# Proposed Revisions to RF Sections of IRIG 106

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## Abstract

Revisions to RF Sections of IRIG 106. The RF sections of IRIG 106 Telemetry Standards have changed little over the last twenty years, although use of the VHF bands and higher data rates dictate a reanalysis of the basic assumptions underlying RF usage on both the sending and receiving ends of the telemetry link. This paper includes an annotated "work in progress" for inclusion in the 1992 version of the standards, and discusses the underlying philosophy for the proposed revisions, and cites more recent source materials than the current 1986 revision.

IRIG-106, the "Telemetry Standards" document used by US test ranges and defense contractors who provide or operate telemetry systems, has been around in some form since 1960, with earlier Inter-Range Instrumentation Group [IRIG] [1] papers before that. The RCC consists of several groups and ad-hoc committees, which attempt to standardize systems for uses on test ranges. The telemetry standards documents undergo periodic revision, in part to keep up with the state of the art, and in part to accommodate changing requirements. The 1992 revision presently envisioned will have added or modified sections on digital multiplexing systems, rotary-head tape recording, and RF system characteristics, removing much of the pre-1970 references to the now-uncommon use of the VHF band from 216-265 MHZ for telemetry.

The task of the RF Systems Committee of the Telemetry Group includes those sections of IRIG-106 dealing with transmitters and receivers, which is Chapter 2 and Appendix A of that document, annotated revisions of which are shown in this paper.

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[1]The IRIG changed names to the Range Commanders's Council [RCC] in 1970, but some documents still carry the older designation for the purposes of continuity.

Other efforts in process include a manual on vehicular antennas (not now addressed in RCC/TG literature), and investigations of phase-shift keying [PSK] for bandwidth conservation.

As part of the approval process, copies of new documents and revisions of old ones are made available for comment both within and from outside the RCC; other groups are invited to formally comment on any documents in what is called the "pink sheet" process. Copies of the two sections shown here were presented to the RCC Frequency Management Group at their meeting in March, 1991. The author welcomes comments from anyone interested enough to make any.

The revised sections follow. To make the text more readable, the parts intended to be in the final copy are typeset in sans serif typeface, and all comments are in slanted type. Footnotes not intended to be in the actual final version are also in slanted type.

## Chapter 2: Transmitter and Receiver Systems

2.1 Radio Frequency Standards for Telemetry. These standards provide the criteria to determine equipment and frequency use requirements. These standards are intended to ensure efficient use of equipment, and interchange of operations and data between test ranges. Systems not conforming to these standards require justification upon application for frequency allocation, and the use of such systems or frequencies is highly discouraged.

2.2 VHF Band. The frequency band from 225-260 MHZ is allocated to government fixed and mobile communications service. Telemetry operations on this band were not allocated after 1969, in favor of the UHF bands described in §2.3. Allocations for operation in the VHF band are granted only upon a showing that the UHF frequencies intended for that purpose are unacceptable. As such, allocations are granted on a secondary, nonprotected basis only. Standards pertaining to VHF telemetry operation have been deleted from this edition.

2.3 UHF Bands. The UHF bands used for telemetry are described unofficially as the "L-Band", from 1435-1535 MHZ; the "S-Band", from 2200-2300 MHZ; and the "Upper S-Band", from 2310-2390 MHZ. While these band designations are common in telemetry parlance, they may have no specific meaning to anyone else.

2.3.1 Allocation of the L-Band (1435-1535 MHZ). This band is allocated in the US and posessions for government and nongovernment aeronautical telemetry use on a shared basis. Telemetry assignments are made for testing[2] of manned and unmanned aircraft, missiles, space vehicles, rocket sleds and systems carried on such sleds for testing, or their major components.

2.3.1.1 1435-1535 MHZ Channels. The frequencies in this range will be assigned for aeronautical telemetry and associated remote control[3] operations for testing of manned or unmanned aircraft, missiles, rocket sleds, and other vehicles or their major components. Permissible usage includes telemetry associated with launching and reentry into the earth's atmosphere as well as any incidental orbiting prior to reentry of manned or unmanned vehicles undergoing flight tests. The following frequencies are shared with flight telemetering mobile stations: 1444.5, 1453.5, 1501.5, 1515.5, 1524.5, and 1525.5 MHZ.[4]

2.3.1.2 1530-1535 MHZ Channels. In the frequency range from 1530 to 1535 MHZ, the Maritime Mobile-Satellite Service will be the only primary service after 1 January 1990.

2.3.2 Allocation of the S-Band (2200-2300 MHZ). Frquencies in this range are for telemetering other than manned vehicles. See Appendix A for channel assignments for specific bandwidths.

2.3.2.1 2200-2290 MHZ Channels. These channels are shared equally with the government's fixed, mobile, and space research services. These frequencies include telemetry associated with launch vehicles, missiles, upper atmosphere research rockets, and space vehicles, regardless of their trajectories

2.3.2.2 2290-2300 MHZ Channels. Allocations in this range are for deep-space research telemetry on a shared basis with fixed and mobile service. Telemetry for other than deep-space uses may not be assigned on these frequencies.

2.3.3 Allocation of the Upper S-Band (2310-2390 MHZ). This band is allocated in the US for government and non-government telemetry use on a co-equal shared basis with radiolocation service, in a manner similar to that of the L-Band.

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[2]As such, a telemetry system as defined here is not critical to the operational (tactical) function of the system.

[3]The word used for remote control operations in this band is telecommand.

[4]Frequency management terminology for "weather balloons".

2.3.3.1 Flight Testing. Telemetry assignments are made for flight testing of manned or unmanned aircraft, missiles, space vehicles, or their major components.

2.4 UHF Telemetry Transmitter Systems. Air- and space-ground telemetry is accomodated in the appropriate allocated UHF bands 1435-1535, 2200-2300, and 2310-2390 MHZ as described in §2.3 above.

2.4.1 Center Frequency Tolerance. Unless otherwise specified for a particular usage, frequency tolerance for a telemetry transmitter shall be ±5% of the 99% bandwidth. For standard bandwidth channels (see Appendix A for definitions), frequency tolerance is thus ±50 kHz, or approximately ±0.003% for L-band systems and ±0.002% for S-band.

NOTE

> Between one and 5 seconds after initial turn-on, the unmodulated transmitter frequency shall remain within twice the specified limits for the assigned radio frequency. After five seconds, the standard frequency tolerance is applicable for any and all operations where the transmitter power output is -25 dBm or greater (or produces a field strength greater than 500$\mu$V/M at a distance of 30 meters from the transmitting antenna, in any direction.)

2.4.2 Channel Spacing. Standard bandwidth channels are spaced at increments of 1 MHZ, beginning 500 kHz above the lower edge of each band (1435.5, 1436.5 ... 1529.5; 2200.5, 2201.5 ... ). Wider bandwidths are permitted, centered on standard bandwidth channels which do not allow the resulting spectrum to fall outside the bands; narrow bandwidth channels may be assigned between standard channels for multiple-carrier uses upon a showing with the application; under no circumstances will such channels be separated in center frequency by less than 100 kHz, and spaced at integral tenths of MHZ within the “split” channel(s) used (2201.1, 2201.2, 2201.3... ).[5]

2.4.3 Output Power. The output power of a telemetry transmitter (and the effective radiated power, if substantially different) shall be the minimum possible required for the application, and in no circumstances should it exceed 100 watts EIRP in any direction.

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[5]The use of narrowband channels requires receiver capabilities that may not be available at all test ranges.

2.4.4 Modulation Polarity. An increasing voltage at the input of an FM transmitter shall cause an increase in output carrier frequency. An increase in voltage at the input of a PM transmitter shall cause an advancement in the phase of the output carrier. An increasing voltage shall cause an increase in the output power of an AM transmitter.

2.4.5 Spurious Emission and Interference Limits. Spurious emissions from the transmitter case, through input and power leads, and at the transmitter RF output(s) and antenna-radiated spurious emissions are to be within required limits when measured by the methods and equipment shown in MIL-STD-461 and 462, or other applicable military standards and specifications.

2.4.5.1 Transmitter-Antenna System Emissions. Emissions from the antenna are of primary importance. A "tuned" antenna may or may not attenuate spurious frequency products produced by the transmitter, and an antenna may generate spurious outputs[6] when a pure signal is fed to its input. The transmitting pattern of such spurious frequencies is generally different from the pattern at the desired frequency. Spurious and harmonic outputs in the transmitter output line shall be limited to -25 dBm, unless additional filtering is provided in the antenna system. Antenna radiated spurious and harmonic outputs shall be no greater than 320$\mu$V/meter at 30 meters. in any direction.

NOTE

> Radiated tests will be made in lieu of transmitter output tests only when the transmitter is inaccessible Radiated tests may still be required if the antenna is intended to be part of the filtering of spurious products from the transmitter or is suspected of generating spurious products by itself or in interaction with the transmitter and feedlines. The tests should be made with normal modulation with FM, PM, SSB or DSB systems.

2.4.5.2 Conducted and Radiated Interference. Interference (and the RF output itself) radiated from the transmitter or fed back into the transmitter power, signal, or control leads may interfere with the normal operation of the transmitter or the antenna system to which the transmitter is connected. All signals conducted by the transmitter's leads (other than the RF output cable) in the range of 150 kHz to 25 MHZ, and all radiated fields in the range of 150 kHz to 10 GHz (or other

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[6]Note that harmonics of the carrier and of the multipliers used to produce it are spurious (i.e. unwanted) outputs as are those not clearly related to the transmitter frequency.

greater frequency ranges as specified) must be within the limits of the applicable military standard(s) or specification(s).

2.4.6 Operational Flexibility. Each transmitter shall be capable of operating at all frequencies within its allocated band without design modification.

2.4.7 Modulated Transmitter Bandwidth. Refer to Appendix A for standards for emission outside authorized bandwidths.

2.5 UHF Telemetry Receiver System. UHF receiver systems shall have, as a minimum, the following characteristics.

2.5.1 Spurious Emissions. RF energy, radiated from the receiver itself or fed back into power, RF input, output, and control leads in the range from 150 kHz to 10 GHz shall be within the limits specified in MIL-STD 461 and tested in accordance with MIL-STD 462 or IRIG 118.

2.5.2 Frequency Tolerance. The accuracy of all local oscillators within the receiver shall be such that a conversion accuracy at each stage and overall is within ±0.001% of the indicated tuned frequency under all operating conditions for which the receiver is specified.

2.5.3 Spurious Responses. Reception of any frequency other than the one to which the receiver is tuned shall be a minimum of 60 dB below the desired signal over the range 150 kHz to 10 GHz.

2.5.4 Operational Flexibility. All ground-based receivers shall be capable of operating over the entire band for which they are constructed. External downconverters may be either intended for the entire band or a small portion thereof, but capable of retuning anywhere in the band without modification.

2.5.5 Intermediate Frequency Bandwidths. The standard IRIG receiver IF bandwidths are as shown below. These bandwidths are separate from, and should not be confused with, post-detection lowpass filtering that receivers provide, although the two interact.[7] NOTE: The IF bandwidth for most purposes should be selected in such a way that 98-99% of the transmitted spectrum is received. In most cases the bandwidth used for optimal reception will be a far lower number than the bandwidth measured by any method in accordance with Appendix A

[7] This footnote is unreadable in the Proceedings.

Table 1: STANDARD RECEIVER IF BANDWIDTHS

| | | |
|---|---|---|
| 12.5 kHz† | 500 kHz‡ | 3.3 MHZ⋆ |
| 25.0 kHz† | 750 kHz‡ | 4.0 MHZ⋆ |
| 50.0 kHz† | 1000 kHz‡ | 6.0 MHZ⋆ |
| 100.0 kHz† | 1500 kHz⋆ | 10.0 MHZ⋆ |
| 300.0 kHz† | 2400 kHz⋆ | 20.0 MHZ⋆ |

NOTES:

1. Bandwidths are expressed at the points where response is 3 dB below the response at the design center frequency. This assumes that passband ripple is minimal, which may not necessarily be the case. The 3 dB bandwidth is chosen because it matches closely the noise bandwidth of a “brick-wall” filter of the same bandwidth. Because the term “bandwidth” has several meanings, the bandwidth required for a specific purpose may be other than that stated here. Ideal IF filter response is symmetrical about its center frequency; in practice this may not be the case.
2. Not all bandwidths must be available on all receivers or at all test ranges. In addition to the bandwidths listed, receivers may have other bandwidths available.
3. Bandwidths marked by a dagger (†) are for use with narrowband channels. Narrowband channels may require greater transmitter and receiver stability than those required in the standards to operate properly.
4. Bandwidths marked by a double dagger (‡) are for use with standard bandwidth channels.
5. Bandwidths marked with a star (⋆) are for wideband systems only. Bandwidths greater than about 5 MHZ are not obtainable on receiver with 10 MHZ IF frequencies.

## Appendix A: Frequency Management Plan for Telemetry

1. Purpose. This plan was prepared with cooperation and the assistance of the RCC Frequency Management Group [RCC/FMG] to provide guidance to telemetry users for the most effective use of allocated UHF telemetry bands 1435-1535 MHZ, 2200-2290 MHZ, and 2310-2390 MHZ and to retain documentation regarding special telemetry operations in the other bands.

2. Scope. This plan is to be used as a guide by frequency managers and users of telemetry frequencies at DoD-related test ranges and contractor facilities. The goal of frequency management is to encourage maximal use and minimal

interference among telemetry users and between telemetry users and other users of the electromagnetic spectrum.

3. VHF Band. After 1 January 1970, telemetry operations in the VHF band from 216-265 MHZ were to cease entirely except in certain instances. The P-Band in use prior to 1970 included 44 channels of 500 kHz maximum bandwidth. New assignments in the VHF band are made only in instances where standard UHF assignments are unacceptable.

4. UHF Telemetry Frequency Assignments. Air- and space-to-ground telemetering is allocated the UHF bands 1435-1530, 2200-2290, and 2310-2390 MHZ, commonly (but unofficially) known as the L-band, the S-band, and the Upper S-band, respectively. Telemetry assignments in any other frequency range are permitted only upon a special showing that the standard bands are unsatisfactory for some specific purpose.

4.1 Application Process Frequency allocation and assignment are obtained for a program through a two-step process commencing with the government agency requesting frequency band allocation on a standard form DD 1494. After granting of the allocation (called a “J/F-12”), specific frequencies may be requested in the second step. NOTE: This complete process normally takes a year or more.

4.2 Other Users. The bands 1435-1530 and 2310-2390 MHZ are nationally allocated for government and nongovernment telemetry use for testing of manned and unmanned aircraft, missiles, space vehicles, and their major components on a shared basis. The 2200-2290 MHZ band is allocated to government fixed and mobile communications and telemetry on a coequal basis. Frequencies from 2290-2300 MHZ are for exclusive use in space-to-ground and ground-to-space communications and telemetry.

4.3 Channelization. Channel spacings for all types of telemetry uses shall be as follows:[8]

4.3.1 Narrowband Channels. Narrowband telemetry channel spacing is in increments of 100 kHz beginning 100 kHz from the lower bandedge (1435.1, 1435.2, 1435.3, etc.), assigned in such a way that transmitting bandwidths greater than 200 kHz do not fall outside the allocated band. NOTE: Not all test

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[8]These designations were changed to reflect reality. Since standard channel spacing is 1 MHZ, a “standard channel” is a channel which can be used with a 1 MHZ receiver IF bandwidth.

ranges can accommodate narrowband channels, which require high frequency stability local oscillators in transmitters and receivers.

4.3.2 Standard Bandwidth Channels. Standard bandwidth channel spacing is in increments of 1 MHZ, beginning 500 kHz from the lower bandedge (1435.5, 1436.5, 1437.5 etc.). By definition, the bandedges of a standard bandwidth channel cannot fall outside the allocated band.

4.3.3 Intermediate and Wide Bandwidth Channels. Channels with bandwidths greater than 1 MHZ are assigned channels on spacings as standard bandwidth channels, or in the case of channels whose bandwidths are greater than 2N+1 and less than 2N+2 MHZ in bandwidth, N an integer, may be assigned channels on integral frequencies (1436, 1437, 1438, etc.), assigned in such a way that transmitting bandwidths do not fall outside the allocated band. NOTE: Synthesized receivers may not have the capability to tune integral frequencies.

5. RF Bandwidth Definitions. The OTP manual defines the "occupied bandwidth" as being the bandwidth over which 0.5% of the total spectral energy falls below and 0.5% falls above. Modern spectrum analyzers can calculate total integrated power easily, ane the readings thus obtained are less likely to depend on IF and video bandwidth settings, or peak versus average readings. The 99% power bandwidth is approximately equal to the band of frequencies outside of which the power in any 10 kHz segment is at least 40 dB below the power of the unmodulated carrier. Similarly, the 99.9% point is approximately equal to the -60 $dB_{uc}$ bandwidth asked for by the DD 1494.

5.1 Asymmetrical Spectra. If a signal is such that its spectrum is asymmetrical with respect to its center (or carrier) frequency, bandwidth is taken to be twice the distance between the unmodulated carrier frequency and the sideband skirt which is farther.[9]

5.2 Narrowband Signal. A narrowband signal is a signal which occupies a bandwidth of 500 kHz or less.

5.3 Standard Bandwidth Signal. A standard bandwidth signal is a signal that occupies a bandwidth of 500 kHz to less than 1 MHZ.

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[9]This section was added to acknowledge that asymmetrical spectra may preclude use of adjacent channels while center frequency stability would otherwise appear to permit the use. Asymmetrical spectra were not acknowledged in previous editions, but PAM and unrandomized PCM bitstreams produce such spectra.

5.4 Intermediate Bandwidth Signal. An intermediate bandwidth signal is a signal that occupies a bandwidth of 1 MHZ to less than 3 MHZ.

5.5 Wide Bandwidth Signal. A wide bandwidth signal is a signal that occupies a bandwidth greater than 3 MHZ.[10]

5.6 Frequency Assignments. Frequency scheduling for simultaneous use at the same location shall not be made for systems whose closest 99% power bandedges are separated by less than the 99% bandwidth of the wider of the two. Frequency use schedules for multiple users at the same or overlapping locations shall be such that the closest 99.9% power bandedges do not overlap.[11]

6. Frequency Usage Guidance. Frequency uses are controlled by scheduling in the area(s) in which the tests will be conducted. The following recommendations are based on good engineering practice for such usages.

6.1 Geographical Separation Two or more telemetry systems operating in a given geographical area[12] should be separated in frequency such that overlap between spectra for each pair of signals is less than 0.5% of the power of either in the -20 dB receiver passband of the other. This separation can be provided by a combination of frequency selection, power levels, antenna positioning and aiming, and geographical separation.

6.2 Simultaneous Operation. Standard practice for multiple emitters at the same location, power level, bandwidth, and transmitting antenna direction (if applicable) should have spectra which are separated from one another by a "guard band" greater or equal to the bandwidths of either transmitter. When more than one transmitter is used on the same host vehicle, frequency selection should be made to minimize spectrum overlap and RF interactions including intermodulation between the transmitters. Multichannel operations should avoid channels separated by the IF freqencies of the receivers used if possible.[13]

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[10]Bandwidths for telemetry systems greater than 10 MHZ operating on the standard telemetry bands are highly discouraged.

[11]This section has been modified significantly, since it purported to assist in selecting specific frequencies for specific users and did not.

[12]The extent of a geographical area over which the frequency use must be protected varies with the nature of the usage. For airborne systems, such an area is specified by the actual aircraft flight path, but its maximum altitude as well.

[13]In theory, at least J/F-12 data exists on all receivers as well as transmitters.

6.3 Multicarrier Operation If two transmitters are operated simultaneously and sent or received through the same antenna system, interference due to intermodulation is likely at ($2f_1$ - $f_2$) and ($2f_2$ - $f_1$). Between three transmitters, the two frequency possibilities exist, but also intermodulation products may exist as well at ($f_1 + f_2 - f_3$), ($f_1 + f_3 - f_2$), and ($f_2 + f_3 - f_1$), where $f_1$, $f_2$, and $f_3$ represent the output frequencies of the transmitters. Intermodulation products arise from slight nonlinearities in the antenna systems, and harmonics present in the transmitted signals themselves. The general rule for avoiding third-order intermodulation interference is that in any group of transmitter frequencies, the separation between any pair of frequencies is not equal to the separation between any other pair of frequencies. Since the individual signals have sidebands, it should be noted that intermodulation products have sidebands spectrally wider than the sidebands of the individual signals that caused them.

7. Bandwidth. The definitions of bandwidth in this section are universally applicable. The limits shown herein are applicable for telemetry operations in the telemetry bands 1435-1530, 2200-2290, and 2310-2390 MHZ. How bandwidth is actually measured and what the limits are expressed in terms of that measuring system are determined by the service used.

7.1 Concept The term “bandwidth” has an exact meaning in situations where an AM, DSB, or SSB signal is produced with a band-limited modulating signal. In systems employing frequency modulation [FM] or phase modulation (PM], or any modulation system wherein the modulating signal is not band-limited, bandwidth is infinite, with energy extending toward zero and infinite frequency falling off from the peak value in some exponential fashion. In this more general case, bandwidth is defined as the band of frequencies in which “most” of the signal’s energy is contained, wherein the definition of “most” is imprecise. One measure is the bandwidth necessary in a receiver to receive the signal with “negligible” distortion; this bandwidth is lower than a measure of the interaction between two adjacent frequencies to determine if overlap between them will interfere with reception of either signal. The overlap problem is exacerbated if the desired signal is lower in power than the interfering signal or if the two signals differ in bandwidth (however defined) or modulation type (AM, FM, etc.). The following terms are applied to bandwidth:

- Authorized Bandwidth—the bandwidth, however measured, authorized for a particular use. This number is fixed, no matter what actual modulation bandwidth is used; the actual number authorized should resemble what is actually used.

- Occupied Bandwidth—the bandwidth, measured in the same terms as the "authorized" bandwidth above, that a transmission actually uses. Note: Occupied bandwidth may vary with the characteristics of the modulating signal,[14] but should never exceed the authorized bandwidth.

- Emission Bandwidth—same as occupied bandwidth, here indicating the bandwidth emitted by the transmitter or antenna system.

- Necessary Bandwidth—three definitions: (1) the minimum bandwidth required to transmit a given modulating signal (generally one to about 2.5 times the modulating signal bandwidth); or (2) the minimum bandwidth required to receive a specific baseband signal; and (3) the minimum bandwidth required to receive a specific modulated signal. Note: These three definitions are different from each other, so the term "necessary bandwidth" should be avoided altogether.

- Received (or Receiver) Bandwidth—the bandwidth of the RF/IF section of the receiver, however defined, often the ±1 or –3 dB points with respect to center frequency required to reproduce the original modulating signal at the output of the receiver with negligible distortion. Because the received bandwidth and occupied bandwidth are measured in different ways, they are not the same number even for the same signal, and in general the received bandwidth is lower than the emission bandwidth.

7.2 Bandwith Estimation and Measurement. The methods used to measure bandwidth of a signal that is not band limited vary. The most common methods are:

- Carson's Rule. Carson's Rule is an empirical way to determine the bandwidth occupied by at least 98% of the energy (power) in a signal for FM. Carson's rule is:

$$\% = 2 \times (\Delta f + f_{max}) \qquad (1)$$

  where % is the bandwidth, $\Delta f$ is the one-way peak deviation of the carrier frequency, and $f_{max}$ is the highest frequency in the modulating signal.[15]

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[14]In systems involving a baseband signal, for example, the bandwidth will increase as the amplitude of the baseband signal increases.

[15]Many types of modulating signal are not band-limited, such as PAM and PCM signals. In these cases a "premodulation filter" reduces energy in those frequencies beyond those which are necessary to allow a reconstruction of the signal at the receiving end.

Carson's Rule will result in a number greater than the bandwidth if little of the carrier deviation is due to high-frequency energy in the modulating signal (i.e., if pre-emphasis is not used). Carson's Rule results in a value close to the measured 99% power bandwidth or the –40 $dB_{uc}$ bandwidth.

- "Below unmodulated carrier". To measure actual spectrum on a spectrum analyzer, a calibration is required which places the unmodulated carrier at the zero dB reference (the top of the display). In AM systems, the carrier power never changes; in FM systems, an unmodulated transmission must be used for calibration. Since frequency modulation by its nature spreads the spectrum of a constant amount of power, this calibration is required. With the spectrum analyzer set for a specific bandwidth, say 10 kHz,[16] the bandwidth is taken as the distance between the two points outside of which the spectrum is thereafter some number (say, 40 dB) below the original unmodulated carrier point. The 40 dB points in such a measurement on an optimized ("flat-topped") system are close to the bandwidth predicted by Carson's Rule.

- "Below Peak". The modulated peak is the least accurate measurement method, measuring between points where the spectrum is thereafter XX dB below the level of the highest point on the modulated spectrum. Since the most-efficient modulation methods spread energy evenly over a large portion of the spectrum, a below peak reading overstates the bandwidth most extremely on the most optimum signals. In the absence of an unmodulated carrier to use for calibration, the below peak measurement is often (erroneously) used and described as a below unmodulated carrier measurement; using "peak hold" intended for measurement of pulsed systems exacerbates this effect still further. In all instances the bandwidth is overstated, but the amount varies. A 20 dB below-peak bandwidth can correspond fairly closely to the Carson's Rule prediction, but difficult to measure in systems with deviation close to optimal. "Spread spectrum" systems, which employ spectral widths far in excess of optimal, may have no meaningful 20, or even 50 dB, bandwidth.

- 99% Power. A measure of the bandwidth containing 99% of the total modulated power. If the two points which define the edges of the band are not symmetrical about $f_0$, their actual frequencies should be noted as well as their difference.

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[16]For digital spectrum analyzers, bandwidth is replaced by resolution, which represents "bin size".

- Receiver Bandwidth. Receiver RF/IF bandwidth is measured at the points where the response to the carrier before demodulation is ±1 dB or ±3 dB from the center frequency response. The carrier bandwidth response of the receiver is, or is intended to be, symmetrical about the carrier in most instances. Outside the stated bandwidth, the response usually falls sharply, with the response often 20 dB or more below the passband response at 1.5 times the passband response or so. The rapid falloff outside the passband is to reduce interference from nearby channels, and has no other effect on data. The receiver bandwidth for most signals is equal to, or slightly larger than, the emission bandwidth predicted by Carson's Rule.

- Receiver Noise Bandwidth. For the purpose of calculating noise in the receiver, the bandwidth of the RF/IF path must be considered, integrated over the actual shape of the IF, which in general is not a square-sided function. Typically the figure used for noise power calculations is the 3 dB bandwidth of the receiver.

7.3 Phase-Modulated Systems. Telemetry systems using phase modulation [PM] rather than frequency modulation [FM] produce spectra which are considerably wider than FM. This sideband energy is reduced in most systems by filtering at the transmitter output, and sideband energy is reconstructed in the receiving apparatus as part of the demodulation process. Phase-modulation systems, even with more than one data bit per symbol, are not necessarily more spectrally efficient than FM transmissions.

7.4 Other Notation. The following notation is used herein and in frequency management literature:

| | |
|---|---|
| $P_t$ | transmitter power output in watts or dBm |
| $P_r$ | received power in dBm |
| $f_0$ | assigned center frequency |
| $f_U$ | upper carrier deviation limit |
| $f_L$ | lower carrier deviation limit |
| % | bandwidth (IRAC/FMG definition) |
| AA' | -40 $dB_{uc}$ bandwidth |
| BB' | -25 dBm/10 kHz limit |
| EIRP | effective isotropic radiated power, in watts or dBm |
| TPO | transmitter power output at the antenna connector, in watts or dBm |
| $dB_{uc}$ | deciBels above or below the power level of an unmodulated carrier |

The BB' limit measures the bandwidth over which output is greater than -25 dBm in a 10 kHz bandwidth, which, with higher-power transmitters can be wider than the AA' limits.

7.5 Symmetry. Most modulating schemes produce a spectrum which is asymmetrical with respect to the carrier frequency when FM, transmission is used. The exceptions to this are FM subcarrier systems and PCM NRZ systems using randomization and/or BIΦ formats, placing $f_0$ halfway between A and A' (and halfway between B and B'). The most extreme case of asymmetry is due to single-sideband transmission, which places $f_0$ at the end of the spectrum defined by AA' or slightly outside it. If the spectrum is not symmetrical about the band center, the bandwidth and the extent of asymmetry must be noted for frequency management purposes.

8. Bandwidth Measurement. A typical spectrum resulting from random analog or digital frequency modulation produces the patterns shown in Figure 1. A calibration made with the unmodulated carrier shows that the modulated signal is spread over a spectral range and thus has lower power at any point, so the maximum amplitude of the modulated spectrum is everywhere lower than the unmodulated carrier. The drop in peak energy between the unmodulated case varies with the detection bandwidth of the analyzer and the FM noise of the unmodulated carrier, among other factors. In this example, a measurement at the -30 $dB_{uc}$ points is possible, but at levels greater than -20 $dB_{uc}$ the measurement is meaningless; the point where this occurs varies from system to system. In the example shown, the 40 dB bandwidth is less than the spacing betweeen the nulls, and a measure of the 50 dB bandwidth includes energy beyond the nulls. The 40 dB bandwidth is greater than the bandwidth containing 99% of the power, but this is not evident in a logarithmic display. In a binary FM transmission system where the bit rate is less than the peak deviation, the null spacing can be used to determine the peak deviation using

$$\Delta f = bit\ rate - \frac{null\ spacing}{2} \qquad (2)$$

Below some point, spectral energy is unreadable because of system noise.

In all cases, % is the bandwidth measured, but the measurement method must be specified to be of use. The unmodulated carrier frequency $f_0$ will between the upper and lower limits defining %, but not necessarily centered between the limits. For asymmetrically-distributed signals, bandwidth is taken to be twice the greatest difference between $F_0$ and the band limits, see §7.4. The measurement limits AA' and BB' differ when signals outside the bandwidth, however measured, exceed -25 dBm in a 10 kHz bandwidth even when lower than -40 $dB_{uc}$ which is significant mainly in higher-power transmissions

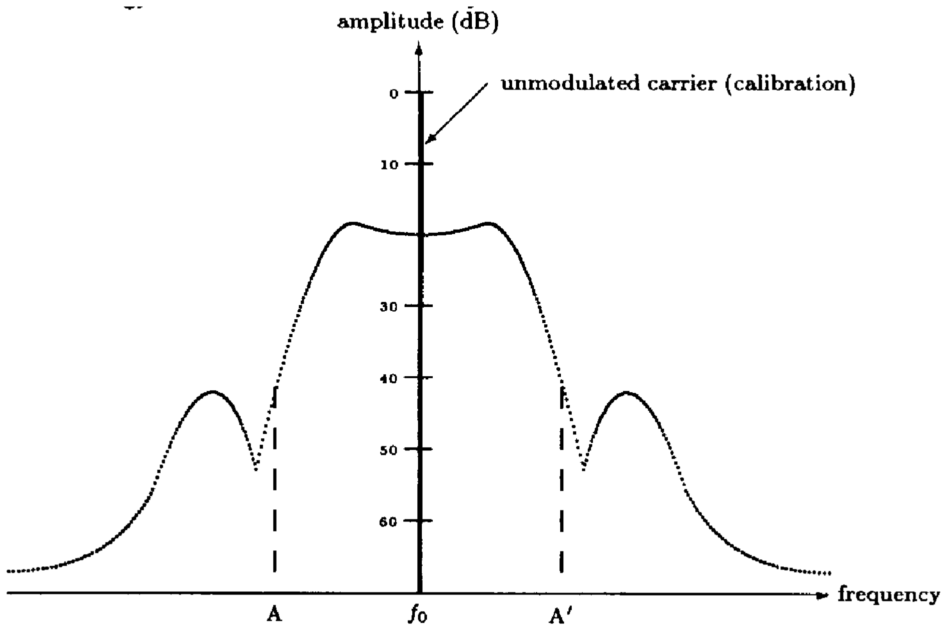


Figure 1: Typical Spectrum for Symmetrical FM Carrier