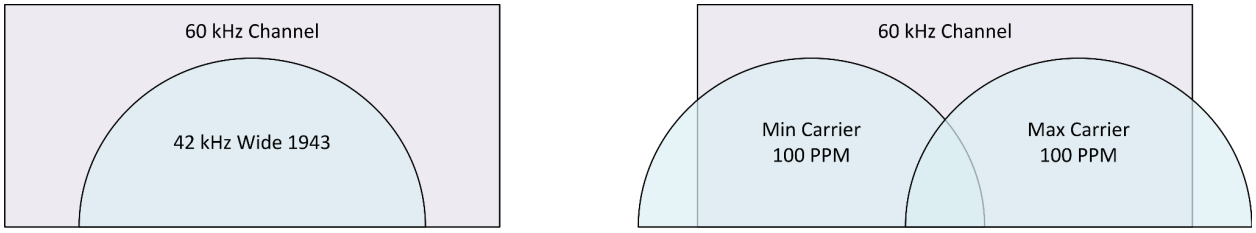


Figure 1. - Showing the signal in it's channel and the worst case actual location of the carrier

By 1953, the FCC imposed the first limits on FM in it's rules[23]:

CFR 1953 - Part 11-Industrial Radio Services

- §11.104 - emission limits on FM: **40 kHz**.
- §11.105 - Modulation requirements
  - (a) Max audio frequency is 3000 Hz
  - (c) Max deviation for FM is 15 kHz
  - (d) Any transmitters after 1950 must include a limiter, unless it's low power (under 3w)

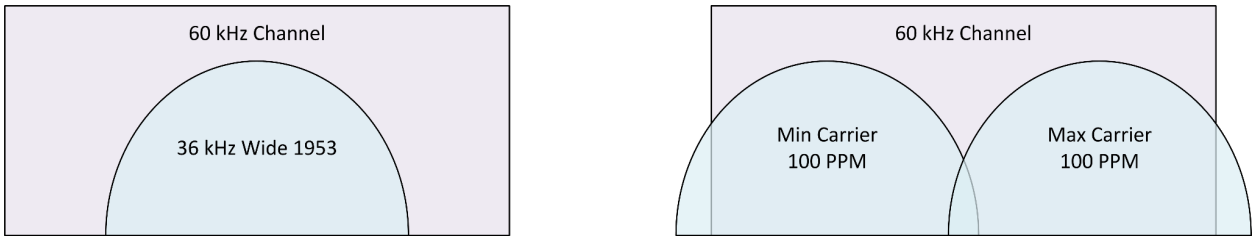


Figure 2. - FM signal in it's channel and the worst case actual location of the carrier (1953)

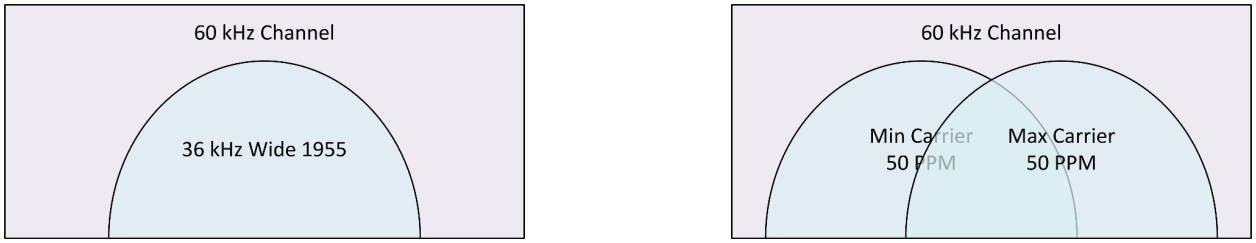


Figure 3. - FM signal in it's channel and the worst case actual location of the carrier (1955)

These requirements set standards which could be met by the basic tube type equipment of the day. Frequency stability was increased not by the FCC, but rather private industry[24] as a means to increase reliability of their customers' communications systems. Commercial frequency coordinators immediately were able to use this increased stability to further split the 60 kHz channels into 30 kHz channels. As an

[23] FCC Industrial Radio Services, 47 C.F.R. § 11 (1953)

[24] FCC Narrowband NPRM Docket 11253 Section 8: "Major equipment manufacturers producing ovenized elements are now commonplace."

analog FM signal does not occupy the entire 38 kHz bandwidth 100% of the time, offset channels spaced 30 kHz apart are usable with minimal overlap.

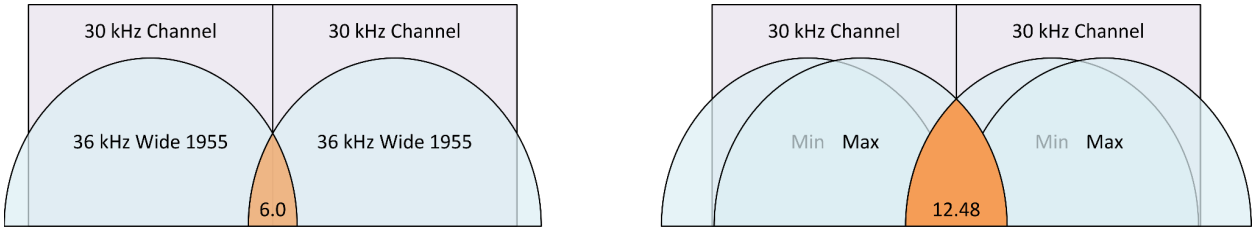
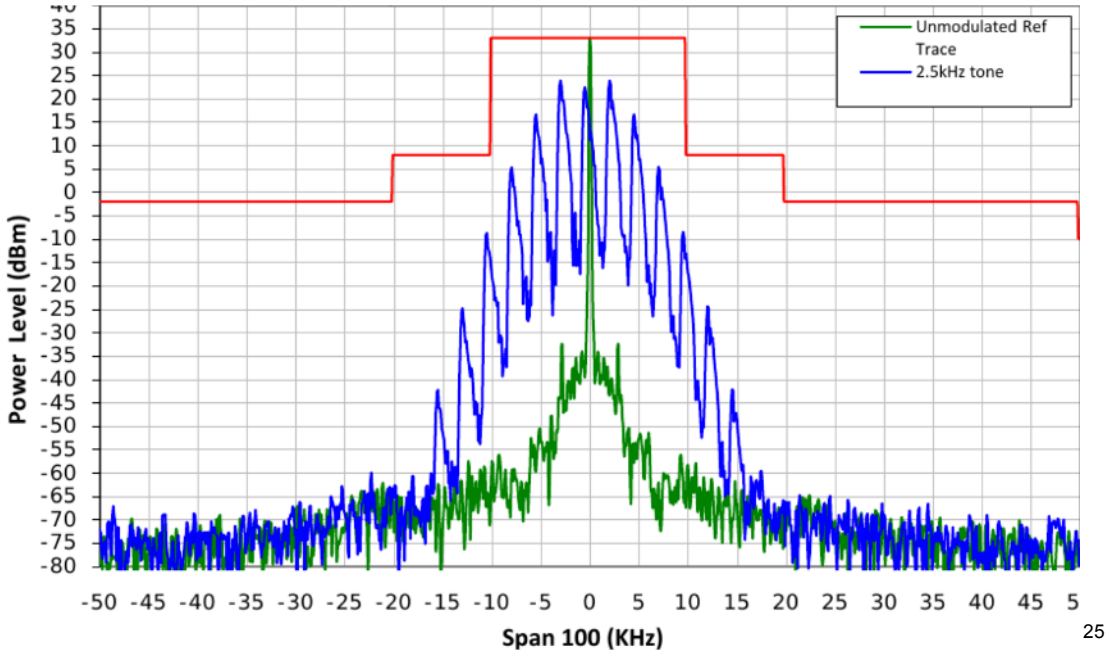


Figure 4. - Two Wide Band Carriers in 30 kHz split channels (1955)

This is easily understood in that the power of an analog FM signal decreases or rolls off the further away from the carrier it is measured, and its bandwidth will only be at maximum or close to during loud and high frequency modulation. Thus in the overlap between two channels the energy falling into the channel from the adjacent transmitter will only be there at modulation peaks, and be at a much lower level than the on carrier signal. Combined with the capture effect of FM, this ensures adjacent users will not materially degrade communications of receivers in their assigned coverage area.

In the first image a modulated and unmodulated FM signal is shown. Note how the power drops off from the carrier frequency.



[25]

[25] TIA/EIA TSB-88 reference data - This reference has the spectrum masks for most commercial radio modulations in use today. There is direct comparison between each modulation and adjacent channels of varying offset.

Figure 5. - the bandwidth of a modulated and unmodulated 5 kHz FM signal

In the next image, adjacent users are shown, and the little bit of bleed over signal is minimal. In all cases, power of adjacent users would not be equal to the intended user, and these overlap signals would be at even lower levels. Frequency coordinators are trained and have standards for this when suggesting frequencies for commercial and public safety users[26]. The FCC also expects users to monitor before use.[27]

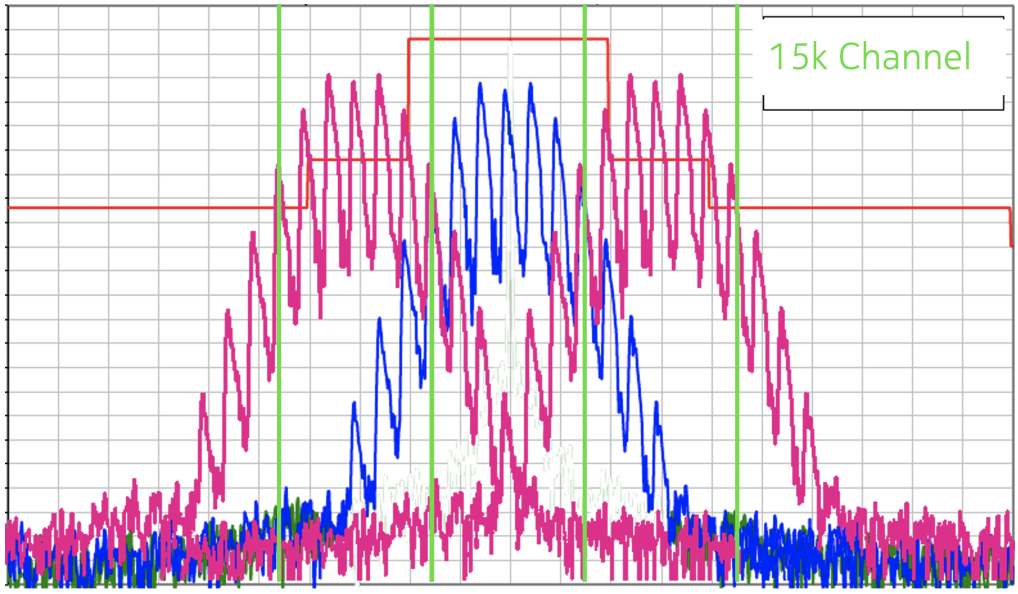


Figure 6. - Co Channel fully modulated FM signals overlap

Starting in July 1951 and through December 1954 the FCC's Joint Technical Advisory Committee formed a Subcommittee to study the feasibility of "splitting" the channels in VHF (152-162 MHz) band from 30 to 15 kHz. There was much input from industry, commercial users and public safety to the subcommittee. Two years prior in 1949, GE demonstrated the viability and audio quality of 5 kHz deviation FM compared to 15 kHz FM in Syracuse NY, for commission representatives. This proved the "narrowband" audio quality was substantially similar and performed within 3 dB of standard wideband FM.[28]

In January 1955 the JTAC subcommittee published a remote on their findings to the the commission[29]. This was compiled into the NPRM 11253, and submitted for public comment in January and extended[30] through May of 1955. Over 130 comments were

[26] TIA/EIA TSB-88 and other standards are used
[27] Regulation of Wireless Communications Systems pg. 83 Paragraph 3
[28] McCormic, J. A. "MILESTONES IN THE LAND-MOBILE RADIO SERVICE," GE, Sept. 1966
[29] Regulation of Wireless Communications Systems pg. 174
[30] FCC Narrowband NPRM Docket 11253 extension, 20 Fed. Reg. 65 (April 2, 1955) pg. 2090

filed, about 40/60 % against/for the proposal, but few hard recommendations other than from vendors and the JTAC committee. The FCC found the state of the art reasonably permitted use of 15 kHz channels with +/- 5 kHz deviation FM would support the public's communication needs.

> In the light of the comments filed , and of the Joint Technical Advisory Committee (JTAC) reports which have been made a part of this record , the Commission concludes that the state of the radio art is such as to permit a reduction in channel spacing without significant degradation of service, and that it is in the public interest to go forward with this matter at this time[31]

This report and order required the existing equipment be modified or replaced by October 31, 1963, and a ban on new wideband equipment authorization after October 31, 1958. This was a rather fast sunset period, compared to the new narrowband process of the mid 1990s finally sunsetting in 2013[32]. This shows the early FCC realizing the immediate need to push technology forward, inconveniencing the rather small number of licensees in the mid 1950s. Even waiting just a few years would have had most of the USA major markets airwaves packed full and no free channels for newcomers. If this was allowed to happen the two-way radio industry may have never grown at the rate it did in the 1960s.

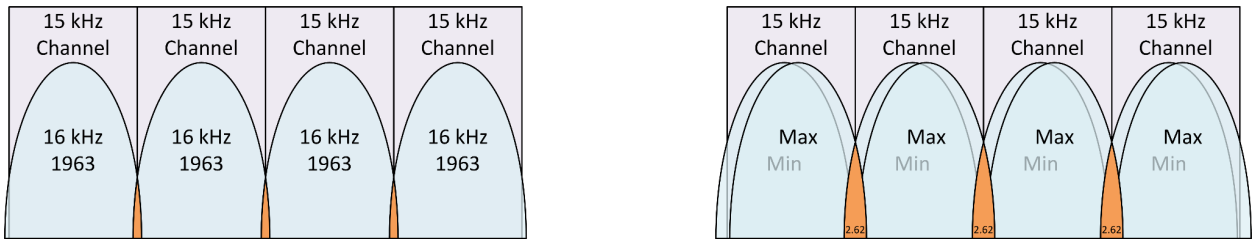


Figure 7. - four 5kHz (NBFM) carriers in the space of one 60 kHz channel (1963)

What this provided for amateurs was a massive glut of equipment not legal for use on the commercial spectrum. The post war amateur technician licensing boom and proximity of the new amateur bands primed VHF FM to become the dominant mode through the next five decades.

[31] Decisions and Reports of the FCC March, 1939 to June 30, 1965 Vol. 39, pg. 490
[32] Bercovici, Martin W. "FCC Narrowbanding Mandate: A Public Safety Guide for Compliance." pg. 6 discusses refarming starting in 1991 and Regulation of Wireless Communications Systems pg. 178 The FCC discusses this in NPRM 95-255 which in section III mentions this was started in 1991.

The Booming 1960s

In the 1960s amateur radio FM repeaters took off. Pioneering work took place in repeater design, with the advent of surplus wideband crystal controlled Two-Way FM equipment.

The first inkling of amateur two-meter FM was by James Aagaard, K9OJV[33]. The W6FNO 146.70/146.82 was one of the first FM repeaters in Los Angeles as well[34]. It was in this initial time that the two-meter sub-bands as we know it were created. These bandplans were forged at the intersection of FCC rules, technical possibility and the capabilities of the equipment of the day.
The first two-meter band plan largely copied the channelization of the commercial spectrum of 60 kHz channels in the 146-148 MHz portion of the two-meter band. It was not until 1978[35] when the FCC removed the requirement for a separate license requirement for repeaters. It was this same major overhaul which created the 144.5-144.5 repeater subband and eliminated the requirement to record all traffic via the repeater.

Equipment was generally surplus GE or Motorola tube wideband radios with crystals and tuning for the lower ham band. This surplus equipment was tube-based and had a narrow tuning range of +/- 250 to 400 kHz. As the hams of the day were using crystal control on FM, one or two crystals would be all they may need. The old wideband commercial radios were perfect for such a use, at least for a mobile station.

Looking at the regulation for these first repeaters in amateur radio from 1959-1972 the following requirements existed (amongst others):

- Must be between 146-147.9 MHz
- If open for tech use, 146-147 MHz
- All transmissions must be logged

---

[33] Aagaard, James S. “Two-Meter F.M. for Noise-Free Local Communications.” *QST*, July 1960, pp. 33–35.
[34] Sessions, K. W. (1969). Radio Amateur's F-M Repeater Handbook.
[35] FCC Rules to Simplify the Licensing and Operation of Complex Systems of Stations and Modify Repeater Subbands in the Amateur Radio Service Docket No. 21033, 43 Fed. Reg. 71 (April 12, 1978). pp 15334 - end

This is the major rewrite of repeater rules where the repeater licensing and logging requirements were removed. The modern repeater rules stem from this.
Excerpt for this

- Must describe, in detail, the control circuits to meet FCC regulations[36]

As amateurs took their frequency spacing from the commercial users wideband layout of 60 kHz, The first channel was 146.040 (band edge +10 kHz guard and 30 kHz lower half) and then every 60 kHz until 147.840. This gave 11 channels as follows:

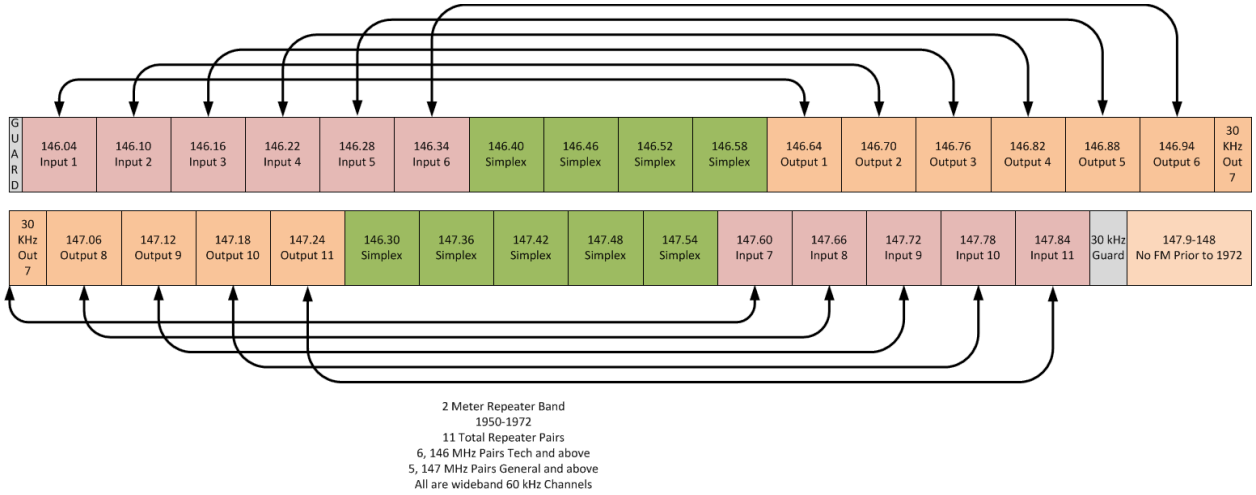


Figure 8. - 2 meter repeater band 1950-1972

This presented a difficult problem for repeater frequency selection as FCC rules on technician licenses limited them to 146-147 MHz[37]. If a repeater wished to be available for technician license use, it had to receive and transmit within 146-147 MHz. The transmitter and receiver at the repeater site had to work simultaneously in this narrow 1 MHz band. Simple physics shows it is easier to filter frequencies further apart than close together. Taking into account the tuning range of the radios, we could divide the spectrum in half but there is from TX to RX closer than can be reasonably filtered. Via experiments, it was shown 600 kHz worked well with basic cavity filters.[38] Of further note, the tube type power amplifiers were exceptionally clean in regards to wideband noise, making 1-2 cavity duplexer filters possible with a narrow split. Modern commercial Mobile Relay Station (repeater) users are typically 1-4 MHz.[39]

As there cannot be a repeater input next to an output at the middle of the band, this 600 kHz “split” provided a natural gap of 4 channels. 146.520 became the default simplex

[36] Sessions, K. W. (1969). Radio Amateur's F-M Repeater Handbook. Chapter 3 and FM and Repeaters for the Radio Amateur. Chapter 14 The Sessions text lays this out a bit simpler, and presents real applications to the FCC. Ken Sessions was widely published in 73 magazine and there was a bit of an east coast (ARRL)/West Coast difference in how repeaters we viewed in amateur radio.

[37] FCC Amateur Radio Service Rules, 47 C.F.R. § 12.23(d) (1962), amended via 24 P.R. 5842 July 22, 1959

[38] Sessions, K. W. (1969). Radio Amateur's F-M Repeater Handbook. pg. 133-145

[39] APCO/NPSTC 1.104.2-2017 standard, FCC also would not grant duplex station use in VHF until the 1980’s (ibid)

FM channel as it was one channel away from first repeater output at 146.64. This made six repeater channels open 146.64, 146.70, 146.76, 146.82, 146.88, 146.94, paired with a receive channel 600 kHz below.

The 147-147.9 band followed a similar layout. As this was a band restricted to General class or higher, it was the more exclusive band. The split was kept the same, but a low out high in method was used so that 147.00 would be an output next to an output of 146.94. Given the restriction at 147.9 MHz for the last FM, this made the last usable input frequency 147.84 MHz. This made 147.00, 147.06, 147.12, 147.18 and 147.24 output. This left five FM simplex channels 147.30, 147.36, 147.42, 147.48 and 147.54.

Recalling the tuning range of the radios in use, most radios could be pushed for amateur service to +/- 400-500 kHz crystal range. This allowed a person to align their radio receiver strip to cover 146.52 - 146.94 MHz; all six repeater outputs and two simplex channels. The transmitter would be optimized for the chosen repeater and see a few dB drop off on simplex, which was more than acceptable. A technician operator could participate in the fun of FM and repeaters with such a setup.

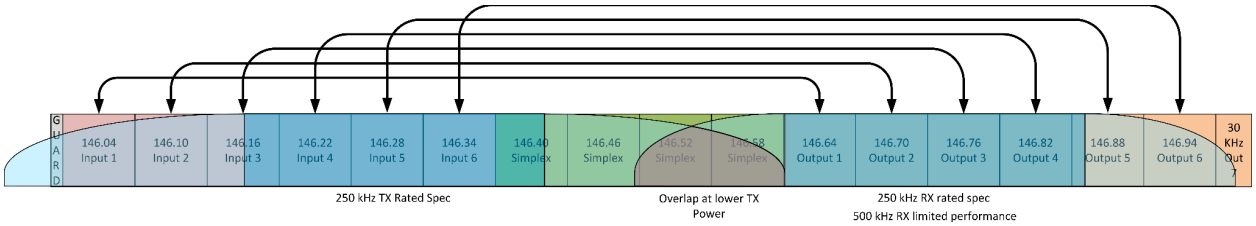


Figure 9. - TX and RX tuning range of GE Progress Line.

1970s Boom

As amateurs ushered in the new decade, change was in the air. In 1972 the FCC formalized a number of changes to Part 97, chief among them was formal repeater rules for the first time. This rule change also opened up 145-148 MHz to technicians removing the exclusivity from 147 MHz repeaters and allowing FM above 147.90 MHz[40]. Autopatch was allowed and hams became able to utilize repeaters for direct contact to public safety. This ability to get a phone line anywhere would be exclusive to amateurs until the first cellular service launched in the mid-late 1980s.

This predictably caused the explosion of users and repeaters. As there existed eleven 60 kHz repeater pairs from 146-148 MHz and limited tuning of typical radios, it limited participation. A city would be 146 or 147 MHz at first and a mobile unit unable to cover

[40] FCC Amateur Radio Service Rules, 47 C.F.R. § 97.7(c) (1973)

the entire band. This caused people to have to pick where they would invest their crystal money. The first proposal which happened almost overnight was the splitting to 30 kHz channels however the typical wide band transceiver would still have poor filtering in packed spectrum. The band plan started at 146.61 to 147.39 with 27, 30 kHz channels, a great improvement over eleven wide-band channels.

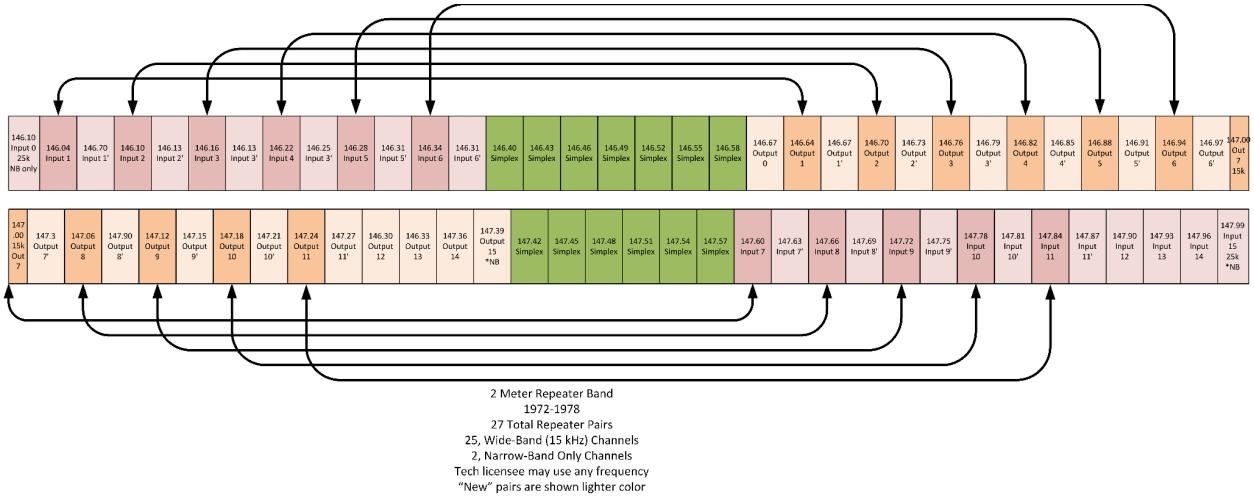


Figure 10. - 2 meter repeater band 1972-1978

As the 1970s close, we see a 145 MHz repeater subband opened from 144.5 to 145.5 MHz in 1977, and a massive rewrite of the repeater rules in 1978[41]. This does away with the station contact log requirement, and the repeater license requirement; now any technician or higher class may operate a repeater. Importantly, this is the first recognition of amateur coordination by the FCC as being a good thing[42]. Also in 1978, technicians were permitted all frequencies above 50 MHz.

[41] FCC Rules to Simplify the Licensing and Operation of Complex Systems of Stations and Modify Repeater Subbands in the Amateur Radio Service Docket No. 21033, 43 Fed. Reg. 71 (April 12, 1978). pp 15334 - end
FCC Docket 20282, RM 1016, 1363, etc. Effective May 15, 1978
[42] FCC part 97

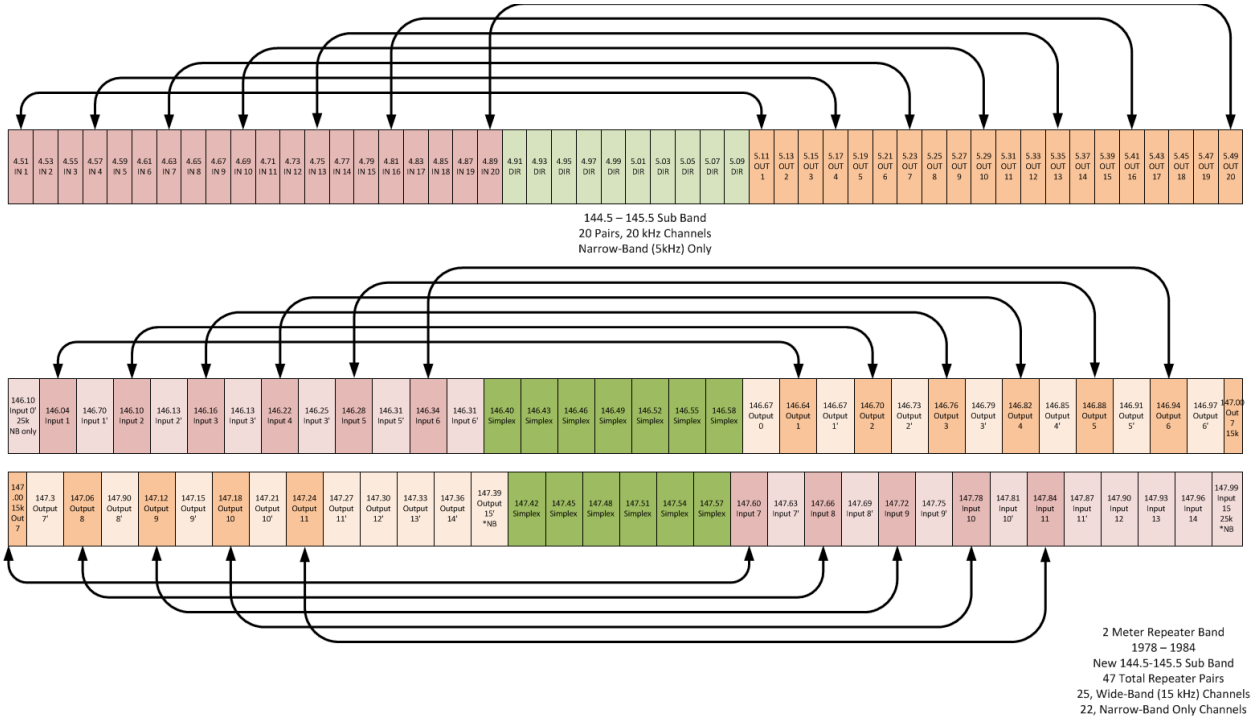


Figure 11. - 2 meter repeater bands 1978-1984

FM repeaters enter mainstream and as the 1980s approach, the bands are filling up again. The 144.5 to 145.5 MHz band is additional spectrum, but the narrow banding to +/- 5 kHz deviation is coming. Amateurs now have the advantage of learning from the commercial narrowbanding. Once 30 kHz channels were split, it was found that a narrowband signal at 16 kHz wide needed a larger adjacent protection interval than the 30 kHz wide-band channels did. In both cases the signal was wider than the channel, however wide-band was more tolerant of slight overlap. Amateur band planners learned from this, that a 20 kHz channel would be more suitable and allow the need to forgo adjacent planning, as 25 kHz eliminated this need on UHF.

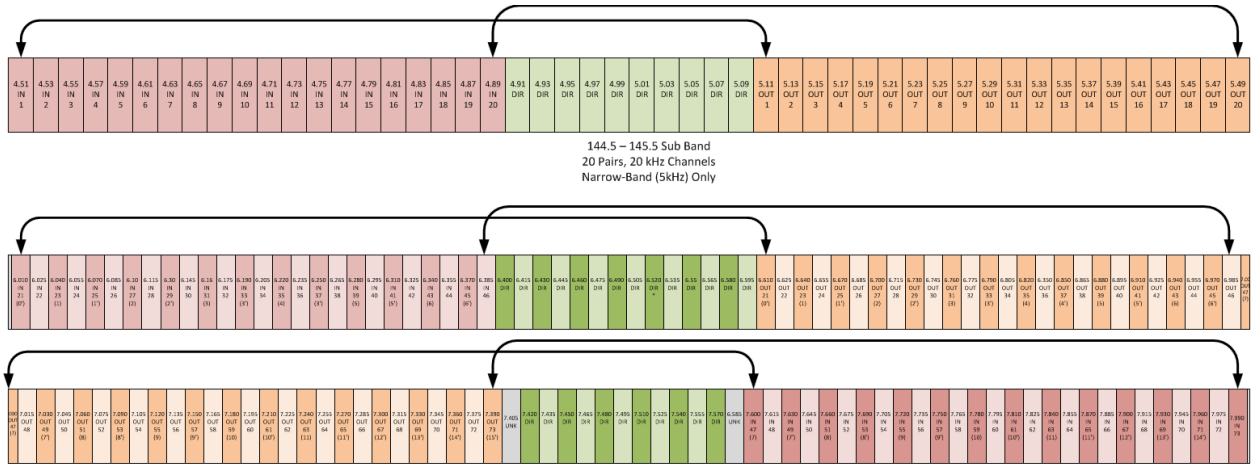
Thus the 145 MHz repeater band was “born narrow-band”. Starting at 145.11 to 145.49 are 20, 20 kHz repeater pairs. There are ten 20 kHz simplex and experimental channels. Growth on these frequencies takes off slowly. Packet operation is proposed in some areas and comes into its own during the 1980s packet boom.

Into the 1980s and Beyond

Repeaters modernized and the first generation of fully transistorized, used narrow-band equipment now is showing up on the secondary market[43]. Wideband power amplifiers (PAs) and digital PLL transceivers arrive for the commercial user allowing coverage across 10 MHz or more of spectrum in 16-48 user programmable channels.[44] The Motorola Micor and GE MASTR are police surplus and the vast majority of old wide-band FM gear is aging out from the amateur station.

Packet radio is booming and most of the ten 145 MHz simplex channels officially become packet channels across most of the country. APRS growth in the 1990s drives a dedicated APRS channel and this is taken at 144.390 MHz, as the planned OSCAR use of 144.3-144.5 moves to 145.8-146.0 MHz to harmonize it internationally.[45]

By this time most if not all amateur coordination bodies and amateurs had moved or were in the process of moving to narrow-band FM. In fact, NBFM was already in use as early as the 1969 in Los Angeles and other west coast areas.[46] This now permitted 53, 15 kHz repeater channels, and 24-26 15 kHz simplex channels in the 146 and 147 MHz bands. This splitting followed the commercial users through splitting channels like the commercial VHF high band.



[43] Motorola Micor was released 1971 -Motorola. *Motorola MICOR Base Stations.*
[44] Motorola Syntor and MX circa 1982
[45] Paul Stoetzer, N8HM of AMSAT states via email "only 145.8-146 MHz and 144.0-144.025 MHz are recognized internationally" for satellite use. In *144 / 435 MHz APRS Harmonisation*, Vol. VIE16_C5_41, from the IARU this "New" OSCAR band is stated that it will not be used and the recommendation is to not plan on it for satellite use. It would appear that 144.3 to .5 is left to local regulations.

[46] Sessions, K. W. (1969). Radio Amateur's F-M Repeater Handbook. Preface

Figure 12. - two meter band 1984 to present

Several states[47] or regions bucked the trend of 30 >15 kHz and moved to 20 kHz in line with 145 MHz. There is great evidence this may be superior to 15 kHz [48], as adjacent channel repeaters interference is almost a non-issue, and 20 splits to 10, which holds all known digital narrowband modulations with 1 or more kHz of guard space. In many cases a ultra-narrowband user (NXDN or DSTAR) is able to be placed on a 10kHz splinter channel with adjacent wideband users not affected with no or little adjacent protection area.

A Note on Narrow-Band (Again)

As the 1990s came to a close, commercial users were again up against the limits of VHF High Band channels. The FCC proposed in 1995 to split channels once again in VHF High and UHF (not T-Band or 800 MHz)[49]. This leaves a 7.5 kHz channel assigned at VHF High for most users with the intention to sunset all 15 kHz (wideband) by January 1, 2005[50]. Cited in this study was the ease of this transition for most users, as the FCC expected ACSSB and other digital narrow band techniques to motivate users to transition. In reality this date was not met, and ACSSB/analog narrowband was an abject failure[51].

Amateurs will note that the loss of 220-222 MHz as United Parcel Service (UPS) use never happened and 220-222 MHz largely sat empty from 1988-1999. It was auctioned off[52], but with the requirement that 5 channel blocks be adjacent making the combiner requirements challenging and adding 70-100k USD per site in costs. Some ACSSB systems did go into operation (NYC famously had one), but most users desired FM use and commercial use in most of the US never occurred. The only “220” use in Florida was a commercial Passport trunking system in the 216-219 MHz AMTS band[53], not 220-222. Even this was a failure as the FCC only granted licenses in 2002 and build-outs didn’t happen until 2004. By this time, most potential customers had

[47] AZ, HI, LA, NV, NM, OR, PR, and TX coordination bodies have 146-148 MHz as 20 kHz spacing. Refer to the coordination body tracking google spreadsheet.
[48] Kelley, Chris, and Virgil Leenerts. “FM Repeater Separation - 20 KHz Yes, 15 KHz No.” Ham Radio, Aug. 1985.
[49] Regulation of Wireless Communications Systems, Pg 178
[50] Regulation of Wireless Communications Systems, Pg 180
[51] Ellis, T. (2002, March 6). *Why 220MHz?* 220MHz: A Mobile Radio Technology Special Report. Retrieved May 25, 2022 This is a great summary of why commercial 220 failed and sat vacant for years. Currently the major use for the 220-222 spectrum is positive train control. The major 220 trunking systems in Florida were deployed in the AMTS spectrum at 216/217 MHz.
[52] https://www.fcc.gov/auction/18/factsheet
[53] FCC Report and Order 01-382

migrated to cellular data and other services as UPS had. NJ Turnpike was one of the successful private users in this spectrum[54].

The sad state is that this is considered a success in spectrum management by the FCC as it generated some 50M+ USD of revenue. As then Vice President Al Gore wrote to the FCC:

> "Thanks for making the Federal Government Billions out of thin Air"[55]

The bit of good that did come from the narrowbanding rules was establishing a minimum loading in bits per Hertz for a given channel across the spectrum. The FCC held that 4,800 bits per 6.25 kHz (.768 bits/Hz) and one voice path per 12.5 kHz was their intent.[56] The rules also permitted aggregation or bonding of adjacent channels, so long as the loading requirements were met. The narrow banding of commercial radio did happen, but the deadline was pushed back to January 1, 2013, well over a decade from the original January 1, 2005 date[57].

Summary

The key take-away from this treatise should be a better understanding of why the two-meter amateur radio band is so disjointed in most regions. Two-meters is not just one band 144-148 MHz, but rather three different 1 MHz bands which have been merged together. Had commercial wide-band established earlier better frequency control, or 80 or 50 kHz channel rather than 60, two-meters may have found itself with a more sane channel raster. Had the FCC opened the entire top 3 MHz to FM and technicians from day one, amateurs may have found a 2 MHz split ideal. It certainly would have made duplexing easier and more in line with the eventual VHF high-band commercial repeaters.

Looking forward to the next possible narrow-banding coming is the next split, again following the FCC commercial requirements to end all +/- 5 kHz (old narrow-band) FM in 2013 and move to +/- 2.5 kHz (new narrow-band) analog FM. Even this was short lived in the commercial and public safety space. Most users migrated directly to digital modulation for public safety (P25) and many commercial users did the same, using one of the digital methods. Some commercial bands were even "born +/- 2.5 kHz

---

[54] https://www.radioreference.com/apps/db/?sid=6842
[55] Regulation of Wireless Communications Systems, Pg 81
[56] Regulation of Wireless Communications Systems, Pg 180 - The billions Vice-President Goes was speaking of here referred to the cellular and PCS spectrum, but these first auctions changed the way spectrum was allocated going forward.
[57] FCC Narrowbanding Mandate: A Public Safety Guide for Compliance. Pg. 4 & Ch. 2

narrow-band", the 941 MHz commercial band and 218 MHz AMTS bands for example, while others have resisted going to narrow (T-Band and 800 MHz). In the FCC R&O[58] The Commission mentioned their desire to move to a 6.25 kHz equivalent channel. While the FCC has not moved to split 12.5 kHz or 7.5 kHz channels once again, we have seen a number of digital systems with 6.25 kHz equivalence or outright 6.25 kHz channel support. Indeed it is a highly touted feature of NXDN[59], but TDM based systems like DMR and TETRA may be the way forward for most trunking as there is half or a forth of the transmit combining needed. The commercial market will determine what wins, and amateurs will get to experiment. It is in the best interest of amateurs to be adjacent to commercial users, as high quality surplus equipment benefits amateur operations. 220 had scant commercial gear until SEA, Motorola, PY and others brought it forward for the UPS and AMTS spectrum users.

Simultaneously, amateur repeater operations are dropping off. While there are still thousands of repeaters on the air, overall use is markedly down from years past. Amateurs have been quick to embrace digital voice on their repeaters. For many it has fractured the systems, as DMR/DSTAR/NXDN/TETRA/P25 is mutually incompatible; but for many amateurs this is not undesirable. Coordination bodies have been quick to push amateurs to narrow modes, but +/- 5 kHz wideband FM is sticking around for the foreseeable future as there is a marked difference in narrowband FM coverage and voice quality for most users.

As more amateurs move to 100% digital, all digital operations are narrowband. However for 146-148 MHz channels, 7.5 kHz splitting would not work as 7.5 kHz is simply too small for any digital mode other than NXDN. DMR is 7.6 kHz, p25 is 8.1 kHz and this overlap would render the adjacent user unacceptable interference. This is due to the 100% modulated nature of digital, whereas an analog FM signal is not at 100% other than for voice peaks. The energy into an adjacent channel is minimal for FM and on average power doesn't exist there. The 145 MHz channels split much nicer to 10 kHz and would present a good option.

What coordination bodies do see is the desire to "keep a wideband channel" by listing a DMR repeater, a dual mode wide FM and DMR. This does not protect the users frequency any better, and makes it harder for everyone to coordinate in the future. As the vast majority of amateur DMR repeaters are not dual mode and the ones which are

[58] FCC R.O. & NPRM 95-255 "Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and Modify the Policies Governing Them and Examination of Exclusivity and Frequency Assignment Policies of the Private Land Mobile Radio Services." PR. Docket No.92-235 June 23, 1995

[59] http://www.fleettalk.net/about.html - The top selling point of Fleettalk "Very narrow band 6.25 kHz channel width, means we are already there!"

dual mode, are not wide FM and DMR. Where coordinators do see this is Yaesu Fusion and wide FM, but the majority of use in this case is wide FM, with Fusion taking a back seat to analog. Perhaps this will change in the future. For wide band FM and a digital mode, the dominant mode in Florida is P25 Phase 1 and wide FM. The surplus Quantars support this as do growing numbers of MMDVM-based repeaters.

Forward Study

It is the ultimate goal of FASMA to make more intelligent and wider use of our amateur bands. To this end, we are studying a number of options at two meters and encouraging policy proposals from the community. Should anyone have a formal proposal, we would like to consider it and submit it to the community for debate and input from all amateurs.

FASMA has no formal proposals yet but many amateurs have commented informally on the following possibilities.

Of interest to FASMA in the two meter band:

- Is there a need for 200 kHz of packet spectrum at 145 MHz?
- Use of 144.3-144.5 MHz, as it is no longer used for OSCAR and cannot be used for repeaters or auxiliary stations[60]
- 145.5-145.8 MHz: This is currently listed as experimental, but casual monitoring has shown some simplex use. FASMA doesn't suggest any use for it or accepted channelization.
- 146 and 147 MHz: Simplex use, is 405 kHz of spectrum appropriate for simplex use? Several states have local option repeater pairs in this spectrum.
- Is weak signal sufficiently protected in 2 meters and other bands?
- Typical 2 meter FM radio in use. What percentage are narrowband capable? Should FASMA establish a baseline of performance for receivers?

FASMA is interested to hear from all spectrum users in Florida.

[60] FCC Current Part 97: §97.201(b) & § 97.205(b)

Timeline

- 1927 - Federal Radio Commission was formed
- 1922 - KOP starts the first One-Way AM dispatch to police cars
- 1933 - Bayonne, NJ police become the first Two-Way users with AM on 33.1 MHz
- 1934 - Federal Communications Commision takes over from the FRC
- 1934 - Amateurs get access to all bands above 110 MHz
- 1936 - GE and RCA ship the first mobile radios
- 1937 - Motorola enters the mobile business
- 1937 - In October the FCC grants the first VHF channels at 30-39 MHz to Police and establishes basic rules for emergency services
- 1938 - FCC established the first frequency tolerance requirements of .05% for commercial systems
- 1938 - FCC establishes the 2 ½ and 1 ¼ meter bands
- 1939 - Connecticut State Police become the first statewide VHF FM Two-Way system proving the superiority of FM vs AM for Two-Way radio
- 1940 - From June 1940 FCC bans amateurs from international contacts.
- 1941 - December 8 the FCC prohibits amateur operation for the duration of WWII
- 1943 - First rules for emergency radio services established under part 11:
    - .01% frequency tolerance from 30-40 MHz.
    - Modulation may not exceed 75% of channel spacing.
- 1945 - Amateurs get access to 1 ¼ and then parts of 2 ½ meter bands after the war
- 1945 - In September the Inter-American Radio Conference is held in Rio de Janeiro, At this conference the modern VHF and UHF amateur, commercial and aviation bands are established. 5 and 2 ½ meters becomes 6 and 2 meters.
- 1953 - FCC established the 40/60/100 kHz channels for VHF-Low/VHF-High and UHF respectively. The first modulation limits for FM came about.
- 1954 - Edwin Armstrong commits succide over years of litigation regarding FM patents
- 1955 - FCC formally recommends moving to 5 kHz Narrow-Band FM by Nov 1, 1963
- 1958 - New Wide-Band FM equipment not permitted to be sold after Oct 31, 1958
- 1959 - First FM repeater authorized for automatic use by the FCC
- 1959 - Tech licenses receive access to 145-147 MHz
- 1960 - James Aagaard K9OJV and W6FNO publish about amateur use of FM
- 1964 - FCC Amatuer rules move from Part 12 to Part 97
- 1967 - Motorola was denied appeal and decided in favor of Armstrong after 19 years.
- 1970 - T-Band is opened up for use in certain areas
- 1971 - Motorola releases the MICOR
- 1972 - FCC releases first repeater rules/standards
- 1972 - Tech licenses receive access to 145-148 MHz
- 1972 - ARRL establishes a national band plan for 2m and 146.520 for calling
- 1974 - WR prefix for repeater call signs appear
- 1977 - FCC establishes a new repeater subband at 145 MHz
- 1978 - Tech's permitted all frequencies above 50 MHz
- 1982 - Motorola releases the first synthesized mobile radios

- 1984 - Florida Repeater Council (FRC)(predecessor to FASMA) is Incorporated.
- 1984 - FRC establishes sunset to wide band FM repeaters and migrates to a 15 kHz raster above 146 MHz.
- 1988 - FCC transfers 220-222 MHz to UPS for their use. The process takes so long that UPS never makes use of the spectrum.
- 1995 - FCC simplifies the commercial licensing into two major branches
- 1995 - FCC mandates Narrow-Band and splits VHF into 7.5 kHz channels.
- 2002 - FCC auctions the 220-222 MHz Band.
- 2005 - FCC original Wide-Band sunset date January 1, 2005.
- 2013 - Commercial Wide-Band is no longer permitted after January 1, 2013
- 2017 - FASMA is founded and the FRC transfers all duties to FASMA Dec 17.

References

Aagaard, James S. “Two-Meter F.M. for Noise-Free Local Communications.” *QST*, July 1960, pp. 33–35.

“AM_expanded_band in the United_States.” Wikipedia, Accessed 22 May 2022.

APCO/NPSTC 1.104.2-2017 standard

ARRL. “Amateur Band Plans 1940.” The Radio Amateur's Handbook, ARRL, 1940.

ARRL, The Radio Amateur's Handbook (1970), ARRL, 1970.

Bercovici, Martin W. “FCC Narrowbanding Mandate: A Public Safety Guide for Compliance.” International Association of Fire Chiefs (2006)

Brooking, Robert E. IEEE, NA, VA, 1982, pp. 129–132, Meeting the Challenge of Limited Resources.

Cobb, Lee. “Modulation Standards for VHF FM.” Ham Radio, June 1970.

Day, Frederick J., and Tran Huong N. Regulation of Wireless Communications Systems. Government Institutes, Inc., 1997. - This is a now out of print book detailing the regulatory history of land mobile radio.

Decisions and Reports of the FCC December 15, 1965 to March 25 1966 Vol. 2, FCC (1967)

Decisions and Reports of the FCC March, 1939 to June 30, 1965 Vol. 39, FCC (1970)

Ellis, T. (2002, March 6). *Why 220MHz?* 220MHz: A Mobile Radio Technology Special Report. Retrieved May 25, 2022

Farquhar, Michele. FCC, Washington, DC, 1996, pp. 1–78, Private Land Mobile Radio Services: Background. - This is an excellent staff paper of the FCC explaining the history and regulatory framework for Land Mobile Radio.

FCC Public Release Regarding Allocation in the 30 to 300 MHz Bands. FCC. (March 13, 1939)

FCC Emergency Radio Services, 47 C.F.R. § 10 (1943)

Proceedings of the International Telecommunications Conference, Atlantic City, NJ 1947. ITU, Documents of the International Telecommunications Conference, 1947, pp. 1–15.

FCC Narrowband NPRM Docket 11253, 20 Fed. Reg. 14 (January 20, 1955)

FCC Narrowband NPRM Docket 11253 extension, 20 Fed. Reg. 65 (April 2, 1955)

FCC. (1956). Annual Report for 1955.

FCC Guide for Public Safety Radio Services, 21 Fed. Reg. (October 3, 1956)

FCC Industrial Radio Services, 47 C.F.R. § 11 (1953)

FCC Industrial Radio Services, 47 C.F.R. § 11 (1957)

FCC Amateur Radio Service, 47 C.F.R. § 12 (1957)

FCC Amateur Radio Service, 47 C.F.R. § 12 (1958)

FCC. (1960). Annual Report for 1960.

FCC. (1963). Annual Report for 1963.

FCC. (1964). Annual Report for 1964

FCC Amateur Radio Service, 47 C.F.R. § 12 (1962)

FCC Amateur Radio Service, 47 C.F.R. § 12 (1963)

FCC Amateur Radio Service, 47 C.F.R. § 97 (1964)

FCC Amateur Radio Service, 47 C.F.R. § 97 (1965)

FCC Amateur Radio Service, 47 C.F.R. § 97 (1972)

FCC Amateur Radio Service, 47 C.F.R. § 97 (1974)

FCC Amateur Radio Service, 47 C.F.R. § 97 (1975)

FCC Land Transportation Radio Services, 47 C.F.R. § 93 (1970)

FCC Order No. 19, October 13, 1937

FCC Public Safety Radio Services, 47 C.F.R. § 89 (1964)

FCC Public Mobile Radio Services, 47 C.F.R. § 22 (1980)

FCC Private Land Mobile Radio Services, 47 C.F.R. § 90 (1979)

FCC Private Land Mobile Radio Services, 47 C.F.R. § 90 (1982)

FCC Private Land Mobile Radio Services, 47 C.F.R. § 90 (1990)

FCC R.O. & NPRM 95-255 “Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and Modify the Policies Governing Them and Examination of Exclusivity and Frequency Assignment Policies of the Private Land Mobile Radio Services.” PR. Docket No.92-235 June 23, 1995. - This is the NPRM for narrowbanding started in July 1991.

FCC. R.O. 01-382 “Amendments to Part 90 of the Commission's Rules Concerning Private Land Mobile Radio Services.” Jan. 2002.

FCC Report Frequency Allocations from March 3, 1939 to June 30, 1965, FCC (June 1, 1970)

Final Report of the Advisory Committee for the Land Mobile Radio Service to FCC Volume 1, FCC (1967)

FCC Rules to Simplify the Licensing and Operation of Complex Systems of Stations and Modify Repeater Subbands in the Amateur Radio Service Docket No. 21033, 43 Fed. Reg. 71 (April 12, 1978). pp 15334 - end

FCC R&O for narrow band 2.0

Fields, Bryan “Spreadsheet of the various coordination bodies in the US.” Google Sheets. 2022

”Foreign Amateur Communications Banned.” FCC Order #72, June, 1940

Fors, Geoffrey C. “*General Electric FM MOBILE RADIO HISTORY: Part One, 1940 - 1965*,” Feb. 2022.

”Frequency Modulation: Modulation Index.” Wikipedia, Accessed 22 May 2022

Green, James P. “V.H.F. Repeater Problems and Possibilities” QST. July 1962, pp 26-29

Hull, Ross A. “Practical Communications on the 224-Mc. Band.” QST, Nov. 1934, pp. 8–66.

Kelley, Chris, and Virgil Leenerts. “FM Repeater Separation - 20 KHz Yes, 15 KHz No.” Ham Radio, Aug. 1985.

Karthikeyan, A. “Carbon Microphones.”

Kaufhold, Kevin. *ON THE ULTRA HIGHS: A History of Amateur Radio VHF Activities*. 2008.

McCormic, J. A. “MILESTONES IN THE LAND-MOBILE RADIO SERVICE,” GE, Sept. 1966.

McMullen, Thomas, editor. FM and Repeaters for the Radio Amateur. First ed., ARRL, 1972.

Milestones: One-Way Police Radio Communication, Detroit Free Press.

Motorola. *Motorola MICOR Base Stations.*

Murphy, Richard. “Canadian Inventions – The Quartz Clock.” *Deeth Williams Wall LLP*., Nov. 2002.

Noble, Daniel E. “The History of Land-Mobile Radio Communications.” Proceedings of the IRE, May 1962.

“Police Use Two-Way Radios in American Cities.” Popular Mechanics, Dec. 1933, pp. 808–808.

Regnault, John. *144 / 435 MHz APRS Harmonisation*. Vol. VIE16_C5_41, IARU, 2016.

Sager, Phil, and Rick Palm. “An Overview of Amateur Call Signs - Past and Present.” QST, May 1994, pp. 54–59.

Sessions, K. W. (1969). Radio Amateur's F-M Repeater Handbook. Editors and Engineers, LTD.

Sundstrom, Tom. ”Frequency Coordinators.” Accessed 22 May 2022l - A definitive list of frequency coordinators in the US and canada.

TIA/EIA TSB-88 reference data

Van Wagenen, Juliet. “The First Police Radio Stopped Bootleggers in Their Tracks.” StateTech , 9 June 2017, Accessed 22 May 2022.

”WAR COMES! / FCC Order #87, December 8, 1941” QST. Jan 1942

”War Emergency Radio Service.” Wikipedia, Accessed 22 May 2022

Wayne, Green, editor. “National Standards for FM Operation.” *73 Magazine*, Apr. 1973, pp. 100.

License