IVHS ROADWAY ENVIRONMENT

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J. R. Hoffinan
A. D. Spaulding
M. G. Cotton

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J.R. Hoffman, A.D. Spaulding and M.G. Cotton*

The objective of this report is to provide information for the intelligent vehicle/highway system (IVHS) program by detailing the expected RF environment This was accomplished by a review of the literature and use of internal ITS knowledge. It is anticipated that some IVHS systems will involve communications between vehicles and the roadside. This will probably be implemented using short, radio communication links of a few hundred meters in length or less. Collision avoidance radars will work over similar short distances. Sufficient knowledge of radio wave propagation on short paths in the roadway environment is limited. The purpose of this report is to identify potential sources of electromagnetic interference (EMI). While there are many natural and man-made sources of interference, a worst-case scenario has been emphasized in this report. The three most significant EMI sources are unintentional radiated noise, radar emissions and broadcast emissions. Each is discussed in this report.

Key words: IVHS; electromagnetic interference; noise; spectrum usage; radar; radiolocation; broadcast

1. INTRODUCTION AND BACKGROUND

Noise due to unintentional radiated emissions can be a significant source of EMI in the roadway environment. Much of the noise is due to automotive ignition systems. Another source is high-powered transmission lines which by the very nature of vehicles, can be approached at close range. Often, these noise sources are highly non-Gaussian which can seriously degrade most conventional systems that are designed for optimal or near optimal performance against white-Gaussian noise. In the discussion which follows, characteristics of the roadway natural and man-made noise environment are examined for the frequencies of interest.

Radar and broadcast emissions has potential for the greatest transmitted power and, therefore, the greatest EMI from intentionally radiated signals. This is accentuated by the fact that many transmitters from these devices can be approached in close proximity by vehicles.

Radar emissions are discussed band-by-band for the frequencies between 5 MHz and 17.7 GHz. General characteristics of each band are given, followed by a listing of specific radars located in the band. These listings provide several emission characteristics of the radars located in the band. These listings provide several emission characteristics of the radars, thus making it possible to identify the greatest sources of interference. Appendix A contains the Radar Spctrum Engineering Criterion that provides standards that bound the spectrum-related parameters and characteristics of the radar emissions.

Included within the discussion of the radar, is a more extensive description of the 902-928 MHz band. This band has been designated for Automatic Monitoring and Location Services (AML) used in vehicle identification. While this band appears relatively quiet, there is potential for significant interference.

Transmission characteristics for broadcast services are described by summarizing the regulations governing these emissions, contained in the Code of Federal Regulations (CDF Title 47, Part 73).

2. THE ROADWAY NATURAL AND MAN-MADE NOISE ENVIRONMENT

2.1 Introduction and Definitions

Natural and man-made noise and interference determine the limiting performance of radio systems. This has become more and more significant as the spectral use environment becomes increasingly crowded along with the proliferation of noise producing devices. In addition, the nature of the interference environment being, in many cases, highly non-Gaussian seriously degrades most conventional systems which are designed for optimal or near optimal performance against white-Gaussian noise. Therefore, it is important that the real-world EM environment be appropriately modeled so that correct system design and analysis can be carried out [1]. A summary of non-Gaussian noise models has been given by Spaulding [2]. Impulsive noise models have also been reviewed by Sheikh [3], who develops an ignition noise model.

It is the purpose of this section to show the natural and man-made noise levels likely in highway and other high traffic density locations. There is current emphasis on “intelligent highways” and the telecommunication systems required to achieve this “intelligence”. These systems must function in the background noise and interference. The frequencies of interest are mainly in the 0.9 to 3 GHz range, but there is also interest around 100 MHz. In this frequency range, the noise is primarily due, naturally, to impulsive automotive ignition systems, although at lower frequencies, nearby power transmission lines can have an effect. Here we want to summarize what is known about this noise environment and also give some indication as to its statistical character. This environment then must be combined with cochannel interference (intentionally radiated signals) to obtain the overall interference process.

This introduction continues with background discussion and noise parameter definitions and then gives an overall look at the natural noise background. The next section gives the general background noise level and noise character in our frequency range of interest and also looks at the trend of the noise level with time.

This report addresses the background noise environment from natural and man-made sources, sometimes termed incidental radiation devices, but does not cover interference from intentionally radiated signals. A feel for the nature of the interference environment due to these intentional signals, can be obtained from [4,5,6].

It has been widely recognized since approximately 1945, that an effective study of communications systems and devices cannot be carried out in terms of an individual message or signal alone, nor can the inhibiting effects of the background noise or other interference on performance be neglected. Rather, one must consider the set, or ensemble, of possible signals for which the system is designed, the ensemble appropriate to the accompanying noise, and the manner in which they combine in the communications process itself It is these which are ultimately significant in analysis, design and performance. Thus, the methods of probability and random processes provide the required approach. Advances in communications technology rest on the foundation of Statistical Communications Theory. Indeed, this rigor tells what is *required knowledge* about noise and signal processes.

Environmental noise (man-made noise, atmospheric noise, interfering signals, etc.) is a random process. This is true for noise from a single source, like an automobile, as well as the more general case in which the interfering noise is from a collection of many individual sources. The fact that we are dealing with a random process means that the noise can be described only in probabilistic or statistical terms and cannot be represented by a deterministic waveform or any collection of deterministic waveforms. In addition, environmental noise is basically nonstationary and, therefore, great care must be exercised in the planning and making of measurements and in the interpretation of the results. We must measure long enough to obtain a good estimate of the required parameter, but be certain that the noise remains "stationary enough" during this period. This is no small point and is frequently overlooked in the design of measurement experiments. We assume that the random noise process is stationary enough over some required time period for us to obtain the required statistics. How these statistics change with time, as from day to day, as well as with location, now becomes important.

The basic description of any random process is its probability density function (pdf) or distribution function. The first order pdf of the received interference process is almost always required to determine system performance (i.e., always necessary, but sometimes not sufficient).

Although a random process, *X(t)*, is said to be completely described if its hierarchy of distribution is known, there are other important statistical properties (important to communications systems) which are not immediately implied by this hierarchy. Moments and distributions of level crossings of *X(t)* within a time interval, moments and distributions of the time interval between successive crossings, distribution of extremes in the interval, and so on, are typical examples.

For analysis or design of a communications system, the noise process of interest is the one seen by that part of our receiving system in which we attempt to extract information from the desired signal. In communications theory terms: We require the projection of the noise on the "signal space" of our receiver. We are also almost always interested in "narrowband" noise processes. Here "narrowband" means "characterized by an envelope and phase." A narrowband process results whenever the bandpass of the system is a small fraction of the center frequency. The noise process, *n(t)*, at the output of a narrowband filter is given by

$$n(t) = v(t)\cos\left[\omega_{ct} + \Phi(t)\right] , \tag{1}$$

where v(t) is the envelope process and Φ(t) is the phase process. In the absence of discrete signals, Φ is generally uniformly distributed; that is

$$p(\Phi) = \frac{1}{2\pi}, \ -\pi \le \Phi < \pi . \tag{2}$$

Therefore, we usually concentrate on the statistics of the envelope process, v(t). In general, for system analysis and design, the required statistics that determine performance are either the envelope statistics directly or are obtainable from the envelope and phase statistics. For noise from some discrete sources, or for general background noise plus interfering signals, Φ(t) may not be uniformly distributed, and the statistics of the Φ process must also be known.

The envelope probability function is normally given as an exceedence distribution. The envelope exceedence distribution is defined as follows:

The amplitude probability distribution (APD) is the fraction of the total measurement time, T, for which the envelope was above level v_i;

$$D\ (v)\ =\ Prob\ [v \geq v_i]\ =\ 1\ -\ P\ (v)\ , \tag{3}$$

where P(v) is the cumulative distribution function. The pdf of v is given by the derivative of P(v). The appropriate envelope statistics are computed from the APD. [Measurement examples for automotive ignition noise are shown in the next section.]

The average envelope voltage is termed the expected value of *v*, *E[v]*;

$$v_{av}\ =\ E\ [v]\ =\ \frac{1}{T}\int_0^T v\ (t) dt\ =\ \int_0^\infty v^2\ dD\ (v)\ . \tag{4}$$

where,

$$-dD\,(v)\ =\ p\,(v) dv\ .$$

The rms voltage squared, (proportional to energy, or power) $E[v^2]$, is

$$v_{rms}^2\ =\ E\,[v^2]\ \frac{1}{T}\ \int_0^T v^2(t) dt\ =\ -\int_0^\infty v^2 dD\,(v)\ . \tag{5}$$

The rms voltage is the main single parameter of importance, giving the mean noise power and with proper calibration, determines the mean field strength impinging on the receiver antenna. It is important to note that most commercial field strength meters specify the field strength correctly only for a CW signal (or white-Gaussian noise if used in the "noise" mode) although true rms measurement devices are available.

The noise power, while needed in determining the signal-to-noise ratio for example, is seldom sufficient by itself to determine system performance. Quite often, the external noise is expressed as an antenna noise factor, so that it can be combined with the noise generated within the receiving systems to give an overall operating noise factor. The overall operating noise factor, f, for a receiving system, is composed of a number of noise sources at the receiving terminal of the system. Both internal and external noise must be considered. As derived in CCIR report 413 [7], the only appropriate reference point for the overall operating noise factor for a radio receiving system is the input of an equivalent loss-free receiving antenna.(The terminals of this lossless antenna do not exist physically.) The rms voltage can be referred by calibration to the terminals of an equivalent lossless antenna to give the available noise power, P_a.

For receivers free from spurious responses, the system noise factor is given by:

$$f = f_a + (f_c - 1) + l_c (f_t - 1) + l_c l_t (f_r - 1) \qquad (6)$$

where:

f_a = the external noise factor defined as

$$f_a = \frac{P_n}{k t_o b} \qquad (7)$$

[F_a is the external noise figure defined as

$$F_a = 10 \log f_a.]$$

p_n	=	the available noise power from an equivalent lossless antenna
k	=	Boltzmann's constant = 1.3 8 x 1 0^{-23} J/K
t_o	=	the reference temperature in K, taken as 290 K
b	=	the noise power bandwidth of the receiving system in Hz
l_c	=	the antenna circuit loss (available input power/available output power)
l_t	=	the transmission line loss (available input power/available output power)
f_r	=	the noise factor of the receiver

[F_r is the receiver noise figure defined as

$$F_r = 10 \log f_r.]$$

f_c is the noise factor associated with the antenna circuit losses,

$$f_c = 1 + (\ell_c - 1)\left(\frac{t_c}{t_o}\right), \tag{8}$$

f_t is the noise factor associated with the transmission line losses,

$$f_t = 1 + (\ell_t - 1)\left(\frac{t_c}{t_o}\right), \tag{9}$$

where:

t_c	=	the actual temperature, in K, of the antenna and nearby ground.
t_t	=	the actual temperature, in K, of the transmission line.

If $t_c = t_t = t_o$, (6) becomes

$$f = f_a - 1 + f_c f_t f_r. \tag{10}$$

Figure 1 shows the receiving system and how the noise factors can be combined. Relation (6) (or 10) provides the means to determine an appropriate receiver noise figure, F_r, for an external noise level, f_a.

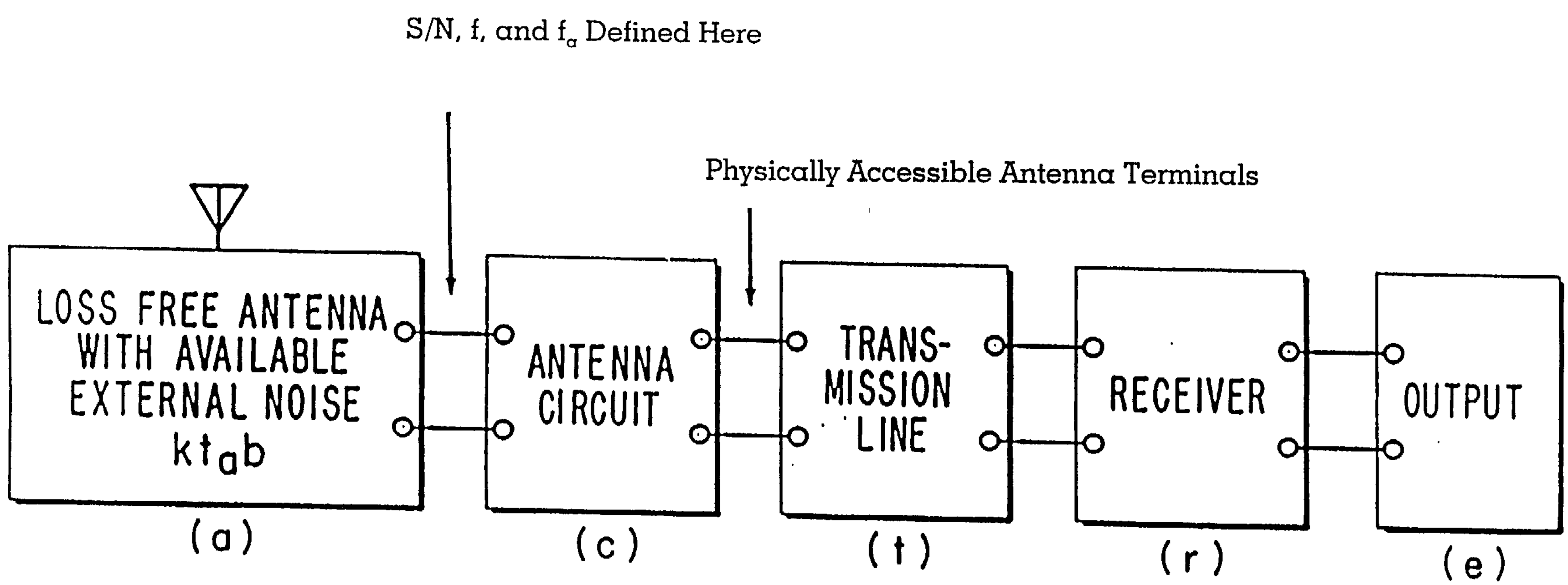
Relation (7) can be written

$$P_n = F_a + B - 204 \ dBW \tag{11}$$

where:

P_n	=	$10 \log p_n$ = available power in watts,
B	=	$10 \log b$, and $-204 = 10 \log kt_o$.

In general, since different antennas have different effective length-to-radiation resistance ratios, they can have different f_a's for a given field strength [8]. One converts the specified f_a data (particular to the reference antenna) to the corresponding field strength. This field strength is then applied to the



$\ell_a = 1,\ t_a$ $\qquad \ell_c,\ t_c$ $\qquad \ell_t,\ t_t$

$f_a = t_a/t_o$ $\qquad f_c = 1 + (\ell_c - 1)(t_c/t_o)$ $\qquad f_t = 1 + (\ell_t - 1)(t_t/t_o)$ $\qquad f_r$

$$f = f_a + (\ell_c - 1)(t_c/t_o) + \ell_c(\ell_t - 1)(t_t/t_o) + \ell_c\,\ell_t(f_r - 1)$$

Figure 1. The receiving system and it's operating noise factor, f (from CCIR [9[)

antenna of interest to obtain its f_a. Equation (7) (or 11) relates available power and f_a. The available power is given, in general, for an antenna by

$$P_n = \frac{\left(\bar{e} \bullet \bar{\ell}_{eff}\right)^2}{4R_{rad}} , \tag{12}$$

where $\bar{e}$ is the field strength (in a bandwidth b), ℓ_{eff} is the vector effective length of the antenna and R_{rad} is the radiation resistance of the antenna.

For a short ($<< \lambda$) grounded vertical monopole, from (7) and (12), the vertical component of the rms field strength is given by

$$E_n + F_a + 20 \log f_{MHz} + B - 95.5\, dB \; (\mu V/m) \tag{13}$$

where:

E_a is the field strength in bandwidth b, and
f_{MHz} is the center frequency in MHz.

Similarly, for a half-wave dipole in free space,

$$E_n = F_a + 20 \log f_{MHz} + B - 99.0 \; dB \; (\mu V/m) \; . \tag{14}$$

The external noise factor, especially at higher frequencies, is also commonly expressed as a temperature, t_a, where, by definition of f_a,

$$f_a = \frac{t_a}{t_o} , \tag{15}$$

t_a is the effective antenna temperature due to external noise.

Noise from individual sources such as the sun, atmospheric gases, the Earth's surface, etc., are usually given in terms of a brightness temperature, t_b. For our purposes here, the brightness temperature t_b and the effective antenna temperature t_a, are completely equivalent.

Measurement data is given in terms of F_a, usually distributions of F_a values for various time periods. Measurement data is also given directly in field strength. It often is not known if this "field strength" is the actual field strength based on proper rms measurements. Often, "peak" measurements are used for automobitve ignition system measurements. The peak value is the maximum value measured over some specified measured time. In terms of our envelope random process, it generally corresponds to the value exceeded about 0.01% of the time (probability of 10^{-4}) The voluntary standard [9] of the Society of Automotive Engineers (SAE) is primarily based on peak measurements and it specifies measurement procedures for individual vehicles. Measurements at both vertical and horizontal polarizations are required. The SAE standard (J55 1) covers the frequency range 20-1,000 MHz.

The above discussion has been to show the relationship between F_a and field strength so that various diverse measurements can be interrelated. It has also been to define a receiving system's overall operating noise factor. This is especially useful to determine an appropriate receiver noise figure. It makes no sense to use a receiver with more sensitivity than at dicated by the external noise. It is also desirable to know the effect of the receiving systems internal noise on the overall interfering noise proess.

For impulsive noise processes at the higher frequencies (i.e., > about 1 GHz), F_a values can be quite low and only the higher magnitude pulses appear above the measurement receiver's noise threshold. Description here can take the form of peak values for a given time period, exceedance probabilities at these higher levels, pulse counts at these higher levels, etc.

Before proceeding to the next section where we look at the noise level (F_a, E_a, etc.,) background measurements and the noise levels from particular sources in our frequency range of interest, we want to look at the general overall background from nautral sources.

Figure 2 shows this background in the frequency range 1 Hz to 1 THz. Notice that in our main frequency range of interest (0.9-3 GHz), the natural noise background is extremely low. This is especially true in our case since curves L_D, L,, F, H, and M, all refer to very narrow-beam antennas pointing directly at the source (e.g., glactic center, sun, etc.). In fact, this frequency range is the one in which one can get clear down to the cosmic background (t_a = 2.7K).

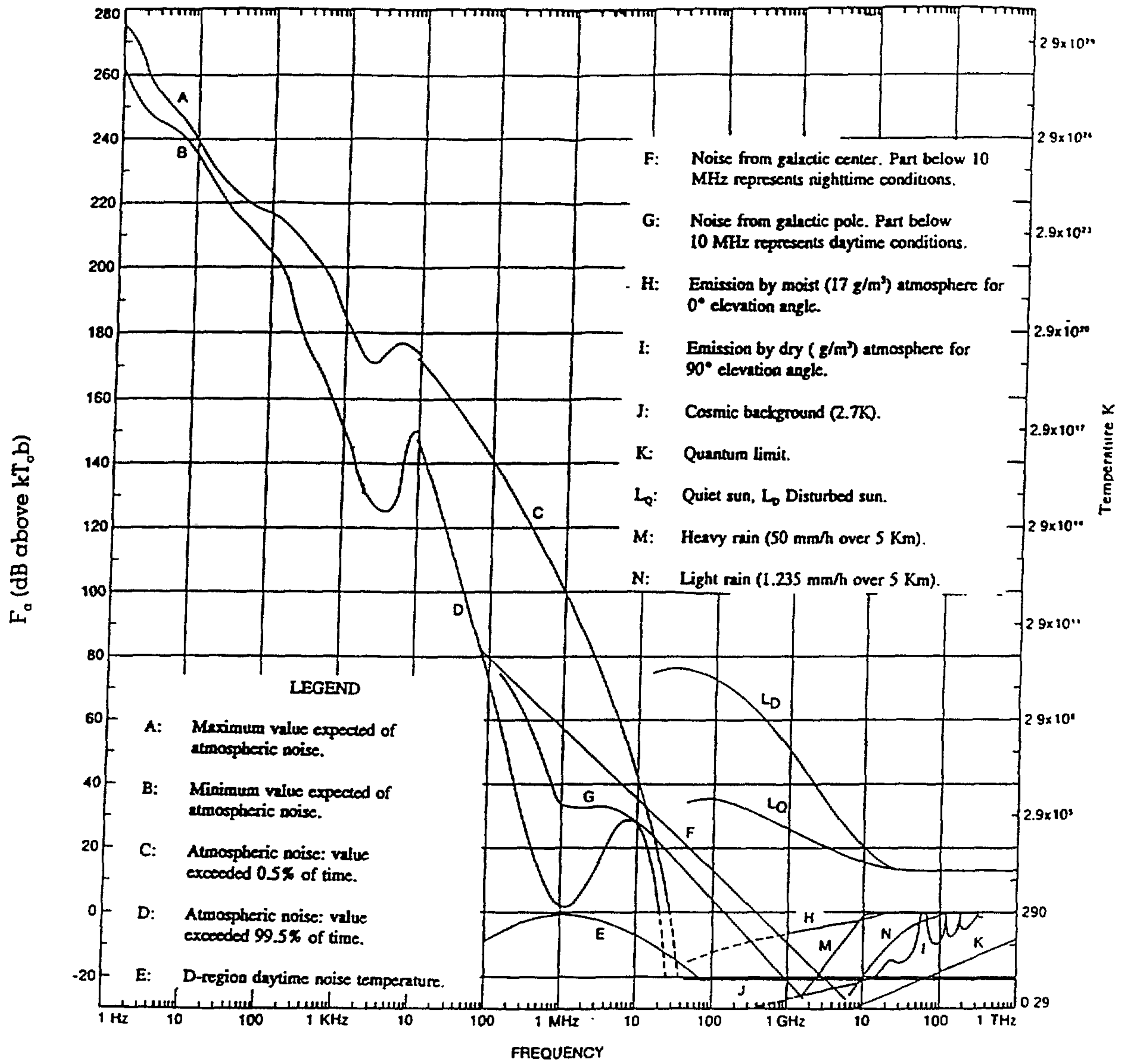


Figure 2. Natural radio noise

Figure 3 (a corrected figure from CCIR Report 670 [10] shows much of the same information as Figure 2, but over the frequency range 100 MHz to 100 GHz. Figure 3 also has curve A, which is the man-made noise background in a business (urban) area. Extending Curve A a bit, the background noise at 2 GHz (say) is around $F_a = 5$ dB.

One other nautral source that might affect sensitive systems, especially at the lower frequencies, is nearby lightning. Figure 4 from [l l] gives a summary of local lightning peak field strengh measurements. The results on Figure 4 are in terms of peak field intensity (dB uV/M, 1 kHz bandwidth). At 100 MHz, say, the value for lightning one mile distant is 47 dB uV/m. Lightning is a highly impulsive process, and in a 1 kHz bandwidth, the rms level is at least 20 dB below the "peak" level (probably even more than this below the "peak" level, depending on the frequency). A rms field strength of 27 dB uV/m in a 1 kHz bandwidth, corresponds to an F_a value of 47 dB using (13). Comparison of this value at 100 MHz with the general background given on Figures 2 and 3, shows that nearby lightning can be a significant (but short term) impulsive interference source (at 100 MHz). At 1 GHz (5 dB uV/m peak), however, the corresponding F_a value is approximately - 15 dB, using the same 20 dB difference between peak and rms. Nearby lightning could easily disrupt sensitive systems at 100 MHz but at 1 GHz, is well below the background and has approximately the same level as galactic noise (Figure 3).

The above introduction has been to define the parameters in which most noise measurements and data are presented and to give the general natural background noise levels. In the next section, we look at automotive ignition noise, since in urban areas, and especially in roadway situations, it is the main source at frequencies above HF (3-30 MHz). Nearby power transmission lines can be a source of interference at 100 MHz but probably not in the GHz ranges except in bad weather conditions. After ignition noise, we will briefly look at power lines.

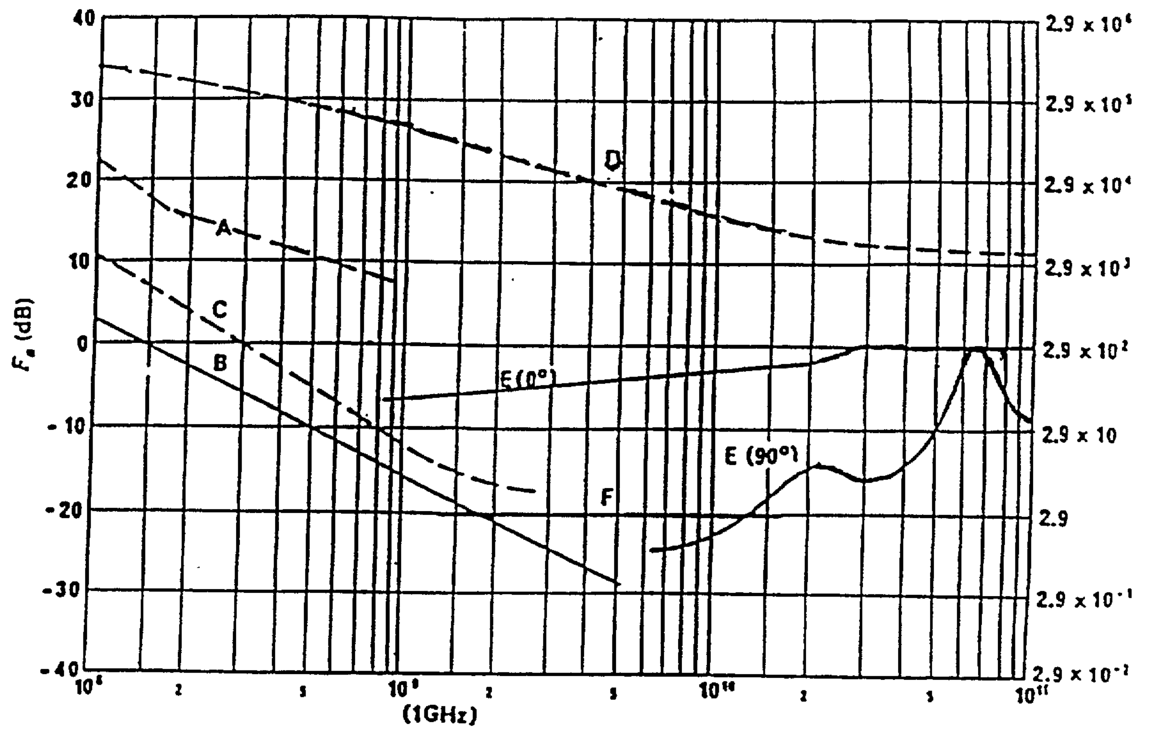


Figure 3. F_a versus frequency (100 Mhz to 100 Ghz)

A. Estimated median business area man-made noise

B. Galactic noise

C. Galactic noise (toward galactic center with infinetly narrow beamdwidth)

D. Quiet sun (1/2° beamwidth directed at sun)

E. Sky noise due to oxygen and water vapor (very narrow beam antenna); upper curve 0° elevation angle, lower curve, 90° elevation angle

F. Cosmic background, 2.7K

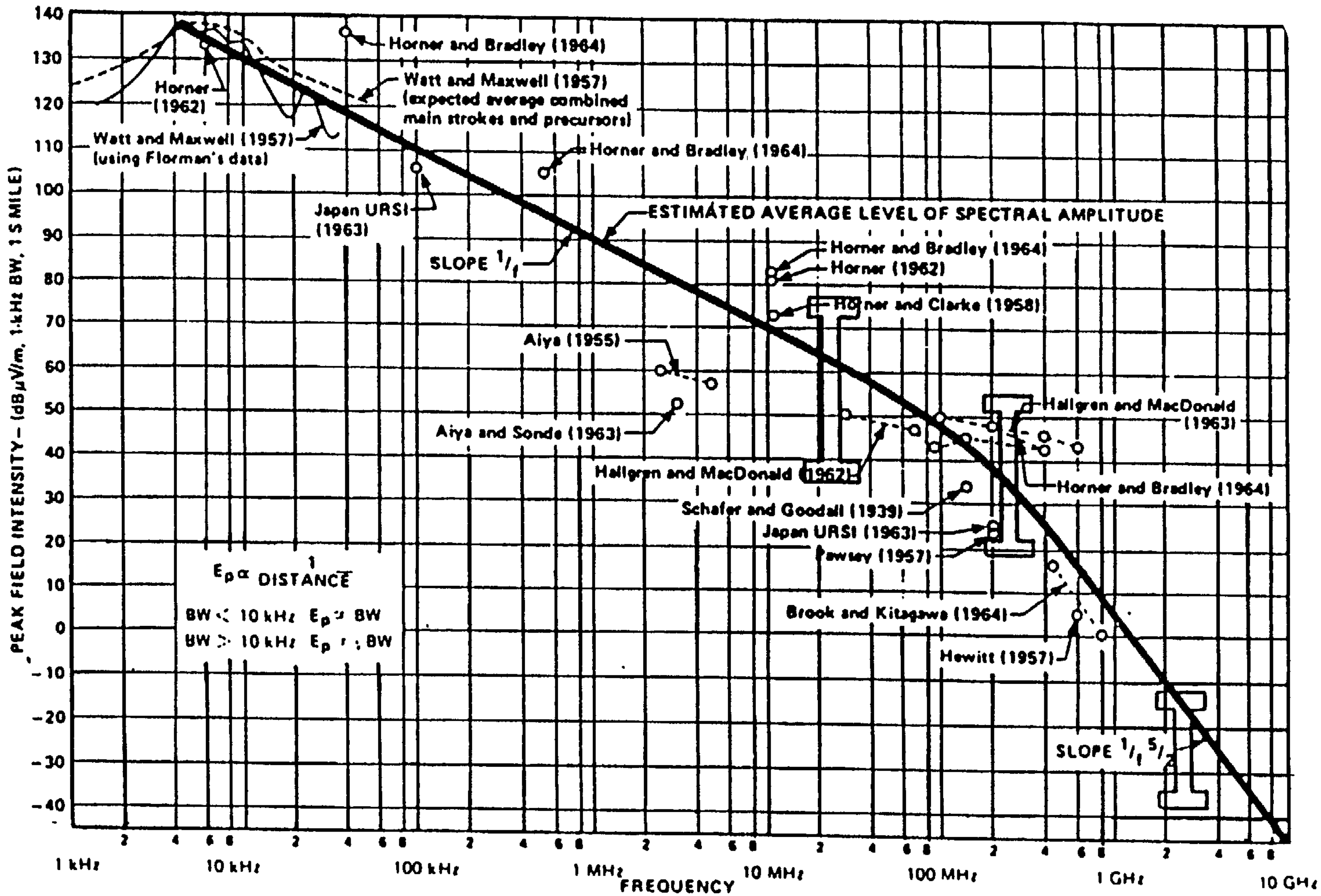


Figure 4. Lighting emission peak field strength, 1 mile distant [28]

2.2 Automotive Ignition Noise

In this section we want to look at the noise background levels on and along roadways due to automotive ignition systems. Most available studies of ignition noise, both from individual vehicles and various collections of vehicles, i.e., traffic, were performed some time ago in the mid-70's Vehicles have changed since then and as we will see, the overall noise background due to ignition systems, has decreased substantially (on the order of 20 dB).

The statistical character of the interference (as given by the ASPD, for example) has not changed, but the rms level (power) has decreased. Also, the distribution of radiated power from individual vehicles is probably still similar, but with a lower median value. We will start by looking at the earlier results in our frequency range (essentially 100 MHz on). For this frequency range, the background noise in urban areas is, in general, due almost entirely to ignition noise, except in special situations involving nearby individual sources (various industrial machinery and transformer substations for example). We will also look at some quite extensive studies of radiation from individual vehicles and the distributions of this radiation, i.e., differences between vehicles. We will then look at more recent measurements and indications as to the trend with time of the background level in order to get a feel for what this level might be now. After this, we look at the impulsive statistical characterof the ignition noise background. Finally, we will summarize the results of a study which developed means to obtain the background level for various traffic situations from the distribution of radiation from individual vehicles.

In the early 1970's, the ITS (Institute for Telecommunication Sciences), made man-made noise measurements throughout the country using a mobile measurement system. This extensive set of measurement data has become the basis for most "standard" man-made noise estimates (e.g., CCIR) at frequencies below 250 MHz, the highest ITS measurement frequency. Figure 5, from Spaulding and Disney [12] gives the overall results for interstate highways.Note that the 100 MHz value for F_a is 18 dB. Skomal [13] in his noted book on man-made noise gives quite similar results for two different traffic densities. Figure 6, from Skomal, shows this, again with a 100 MHz F_a value of around 18 dB (extending the given curves.)

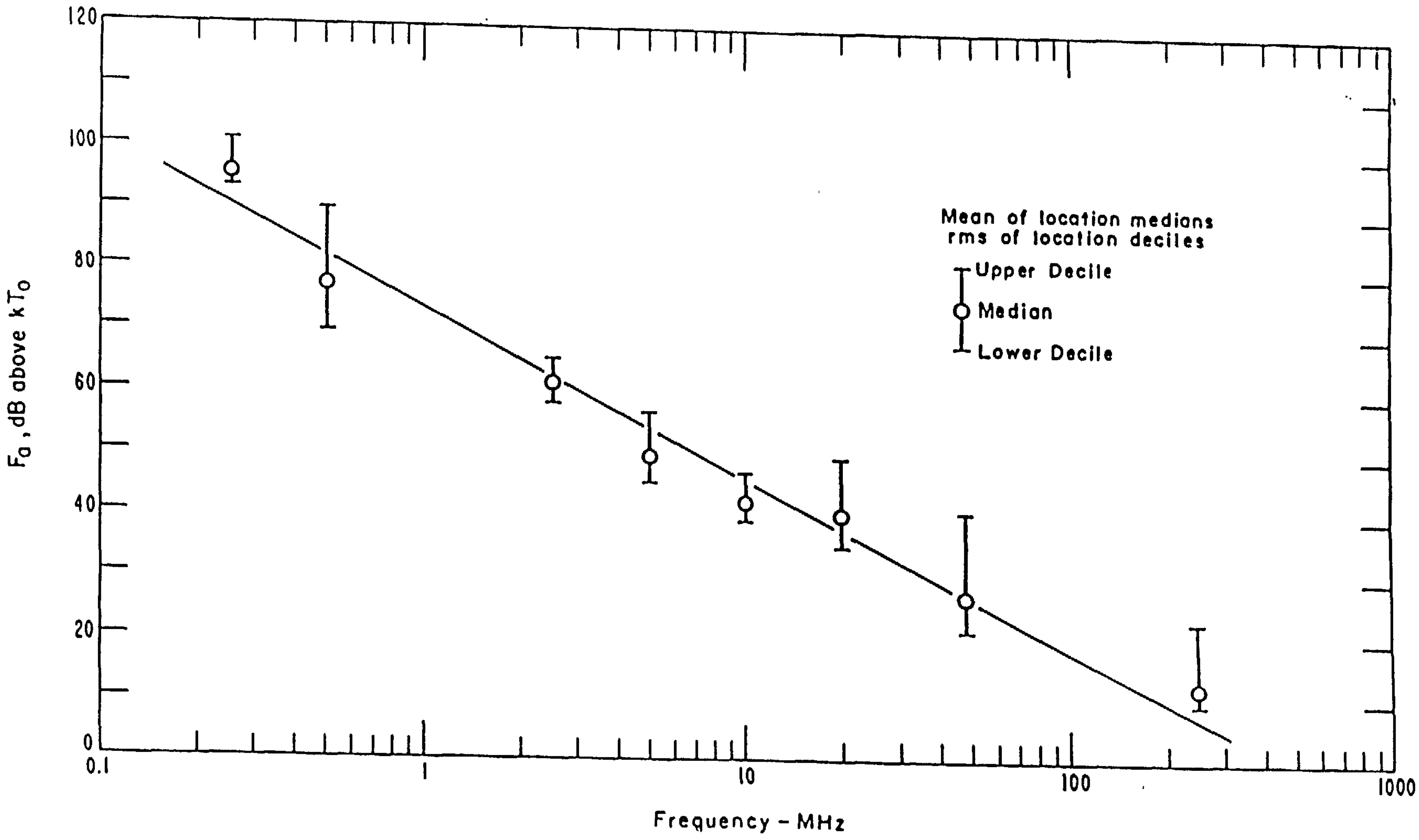


Figure 5. Estimates of man-made noise levels and their variation within an hour for interstate highways

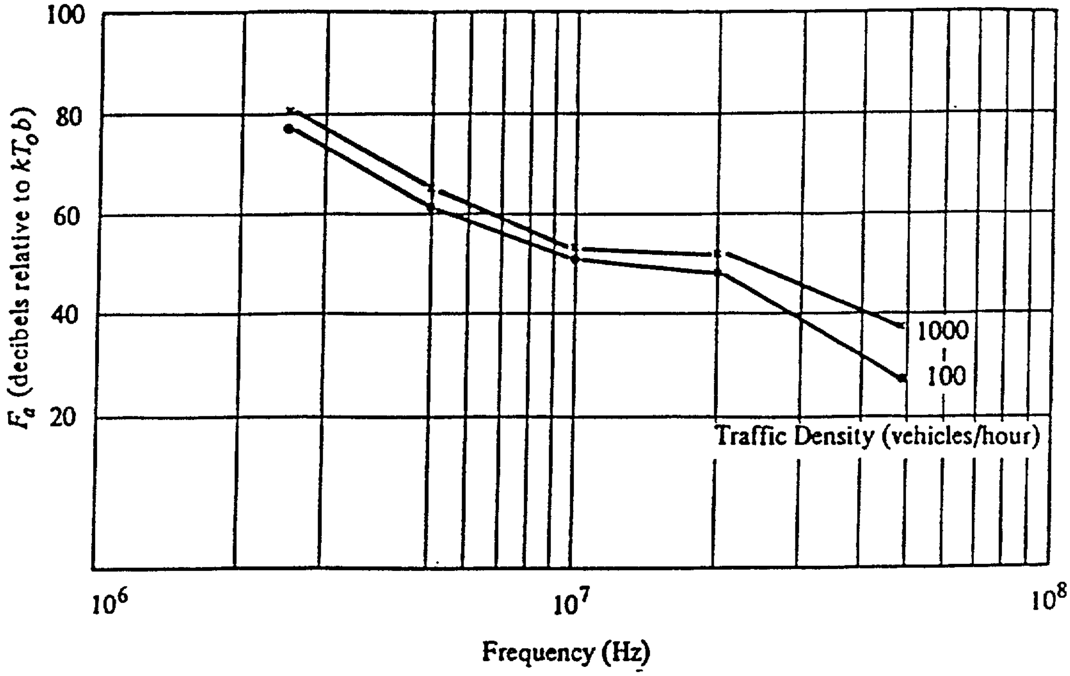


Figure 6 Average automotive-traffic-noise power for two traffic densities, as a function of frequency

These earlier results are generally for frequencies below our main frequencies of interest. Note that the slope or rate of decrease of the noise power with frequency shown on Figure 5, is 27.5 dB/decade. At frequencies above about 2100 MHz, the noise power still decreases with frequency, but at a much slower rate as indicated on Figure 3, Curve A. Figure 7, from Skomal [13], shows an example of this for urban man-made noise measurements.

In the mid-1790's, a very extensive study of vehicle ignition radiation was performed by SRI International (then Stanford Research Institute) for the MVMA (Motor Vehicle Manufacturing Association). In this study, approximately 10,000 individual vehicles (in motion) were measured. The measurements were of peak field strength since, as noted earlier, the SAE standard is in terms of "peak". The results of the part of this study in our frequency range of interest, are contained in the references [14, 15, 16]. Also, in the same time frame, studies to develop methods for additional ignition noise suppression were undertaken. SRI developed methods in a study for the FCC (Federal Communications Commission) [17] and the NBS (National Bureau of Standards) along with the Law Enforcement Standards laboratory, studied supporession methods for the national institute of Justice [18].

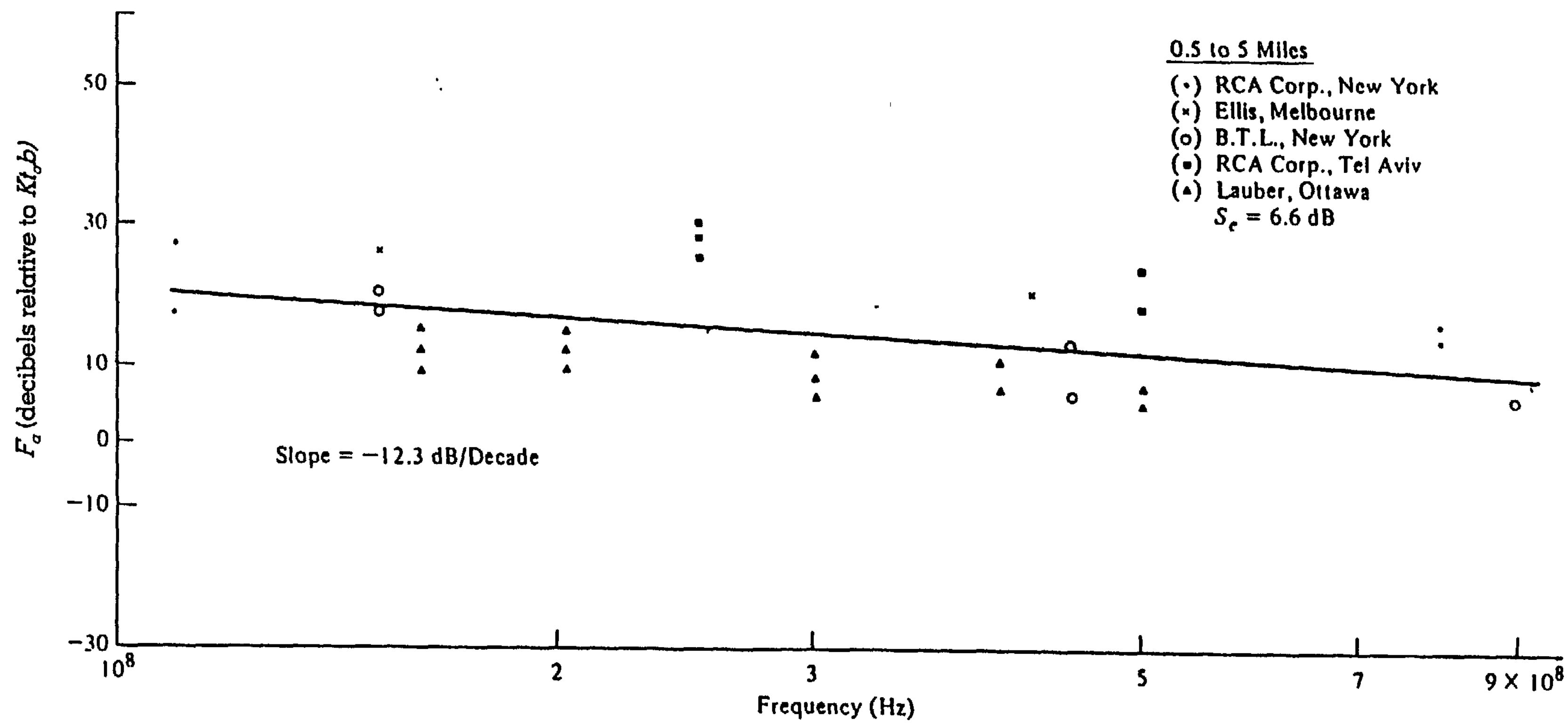


Figure 7. F_a versus frequency for urban man-made noise (from Skomal, 1978)

The SRI measurements of interest to us covered the frequency range of 50 MHz to 7 GHz. Figure 8 (from [15] shows examples of the individual vehicle measurements at 300 MHz and 4 GHz, giving the distributions of vehicle peak radiation for a sample of moving vehicles. The measurement anetnnas were 10 meters from the vehicles and in all cases, the measurement bandwidth was 300 kHz. Both vertical and horizontal polarizations were measured. Figure 9 (from [15]) summarizes the data for all the measurement frequencies. It points out that sa small percentage of vehicles (using peak measurements) greatly exceed the median (50%) vehicle, sometimes on the order of 30 dB or more.

The effects of these super noisy vehicles upon land mobile communications have been summarized by Dietz, et. al., [19]. measurements of the rms field strength have shown this same super noisy vehicle phenomena [20, 21]. The obvious hump in the area of 300 MHz on Figure 9, is the VHF automobile resonance. This resonance is probably due to various parts of the vehicle's wiring and other structures being of the right dimensions to radiate most efficiently in the 300 MHz range. We will see another example of this later when we look at noise level as a function of time to get a feel as to what the level might be now.

Figure 9 shows distributions of vehicles peak field strength for the various measurement frequencies. Later we will give a method to determine the noise level from the distribution of vehicles radiated power (rms, not peak). One cannot obtain such a distribution from peak values. Figure 10 from [22] shows a distribution of vehicle radiated power, but at 48 MHz. Such distributions are apparently not available for modern vehicles or for our frequencies of interest.

One of the sets of data used by Skomal that involved actual roadway measurements was obtained by Lauber and Bertrand [33] in 1984, in Ottawa, Canada. They obtained data for business, residential and rural areas of five frequencies, 600, 700, 800, 900 and 950 MHz. The measurements were of noise power in terms oft, (15). A minimum of 1800 measurements for each area were used to obtain of the noise power. Table 1 shows the mean and median distributions values (converted to F_a via relation 15) for the urban core, 4-lane highway, and arterial road.

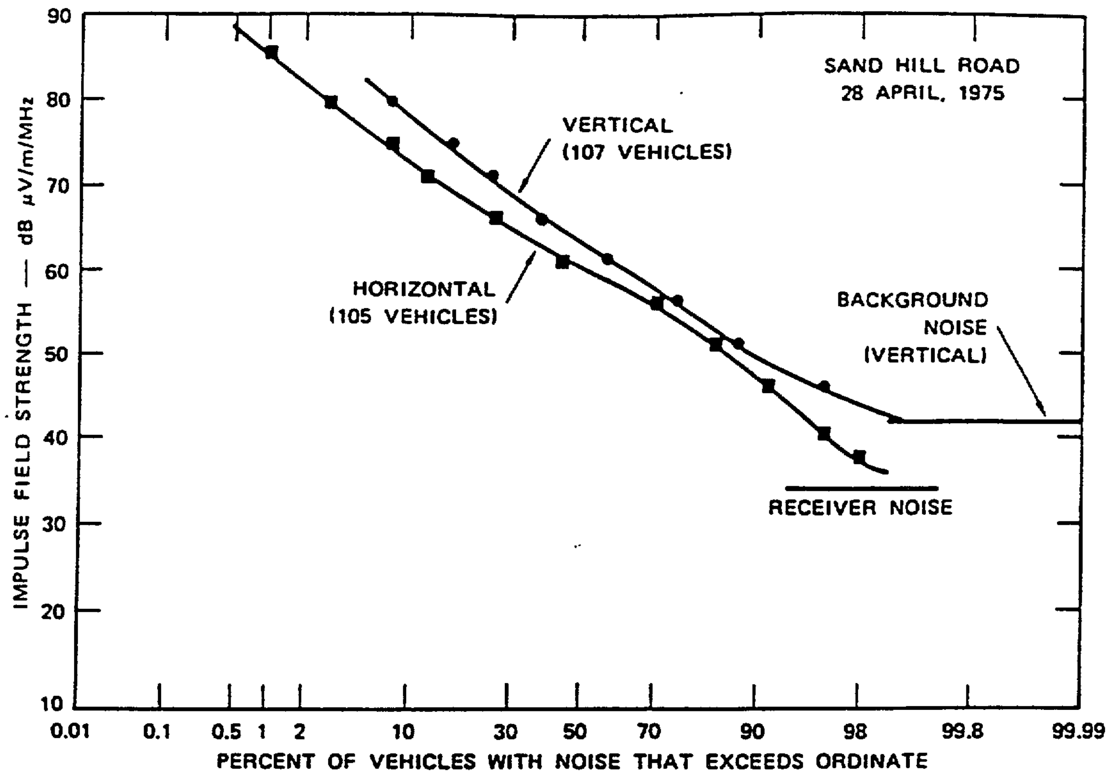


Figure 8a. Distributions of peak field strength from individual vehicles at 300 MHz, 300 Khz bandwidth.

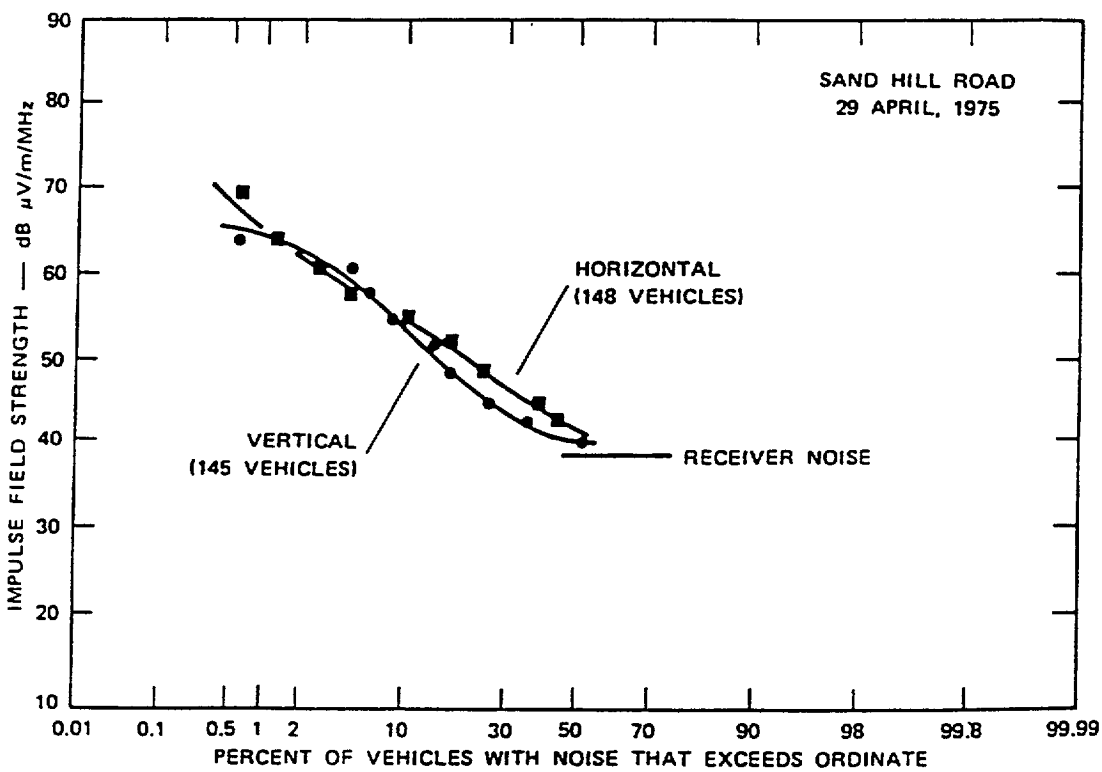


Figure 8b. Distributions of peak field strength from individual vehicles at 4 Ghz, 300 kHz bandwidth.

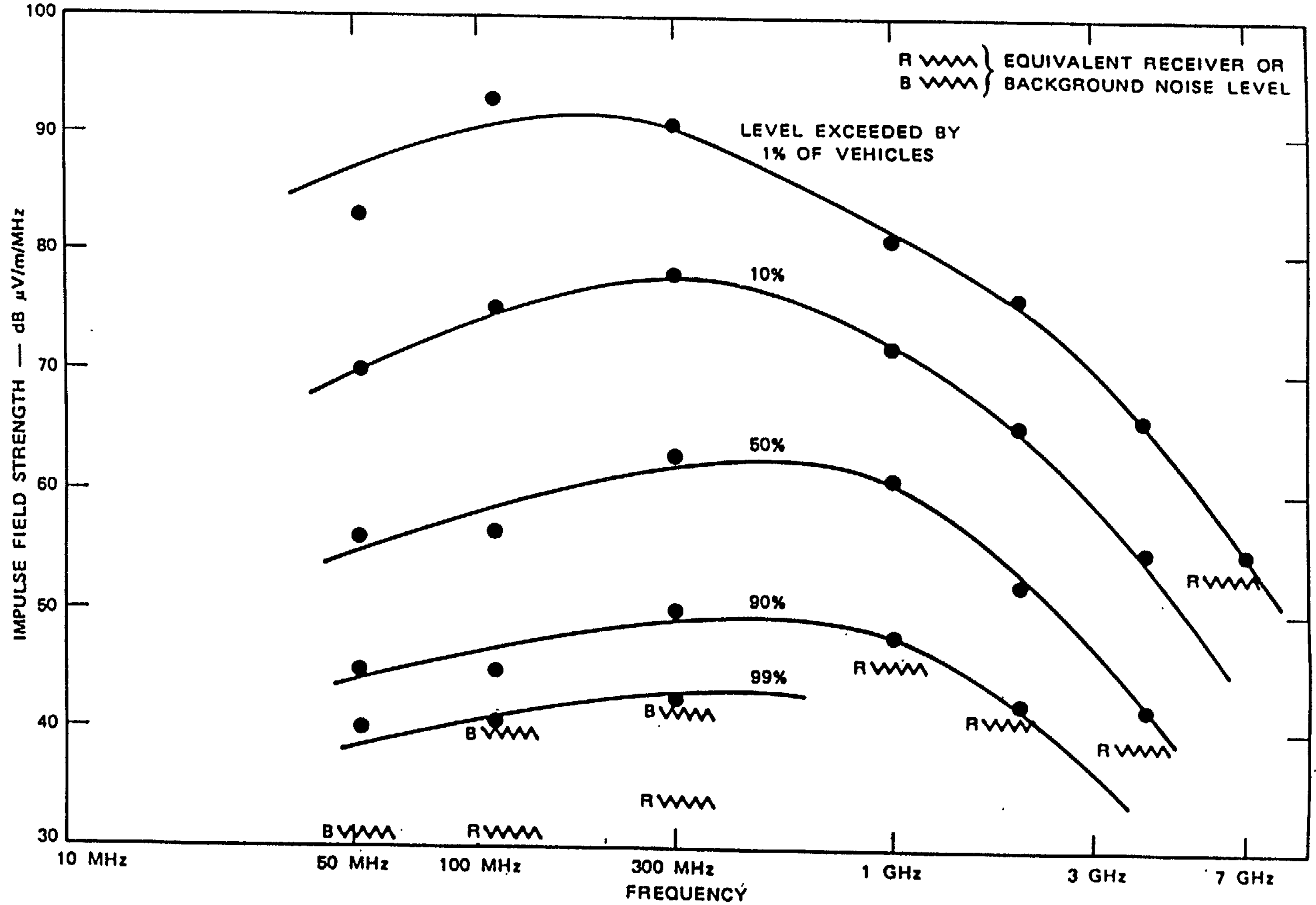


Figure 9. Ignition field strength from individual vehicles

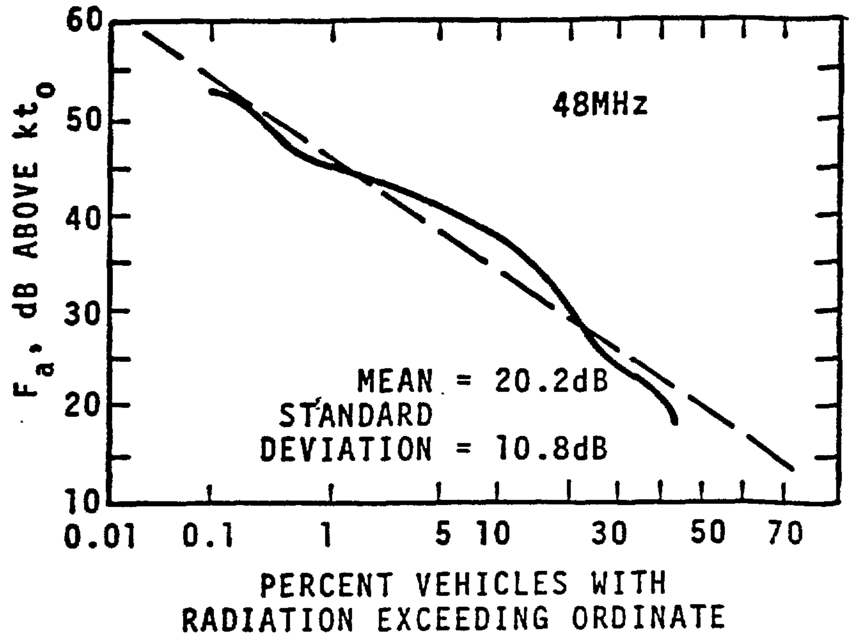


Figure 10. Distribution of radio noise power at 48 MHz radiated from 958 individual vehicles. Values measured at 50 ft from vehicles.

In 1992, Freeman [24] attempted to develop a trend with time for urban man-made noise in the frequency range 200 to 950 MHz using essentially the same data used by Skomal [23, Figure 11]. He developed a linear trend with time (years) for P_n (power in dBm/kHz) using frequency and population as contributing variables. His results are shown on Figure 12, which uses the measurement data given in references [25-34]. Note, from (11) that an available power of -130 dBm/kHz (say) corresponds to an F_a of 14 dB. Freeman's trend analysis indicates that the noise level now (1993) should be given by an F_a at about 15 dB less than in 1975, or on the order of -5 dB at 1 GHz (using the "1975" 1 GHz value of 10 dB from Figure 7). Of course the probable decrease depends on frequency as shown in Figure 11, but the above should be a reasonable estimate.

Recently, Yamanaka and Sugiura [35] presented an extensive set of noise measurements in urban areas (general streets and metropolitan expressways in Tokyo) in the 1-3 GHz range. Table 2 summarizes some of their measurements made at 1.48, 2.34 and 2.68 GHz. APD measurements were made and Table 2 shows field strengths in a 100 kHz bandwidth exceeded .01% and .001% of the time (probabilities of 10^{-4} and 10^{-5}). Figure 13 shows an APD measurement from [35] at 2.335 GHz. The measurement system noise is also shown on Figure 13. Note that the background noise showed above the system noise only about 10% of the time. Even so, a reasonably good estimate of the rms level can be obtained from this APD using (5) since most of the energy is in the portion exceeding the systems noise. In [35], the E_{rms} for this APD, is found (using (5)) to be 20 dB uV/m (100 kHz SW). This corresponds to a F_a of -1.9 dB, which corresponds reasonably well with Freeman's trend analysis.

On Figure 13, the Rayleigh distribution (envelope of Gauss) plots as a straight line of slope -1/2 as seen in the system noise measurement. If we define "peak value" as the value exceeded .00 1% of the time, then the difference between "peak" and rms (which occurs at a probability of .36) for Gaussian noise, is 11 dB. This difference for the background noise on Figure 13, is on the order of 23 dB. The difference between "peak" and rms could be used as a measure of impulsiveness (although the difference between average and rms is normally used). This difference is, of course, a function of bandwidth (except for Gaussian noise). We see that the background noise given by the measured APD of Figure 13 is not very impulsive, as it has a peak to rms difference of 23 dB in a 100 kHz bandwidth.

Table 1. Mean and Median Business F_a (dB)

Subarea/Parameter	Frequency(MHz)				
	600	700	800	900	950
Urban Mean	2.0	1.6	0.4	0.2	0.4
Core Median	1.1	0.1	-0.3	-0.8	-0.5
4 Lane Mean	3.1	0.3	-0.5	0.7	0.3
Highway Median	1.0	-1.2	-2.1	-1.9	-1.7
Arterial Mean	1.1	1.1	-0.4	-0.4	-1.0
Road Median	-0.9	-0.3	-1.5	-1.6	-2.1

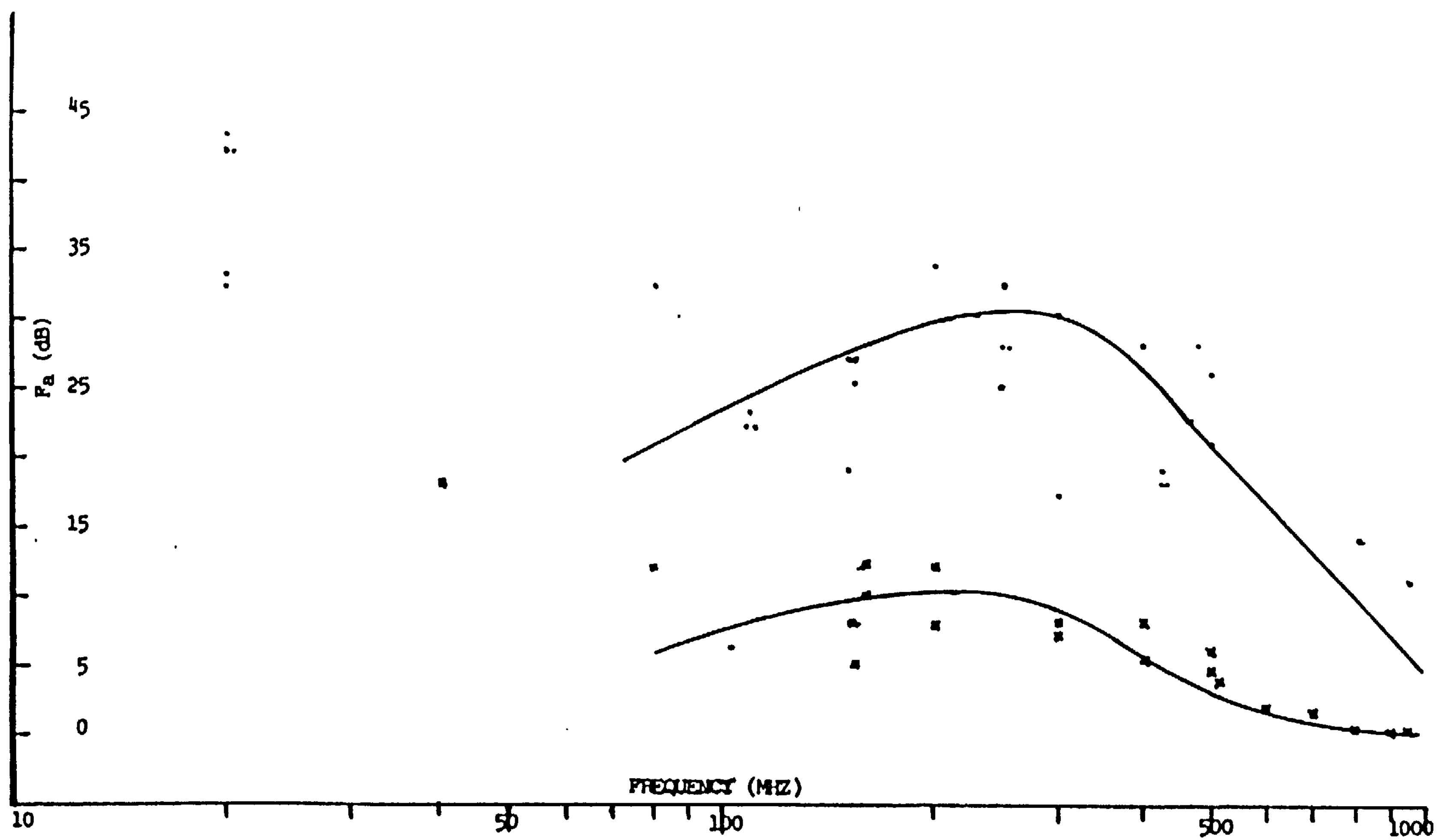


Figure 11. Incidental urban radio noise power measurements. Upper curve for data from 1951-1970, and lower curve for data from 1975-1983.

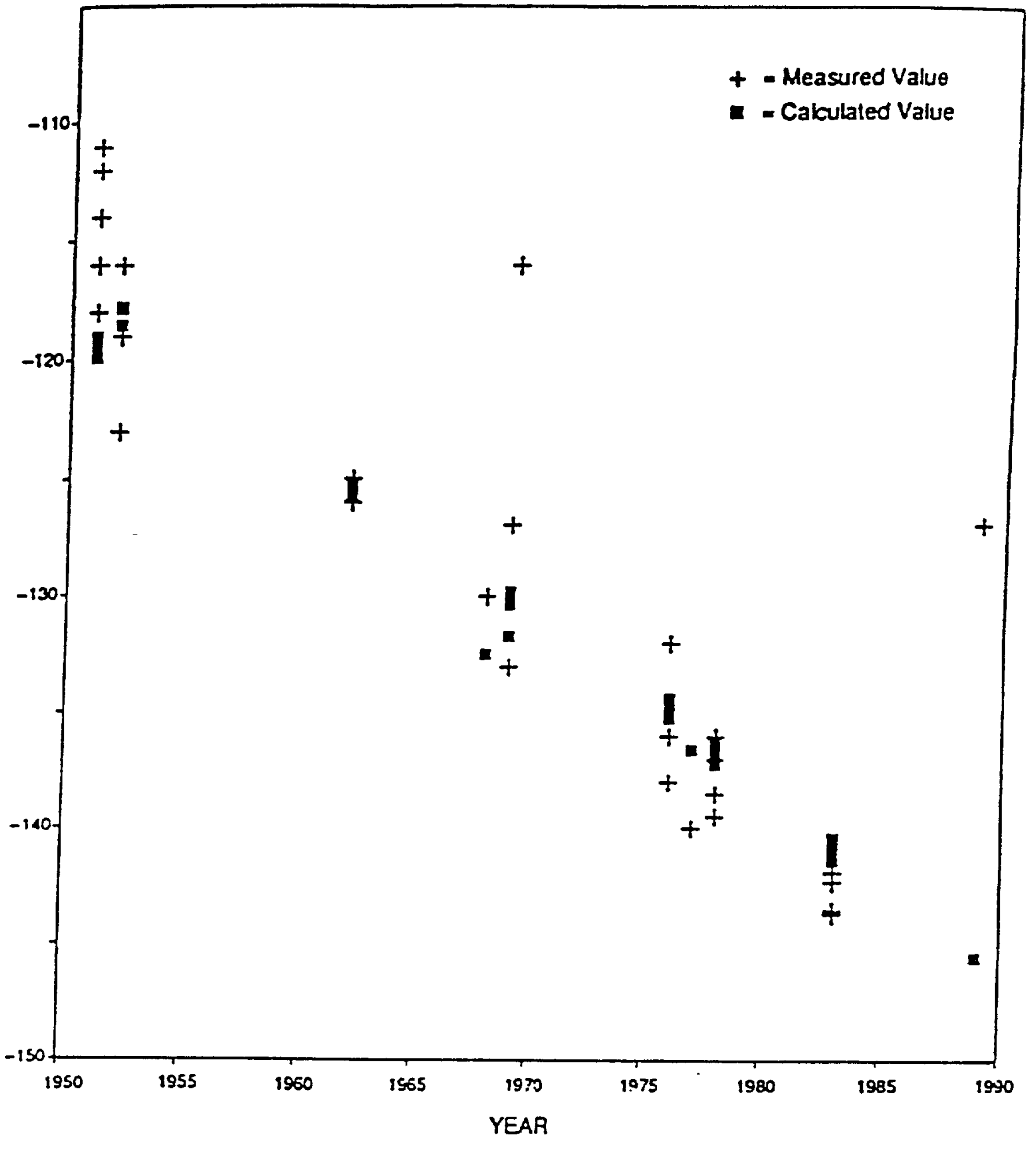


Figure 12. Average man-made incidental noise power

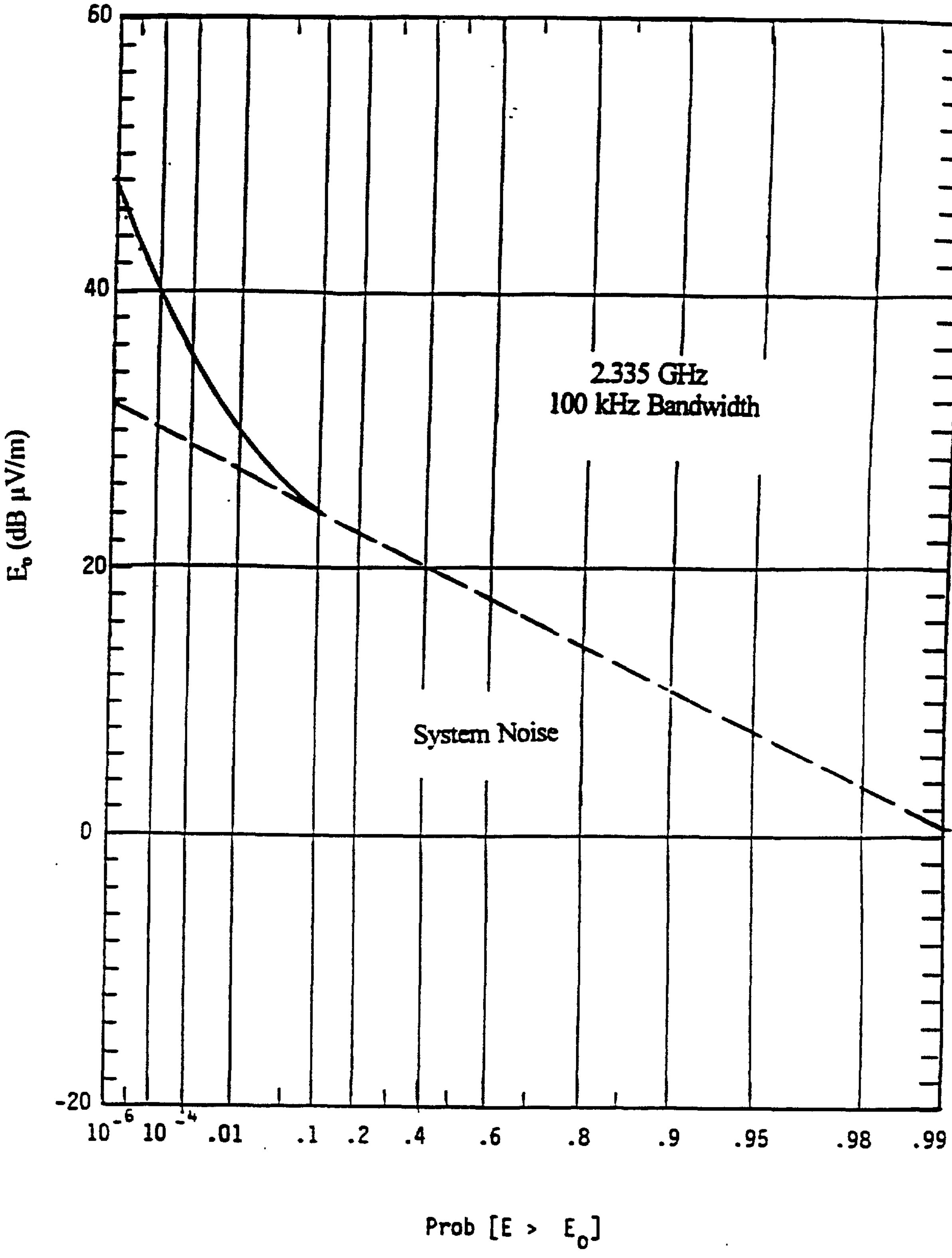


Figure 13. Amplitude probability distribution (APD) of system noise and ignition.

Table 2. Radio Noise Measurements

Frequency (Ghz)	Average Field Strength Exceeded, dBuV/m, 100 kHz BW		Standard Deviation		Measurement Place
	Prob of 10^{-4}	Prob of 10^{-5}	10^{-4}	10^{-5}	
1.48	39.7	47.0	3.7	3.0	Street
1.48	30.6	36.3	3.4	3.8	Expressway
2.34	32.7	39.4	3.6	3.7	Street
2.34	33.5	37.4	4.5	4.6	Street
2/34	30.3	33.4	3.3	4.5	Expressway
2.68	30.4	36.6	2.6	4.0	Street
2.68	32.8	36.4	1.5	3.5	Expressway

Above, we have summarized the available information on the background noise levels in urban areas, paying particular attention to traffic situations. It was noted that the noise level now is probably substantially less than in the 1970's when most available detailed measurements were conducted. In addition to just the noise level (F_a), we need information on its impulsive statistical characteristics in order to determine the affect on telecommunication systems and in order to design appropriate systems. Figure 13, has given one recent APD measurement at 2.335 GHz. We want to look briefly at some other measurements at other frequencies (and bandwidths) to gain information on the ignition noise impulsive nature. Figure 14 shows APD measurements for a single vehicle and 12 vehicles from Spaulding [36] at 900 MHz in a 300 kHz bandwidth. The vehicles were located three meters from the measurement antenna, with the 12 vehicles in a three-meter radius circle around the antenna. Voice system performance was measured (both articulation score and articulation index) simultaneous with the noise measurement. In Figure 14, the AN/GRC-103 denotes a tactical or fixed 12- or 24-channel 695-1000 MHz FM/PCM modulation voice and data communications system. Figures 15 - 17, show additional examples of APD measurements (ITS). Figure 15 is from ignition noise in central Colorado Springs at 250 MHz in a 4 kHz bandwidth. Note that F_a was 18.9 dB.

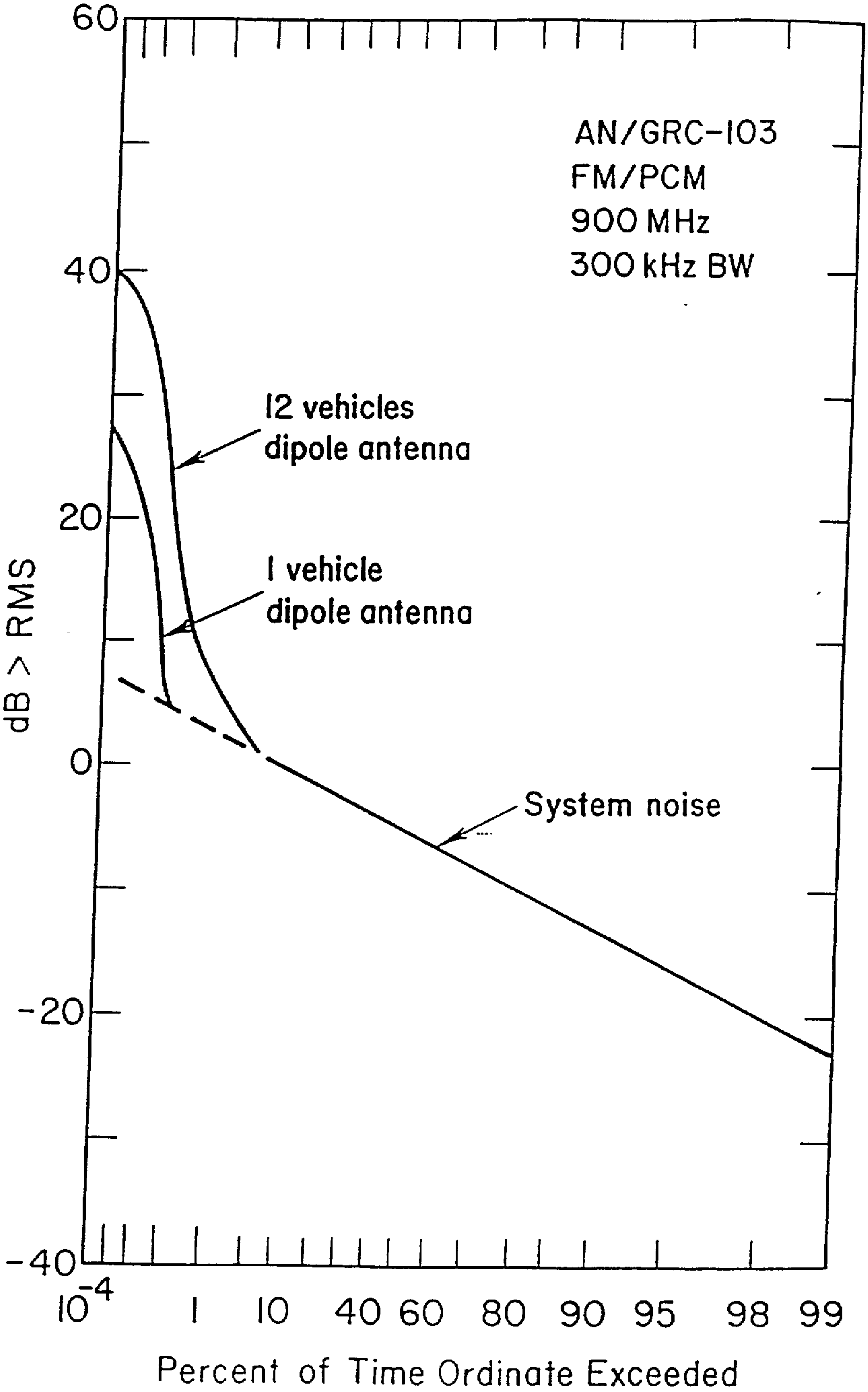


Figure 14. Amplitude probability distributions for 1 and 12 vehicles, 3 meter distant, 900 Mhz.

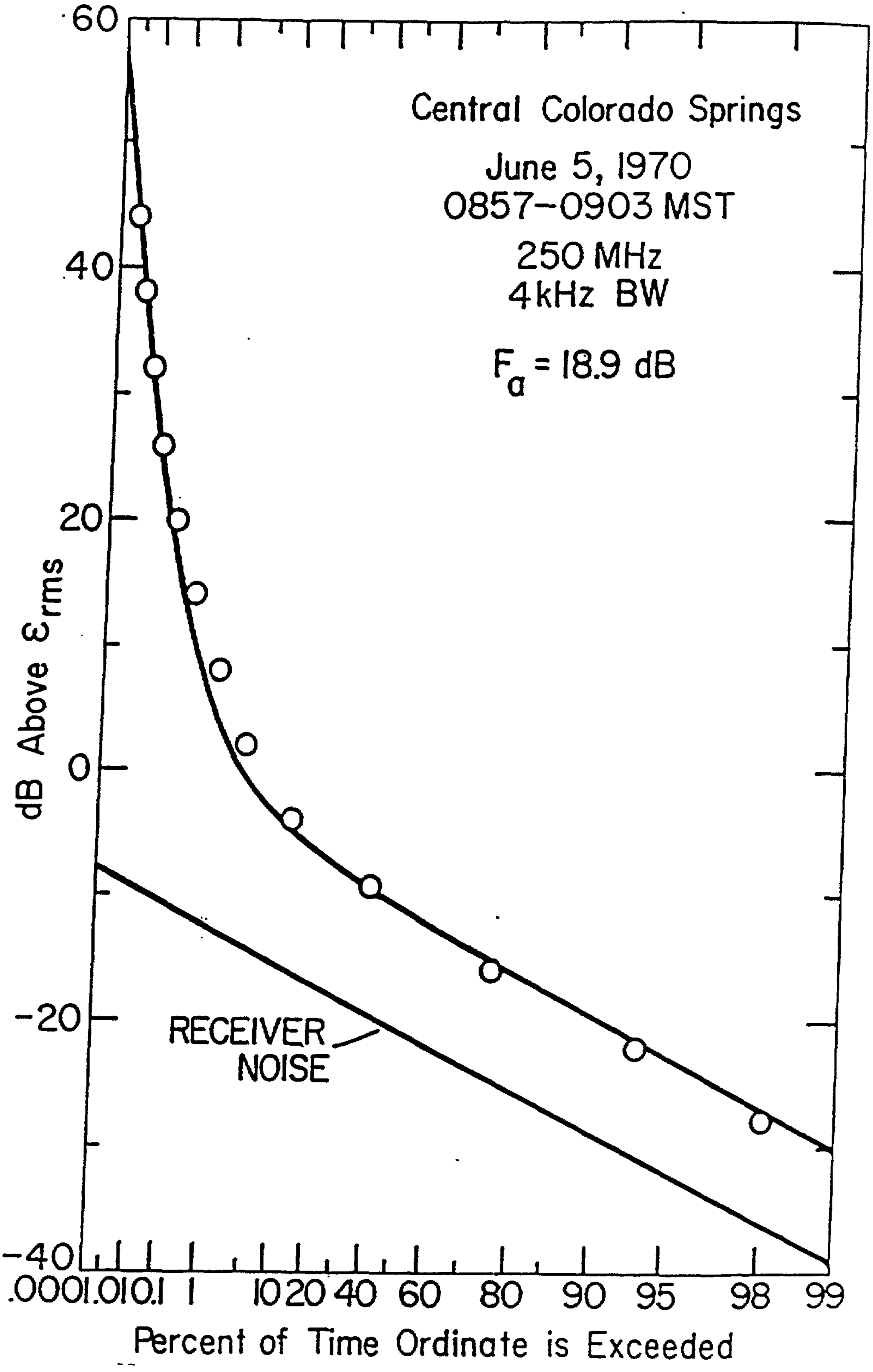


Figure 15. Amplitude probability distribution of ignition noise at 250 Mhz.

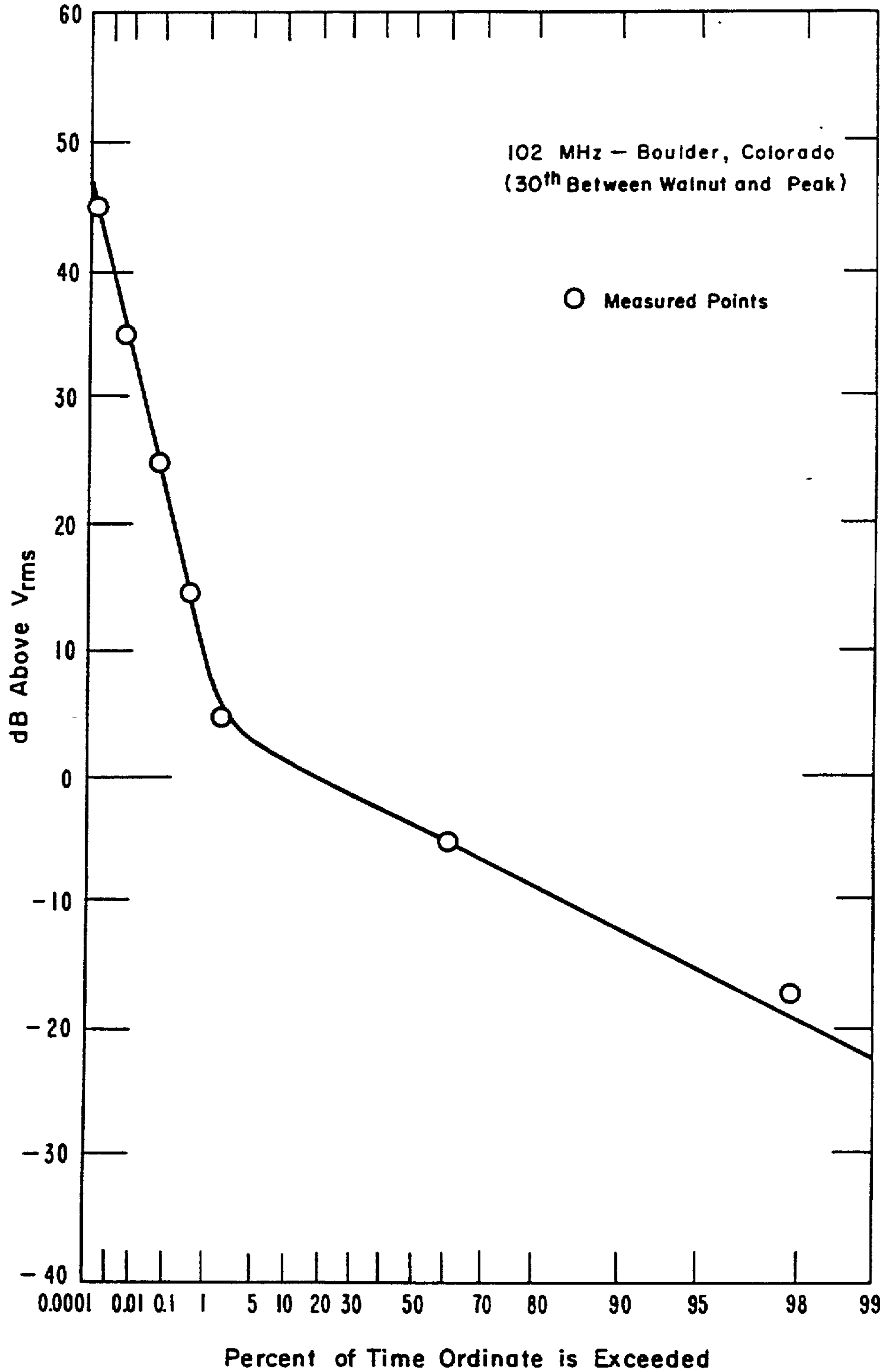


Figure 16. Amplitude probability distribution of ignition noise at 102 MHz, 10 kHz bandwidth.

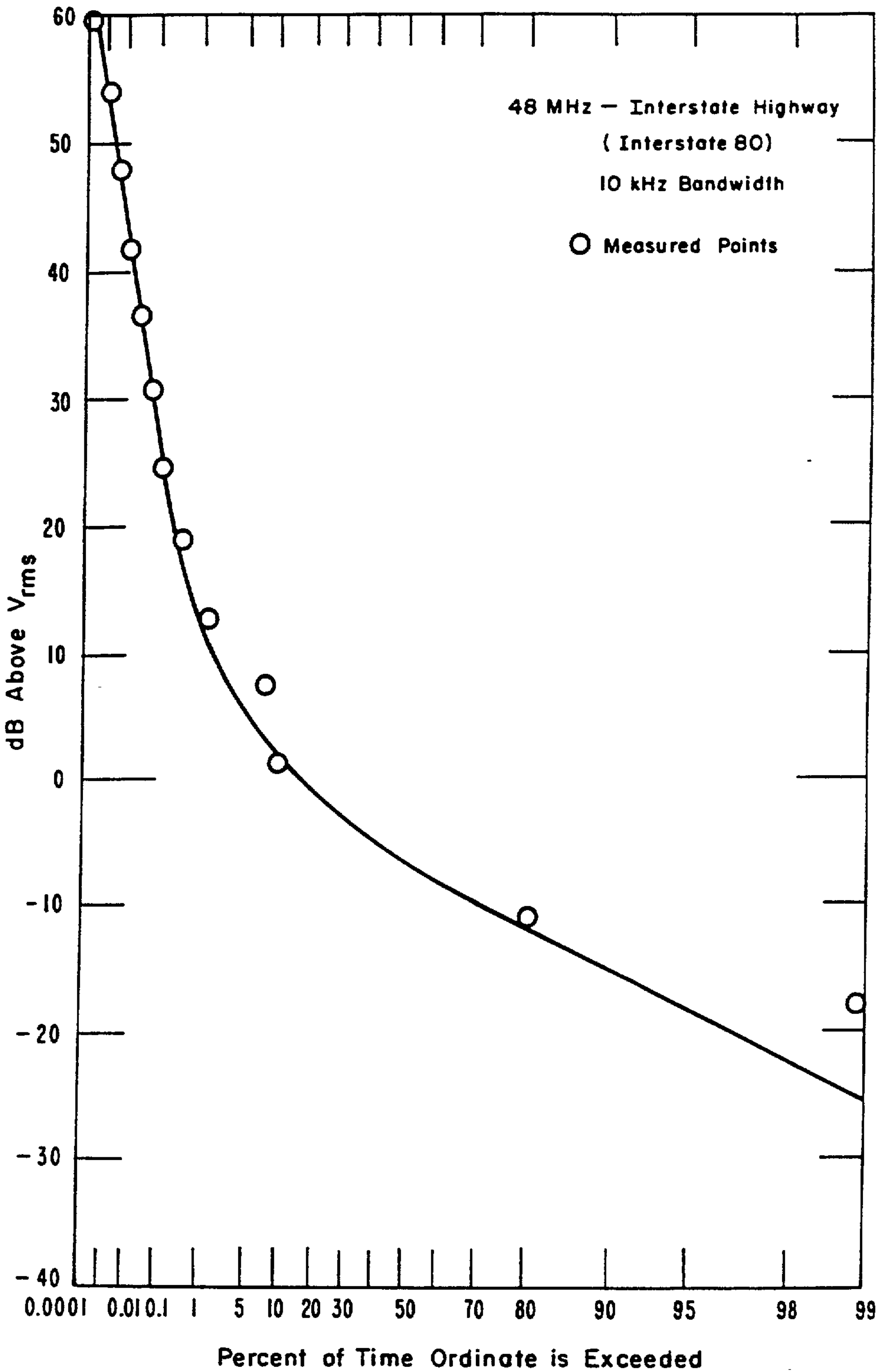


Figure 17. Amplitude probability distribution of ignition noise on an interstate highway at 48 MHz.

Figure 16 is ignition noise in downtown Boulder, Colorado, at 102 MHz in a 10 kHz bandwidth and 17 is a measurement on Interstate 80, 48 MHz and 10 kHz bandwidth.

As the example APD's show, ignition noise is quite impulsive with large dynamic ranges, especially at lower frequencies. As an example, Figure 18 shows a randomly selected 200 ms sample of the noise envelope from a six-minute recording at 250 MHz. The APD for this six minutes, was given in Figure 15. This means that the noise can have serious degradation effects on communications and control systems, especially "normal" systems, that is, those designed to be optimum in white Gaussian Noise. The recent measurement shown at 2.335 GHz did not have a high dynamic range. The noise was not highly impulsive (in the 100 kHz bandwidth), but still "impulsive enough" to be disruptive to normal systems.

Most of the amplitude distributions shown were measured in the 1970's timeframe, and as noted earlier, the overall background ignition noise F_a (or rms) values have probably decreased significantly. It is likely, however, that the APD of the received noise envelope is still similar to those shown (highly impulsive, in general) but with a lower rms level. Modem detailed measurements, however, are needed to precisely determine the overall characteristics of current. ignition noise. Such measurements are, apparently, not now available.

We want to finish this section of ignition noise by giving the results of an analysis some time ago that gives a simple means of determining the total received power from traffic statistics and the distribution of radiated power from individual vehicles. This could be useful in determining the background noise environment for various highway traffic situations, since measurements cannot be made for all conceivable situations. These results are based on an analysis by Spaulding [37].

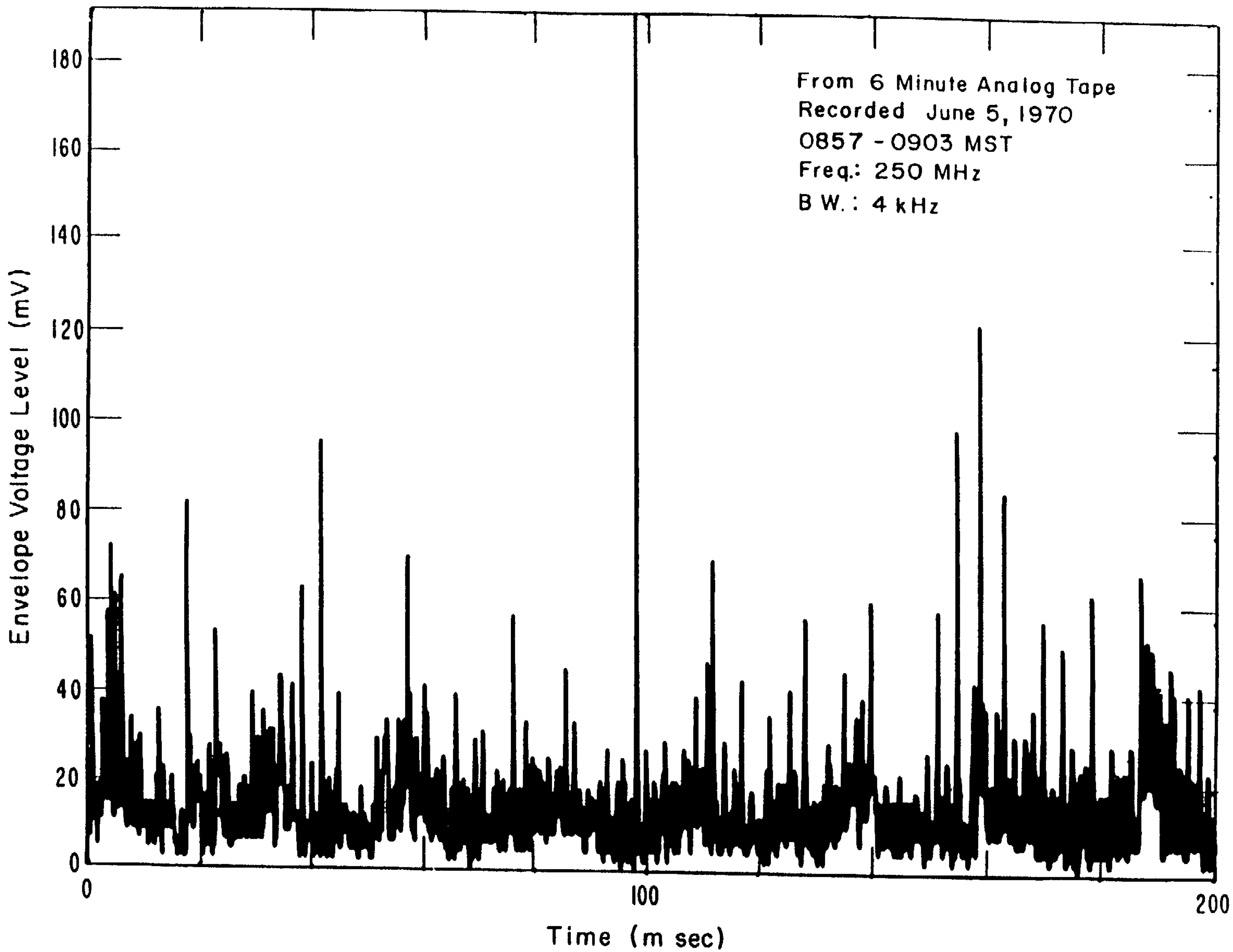


Figure 18. Randomly selected 200 ms sample of noise envelope from a 6-minute, 250 MHz central Colorado Springs recording

Figure 10, shows a measured distribution of radiated power from individual vehicles. The distribution is log normal, that is, if y = 10 log x, y is normally distributed with a mean μ (dB) and a standard deviation σ (dB). The mean and variance of the real power x (watts) is given by

$$\begin{aligned} \bar{x} &= 10^{0.1\mu \; = \; 0.0115\,\sigma^2} \\ Var[x] &= \left(10^{0.2\mu \,+\, 0.023\sigma^2}\right)\left(10^{0.023\sigma^2} - 1\right) \end{aligned} \quad . \tag{16}$$

Distributions of power from modern vehicles are apparently not available for our frequencies of interest (or any other), but they are undoubtedly log normal.

Since, for surface wave propagation and for distances and frequencies of interest here, the received power falls off essentially as distance to the fourth power, the power p_i, received from the ith car along the highway is

$$p_i = \frac{x_i \, d_m^4}{\left(d^2 + s_i^2\right)^2} , \tag{17}$$

where,

d is the perpendicular distance from the point of interest to the highway,

d_m is the distance at which x was measured, and

s_i is the distance along the highway to the ith vehicle.

The total received power p_T from an infinite line (lane) of vehicles is given by

$$p_T + \sum_{i=-\infty}^{\infty} p_i = \sum_{i=-\infty}^{\infty} x_i \left(\frac{d_m^2}{d^2 + s_i^2}\right)^2 , \tag{18}$$

where the x_i's are log normally distributed as discussed above. We want to compute the mean and variance of p_T. Of course, if we have many lanes of traffic, or a divided highway, etc., we can sum the contributions from each lane at our point of interest.

The spacing between vehicles will have some distribution. In traffic studies, the vehicle spacings are taken to be either equal or exponentially distributed. Which vehicle spacing assumption is best depends on the particular traffic situation. In reference [37] the mean and variance of p_T are evaluated for both cases as well as for various propagation conditions.

For equal car spacing, s,, i.e., s_i = is, the mean and variance of p_T is given by

$$\overline{p_T} = \bar{x} \sum_{i=-\infty}^{\infty} \left(\frac{d_m^2}{d^2 + (is)^2} \right)^2 \tag{19}$$

and

$$Var[p_T] = Var[x] \sum_{i=-\infty}^{\infty} \left(\frac{d_m^2}{d^2 + (is)^2} \right)^4 .$$

Reference [37] obtains the summations in closed form. A simple special case, when d/s > 1, is given by

$$\begin{aligned} \sum &\cong \frac{\pi d_m^4}{2sd^3} \ for \ \overline{p_T} \ , \ and \\ \sum &\cong \frac{5\pi d_m^8}{16sd^7} \ for \ Var \ [p_T] \ . \end{aligned} \tag{20}$$

In some of our cases, d/s may not be greater than one, i.e., the distance to the point of interest may not be greater than the vehicle spacing. Reference [37] gives the general results (more complicated than (20)) as well as general results for exponentially spaced vehicles. In [37], calculated values from the analysis are compared favorably with measurements.

In this section we have tried to indicate what the background noise level is now in highway situations based on earlier measurements, trend analysis, and one recent measurement in Tokyo. We have also suggested that if distributions of radiated power from modem vehicles were available, we could calculate the background for situations of interest in "intelligent highways" studies and design.

The other source of incidental interference that might affect the highway situation (especially at 100 MHz) is nearby power transmission lines. The next section briefly takes a look at this source.

2.3 Power Transmission Lines

In general, in urban areas, the man-made noise background below about 20 MHz is due to power transmission systems and due to automotive ignition systems above this frequency. In our highway case, however, nearby power lines can have an effect, especially at 100 MHz, and in wet weather, even at 1 GHz.

In the last section, we saw that in the 1970's timeframe, the highway background ignition noise at 100 MHz was on the order of an F_a of 20 dB, but is now probably 10 to 20 dB less. Figures 19 and 20 from Spaulding and Disney [12] show typical power line noise measurements. Figure 19 shows measurements under a 115 KV line and one-fourth mile distant. Note that at 100 MHz, under the line, F_a is 30 dB Figure 20 shows the fall-off of radiated power at 102 MHz with distance from the 115 KV line and a 250 KV line. For both lines, the F_a at a 0 distance is about 30 dB. Figure 2 1from Hagn [38] shows a summary of various power line measurements. Again, at 100 MHz, F_a is in the 20-30 dB range. The Disney and Longley reference on Figure 21, is given as reference [39] here. Skomal [13] gives numerous other power line measurements with essentially the same results as shown here. Herak and Kink [40] gives results of power line measurements for a number of transmission lines (24, 66, 115 and 230 KV, +300, -450 and +300 KVDC) in Canada. The F_a values for these lines at 100 MHz ranged from 5-30 dB. Herak and Kink [40] attempted measurements at frequencies in the GHz range, but the power line noise was well below their measurement receiver's

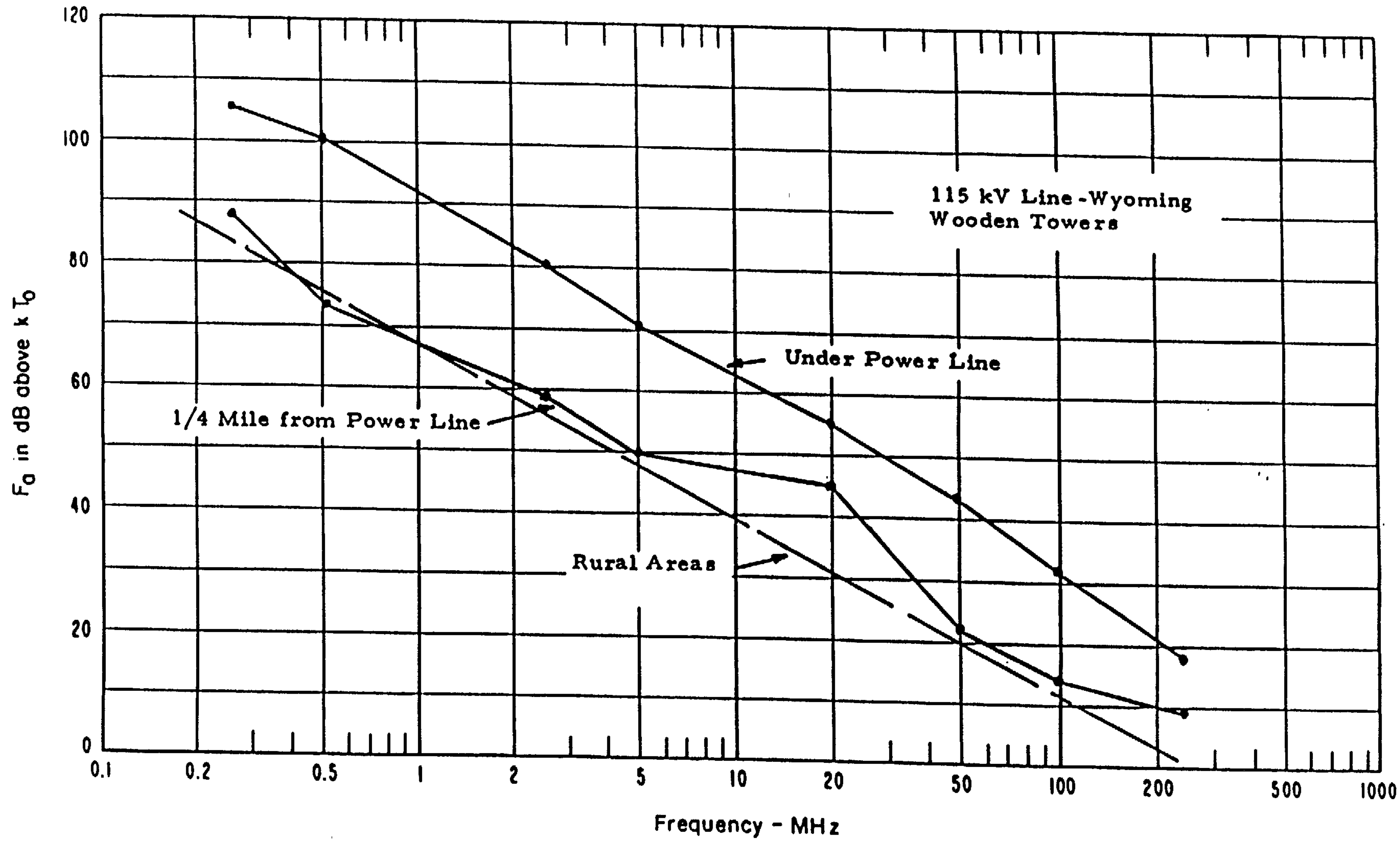


Figure 19. Power line noise measurements taken moving parallel to a 115 KV line in rural Wyoming, both under and one fourth mile from the line (from Spaulding and Disney, 1974)

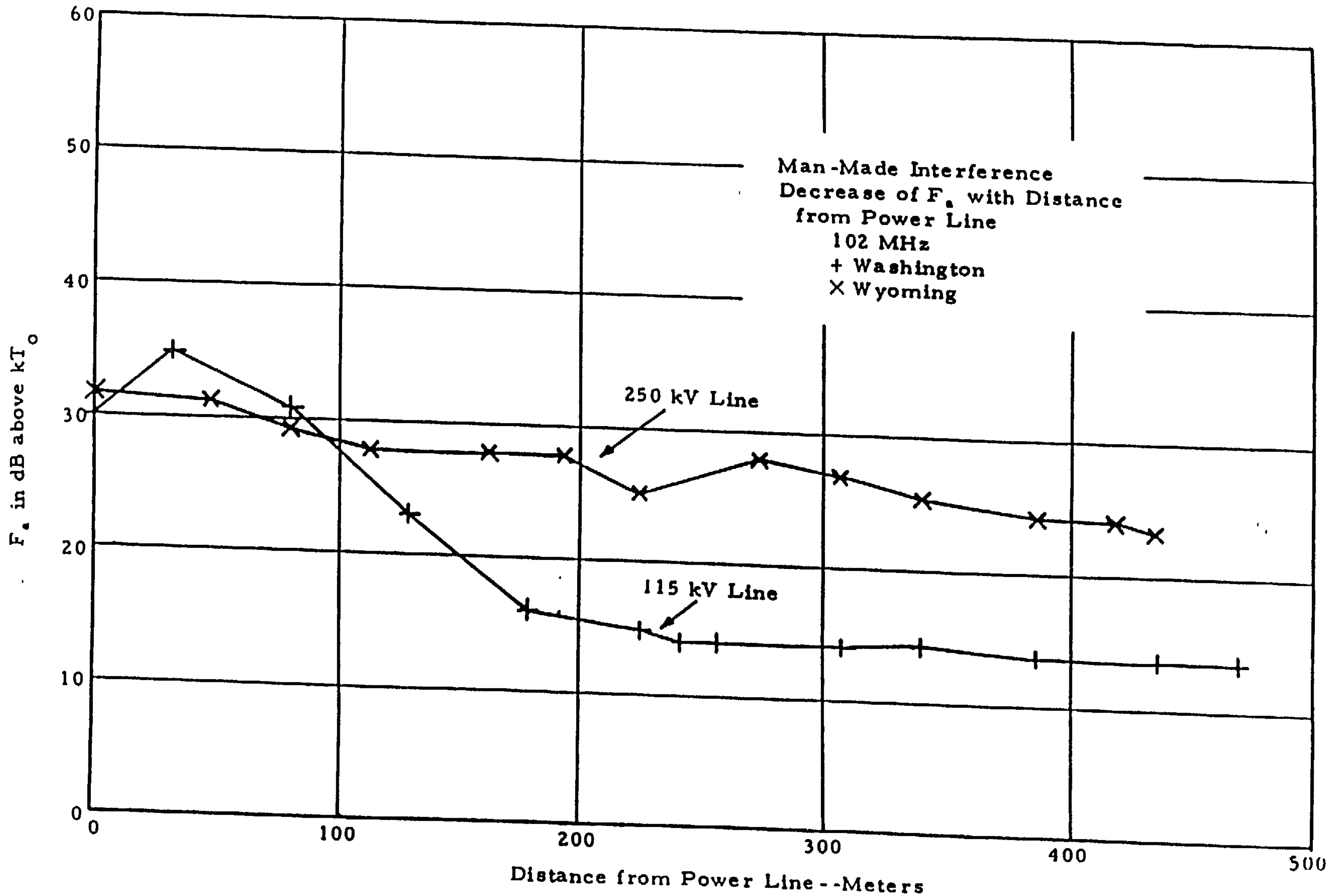


Figure 20. Decrease in power line noise with distance at 102 MHz (from Spaulding and Disney, 1974)

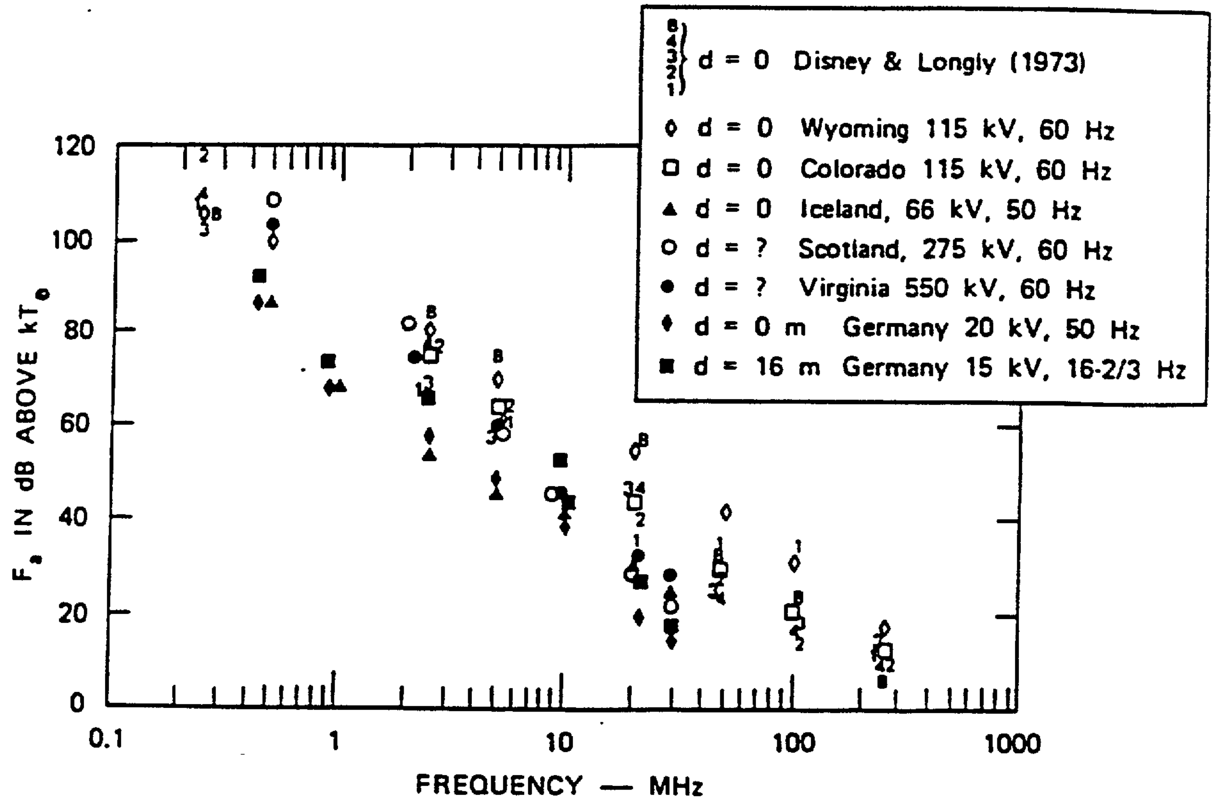


Figure 21. Average noise power approximately underneath selected power lines

sensitivity. In general, the trend with frequency shown on Figures 19 and 21 continues giving F_a values at 1 GHz well below 0. Unlike automotive ignition noise, power line noise probably has not decreased significantly with time. Power line noise is impulsive in character. Two types are common-gap discharge noise and corona. Also, the power line noise often consists of impulsive processes composed of interference re-radiated from the lines, the source being equipment fed by the lines. Skomal [13] summarized numerous power line APD measurements but all at frequencies well below our frequencies of interest. In general, the APD's are impulsive in character but with rather small dynamic range. That is, not "real" impulsive. This is especially true for corona noise. While corona noise is non-Gaussian, it does not have large dynamic range excursions. An extensive power line noise measurement program was conducted in 1967 by Pakala, et. al. [41]. Typical results at 1 GHz are given in the following Table 3.

Table 3. High-Voltage Transmission Line Noise

1 GHZ

Line (kV)	Lateral Distance from Line (ft)	Peak Field Strength (dB uV/m/MHz)	Type of Noise
4.16	*50*	*30*	Gap Discharge
69.00	*200*	*40*	Gap Discharge
244.00	*200*	10 (fair Weather)	Corona
244.00	*200*	40 (Sleet)	Corona
525.00	*50*	*20*	Corona
735.00	*50*	*30*	Corona

Table 3 shows measurements for gap discharge noise, which even at 1 GHz, is probably quite impulsive. The corona noise, however, is probably close to Gaussian, since at lower frequencies, corona noise is not very impulsive. For illustration, we will assume that there is about 10 dB difference between the peak field strength given for corona noise and the corresponding rms field strength. For the 244 KV line, the fair weather corona noise (10 dB peak or 0 dB rms) gives an F_a from (13) of -24.5 dB. However in the sleet condition, the corona noise is 30 dB higher or an F_a of 5.5 dB, enough to be of concern to us.

We have seen above that even at 1 GHz, power transmission line noise from nearby lines cannot be totally ignored as a contributor to the highway noise background. At 100 MHz, power line noise can exceed the automotive ignition noise background.

2.4 Summary and Conclusions

We began by giving an overall look at the natural noise background. For our frequency range, the natural background is quite low, with F_a on the order of -10 dB in the l-3 GHz range. At 100 MHz, the natural background is Galactic noise with an F_a of 3 dB. Nearby (one mile) lightning produces very low noise levels in the l-3 GHz range, on the order of an F_a of -15 dB However, at 100 MHz. the nearby lightning can produce an F_a of 47 dB, well above the man-made noise background and certainly capable of short-term disruptions of sensitive telecommunication systems.

The man-made noise background in urban areas and on and along highways is due primarily to automotive ignition systems. We gave summary of measurement data from the 1970's and various trend analysis and a few recent measurements to try to ascertain with the ignition noise levels might be now (1994). At 100 MHz in the 1970's time frame, F_a was on the order of 20 dB but now is probably approximately 20 dB less. In the 1-3 GHz range, F_a was on the order of 7 dB, but now is in the range -5 to 0 dB. We also gave a technique for computing the ignition noise from the distribution of power radiated from individual vehicles and traffic statistics. Such individual vehicle distributions for modern vehicles are apparently not available. The impulsive character of automotive ignition was treated, by example, showing a very impulsive process at 100 MHz. One measured APD was given at 2.335 GHz. While the noise was not as impulsive at this frequency compared to a lower frequency, it is still non-Gaussian and impulsive enough to degrade normal systems.

In general, power transmission lines are the main source of man-made noise in urban areas at frequencies below about 30 MHz. We have seen, however, that nearby power lines can also have an effect at our frequencies of interest. At 100 MHz, the noise underneath and very near to high voltage transmission lines is on the order of an F_a of 20 to 30 dB. In the l-3 GHz range, the power line noise is usually quite small, on the order of an F_a of -20 dB. However, we saw a foul weather situation (sleet), where corona noise had an F_a of about 5.5 dB, 200 feet from a 244 KV line at 1 GHz. While the power line results are based on measurements made some time ago, for the most part, it is unlikely that power line noise has decreased significantly with time, unlike the automotive ignition noise. Power line noise is also a non-Gaussian impulsive process, especially gap discharge noise. Corona noise is also non-Gaussian, but generally does not have a wide dynamic range.

As noted, the background noise must be combined with interfering cochannel signals to obtain the overall interference environment. Middleton's Class A model [1, 2] (or his Class B model in the absence of interfering signals) should be a good model to use to model the overall environment.

This short survey makes it clear that additional current proper measurements are required to adequately characterize the background noise environment for IVHs systems.

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3. RADIODETERMINATION BANDS

3.1. Introduction

This section describes the most significant radiodetermination bands, all of which are contained in the frequencies between 5 MHz and 17.7 GHz. Included are thirteen bands or band groupings, At the beginning of this section are definitions for various related terms. This is followed by a band-by-band description of the contents of the bands, including the number of Government Master File (GMF) assignments for diierent agencies*. For those bands that consist of a grouping of smaller bands, the description is followed by a listing that shows each of the band subcategories as defined in the Code of Federal Regulations. For some bands, this is followed by a table of various radars located in the associated frequency band. These tables are by no means exhaustive They simply serve the purpose of showing the characteristics of typical radar equipment used in each of the bands. For some radars, specific frequency characteristics were not obtained but were grouped into lettered bands such as L, S, X, etc. These radars are located in tables grouped according to these associated lettered bands. The band 902 - 928 MHz is described in greater detail since it has been allocated for Automatic Monitoring and Location Services (AML).

Information for the radar characteristics is derived from various references as listed at the end of this section. Tables of individual radar characteristics include a column (the first column) which associates a reference (or references) with each of the radars. Most of the radar descriptions come from the *United States Radar Equipment: Military Standardization Handbook* (U. S. Radar Equipment, 1973) [1] While the latest version of this handbook is dated 1973, many of the radars listed are still in existence. In fact, many of the more recent radars are improved versions of these radars using updated receivers, but still having the same emission characteristics. Some of the other references are non-military publications that contain information about various radars, some of which are considered classified. We cannot endorse or confirm these non-government references as valid sources of information. This report represents only a search for emitter characteristics as referenced in open literature and at no time were these characteristics verified against the Government Master File (GMF).

Many of the radars are listed according to standard military nomenclature and have the following format: AN/XYZ The AN refers to military. The XYZ designator is described as follows:

X = A = Airborne
= C = Air transportable (inactivated)
= D = Pilotless carrier
= F = Fixed, static
= G = Ground
= M = Mobile, installed on vehicle dedicated to transporting radar
= P = Portable
= S = Shipbome
= T = Ground, transportable
= U = General utility (two or more platforms: airborne, shipboard, and ground)
= V = Ground, vehicular
= W = Water surface and underwater combination
= Z = Piloted and pilotless airborne vehicle combination

Y = F = Photographic
=P=Radar
= S = Special types, magnetic, etc., or combinations of types

Z = D = Direction finder, reconnaissance and/or surveillance
= G = Fire control or search light directing
= N = Navigational aids (landing, altimeters, beacons, etc.)
= Q = Special, or combination of purposes
= S = Detecting and/or range and angle measurement system
= W = Automatic flight or remote control
= X = Identification and recognition
= Y = Surveillance (search detect, multiple target tracking) and control (both fire control and air control)

In Appendix A of this manual is a copy of the Radar Spectrum Engineering Criterion (RSEC). These are rules that bound the spectrum-related parameters of radar emissions for radars under the jurisdiction of NTIA..

3.2. Terms and Definitions:

Aeronautical Radionavigation-Satellite Serivce. A radionavigation-satellite service in which earth stations are located on board aircraft.

Aeronautical Radionavigation Services A radio-navigation service intended for the benefit and for the safe operation of aircraft.

Maritime Radionavigation-Satellite. A radionavigation-satellite service in which earth stations are located on board ships.

Maritime Radionavigation Services. A radionavigation service intended for the benefit and for the safe operation of ships.

Marker Beacon. A transmitter in the aeronautical radionavigation service which radiates vertically a distinctive pattern for providing position information to aircraft.

Radar. A radiodetermination system based on the comparison of reference signals with radio signals reflected, or retransmitted, from the position to be determined.

Radiobeacon Stations. A station in the radionavigation service the emissions of which are intended to enable a mobile station to determine its bearing or direction in relation to the radiobeacon station.

Radio&termination. The determination of the position, velocity and/or other characteristics of an object, or the obtaining of information relating to these parameters, by means of the propagation properties of radio waves.

Radiodetermination-Satellite. Service. A radiocommunication service for the purpose of radiodetermination involving the use of one or more space stations. This service may also include feeder links necessary for its own operation.

Radiodetermination Service. A radiocommunication service for the purpose of radiodetermination.

Radiodetermination Station. A station in the radiodetermination service.

Radiolocation Radiodetermination used for purposes other than those of radionavigation.

Radiolocation Land Station. A station in the radiolocation service not intended to be used while in motion.

Radiolocation Mobile Station, A station in the radiolocation service intended to be used while in motion or during halts at unspecified points.

Radiolocation Service. A radiodetermination service for the purpose of radiolocation.

Radionavigation. Radiodetermination used for the purposes of navigation, including obstruction warning.

Radionavigation Land Station. A station in the radionavigation service not intended to be used while in motion.

Radionavigation Mobile Station. A station in the radionavigation service intended to be used while in motion or during halts at unspecified points.

Radionavigation-Satellite Services. A radiodetermination-satellite service used for the purpose of radionavigation. This service may also include feeder links necessary for its operation.

Radiunavigation Service. A radiodetermination service for the purpose of radionavigation.

3.3. Region: 5 MHz - 28 MHz

This region is occupied by over-the-horizon backscatter (FPS- 118, also designated OTHB). radars, and by relocatable over-the-horizon radars (ROTHER). OTHB, which is Air Force, has a strategic mission (detection of low-altitude airborne targets), while the Navy's ROTHR has a tactical mission (ocean surveillance). OTHB transmit and receive sites are located about 100 miles apart. Each OTHB transmitter emits CW energy from six subarrays each containing twelve 100-kilowatt transmitter elements. The effective radiated power (ERP) of the unit is 100 MW with a range of 1800 nautical miles. The only operational unit is located near Bangor, Maine. Follow-on units will be installed in the north-central U.S., the Pacific northwest, and Alaska. Sites may eventually be built in the western Pacific. The Alaska OTHB is currently under construction at Gulkana and Tok. The radar in the north-central U.S. will look south, not north. OTHB propagation does not work for radar applications in polar regions. OTHB signals may be received worldwide, and other countries besides the United States operate similar systems. One example is the radar at Krasnoyarsk, in Siberia (Defense Electronics, 3rd Ed.) [11].

The ROTHR systems use transmit and receive sites that are separated by at least one or two dozen miles, and preferably about 100 miles. With a transmit power of 200 kw, ROTHR has one-sixth the transmit power of OTHB. This makes the ROTHR better suited to remote locations, where power plants may be smaller to conserve energy. The first operational ROTHR transmitter was located at Whitehorse, VA with the receiver at Northwest, VA. That unit has now been moved to Amchitka Island, in the Aleutians. A second unit is being installed in Virginia (Sanders, 1993) [5], (Blake, 1988) [3], (Hughes, 1989) [7].

3.4. Band: 420 - 450 MHz

This band is allocated for Government Radiolocation on a primary basis and Non-Government Amateur and Amateur-Satellite on a secondary basis.

Government radiolocation is primarily for long-range surveillance on land based, ship, and airborne platforms. These uses are essential to the nation’s early warning capability, law enforcement, and tracking objects in space. These systems operate with very high power and wide bandwidths. The band is becoming increasingly important for detection of low observable targets. This band is the only military radiolocation band currently available for this frequency sensitive function.

In the continental U.S., the band is occupied by the Air Force FPS-1 15/FPS-123(V) (PAVE PAWS) radars, which are receivable in many locations on the periphery of the continental U.S. FPS-115/123(V) radars are located at Beale AFB, CA, Cape Cod AFB, MA, Eldorado AFB, TX, and Warner-Robins AFB, GA. Other units are located at Thule, Greenland, and Flyingdales Moor, UK. The FPS-85 radar at Eglin AFB, FL, is similar and also uses this band (Defense Electronics, 3rd Ed.) [8], (Sanders, 1993) [5].

The U.S. Navy also operates radars in this band. The E-2C early warning aircraft use several different models of APS (airborne radar search) radars on these platforms, and in many coastal areas these radars can be received with some regularity. (Friedman, 1989, pp22 l-222) [4]. The Navy also operates some high power, ship-borne air search radars in this band (e.g., SPS-40) and these, too, can be picked up in coastal areas (Friedman, 1989, pp 190- 191) [4].

Most of the radars in this band are high powered (several megawatts to several tens of megawatts). Typically, they have a pulse repetition rate of 200-300 pps, a pulse width of 10-60 us (often with compression), and a scan rate of 6-15 rpm. The Department of Defense has 25 assignments in this band. The Coast Guard has 11 assignments. Table 4 contains detailed descriptions of various radars located within the 420 - 450 Mhz band.

Also included in this band are emitters of varying use. Wind profile radars are beginning to be operated in some locations, but these are low-powered radars, they are operated in remote locations, and their main-beam power is directed nearly vertically. Rapid implementation of this use is expected. NASA and military use of telemetry and telecomrnand is also extensive in this band. Non-Government Amateur services are designated primarily for weak signal modes (432-433) television (420-432, 438-444) repeaters (442-450), and auxiliary links (433-435). There is also some use of spread spectrum and other modes. Amateur satellite activities are conducted (435-438) under RR 664. Land mobile systems are operated in this band along the Canadian border (in accordance with US 230).

Table 4. Radars in the 420 – 450 MHz Band

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/TPS-2	400	400			25 Mi	G	Y					
4	AN/APS-120	400	450	1,000,000			A	Y	300	13 (COMP->0.2)	6 RPM	21.5	7.0 X 20.0
3, 4	AN/APS-125	400	450	1,000,000		250 Nmi	A	Y	300	13 (COMP->0.2)	6 RPM	21.5	7.0 X 20.0
3, 4	AN/APS-138	400	450	1,000,000			A	Y	300	13 (COMP->0.2)	6 RPM	21.5	7.0 X 20
3, 4	AN/APS-145	400	450	1,000,000		350 NMi	A	Y	300	13 (COMP->0.2)	5 RPM	21.5	7 X 20
3, 4	AN/sPS-40	400	450	200,000		320KM	M	Y	300	60 COMPRESSED	7.5, 15	21	11 X 19
4	AN/sPS-40B,C,D	400	450	200,000			M	Y	300, 278, 300	60 COMPRESSED, 3.0, 3.0	7.5, 15	21	11 X 19
2	AN/FPS-49A	404.75	446.25	5,000,000		5000 KM	G	Y	27	2000		38	2.0V, 2.0H
2	AN/FPS-92	404.75	446.25	5,000,000		5000 KM	G	Y	27	2000		38	2.0V, 2.0H
1	AN/APS-95	406	450	2E6-3E6	3360-5040		A	Y	280	6			
1	AN/MSQ-51	406	549.5	1000			G	N					
1	AN/APS-13	410	420	450			A	Y					
1	AN/APN-1X	418	462		0.1	4000 FT	A	N					
1	AN/APS-70	420	430	2,000,000			A	Y	300	6	6 RPM		9.5
1	AN/FPS-49	420	430	5,000,000			G	Y	27	2000		38	2
1	AN/SPS-31(XN-1)	420	430	2,000,000		250 Mi	M	Y	290-310	5.4-6.6		23	9.5H
3	AN/FPS-115/123 PAVE PAWS	420	450	HIGH POWER			G	Y				38.4	
1	AN/FPS-50	425	425	5,000,000	300,000		G	Y	27	2000			1.0V, 0.4H
1	AN/FPS-85	437	447	32, 000,000	160,000		G	Y	1, 10, 40, 200				

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

3.5. Band: 902 - 928 MHz

This band is characterized by multiple assignments, both Government and Non-Government As revealed in a study by NTIA, the band appears relatively quiet in terms of RF emissions. (Wepman, 1991). However, there is potential for strong signals, particularly naval air search radars located in and around naval ports.

The 902-928 band is designated for industrial, scientific, and medical (ISM) applications. Radiocommunication services operating within this band must accept harmful interference that may be caused by these applications. ISM includes items such as microwave ovens and industrial heating equipment. All are non-communication type emitters. The ISM equipment operating in this band is permitted unlimited radiated energy and, therefore, has the potential for emitting strong signals.

Also included in this band are communications type emitters with the following order of precedence: 1) Federal Governments systems (including radar, fixed and mobile), 2) Automatic Monitoring and Location Services (AML), 3) Amateur systems, and 4) Part 15 devices.

Federal Government systems take precedence over all other communication systems, but must accept any harmful interference from ISM applications. Military radiolocation takes precedence over other government assignments. Non-military radiolocation, fixed and mobile (including low power radio control operations) can be assigned on a secondary basis for Government use.

Government use of this band is predominantly for military radiolocation systems. These include low-power devices such a those for tactical and nontactical intrusion detection of military facilities and high power radars used for long-range search, many of which are employed on U.S. Navy ships and aircraft or shore stations. These radars serve a critical role in defense of the fleet. One of the most common moderately high powered maritime radars is the SPS-49. Even though these radars are generally located on ships, they have potential to cause high emission levels along coastal areas if the radars are allowed to emit signals in close proximity to land (Brookner, 1977) [2], (Friedman, 1989) [4].

Besides military radar, there are a few other systems designated for Governments use that can be seen in this band. There are about 125 AN/MSTTl A systems located on military training ranges throughout the U.S. which transmit in this band (as well other bands). These systems are used to simulate a variety of radar systems for electronic warfare training. They have a transmitting power of 30 - 50 kW with high gain antennas and can potentially be approached at close range by automobiles. High powered wind and temperature profilers assignments can be found in this band but these devices are directed vertically and, therefore, are not likely to cause interference on the ground level.

Federal mobile communications applications include video surveillance for law enforcement missions, transmissions of infrared scanner imagery during overflights of disaster areas, and use of high power packet radio systems.

Government Fixed use includes point-to-point TV links for monitoring unmanned ports of entry along borders. Though most low capacity links will be moving to the 932-935 and 941-944 MHz bands, this band will continue to be used for a variety of resource management, power administration, and law enforcement purposes, as necessary.

Automatic Monitoring and Location Services (AML) is allocated to this band subject to not causing any harmful interference to the operation of Government stations authorized in this band. These systems must tolerate any interference from the operation of ISM devices in this band.

Amateur systems is allocated on a secondary basis subject to not causing harmful interference to the operations of Government stations authorized in this band or to AML. Stations in the amateur service must tolerate any interference from the operations of ISM devices. In reality, AML may have to accept interference from Amateur (and ISM) systems since the regulatory process makes it difficult to track down any interference from such systems. Authorized emissions in the band 902-928 MHz include: 1) CW, 2) MCW (tone-modulated international Morse Code), 3) Phone (speech and other sound emissions), 4) Image (facsimile and television emissions), 5) RTTY (narrow-band direct printing telegraphy), 6) Data (telemetry, telecommand, and computer communications),

7) SS (spread spectrum), and 8) test. Maximum transmitter power is 1.5 kW peak envelope power, and for certain restricted areas near military bases the power is restricted to less than 50 W peak envelope power. Amateur services in this band are also restricted from operation in certain areas of Colorado and Wyoming.

Part 15 devices are intentional, unintentional, or incidental radiators that may be operated without an individual license. There is a large market forecast for spread spectrum cordless phones operating as Part 15 devices within this band. Also located in this band are devices used to measure the characteristics of materials, and field disturbance sensors. Field strength of emissions from intentional radiators operating within this band is restricted to less than 50 mV/m at 3 m from the emitter (for the fundamental frequency). Exceptions to this rule are: 1) devices used to measure characteristics of materials (which are restricted to a field strength emission limit of less than 500 uV/m at 30 m) and 2) field disturbance sensors (which are restricted to a field strength emission limit of less than 500 mV/m at 3 m for the fundamental frequency). As with Amateur services, these devices are allocated on a secondary basis subject to not causing harmful interference to the operations of Government stations authorized in this band or to AML (as well as amateur services). However, due to the difficulty of tracking these devices, AML may have to accept interference they may incur.

There are no Government assignments in this band for emitters with a peak power greater than one megawatt. The Department of Defense has 139 assignments greater than 25 kW. There are 19 Non-Government assignments greater than 100 kW, all of which are wind and temperature profilers. Table 5 contains characteristics of a few of the known radars in the 902 - 928 band.

Table 5. Radars in the 902 – 928 MHz Band

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE [2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
2, 4	AN/SPS-49	851	942	360,000			M	Y	280, 800, 1000	125 COMPRESSED 2.0, 2.0	6 RPM	29	3.3 X 9.0
1	AN/TPQ-12(XN-1)	890	940	10,000	200		G	Y	10,000	2			
1	AN/GPX-20	900	1040	1500			G	Y	125-1500	1			4.5H, 30.0V

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

3.6. Region: 960 -1400 MHz

This region is characterized by heavy use in the Radiodetermination Services. Applications include Government as well as commercial flight safety operations such as aircraft identification, tracking, control, navigation, collision avoidance, and landing guidance. Also included are long range air surveillance radars, Global Positioning Systems (GPS), and air-route surveillance radar (Sanders, 1993) [5].

Table 6 shows the distribution of Government Master File radar assignments for the Department of Defense and the FAA. The various services are located in five bands as described in Table 7. Tables 8 and 9 give a detailed descriptions of various radars located in this region. Most of the high powered emitters are long range air search radars with a peak power typically between 0.5 and 5.0 megawatts, a pulse repetition rate of 200-400 pps, a pulse width of 1.0-6.0 us, and a scan rate of 0-l 5 rpm.

Table 6. Radar Assignments in the 960 - 1400 MHz Region

	Number of Assignments 25 - 999 kW Peak Power	Number of Assignments 1.0 MW or Greater Peak Power
DOD	**352**	**37**
FAA	2 (several hundred kW)	**233**

Table 7. Spectrum Allocation in the 960 to 1400 MHz Region

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
0.960-1.215	AERONAUTICAL-RADIONAVIGATION	This band is used heavily for long-established commercial, and private flight safety operations, and is essential for safe travel within the national and international airspace systems. All aspects of aircraft identification, tracking, control, navigation, collision avoidance, and landing guidance are carried out. Many major aeronautical radionavigation systems used in this band including the Microwave Landing System (MLS), Distance Measuring Equipment (DME/P), Air Traffic Control Beacons (ATCRBS, Mode-S, and IFF), and Collision Avoidance System (T- CAS), operate or are being developed to operate in this band to support commercial and private aircraft. They are used throughout the world under International Civil Aviation Organization agreements which have treaty status within the U.S. The frequency 1030 MHz and 1090 Mhz are used for air traffic control radar interrogator beacon systems. Signals will be observed at 1030 MHz whenever a receiver is positioned near an air traffic control radar. Signals will be observed at 1090 MHz from aircraft almost everywhere in the U.S.	AERONAUTICAL-RADIONAVIGATION	This band is used heavily for long-established government flight safety operations, and is essential for safe travel within the national and international airspace systems. All aspects of aircraft identification, tracking, control, navigation, collision avoidance, and landing guidance are carried out. Many major aeronautical radionavigation systems used in this band including Tactical Air Navigation (TACAN), the Microwave Landing System (MLS), Distance Measuring Equipment (DME/P), Air Traffic Control Beacons (ATCRBS, Mode-S, and IFF), and Collision Avoidance System (T-CAS), operate or are being developed to operate in this band. These aviation systems are essential to not only normal aviation traffic, but some, like the TACAN/DME, are also essential to the NASA Space Shuttle program. They are used throughout the world under International Civil Aviation Organization agreements which have treaty status within the U.S. The military departments are also using this band for integrated communications and navigation through the Joint Tactical Information Distribution System (JTIDS) on a non-interference basis. This multibillion dollar development is part of an updated NATO system that provides highly secure, jam resistant communications in a hostile environment. The frequency 1030 MHz and 1090 MHz are used for air traffic control radar interrogator beacon systems. Signals will be observed at 1030 MHz whenever a receiver is positioned near an air traffic control radar.

Reference: (NTIA, 1993) [9]

Table 7. Spectrum Allocation in the 960 to 1400 MHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
1.215-1.240	Earth- Exploration-Satellite Space-Research	While operated by the Federal Government, GPS supports an increasingly wide variety of civil applications, including domestic air navigation.	RADIONAVIGATION-SATELLITE RADIOLOCATION Earth-Exploration-Satellite Space Research	The frequency 1227.6 MHz is designated for the Global Positioning System (GPS) as part of the radionavigation satellite service. This is a multisatellite system (up to I8 are planned) and large numbers of U.S. and international users are anticipated. This band is used for radiolocation performing long-range air surveillance. The military services make use of the band for high-power long-range surveillance radars on land and ships in support of national defense missions. A recent radiolocation application, having high national priority, is the use of radar equipment in support of drug interdiction efforts. In this application, radar equipment is mounted on tethered balloons along the southern border of the U.S. to detect low-flying aircraft entering U.S. airspace. Data is relayed to ground and appropriate action taken. Space research and earth-exploration satellite activities for microwave sensor measurements of ocean wave surface are performed by NASA.

Reference: (NTIA, 1993) [9]

Table 7. Spectrum Allocation in the 960 to 1400 MHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
1.240-1.300	Amateur Amateur-Satellite Earth-Exploration-Satellite Space-Research	Amateur television (1240-1246, 1252-1258, 1276-1282), weak signal modes (1295.8-1297), other modes through the band. Active use of amateur satellite (Earth-to-space) in accordance with Footnote 664.	RADIOLOCATION AERONAUTICAL-RADIONAVIGATION Earth-Exploration-Satellite Space Research	This band is used heavily for radiolocation and radionavigation performing long-range air surveillance and enroute air-traffic control functions. The FAA and aviation users depend upon air-route surveillance radars (ARSRs) to obtain aircraft position information in support of enroute air-traffic control. The military makes use of it for high-power long-range surveillance and air-traffic control in support of national defense missions. A recent radiolocation application, having high national priority is the use of radar equipment in support of drug interdiction efforts. In this application, radar equipment is mounted on tethered balloons along the southern border of the U.S. to detect low-flying aircraft entering U.S. airspace. Data is relayed to ground and appropriate action taken. NASA radiolocation activities in the 1240-1300 MHz band are for an experimental multi-spectral imaging radar using synthetic aperture (side-looking) techniques. NASA also uses this band for space research and earth-exploration satellite in conjunction with microwave sensor measurements of ocean wave surface.

Reference: (NTIA, 1993) [9]

Table 7. Spectrum Allocation in the 960 to 1400 MHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
1.30-1.35	AERONAUTICAL-RADIONAVIGATION		AERONAUTICAL RADIONAVIGATION Radiolocation	This band is used heavily for radiolocation and radionavigation performing long-range air surveillance and enroute air-traffic control functions. The FAA and aviation users depend upon air-route surveillance radars (ARSRs) to obtain aircraft position information in support of enroute air-traffic control. The Air Force makes use of it for high-power long-range surveillance radars and air-traffic control radars, in support of national defense missions. There are three ARSR types currently deployed: ARSR-1, ARSR-3, and ARSR-4, The l's have very extensive emission spectra, produced by an amplitron tube and limited only by output filtering. An ARSR-I will typically dominate most of the band in the vicinity of the radar. By contrast, the ARSR-3 (which uses a klystron) is very clean, but operates on two channels simultaneously. The ARSR-4 is a phased-array, 3 dimensional radar. (Sanders, 1993) A recent radiolocation application, having high national priority is the use of radar equipment in support of drug interdiction efforts. In this application. radar equipment is mounted on tethered balloons along the southern border of the U.S. to detect low-flying aircraft entering U.S. airspace. Data is relayed to ground and appropriate action taken.

Reference: (NTIA, 1993) [9]

Table 7. Spectrum Allocation in the 960 to 1400 MHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
1.35-1.40			MOBILE RADIOLOCATION AERONAUTICAL-RADIONAVIGATION FIXED and MOBILE-SATELLITE Earth-Exploration-Satellite Space Research	This band is heavily used for various military radiolocation applications for high-power long-range surveillance radars. GPS operates on 1381 .05 to relay data on nuclear bursts detected by orbiting satellites. GPS is a multisatellite system and large numbers of U.S. and international users are anticipated, however this specific requirement is limited to U.S. satellites. Radio astronomy observations of highly redshifted hydrogen atoms occur in this band. Knowledge of other galaxies and the early universe comes from these observations. NASA performs passive space research and earth-exploration satellite observations. This band is seeing increased use for fixed links and mobile links, since the Federal Government fixed and mobile service allocations were upgraded to primary in 1989.

Reference: (NTIA, 1993) [9]

Table 8. Radars in the 960 – 1400 MHz Region

REF[1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/GPX-20	900	1040	1500			G	Y	125-1500	1			4.5H, 30.0V
1	MARK 12 MOD 1	920	970	100,000			M	Y	480	1		22	10.0H, 10.0V
1	AN/APN-63	943	993	25		20 MI	A	Y					
1	AN/APX-28	950	1100	1000			A	Y		0.0052 DUTY			
1	AN/APX-29A	950	1150	250			A	Y		0.0052 DUTY			35 DEG
1	AN/APX-6	950	1150	251-1000			A	Y					
1	AN/sPX-1(XN-21)	950	1150				M	Y	3200-4450				
1	AN/sPX-2(XN-21)	950	1150				M	Y	3200-4450				
1	AN/GPX-14	990	1040				G	Y					
1	AN/GPX-17	990	1040	1500			G	Y	180-420	1			4.0H, 12.0V
1	AN/GPX-17A	990	1040	1500			G	Y	180-420	1			4.0H, 12.0V
1	AN/GPX-18	990	1040	1500			G	Y	180-420	1			3.0H, 10.0V
1	AN/GPX-18A	990	1040	1500			G	Y	180-420	1			3.0H, 10.0V
1	AN/GPX-18B	990	1040	1500			G	Y	180-420	1			3.0H, 10.0V
1	AN/GPX-18C	990	1040	1500			G	Y	180-420	1			3.0H, 10.0V
1	AN/GPX-20A	990	1040	1500			G	Y	180-420	1			4.5H, 30.0V
1	AN/GPX-20B	990	1040	1500			G	Y	125-1500	1			4.5H, 30.0V
1	AN/GPX-34	990	1040	1500			G	Y	300, 1200	0.7-1.2, 0.8-1.3			
1	AN/GPX-6	990	1040	20,000			G	Y	180-420	0.7-1.2			
1	AN/GPX-6A	990	1040	20,000			G	Y	180-420	0.7-1.2			
1	AN/GPX-7	990	1040	20,000			G	Y	180-420	0.7-1.2			
1	AN/GPX-7A	990	1040	1,500			G	Y	180-420	1			
1	AN/MPX-7	990	1040	1500			G	Y	125-1500				
1	AN/MPX-7A	990	1040	1500			G	Y	125-1500				
1	AN/TPX-19	990	1040	1500		190 Mi	G	Y		0.7-1.2			
1	AN/TPX-21	990	1040	1500		190 Mi	G	Y		0.7-1.2			
1	AN/TPX-44	990	1040				G	Y					
1	AN/TSQ-96+	990	1040			190 Mi	G	Y					
1	AN/UPX-6	990	1040	1500			?	Y	180-420	1			
1	AN/TPX-27	990	1050	1500		190 Mi	G	Y		0.7-1.2			
1	AN/APX-6B	990	1130	250-1000			A	Y					
1	AN/GPX-35	1000	1140	1500			G	Y	250, 1000	0.7-1.2, 0.7-1.3			
1	AN/UPX-9	1005	1035	1000			?	Y					
1	AN/APX-49	1010	1030	2000			A	Y					

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 8. Radars in the 960 – 1400 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE [2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (µS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APX-7	1010	1030	1000-2000			A	Y					
1	AN/GPX-9	1010	1030	1500		200 Mi	G	Y	1500, 300, 300	0.5, 0.7-1.2, 0.5-10			
1	AN/GPX-9A	1010	1030	1500		200 Mi	G	Y	1500, 300, 300	0.5, 0.7-1.2, 0.5-10			
1	AN/GPX-9B	1010	1030	1500		200 Mi	G	Y	1500, 300	0.5, 0.7-1.2			
1	AN/MSQ-4+	1010	1030				G	Y					
1	AN/TPX-17,A,B,C	1010	1030	1000			G	Y	50-410	0.7-1.2			
1	AN/TPX-18,A	1010	1030	1000			G	Y	50-410	0.7-1.2			
1	AN/UPX-1,1A	1010	1030	1000			MG	Y	50-410	0.7-1.2			
1	AN/TPX-28	1010	1040	2000			G	Y		0.7-0.9			
1	AN/UPX-11	1010	1040	2000			MG	Y	MAX DUTY 1.0%	0.5-1.0, 0.35-0.55			
1	AN/UPX-14	1010	1050	11,000			?	Y	0.8% DUTY	0.7-0.9, 0.43-0.58			
1	AN/UPX-21	1010	1050	11,000			?	Y	0.8% DUTY	0.7-0.9, 0.43-0.58			
1	AN/GPX-8	1018	1042				G	Y	300 - 1500	0.5-10.0			
1	AN/GPX-8A	1018	1042				G	Y	300 – 1500	0.5-10.0			
1	AN/APX-65A	1020	1040	600			A	Y					
1	MODEL 2679 IFF	1029.8	1030.2	200			G	Y					
1	OX-60/FPS-117	1029.8	1030.2	2,000,000		200 NMi	G	Y		1.0% DUTY			
1	AN/APX-83(V)	1030	1030	2000			A	Y		1.0% DUTY			
1	AN/TPS-44+	1030	1030	2000		275 NMi	G	Y	400	0.7-0.9	0-15 RPM		
1	AN/TPX-41	1030	1030	1500		80 Mi	G	Y	450	0.8		19	8.0H, 45.0 V
1	AN/TPX-45	1030	1030	2000		60 Mi	G	Y	450	0.8			
1	AN/TPX-46	1030	1030	2000		200 Mi	G	Y	450	<22.0			
1	AN/TPX-50	1030	1030	165		24 KM	G	Y					
1	AN/UPX-23	1030	1030	2,000			?	Y					
1	AN/APX-34	1080	1100	500			A	Y					
1	AN/APX-35	1080	1100	500			A	Y		1.0% DUTY MAX			
1	AN/APX-37	1080	1100	500			A	Y		1.0% DUTY			
1	AN/APX-46	1080	1100	500			A	Y					
1	AN/APX-64	1080	1100	631			A	Y		0.35-0.55			
1	AN/TPX-22	1080	1130	1500		190 Mi	G	Y		0.7-1.2			

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 8. Radars in the 960 – 1400 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/TPX-26	1080	1130	1500		190Mi	G	Y		0.7-1.2			
1	AN/DPN-82	1087	1093	0.5	5		?	Y					
1	AN/APX-25A	1090	1090	250-1000			A	Y					
1	AN/APX-44, 44B, 44C	1090	1090	250-1000			A	Y	0.35-0.55				
1	AN/APX-72	1090	1090	630			A	Y					
1	AN/APX-88	1090	1090	500-1000			A	Y		1.0% & 0.2% DUTY			
1	AN/APX-89	1090	1090	630			A	Y		1.0% DUTY			
1	AN/APX-90	1090	1090				A	Y					
3	MM/UPX-709	1090	1090				A	Y					
1	AN/APX-44A	1090	1110	250-1000			A	Y					
1	AN/UPX-12, 12A, 12B	1090	1110	10,000			?	Y	500-4000, 500-4000	0.9-1.4, 0.35-0.55			
1	AN/UPX-17	1090	1110	900			?	Y	< 4000 (2% DUTY)	0.35-0.55			
1	AN/UPX-5, 5A, 5B	1090	1110	300			?	Y	500-3200, 3200-4000	0.9-1.4			
2	AN/FPS-108+	1175	1375	15,400,000	920,000	1000 NMi	G	Y	150 – 1500, 2000,1000,1000	0.2, 1.0, 0.005, 0.04			
2	AN/FPS-108	1215	1250	15,400,000	920,000	1000 NMi	G	Y	150 – 1500, 2000,1000,1000	0.2, 1.0, 0.005, 0.04			
3, 4	AN/SPS-58	1215	1365	12,000		25 NMi	M	Y	2290, 3050	5.0, 5.0	20 RPM	26	6 X 16
2	AN/SPS-58A	1215	1365	12,000		25 NMi	N	Y	2290, 3050	5.0, 5.0	15 RPM	23	
4	AN/SPS-62	1215	1365	12,000		25 NMi	M	Y					
3, 4	AN/SPS-65(V`1), (V2)	1215	1365	12,000	260		M	Y	2315, 3064	7.0, 7.0	15 RPM	23	
3	AN/FPS-117	1215	1400	24,750		200 NMi	G	Y					
2	AN/TPS-59	1215	1400	34,900	6280	300 NMi	G	Y		0.4 Compressed	6.0, 12.0 RPM	38.9	1.6V, 3.2H
10	ARSR-4	1215	1400		3,880		G	Y	291.5 (AVE), 312.5 (AVE)	88.8, 58.8			
3	GE 592	1215	1400	25,000		400 KM	G	Y					2.2H, 2.0V
1	AN/FPS-19	1220	1350		1000	120Mi	G	Y	400		3.3-10 RPM		
1	AN/GSS-1	1220	1350	500,000		160Mi	G	Y	360-400	2			4.0H, 12.0V
1	AN/GSS-7	1220	1350	2,000,000		200 NMi	G	Y	360-400	2			1.4H, 5.8V
1	AN/TPS-15	1220	1350	500,000	500	160 NMi	G	Y					
1	AN/TPS-1B	1220	1350			200 Mi	G			4			
1	AN/TPS-1D, E, F, G	1220	1350	500,000		160 NMi	G		360-400	2			4.0H, 12.0V

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 8. Radars in the 960 – 1400 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	SR-3A	1244	1350	750,000		400 Mi	M	Y	150, 600	1.0, 4.0	2.5, 5.0 RPM		3.5H, 10.0V
1	SR-3B	1244	1350	750,000		400 Mi	M	Y	150, 600	1.0, 4.0	2.5, 5.0 RPM		3.5H, 20.0V
1	SR-3C	1244	1350	750,000		400 Mi	M	Y	150, 600	1.0, 4.0	2.5, 5.0 RPM		3.5H, 30.0V
1	SR-6A	1244	1350	750,000			M	Y	300	2	5-10 RPM		
1	SR-6B	1244	1350	750,000			M	Y	300	2	5-15 RPM		
2	S631	1250	1310	0.8E6 & 2.2E6	3000 & 1500		G	Y	220-850 & 220-750	1.5-5.0 & 2.5-5.0	3,4,6,8 RPM	37	
2	S654	1250	1320	2.5E6 & 0.8E6	3000 & 1500		G	Y	220-750, 220-850	2.5-5.0, 2.0	5, 10, 7.5, 15 RPM	33.5	1.7
2	AASR-804	1250	1350	500,000		150-200 NMi	G	Y	360	2	6 RPM	36	
1	AN/BPS-2	1250	1350	50,000			M	Y	150-600	1.0-4.0			4.0H, 10.0V
1	AN/BPS-2(XN-1)	1250	1350	50,000			M	Y	150-600	1.0-4.0			
1	AN/FPS-100	1250	1350	2,000,000	4320	230 NMi	G	Y	360	6	3.3-10.0		1.3H, 5.0V
1	AN/FPS-100A	1250	1350	2,000,000	4320	230 NMi	G	Y	360	6	3.3-10.0		1.3H, 5.0V
2	AN/FPS-107	1250	1350	10,000,000	15,000	260 NMi	G	Y	244	6			
1	AN/FPS-20	1250	1350	2,000,000	4320	230 NMi	G	Y	360	6	3.3-10 RPM		
1	AN/FPS-20B	1250	1350	2,000,000	4320		G	Y	360	6		35	
1	AN/FPS-20C	1250	1350	2,000,000	4320	230 NMi	G	Y	360	6	3.3-10 RPM		
1	AN/FPS-20D	1250	1350	2,000,000	4320	230 NMi	G	Y	360	6	3.3-10 RPM		
1	AN/FPS-36	1250	1350	500,000		230 NMi	G	Y	325-400	2			
1	AN/FPS-64	1250	1350	2,000,000	4320	230 NMi	G	Y	360	6	3.3-10.0 RPM		1.3H, 5.0V
1	AN/FPS-65, 65A	1250	1350	2,000,000	4320	230 NMi	G	Y	360	6	3.3-10.0 RPM		1.3H, 5.0V
1	AN/FPS-66, 66A, 66B	1250	1350	2,000,000	4320	230 NMi	G	Y	360	6	3.3-10.0 RPM	35	1.3H, 5.0V
1	AN/FPS-67	1250	1350	2,000,000	4320	230 NMi	G	Y	360	6	3.3-10.0 RPM		1.3H, 5.0V
1	AN/FPS-67A, 67B	1250	1350	2,000,000	4320		G	Y	360	6		35	
1	AN/FPS-7()	1250	1350			300 NMi	G	Y					
1	AN/FPS-87A	1250	1350	2,000,000	4320	230 NMi	G	Y	360	6	3.3-10.0		1.3H, 5.0V
1	AN/FPS-91, 91A	1250	1350	2,000,000	4320		G	Y	360	6	3.3-10.0 RPM		1.3H, 5.0V
1	AN/FPS-93, 93A	1250	1350	2,000,000			G	Y	360	6		35	
1	AN/GPS-4	1250	1350	2,000,000			G	Y	360	3.2	5 RPM		
1	AN/SPS-12	1250	1350	500,000			M	Y	300, 600	4.0, 1.0			
1	AN/SPS-16	1250	1350	500,000			M	Y	400	2.4			
1	AN/SPS-2	1250	1350	7,000,000			M	Y	244	6			1.3H, 2.5V
1, 4	AN/SPS-6, 6A, 6B	1250	1350	750,000		140 NMi	M	Y	150, 600	4.0, 1.0	5-15, 0-2.5 RPM	27	3.5 X 30
1	AN/SPS-6C	1250	1350	750,000			M	Y	150, 600	4.0, 1.0			30.0V, 3.5V
1	AN/TPS-44	1250	1350	1,000,000		275 NMi	G	Y	800, 533, 267	1.4, 1.4, 4.2	0-15 RPM		

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 8. Radars in the 960 – 1400 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
3	AN/TPS-63	1250	1350	100,000	3000	160 NMi	G	Y					
3	AN/TPS-65	1250	1350	100,000	3000	160 NMi	G	Y				32.5	
1	AN/UPS-1	1250	1350	1,400,000	1600	275 Mi	G	Y	800, 267	1.4, 4.2	0-15 RPM	28.5	10-11V, 3.5-3.7V
1	AN/UPS-1A	1250	1350	1,000,000	1000	200 Mi	G	Y	267, 800	4.2, 1.4	0-15 RPM	28.5	10-11V, 3.5-3.7V
1	AN/UPS-1B	1250	1350	1,400,000	1600	275 Mi	G	Y	267, 800	4.2, 1.4	0-15 RPM	28.5	10-11V, 3.5-3.7V
1	AN/UPS-1C	1250	1350	1,400,000	1600	275 Mi	G	Y	267, 800	4.2, 1.4	0-15 RPM	28.5	10-11V, 3.5-3.7V
2	ARSR-3	1250	1350	5,000,000	3300	> 200 NMi	G	Y	310-364	2	5 RPM	34.5	1.2
2	ARSR-805	1250	1350	5,000,000		200 NMi	G	Y	360	2	6 RPM	36	
2	ASR-803	1250	1350	500,000	880	80 NMi	G	Y	800	1.1	12 RPM	36	
2	ATCR-2T	1250	1350	2,000,000	2500	180 NMi	G	Y	300-800	2.8	6 RPM	36.5	
2	ATCR-4T	1250	1350	500,000	500	100 NMi	G	Y	1000	1	12 RPM	32.5	7.5V, 1.3H
2	LP 23	1250	1350	2,200,000		185 NMi	G	Y	250	3.0, 4.0	3.0, 6.0 RPM	36	1.2
1	SR-3	1250	1350	750,000		400 Mi	M	Y	150, 600	1.0, 4.0	2.5, 5.0 RPM	24	4.0H, 30.0V
1	SR-6	1250	1350	750,000		200 Mi	M	Y	300	2	5.0-15.0 RPM	21	8.0H, 30.0V
2	TRS 2050	1250	1350	2,200,000		185 NMi	G	Y	250	3.0, 4.0	3.0, 6.0 RPM	36	1.2
1	AN/APS-33	1280	1350	1,000,000	1080	200 NMi	G	Y	360	3	6.6-10		
1	AN/FPS-37	1280	1350	1,200,000	1080	200 NMi	G	Y	360	3	6, 12 RPM	36	1.3
1	AN/FPS-37A	1280	1350	1,200,000	1080	220 NMi	G	Y	360	3	6, 12 RPM	36	1.3
1	AN/FPS-8	1280	1350	1,000,000			G	Y	360	3	0-10 RPM		
1	AN/FPS-88(V)1,2	1280	1350	1,200,000	1080	220 NMi	G	Y	360	3	5-10 RPM	35.4	1.3
1	AN/GPS-3	1280	1350	1,000,000		220 NMi	G	Y	360	3	0-10 RPM	30.3	2.5
1	AN/MPS-11	1280	1350	1,000,000	1100	160 NMi	G	Y	360	3	0-10 RPM		2.5H, 9,0V
1	AN/MPS-11A	1280	1350	1,000,000		200 NMi	G	Y	360	3			
2	ARSR-1, 2	1280	1350	4,000,000	2900	200 NMi	G	Y	360	2	6 RPM	34	1.2
3	HIPAR	1350	1450	HIGH			G	Y	417-438	6	6-10 RPM		1.2H, 0-60V

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 9. L Band Radar (1000 – 2000 MHz)

REF [1]	RADAR NAME	BAND	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (μS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
3	AN/MSQ-117	L	1000			G	Y					
2	AN/SPS-58A	L	12,000		25 NMi	N	Y	2290, 3050	5.0, 5.0	15 RPM	23	
2	AN/TPS-34	L	5,000,000		250 NMi	G	Y					
2	**ARGOS-10**	L	> 1,000,000		250 Mi	G	Y				36	
3	ASR-30	L			120 NMi	G	Y					
3	DUAL BAND RADAR+	L				G	Y					
3, 4	MK-23	L	200,000		100 NMi	M	Y	4000, 900			21	3.3 X 75
2	NIKE HERCULES (IMP)	L				G	Y					
3	W_3000 3-D	L			270 NMi	G	Y				35	

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

3.7. Region: 2.30 - 2.50 GHz

This region is relatively quiet as far as radars are concerned. There are only a few high powered radars, all of which are located in remote sites and operate intermittently. Heavy use in this region for telemetry is predicted.. Also included in this band is the operation of millions of microwave ovens and other industrial scientific, and medical (ISM) equipment. Microwave ovens are center-tuned at about 2450 MHz. Although they have a low peak power (compared to most radars), they have a moderately high average power. They are also very numerous, and this contributes to the high probability of observing these emissions (Sanders, 1993) [5]. The various emissions are located in five bands as described in Table 10.

Table 10. Spectrum Allocation in the 2.30 to 2.50 GHz Region

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
2.300-2.310	Amateur	Amateur weak signal modes (≈ 2304), other modes throughout the band.	RADIOLOCATION Fixed Mobile	This band is essential to the protection of deep space Network receivers operating from 2290-2300MHz.
2.310-2.390	MOBILE	Heavy use of this band for telemetry is predicted. The FCC has proposed allocating the 2310-2360 MHz portion of this band for Broadcast-Satellite for high quality radio.	MOBILE RADIOLOCATION Fixed	Heavy use of this band for telemetry is predicted. Footnote US276 is being modified to provide for telemetry communications by fully operational launch vehicles. The Air Force uses this band for aeronautical telemetry. Aeronautical telemetry needs extensive spectrum, and minimal in-band and adjacent-band interference. The 1435-1525 MHz band is filled and new systems are being moved into this band. NASA uses this band for the Venus Radar Mapper (VRM) synthetic aperture radar and associated telemetry. The National Science Foundation and NASA use planetary radars in coordination with research universities. Observations at the National Astronomy and Ionospheric Center (Arecibo) occupy 20 MHz centered around 2380 MHz.

Reference: (NTIA, 1993) [9]

Table 10. Spectrum Allocation in the 2.30 to 2.50 GHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
2.390-2.450	Amateur	Amateur mixed modes (2390- 2400, 2410-2450). Amateur satellite operation (space-to-Earth) occur in accordance with footnote 664 from 2400- 2450 MHz.	RADIOLOCATION	Because of the operation of tens of millions of microwave ovens and other industrial, scientific, and medical (ISM) equipment little use is made of this band and little growth is expected. There is some packet radio development by the Army going on in this band
2.4500-2.4835	FIXED MOBILE Radiolocation	This band is used for fixed and portable transmission of video by TV broadcasters for remote news events. In addition, the band is used for private company fixed service radio relay transmission of voice and data transmissions by private companies.	Radiolocation (FN41)	
2.4835-2.5000	RADIO-DETERMINATION-SATELLITE (space to Earth)	Though this is the downlink band for the Radiodetermination Satellite Service, private company fixed stations and TV broadcaster portable stations that were in operation prior to 1985 may continue to operate on a primary basis. These are multichannel equipment having 10 channels.	Radiolocation (FN41)	

Reference: (NTIA, 1993) [9]

3.8. Band: 2.70 - 2.90 GHz

This band is very heavily used predominantly for air-surveillance radars, It is a critical safety-of-flight band for airport surveillance radars (ASRs) operated by the FAA to provide aircraft position information for air traffic control in the vicinity of airports. These radar have about a 60 mile range at 20,000 feet. This band is busy in and around all major metropolitan areas. ASRs are sometimes received in more remote areas as in the Panamint Valley, CA, where a gap-filler is located (but the band usage is in general lower in such places). ASRs often operate on two frequencies simultaneously (called diplexed operations). The military uses this band for Ground Control Approach functions (GCAs) The Air Force uses it for high-power long-range surveillance radars and air traffic control radars (ATC-type radars and height finders). Weather radars are also operated in this band for severe weather monitoring in support of flight safety (WSR-57, WSR-74s AND WSR-88D radars). NEXRAD, an improved Doppler weather radar, is also being used here when not in conflict with the ASRs. NASA uses the band for tracking for range safety purposes (radiolocation), and for atmospheric research (meteorological aids). (Sanders, 1993) [5]

Table 11 shows the distribution of GMF assignments for different agencies. Table 12 gives a detailed description of various radars located in the 2.70 - 2.90 GHz band. Typically the higher powered radars have a peak power of 200 kW - 5.0 MW, a pulse repetition rate of 400 - 1000 pps, a pulse width of 0.8 - 2.0 us, and a scan rate of 15 rpm.

Table 11. Radar Assignments in the 2700 - 2900 MHz Band

	Number of Assignments 25 - 999 kW Peak Power	Number of Assignments 1.0 MW or Greater Peak Power
DOD	340 (Most are several hundred kW)	180
Commerce	134 (Weather radar)	4 (Weather radar)
Non-Gov	2 (Experimental)	2 (Experimental)
F M	255 (ASR's)	325 (ASR-8 or 9)

Table 12. Radars in the 2700 – 2900 MHz Band

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/CPN-4	2700	2830	60,000			G	Y	1470-1530	0.4-0.6	18-22 RPM		
1	AN/MPQ-10, 10A	2700	2860	180		4 Mi	G	Y	1100	0.8			
1	AN/CPN-18A, 18C	2700	2900			53-70 NMi	G	Y	1500, 900	0.5, 1.0	10 RPM		
1	AN/DPN-3A	2700	2900	50			A	Y					
1	AN/FPN-47	2700	2900	400,000	300-400		G	Y	1200, 1170, 1140, 900				
1	AN/FPN-51	2700	2900	400,000	300-400	60 NMi	G	Y	1200, 1170, 1140, 900	0.001 DUTY AT 1200 PPS			
1	AN/FPN-55	2700	2900	400,000	300-400	60 NMi	G	Y	1200, 1170, 1140, 900	0.001 DUTY AT 1200 PPS			
2	AN/FPS-14	2700	2900	450,000	540	48 NMi	G	Y	1200	1			
2	AN/FPS-18	2700	2900	1,000,000	1200	48 NMi	G	Y	1200	1			
1	AN/FPS-41	2700	2900	500,000		250	G	Y	545, 164	0.5, 4.0			
1	AN/FPS-507	2700	2900	5,000,000		300 NMi	G	Y	300-400	2.0-3.0			
1	AN/FPS-6	2700	2900	5,000,000		200 NMi	G	Y	300-400	2.0-3.0			3.2H, 0.85V
1	AN/FPS-6A	2700	2900	5,000,000		300 NMi	G	Y					
1	AN/FPS-6C	2700	2900	5,000,000		30 NMi	G	Y	300-400	2.0-3.0			
1	AN/FPS-6D	2700	2900	5,000,000		300 NMi	G	Y	300-400	2.0-3.0			3.2H, 0.85V
1	AN/FPS-6E	2700	2900	5,000,000		300 NMi	G	Y	300-400	2.0-3.0			
1	AN/FPS-89	2700	2900	5,000,000		300 NMi	G	Y	300-400	2.0-3.0			3.2H
1	AN/FPS-90	2700	2900	5,000,000		300 NMi	G	Y	300-400	2.0-3.0	20-30 RPM		0.85V
1	AN/GPN-6	2700	2900	500,000			G	Y	1000	0.9			
1	AN/MPS-14	2700	2900	5,000,000		200 NMi	G	Y	300-400	2.0-3.0	20-30 RPM		3.2H, 0.85V
1	AN/MPS-19, 19A	2700	2900	500,000	164	360,000 YRDS	G	Y	300-2000	0.8			3
1	AN/MPS-9	2700	2900	250,000		360,000 YRDS	G	Y	410	0.8			2
1	AN/MSQ-1A	2700	2900	500,000	164	352,000	G	Y	300-200	0.8			
1	AN/MSQ-2	2700	2900	250,000		360,000 YRDS	G	Y	410	0.8			2
2	AN/TPN-24	2700	2900	450,000	470	60 NMi	G	Y	1050	1	15 RPM	33.6	1.73
1	AN/TPS-27	2700	2900	3,500,000		250 NMi	G	Y	297-300	5.5-6.5			
10	ASR-4	2700	2900	600,000		60 NMi	G	Y	800-1200	0.823		34	
10	ASR-5	2700	2900	400,000		60 NMi	G	Y	1200, 1170, 1140, 900	0.001 DUTY		34	
2	ASR-6	2700	2900	400,000	400	60 NMi	G	Y	700-1200	0.833	15 RPM	34	1.4
2	ASR-7	2700	2900	425,000	425	60 NMi	G	Y	713, 950, 105, 011, 201,000	0.83, 0.83, 0.83, 0.83, 0.83	13 RPM	34	1.4
2	ASR-8	2700	2900	1,000,000	618	60 NMi	G	Y	1030	0.6	12.5 RPM	33.5	1.4

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 12. Radars in the 2700 – 2900 MHz Band (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (μS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
10	ASR-9	2700	2900	1,400,000		60 NMi	G	Y	1200	1.06	15 RPM	33.5	4.8V, 1.35H
2	ASR-808	2700	2900	500,000	960	60 NMi	G	Y	960	1.1	15 RPM	34	
2	ATCR-3T	2700	2900	500,000	450	80 NMi	G	Y	1000	1	15 RPM	34	5.0V, 1.5H
1	AN/APW-11	2700	2950	137			A	Y	732	0.8-1.2			
1	AN/MPQ-10B	2700	2960	200,000			G	Y	1000	0.8			
1	AN/CPS-6B	2700	3019	0.9E6-2.0E6		240NMi	G	Y	600, 300, 300	1.0, 1.0, 2.0	0-15 RPM		
1	AN/FPS-10	2700	3019	2,000,000		265 NMi	G	Y	600, 300, 300	1.0, 1.0, 2.0	2-15 RPM		
10	WSR-74S	2700	2900	403,000			G	Y	164, 667	4.5, 1.0	3 RPM	38	2.0
10	WSR-88D (NEXRAD)	2700	3000	750,000			G	Y	318-1304, 318-452	1.57, 4.5	36 DEG/S	45.5	0.95
1	AN/MPN-5+, 5A+	2740	2900	500,000		50 Mi	G	Y	1200	0.8			
2	S669+	2740	2900	2,250,000	3300		G	Y	200-600	2, 5-5.0		40.5	0.6V, 3.7H
1	AN/MPQ-14	2740	2960	200,000		20,000 YRDS	G	Y	1100	0.8			
1	AN/MPQ-14A	2740	2960	200,000	180	20,000 YRDS	G	Y	1100	0.8			
1	AN/DPN-17, 17A, 17B	2750	2950	100			A	Y		0.65			
1	AN/SPS-13(XN-1)	2770	2830	2,250,000	8000	200 NMi	M	Y	360	10		35	2.8V, 1.5H
1	AN/FPN-28A	2775	2900	500,000			G	Y	1200	0.8	15-30 RPM		
1	AN/FPN-28	2780	2820	350,000			G	Y	1200	0.8	16 RPM		
1	AN/FPN-48	2780	2820			60 NMi	G	Y					
1	AN/FPN-50	2780	2820			60 NMi	G	Y					
1	AN/MPN-11B	2780	2820	700,000		30 Mi	G	Y	1500				
1	AN/MPN-13,A,B,C,D,E	2780	2820	700,000		30 Mi	G	Y	1500				
1	AN/MPN-14, 14A-14J	2780	2820	700,000		35 NMi	G	Y	1100				
1	AN/CPN-4A	2780	2830			36 NMi	G	Y					
1	SX	2780	2900	800,000			?	Y	390	1			
1	SX-1	2780	2900	800,000			?	Y	390	1			
1	AN/CPS-1	2800	2800	750,000	263		G	Y	350	1			
1	SP	2800	2800	700,000	420	200 Mi	M	Y	600, 120	1-5, 1-5			
1	SP-1M	2800	2800	700,000	420	200 Mi	G	Y	600, 120	1-5, 1-5			
1	SP-2	2800	2800	700,000	420	200 Mi	?	Y	600, 120	1-5, 1-5			
1	AN/APS-20E	2819	2910	2,000,000			A	Y	300, 900	2.0, 0.67	2.4-16 RPM		
1	AN/APS-20F	2819	2910	2,000,000			A	Y	300, 900	2.0, 0.67	2.4-16 RPM		
1	AN/UPN-7	2820	2820	1000			M	Y	250-4000				
1	AN/APS-20A	2850	2910	750,000	447		A	Y	300, 150	2.0, 2.0			
1	AN/APS-20C	2850	2910	750,000	447		A	Y	300, 150	2.0, 2.0			
1	AN/GPN-2	2860	2900	200,000		30 Mi	G	Y	2000	0.5			

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 12. Radars in the 2700 – 2900 MHz Band (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APX-85	2880	2880		0.002		A	Y					
1	AN/FPN-1A	2880	2880			30 NMi	G	Y	2000	0.5			
1	AN/MPQ-2A	2900	2845				G	Y	731, 1462	0.8, 0.8			

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

3.9. Region: 2.90 - 3.10 GHz

Radiolocation in this band is primarily for the military service and for Government and civilian maritime radars. Limited secondary use is permitted by government agencies in support of experimental and research programs and for survey operations.

This band is used for maritime radars and radar beacons (racons) Radars of this type are required on cargo and passenger ships by international treaty (SOLAS) for safety purposes. Racons operate in conjunction with maritime radars to provide electronic markers to identify maritime obstructions and navigation points. In coastal areas, a large number of short-range maritime surface search radars will be received in the 3025 - 3075 MHz range. These radars are used for navigation, and they may produce more occupancy at night or in bad weather.

This band is also used heavily for a variety of military radars. It contains land based air search and tactical radars. In coastal areas, emissions from Navy air search radars are also commonly seen.

Whether or not much occupancy is seen in this band depends upon proximity to bases and depots where such radars are repaired or used for training. Usage is highly variable. In some cities (e.g. San Diego), it may be heavy. In other cities, it may be almost nonexistent (Sanders, 1993) [5].

Table 13 shows the distribution of GMF assignments for different agencies. Table 14 gives a detailed description of various radars located in the 2.90 - 3.10 Ghz region. Typically the high powered radars have a peak power of 200 kW - 4.0 MW, a pulse repetition rate of 300 - 2000 pps, a pulse width of 1.0 - 6.7 us, and a scan rate of 2 - 6 rpm.

Table 13. Radar Assignments in the 2900 - 3100 MHz Region

	Number of Assignments 25 - 999 kW Peak Power	**Number of Assignments 1.0 MW or Greater Peak Power**
DOD	485 (Most are radar simulators with several hundred KW peak power)	111
Commerce	0	1 (Weather radar)
Non-Gov	4 (Radar Development)	2 (Radar Development)
FAA	1 (Weather radar)	0

Table 14. Radars in the 2900 – 3100 MHz Region

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APW-11	2700	2950	137			A	Y	732	0.8-1.2			
1	AN/MPQ-10B	2700	2960	200,000			G	Y	1000	0.8			
1	AN/CPS-6B	2700	3019	0.9E6-2.0E6		240 NMi	G	Y	600, 300, 300	1.0, 1.0, 2.0	0-15 RPM		
1	AN/FPS-10	2700	3019	2,000,000		265 NMi	G	Y	600, 300, 300	1.0, 1.0, 2.0	2-15 RPM		
1	AN/MPQ-14	2740	2960	200,000		20,000 YRDS	G	Y	1100	0.8			
1	AN/MPQ-14A	2740	2960	200,000	180	20,000 YRDS	G	Y	1100	0.8			
1	AN/DPN-17, 17A, 17B	2750	2950	100			A	Y		0.65			
1	AN/APS-20E	2819	2910	2,000,000			A	Y	300, 900	2.0, 0.67	2.4-16 RPM		
1	AN/APS-20F	2819	2910	2,000,000			A	Y	300, 900	2.0, 0.67	2.4-16 RPM		
1	AN/APS-20A	2850	2910	750,000	447		A	Y	300, 150	2.0, 2.0			
1	AN/APS-20C	2850	2910	750,000	447		A	Y	300, 150	2.0, 2.0			
1	AN/MPQ-2A	2900	2845				G	Y	731, 1462	0.8, 0.8			
2	S631+	2900	3000	1.2E6 & 2.25E6	1500 & 3300		G	Y	270-750 & 200-600	2.0-5.0 & 2.5-5.0	3,4,6,8 RPM	45	
2	S669	2900	3000	1,200,000	1500		G	Y	270-750	2.0-5.0		40.5	0.6V, 3.7H
3, 4	AN/SPS-48	2900	3100	2,200,000		400 KM	M	Y	1250-2000	3	7.5, 15	38.5	1.5 X 1.6
1, 4	AN/SPS-48A(V)	2900	3100	2,200,000		220 NMi	M	Y			7.5, 15 RPM	38.5	
4	AN/SPS-48C	2900	3100	2,200,000		220 NMi	M	Y	1250-2000	3	7.5, 15	38.5	
4	AN/SPS-48D	2900	3100	2,200,000			M	Y	1250-2000	3	7.5, 15	38.5	
1	AN/TPS-43	2900	3100	4,000,000	6700	260 NMi	G	Y	278, 250, 227	6.7, 6.7, 6.7	6 RPM	35.7	1.1H, 1.5-1.8V
3	AN/TPS-43E	2900	3100	4,000,000		408 KM	G	Y		6.5			
1	AN/TPS-48	2900	3100	2,800,000	4700	220 NMi	G	Y	278, 250, 227	6.7, 6.7, 6.7			
3	AN/TPS-70(V)-1	2900	3100	3,000,000	4900	450 KM	G	Y			6 RPM		
2	S669+	2900	3100	2,250,000	3300		G	Y	200-600	2, 5-5.0		40.5	0.6V, 3.7H
3	SERIES 320 3-D	2900	3100	1,100,000		300 NMi	G	Y			6 RPM	41.5	
1	SO	2900	3100	60,000	24	20 Mi	M	Y	400	1	12 RPM		
1	SO-1	2900	3100	75,000	26	20 Mi	M	Y	400	1	12 RPM		
1	SO-10	2900	3100	285,000	30	22 Mi	M	Y	650, 650	0.37, 1.3		28	27.0H, 17.0V
1	SO-13	2900	3100	60,000	26	20 Mi	M	Y	400	1	12 RPM		
1	SO-2	2900	3100	75,000	26	20 Mi	M	Y	400	1	12 RPM		
1	SO-8	2900	3100	75,000	26	20 Mi	M	Y	400	1	8 RPM		
1	SO-8A	2900	3100	75,000	26	20 Mi	M	Y	400, 600	1.0, 1.0	8 RPM		
1	SO-9	2900	3100	60,000	26	20 Mi	M	Y	400	1	8 RPM		
1	SO-A	2900	3100	60,000	24	20 Mi	M	Y	400	1	12 RPM		
2	TRS 2205 (VOLEX III)	2900	3100	1,000,000	2000	110, 155 NMi	G	Y	500	4	3 RPM	40	

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 14. Radars in the 2900 – 3100 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE [2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
3	VTSR	2900	3100	90,000		110 KM	G	Y	1250				
2	AN/TPS-32	2905	3080	2.2E6, 665E3, 60E3		300 NMi	G	Y	265-917	30	6 RPM	41	0.84V, 2.15H
2	AN/TPS-64	2905	3080	2.2E6, 665E3, 60E3		300 NMi	G	Y	265-917	30	6 RPM	41	0.84V, 2.15H
2	AN/TPS-64	2905	3080	2.2E6, 665E3, 60E3		300 NMi	G	Y	265-917	30	6 RPM	41	0.84V, 2.15H
2, 4	AN/SPS-39	2910	3100	1,000,000		100-160 NMi	M	Y	1850, 925	2.0, 4.0	15, 6 RPM	39.5	1.1 X 2.25
3, 4	AN/SPS-39A	2910	3100	1,000,000		100-160 NMi	M	Y	488-2000	2.0, 4.0	15, 6 RPM	39.5	1.1 X 2.25
4	AN/SPS-42	2910	3100	1,000,000		160 NMi	M	Y	1850, 925	2.5, 4.6	15, 6 RPM	39.5	1.1 X 2.25
2, 4	AN/SPS-52, 52B	2910	3100	1,000,000			M	Y					
3, 4	AN/SPS-52C	2910	3100	1,000,000			M	Y					
1	AN/APN-13	2960	3060	500			A	Y	600 PPS	0.4			OMNI
1	SO-7M	2965	3019	80,000			G	Y					
1	SO-7N	2965	3019	80,000			G	Y					
3	AN/APY-2	3000	3000				A	Y			6 RPM		
4	MK-26	3000	3000	50,000		25,000 YRDS	M	Y	540-660	0.5		26	10
1	SJ	3000	3000			12 Mi	M	Y	600, 1800				
1	SJ-1	3000	3000			12 Mi	M	Y	600, 1800				
1	SG-1	3000	3100	60,000			MG	Y	750-850	1.0-2.0	2-16 RPM		
1	SG-1B	3000	3100	60,000			MG	Y	750-850	1.0-2.0	8-16 RPM		
1	SG-1C	3000	3100	60,000			MG	Y	750-850	1.0-2.0	8-16 RPM		
1	SG-1D	3000	3100	60,000			MG	Y	750-850	1.0-2.0	8-16 RPM		
1	SG-25	3000	3100	60,000			G	Y	750-850, 750-850	1.0-2.0	2, 4 RPM		3.0H, 5.0V
1	SG-25B	3000	3100	60,000			G	Y	750-850, 750-850	1.0-2.0			
1	SG-A	3000	3100	60,000			MG	Y	750-850	1.0-2.0	2-18 RPM		
1	SG-B	3000	3100	60,000			MG	Y	750-850	1.0-2.0	8-16 RPM		
1	SG-C	3000	3100	60,000			MG	Y	750-850	1.0-2.0	8-16 RPM		
1	SG-D	3000	3100	60,000			MG	Y	750-850	1.0-2.0	8-16 RPM		
1	AN/SPN-4	3010	4000	15000		50 Mi	M	Y	1000	0.4	60 CPS		3.5H, 11.5V
4	AN/SPS-64+	3025	3075	60,000			M	Y	3600, 1800, 900	0.06, 0.5, 1.0	33 RPM	28	

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

3.10. Region: 3.10 - 3.70 GHz

The region is used by a variety of tactical military radars. Whether or not much occupancy is seen in this region depends upon proximity to bases and depots where such radars are repaired or used for training. Usage is variable but is generally much lighter than in the 2700 - 2900 or 2900 - **3** 100 MHz bands. (Sanders, 1993) [5]

Radar assignments in this region are confined to the Department of Defense. For those assignments with a power greater than 25 kW, there are 18 assignments less than 1 MW (peak power) and 43 assignments greater than 1 MW (peak power). The emissions in this region are located in four bands as described in Table 15. A detailed descriptions of various radars located in this region are listed in Tables 16 and 17. Typically the high powered radars have a peak power of 500 kW - 6.0 MW, a pulse repetition rate of 500 - 1600 pps, a pulse width of 1 .0 - 2.0 us, and a scan rate of 0 - 15rpm.

Table 15. Spectrum Allocation in the 3.10 to 3.70 GHz Region

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
3.100-3.300	radiolocation	Radiolocation stations installed on spacecraft may be employed for the earth exploration-satellite and space research services on a secondary basis.	RADIOLOCATION	Government, non-military radiolocation is secondary to military radiolocation. In making assignments to stations of other service, all practicable steps are taken to protect the spectral line observations of the radio astronomy services from harmful interference. This band is primarily used for military radiolocation, including several multi-billion dollar defense radar systems. Use of this band for these systems is considered critical to national defense. The high-power mobile radars include airborne, land-based, and shipborne applications.

Reference: (NTIA, 1993) [9]

Table 15. Spectrum Allocation in the 3.10 to 3.70 GHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
3.300-3.500	amateur radiolocation	1) Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. 2) Radiolocation survey operations. Max. power: 5 W. Secondary to government radiolocation operations (3.3-3.5 GHz). Amateur satellite service is secondary to space, earth and telecommand stations. In making assignments to stations of other service, all practicable steps are taken to protect the spectral line observations of the radio astronomy services from harmful interference in the band 3.3458 - 3.3525 GHz.	RADIOLOCATION	Limited to military radiolocation. This band is primarily used for military radiolocation, including several multi-billion dollar defense radar systems. Use of this band for these systems is considered critical to national defense. The high-power mobile radars include airborne, land-based, and shipbome applications.

Reference: (NTIA, 1993) [9]

Table 15. Spectrum Allocation in the 3.10 to 3.70 GHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
3.500-3.600	radiolocation		AERONAUTICAL-RADIONAVIGATION (ground-based) RADIOLOCATION	Government, non-military radiolocation is secondary to military radiolocation. This band is primarily used for military radiolocation, including several multi-billion dollar defense radar systems. Use of this band for these systems is considered critical to national defense. The high-power mobile radars include airborne, land-based, and shipbome applications.
3.600-3.700	FIXED-SATELLITE (space-to-earth) radiolocation	Fixed satellite service is limited to international, inter-continental systems and subject to case-by-case electromagnetic compatibility analysis. INMARSAT and INTELSAT have limited use for fixed satellite service earth stations in this band. Each site must be actively coordinated with the U.S. Government with supporting electromagnetic compatibility analysis. See General information above.	AERONAUTICAL-RADIONAVIGATION (ground-based) RADIOLOCATION	Government, non-military radiolocation is secondary to military radiolocation. The principal Federal Government use of this band is to support a Navy radar used for landing operations on aircraft carriers. This high-power radar is operating on Navy ships and at certain shore locations for training.

Reference: (NTIA, 1993) [9]

Table 16. Radars in the 3100 – 3700 MHz Band

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
2, 4	AN/SPY-1	3100	3500	6,000,000	58,000		M	Y	VARIABLE	51, 25.4, 12.7, 6.4		42	1.7 X 1.7
3	FAST+	3100	3500	2,000,000		246	M	Y	50-13000	0.6-200	15 RPM		
1	AN/APX-95	3138	3145				A	Y					
1	AN/APN-7	3220	3320	500			A	Y	600 PPS	0.4			OMNI
1	SCR-720-A+	3253	3253	100,000			?	Y	1600	2.25			
1	SCR-720-B+	3253	3253	100,000		150 Mi	?	Y	1600	2.25			
1	SCR-720-C+	3253	3253	100,000		150 Mi	?	Y	1600	2.25			
1	SCR-720-D+	3253	3253	100,000		150 Mi	?	Y	1600	2.25			
1	AN/CPN-8	3255	3257			100 Mi	G	Y					
1	AN/MPN-8++	3255	3257	1100			G	Y					
1	AN/CPN-3	3256	3256			150 Mi	G	Y					
1	AN/UPN-2	3256	3256	50			GA	Y					
1	AN/APS-2	3256	3300	50,000			A	Y	650 & 325 PPS	1.0 & 2.0			
1	AN/APS-2A	3256	3300	50,000			A	Y	650 & 325	1.0 & 2.0			
1	AN/APS-2G	3256	3300	50,000			A	Y	650 & 325	1.0 & 1.0			
1	AN/MPN-2+++	3267	3333	1100			G	Y					
1	ASC	3300	3300	25000		100 NMi	A	Y	800, 400	1.0, 2.5			9.0H, 11.0V
1	ASC-1	3300	3300	25000		100 NMi	A	Y	800, 400	1.0, 2.5			9.0H, 11.0V
1	SCR-720-A	3300	3300	100,000		150 Mi	?	Y	400	0.75			
1	SCR-720-B	3300	3300	100,000		150 Mi	?	Y	400	0.75			
1	SCR-720-C	3300	3300	100,000		150 Mi	?	Y	400	0.75			
1	SCR-720-D	3300	3300	100,000		150 Mi	?	Y	400	0.75			
1	AN/DPN-25	3380	3460	100			A	Y		0.65			
1	AN/BPS-4	3400	3700	500,000			M	Y	400	1		23.5	5.3H, 50V
1	SG-3	3400	3700	500,000	470	80 Mi	M	Y	750, 750	0.33, 1.25	2.5, 5.0 RPM	30	10.0V, 3.0H
1	SV	3400	3700	500,000			M	Y	400	1	0-6 RPM	23.5	
1	SV-1	3400	3700	500,000			M	Y	400	1	0-6 RPM	23.5	
1	SV-3	3400	3700	500,000			M	Y	400	1	0-6 RPM	23.5	
1	AN/SPS-8	3430	3750	650,000		60 NMi	M	Y	1000, 500	1.0, 2.0	1-10 RPM	37.5	1.1V, 3.5H
1	AN/SPS-8(XN-1)	3430	3750	800,000			M	Y	500, 1000	2.0, 1.0	1-10 RPM	37	1.1V, 3.5H
1	AN/SPS-8A	3430	3750	1,000,000			M	Y	700, 450	2.0, 2.0	1-10 RPM	37.5	1.1V, 3.5H
1	AN/SPS-8B	3430	3750	1,000,000			M	Y	700, 450	2.0, 2.0	1-10 RPM	41	1.1V, 3.5H
1	AN/GSN-5	3488	3488	40,000		4 NMi	G	Y					
1	SX+	3500	3550	500,000			?	Y	1170	1			

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 16. Radars in the 3100 – 3700 MHz Band (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	SX-1+	3500	3550	500,000			?	Y	1170	1			
1	AN/SPN-6	3550	3700	500,000			M	Y	760	0.33-1.25			2.5V, 2.0H
1	AN/SPN-43	3590	3700	850,000			M	Y	1125	0.9	15 RPM	32	

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 17. S Band Radar (2000 – 4000 MHZ)

REF [1]	RADAR NAME	BAND	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
3	AN/MPN-1A	S	80,000		30 Mi	G	Y	2000	0.5			
3	AN/MPN-1B	S	80,000		30 Mi	G	Y	2000	0.5			
3	AN/MPN-3	S			30 Mi	G	Y	2000	0.5-10.0			
3	AN/SPQ-11+	S				M	Y					
3	AN/SPS-30	S		9000		M	Y				41	1.5H, 1.2V
3, 4	AN/UPS-3	S	230	20	20 KM	G	Y				22	8.0H, 17.0V
2	ANTARES	S	1E6/mag	1000/mag	195 NMi	G	Y			6 RPM	45	
2	AR-3D	S	1,110,000	10,000	300 NMi	G	Y	250	36	6 RPM	41.5	2.0V, 1.0H
3	DUAL BAND RADAR	S				G	Y					
3	HADR	S			500 KM	G	Y					
3	ISC CARDION	S	> 100,000			G	Y		1% DUTY	10 RPM		
2	M-33	S	500,000		90 NMi	G	Y	1000	1.3	10, 20, 30 RPM		
1	MARK 27	S	50,000		40,000 YRDS	M	Y	1620-1980	2			
1	MARK 28 MOD 2	S	50,000		44,000 YRDS	M	Y	1500	0.3			
2	MSR	S	> 1,000,000	> 100,000	> 600 NMi	G	Y					
2	NIKE AJAX	S	1,000,000		200 NMi	G	Y	1000	1.3	10, 20, 30 RPM		
2	TH.D.1955	S	20,000,000	20,000	> 215 NMi	G	Y			6 RPM	46	
2	TRS 2210 (MATADOR)	S	600,000/mag	2000/mag	130 NMi	G	Y	500	5.8	5 RPM	40	1.9V, 1.5H
3	VSTAR, VSTAR-PT	S			250 KM	G	Y					

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

3.11. Band: 4.20 - 4.40 GHz

The primary use of this band is for aeronautical radionavigation service, used for aircraft radio altimeters exclusively. Also included are the standard frequency and time signal satellite service (4202 MHz) and passive sensing in the earth-exploration satellite and space research services (assigned on a secondary basis to radionavigation). This band is heavily used (especially near airports) for radar altimeters on board non-government fixed-wing and rotary aircraft. These radars come in two varieties: FM/CW and pulsed. These radars are especially receivable under the approach and departure paths at major airfields. (Sanders, 1993) [5]

Table 18 gives a detailed description of various radar emissions located in tbis band. Altimeters are relatively low powered (less than 2 kW peak power for pulsed - less than 1 W average for CW). Pulsed emitters have typical pulse repetition rate of 1500 - 10000 pps, and a short pulse width (less than 0.1 us).

Table 18. Radars in the 4.20 – 4.40 GHz Band

REF[1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APN-117	4200	4400		1		A	N					
1	AN/APN-22	4200	4400		1		A	N					
1	AN/APN-42A	4220	4230	2000		70,000 FT	A	Y	4916.45 PPS	0.1		17	
1	AN/APN-150(V)	4280	4370		0.224		A	N					
1	AN/APN-141	4290	4310	2 & 1000		5000 FT	A	Y	1500, 1500, 3000	0.010, 0.030, 0.085		7.5	
1	AN/APN-141A	4290	4310	2 & 1000		5000 FT	A	Y	1500, 1500, 3000	0.010, 0.030, 0.085			
1	AN/APN-167	4290	4310	25 & 100			A	Y	9500-10500	0.04 & 0.095			
1	AN/APN-184(V)2	4290	4310			5000 FT	A	Y					
1	AN/APN-171(V)	4300	4300	25-300			A	Y	10KHz	0.025-0.155			

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

3.12. Region: 5.20 - 5.925 GHz

Varied occupancy occurs in this band, including weather radars, maritime surface-search radars, and airborne weather radars. WSR-74C weather radars and their military equivalents are commonly observed especially during severe weather, and may be present in great numbers in areas noted for severe weather. Sometimes, weather radars are not rotated but are left on a single azimuth, still transmitting, until weather observations are required. Maritime surface search radars will be seen in great numbers in this band near any busy harbor. Airborne weather radar signals are highly transient. They usually do not produce much usage (Sanders, 1993) [5]

Table 19 shows the distribution of GMF assignments for different agencies. The various services are located in six bands as described in Table 20, and a detailed descriptions of various radars located in this band are listed in Tables 21 and 22. High powered radars in this region are characterized by a peak power of200 kW - 1.0 MW, a pulse repetition rate of 250 - 700 pps, a pulse width of 0.2 - 3.0 us, and a scan rate of 3 - 40 rpm.

Table 19. Radar Assignments in the 5200 - 5925 MHz Region

	Number of Assignments 25 - 999 kW peak power	**Number of Assignments 1.0 MW or Greater peak power**
DOD	196 (Most have several hundred kW peak power. About half are weather radar)	247
Commerce	72 (WSR-74C)	0
Non-Gov	61 assignments >= 100 kW peak power - probably weather radar	1
FAA	49 (Weather radar - 250 kW peak power)	0

Table 20. Spectrum Allocation in the 5.20 to 5.925 GHz Region

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
5.250-5.350	radiolocation	Radiolocation stations installed on spacecraft may also be employed for earth exploration-satellite and space research services on a secondary basis.	RADIOLOCATION	Government, non-military radiolocation shall be secondary to military radiolocation.
5.350-5.460	AERONAUTICAL-RADIONAVIGATION radiolocation	1) Aeronautical radionavigation service is limited to airborne radars and associated airborne beacons (5.35-5.47 GHz). 2) Radiolocation stations installed on spacecraft may also be employed for earth exploration-satellite and space research services on a secondary basis.	AERONAUTICAL-RADIONAVIGATION RADIOLOCATION	Aeronautical radionavigation service is limited to airborne radars and associated airborne beacons (5.35-5.47 GHz). Government radiolocation is primarily for the military services. Limited secondary use in support of experimentation and research programs (5.35-5.65 GHz).
5.460-5.470	RADIONAVIGATION radiolocation	Non-government radiolocation is secondary to aeronautical and maritime radionavigation and government radiolocation.	RADIONAVIGATION radiolocation	Aeronautical radionavigation service is limited to airborne radars and associated airborne beacons (5.35-5.47 GHz). Government radiolocation is primarily for the military services. Limited secondary use in support of experimentation and research programs (5.35-5.65 GHz).

Reference: (NTIA, 1993) [9]

Table 20. Spectrum Allocation in the 5.20 to 5.925 GHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
5.470-5.650	MARITIME-RADIONAVIGATION METEOROLOGICAL-AIDS radiolocation	Maritime radionavigation (5.46-5.65 GHz) is limited to shipborne radars. Max. power: 20 W E.I.R.P. Meteorological ground-based radar (5.60-5.65 GHz) is on equal basis with maritime radionavigation services. Non-government radiolocation is secondary to aeronautical and maritime radionavigation and government radiolocation.	MARITIME-RADIONAVIGATION METEOROLOGICAL-AIDS radiolocation	Maritime radionavigation. Government radiolocation is primarily for the military services. Limited secondary use in support of experimentation and research programs (5.35-5.65 GHz).

Reference: (NTIA, 1993) [9]

Table 20. Spectrum Allocation in the 5.20 to 5.925 GHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
5.650-5.850	amateur	1) Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. 2) Industrial, scientific and medical (ISM) applications are on a primary basis (5.725-5.875 GHz). ISM equipment operating in this band is permitted unlimited radiated energy. 3) Deep space research service (5.600-5.725 GHz) allocated on a co-secondary basis with amateur service. No amateur radio shall interfere with another nation's radiolocation service	RADIOLOCATION	Government radiolocation is primarily for the military services (5.650-5.925 GHz).

Reference: (NTIA, 1993) [9]

Table 20. Spectrum Allocation in the 5.20 to 5.925 GHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
5.850-5.925	FIXED-SATELLITE (earth to space) ISM APPLICATIONS amateur	1) Industrial, scientific and medical (ISM) applications on a primary basis (5.725-5.875 GHz). ISM equipment operating in this band is permitted unlimited radiated energy. 2) Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. Fixed-satellite service is limited to international, intercontinental services. No amateur radio shall interfere with another nation's radiolocation service.	RADIOLOCATION	Government radiolocation is primarily for the military services (5.650-5.925 GHz).

Reference: (NTIA, 1993) [9]

Table 21. Radars in the 5200 – 5925 MHz Region

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE [2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APQ-13	5200	10500	40000		35000 FT	A	Y					
1	AN/APS-44+	5250	5310	1,000,000			A	Y					
1	AN/APS-44A+	5250	5310	1,000,000			A	Y					
1	AN/MPS-16, 16A, 16B	5250	5310	1,000,000		200 NMi	G	Y	300-265	2.5	20 RPM	43	
1	AN/TPS-37	5250	5310	1,000,000			G	Y	300, 364	2.5, 2.5	0.125 RPM		2.4H, 0.6V
1	AN/TPS-40, 40A	5250	5310	1,000,000			G	Y	300-364	2.5		43	
2	S613	5300	5340	1,000,000	1500		G	Y	300	5		39.5	0.9V, 3.0H
1	AN/DPN-66	5400	5900	500			G	Y	0.002 DUTY	0.25, 0.75			
1	AN/DPN-77	5400	5900	400			?	Y					
1	AN/FSS-7	5400	5900	4,000,000		220-850 NMi	G	Y	95	18,0-20.0	9.38 RPM		
1	AN/SPQ-5(XN-2)	5400	5900				G	Y					
3, 4	FAST	5400	5900	1,000,000		143	M	Y	50-13000	0.6-200	30 RPM		
3	MBAR	5400	5900	70,000		55KM	M	Y	17200 AVERAGE	1.8 AVERAGE	40 RPM	32	
1	AN/FPS-77(V)	5450	5650	250E3-350E3		200 NMi	G	Y	186-324	1.9-2.1			
1	AN/FPS-16(V)	5450	5825	1,000,000		230 Mi	G	Y	341-1707 (12 STEPS)	0.25-1.0 (3 STEPS)			
2	AN/MPS-25	5450	5825	1,000,000		400,000 YRDS	G	Y	341-1707	0.25-1.0			
1, 4	AN/SPS-10	5450	5825	285,000	50		MG	Y	625-650, 312-325	0.25-1.3, 2.25	16 RPM	30	1.5
1	AN/SPS-10B	5450	5825	500,000			MG	Y	625-650, 312-325	0.25-1.3, 2.25	15 RPM		
1	AN/SPS-10C	5450	5825	185,000			MG	Y	625-650, 312-325	0.25-1.3, 2.25	15 RPM		
1	AN/SPS-10D	5450	5825	285,000			MG	Y	625-650, 312-325	0.25-1.3, 2.25	15 RPM		
1	AN/SPS-10E	5450	5825				MG	Y		0.25-1.3, 2.25	15 RPM	30	1.9H, 16V
1	AN/SPS-10F	5450	5825	285,000			M	Y	635-660, 317-330	0.25-1.3, 2.25	15 RPM		
1	AN/SPS-18(XN-1)	5450	5825	170,000			M	Y	683, 228	0.25-1.3, 2.25			
1	AN/SPS-18(XN-2)	5450	5825	170,000			M	Y	683, 228	0.15-1.0, 2.25			
1	AN/SPS-4	5450	5825	180,000			M	Y	625-650	0.37-1.3	5 OR 15 RPM		
1	AN/SPS-5C	5450	5825	350,000			M	Y	683	0.5	17 RPM	29	1.7H, 15.0V
1	AN/SPS-5D	5450	5825	350,000			M	Y	683	0.5	17 RPM	29	1.7H, 15.0V
	AN/SPS-67	5450	5825	285,000			MG	Y	625-650, 312-325	0.25-1.3, 2.25	16 RPM	30	1.5
10	WSR-74C	5450	5825	250,000			G	Y	259	3.0	APPROX. 3 RPM		
2	S613+	5480	5520	1,000,000	1500		G	Y	300	5		39.5	0.9V, 3.0H
1	AN/SPS-21	5500	5600	10,000			M	Y	1500	0.19			

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 21. Radars in the 5200 – 5925 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/SPS-21A	5500	5600	10,000			M	Y	1500	0.19			
1	AN/SPS-21B	5500	5600	10,000			M	Y	1500	0.19			
1	AN/SPS-21C	5500	5600	10,000			M	Y	1500	0.19			
1	AN/SPS-21D	5500	5600	10,000			M	Y	1500	0.19			
1	AN/SPQ-5(XN-2)+	5585	5686				G	Y					

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 22. C Band Radar (4000 – 8000 MHZ)

REF[1]	RADAR NAME	BAND	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
3	AN/FPQ-6	C			60,000 KM	G	Y					
3	AN/FPS-105(V)	C	1,000,000		60,000 KM	G	Y	169-640	0.25, 0.5, 1.0			
3	AN/MPS-36	C	1,000,000		60,000 KM		Y				43	1.2
3, 4	AN/SPG-51	C	30,000			M	Y				39.5	1.6 X 1.6
2	AN/SPG-55B	C	1,000,000		300,000 YRDS	M	Y	427, 427, 427	12.0, 13.0, 0.1			1.6V, 1.6H
3	AN/TPQ-18	C			60,000 KM	G	Y					
3	AN/TPQ-39(V)	C				G	Y					
3	ASTAR-2	C			100 NMi	G	Y					
3	ASTAR-3	C			200 NMi	G	Y					
3	FALCON SERIES	C	60,000	1500			Y					
2	PATRIOT	C	> 100,000	> 10,000		G	Y					

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

3.13. Region: 8.50 - 10.55 GHz

This band is occupied by precision approach radars (PARS) used at airports, maritime surface search units and airborne search, navigation, mapping and fire control radars. The maritime units (usually SPS-66s) are seen in great numbers near major maritime traffic arteries, especially in bad weather. They can be tuned anywhere in the 9345-9405 MHz range, but come from the factory tuned to 9375 MHz, and are usually left at that frequency over their entire lives. The Coast Guards Vessel Traffic Service (VTS) operates an extensive network of land-based radars that monitor shipping traffic. They are tuned in the 9.30-9.50 GHz region. VTS systems are found in many major commercial harbors. While the maritime radars are seen only in coastal areas, airborne radar signals will be received in this band at any and all locations in the continental U.S. These radar signals are seen frequently in the 9.30-9.40 GHz range, and also in the 9.50-l 0.00 GHz range. They produce fairly high occupancy at and around 9.375 GHz.
(Sanders, 1993) [5]

Table 23 shows the distribution of GMF assignments for different agencies, The various services are located in seven bands as described in Table 24. Table 25 gives detailed characteristics of radars located in this region. Typical emissions have a peak power of 50 - 300 kW, a pulse repetition rate greater than 1000 pps, a pulse width less than or equal to 1.0 us, and a scan rate greater than 10 rpm.

Table 23. Radar Assignments in the 8500 - 10550 MHz Region

	Number of Assignments 25 - 999 kW peak power	Number of Assignments 1.0 MW or Greater peak power
Air Force	1299 (Many have peak power > 100 kW. This includes simulators)	Several
Coast Guard	33	Several
Commerce	10	0
Non-Gov	15 assignments > 100 kW peak power - for testing and development	6 (For testing and development)
FAA	3	0

Table 24. Spectrum Allocation in the 8.50 to 10.55 GHz Region

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
8.500-9.000	radiolocation	Secondary Doppler radionavigation aids, government and non-government airborne Doppler radar are permitted (8.750-8.850 GHz). Radiolocation stations installed on spacecraft may also be employed for earth exploration-satellite and space research services (8.5.50-8.650 GHz).	RADIOLOCATION	
9.000-9.200	AERONAUTICAL-RADIONAVIGATION radiolocation	Aeronautical radionavigation is restricted to ground-based, surveillance radar and to associated airborne transponders which transmit only when actuated by radars operating in the same band.	AERONAUTICAL-RADIONAVIGATION radiolocation	
9.200-9.300	MARITIME-RADIONAVIGATION radiolocation	Maritime radionavigation (9.200-9.225 GHz) is limited to shore-based radars. Search and Rescue Transponders (SART) (9.200-9.500 GHz).	MARITIME-RADIONAVIGATION RADIOLOCATION	

Reference: (NTIA, 1993) [9]

Table 24. Spectrum Allocation in the 8.50 to 10.55 GHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
9.300-9.500	RADIONAVIGATION meteorological-aids radiolocation	Aeronautical radionavigation ground-based radar beacons are permitted secondary to the maritime radionavigation service (9.300-9.320 GHz). Aeronautical radionavigation is limited to airborne weather radar, associated airborne beacons, and ground-based radar. Response from radar transponders shall not be able to be confused with racons. Ground-based meteorological service radar is primary to radiolocation. Non-government radiolocation is secondary to government radiolocation.	RADIONAVIGATION meteorological-aids radiolocation	1) Maritime radar units (usually SPS-66's) (9345-9405 GHz) Typical bandwidth: 3.33 MHz - 20 MHz (null to null) 2) Land-based radars used to monitor shipping traffic for the Coast Guard's Vessel Traffic Service (9.30 - 9.50 GHz). Bandwidth: 40 MHz (null to null) 3) Airborne radar (9.30 - 9.40 GHz). Bandwidth: 2 MHz (null to null) (Sanders, 1993)
9.500-10.000	radiolocation	Radiolocation installed in spacecraft can be employed for earth exploration-satellite and space research services on a secondary basis (9.500-9.800 GHz) Meteorological-satellite service is permitted on a secondary basis to weather radar (9.975-10.025 GHz).	RADIOLOCATION	Airborne radar (9.50 - 10.00 GHz). Bandwidth: 2 MHz (null to null)

Reference: (NTIA, 1993) [9]

Table 24. Spectrum Allocation in the 8.50 to 10.55 GHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
10.0-10.45	Amateur Radiolocation	1) Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. 2) Radiolocation is limited to non-pulsed survey operations (not to exceed 5 W into transmitter). Non-government radiolocation is secondary to Amateur. Amateur and radiolocation are secondary to government operations.	RADIOLOCATION	Radiolocation for military use. Also includes radar on meteorological satellites on a secondary basis and government non-pulsed survey operations on a secondary basis.

Reference: (NTIA, 1993) [9]

Table 24. Spectrum Allocation in the 8.50 to 10.55 GHz Region (Con't)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
10.45-10.5	Amateur Amateur-Satellite Radiolocation	1) Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. Amateur also includes amateur-satellite. 2) Radiolocation is limited to non-pulsed survey operations (not to exceed 5 W into transmitter). Non-government radiolocation is secondary to Amateur. Amateur and radiolocation are secondary to government operations.	RADIOLOCATION	Radiolocation for military use. Also includes radar on meteorological satellites on a secondary basis and government non-pulsed survey operations on a secondary basis.

Reference: (NTIA, 1993) [9]

Table 25. Radars in the 8500 – 10550 MHz Region

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE [2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APS-62	7320	9430	425,000	250		A	Y	300	1.8			
1	AN/BPS-13	8500	9600	75,000	19.5		M	Y	570-630	0.5		29.3	2.6H, 12.0V
1	AN/APN-154	8500	9600	1000			A	Y					
1	AN/APQ-122(V)	8500	9600	75000			A	Y					
1	AN/APS-80	8500	9600			30,000 FT	A	Y				35	2.5H, 3.5V
1	AN/BPS-12	8500	9600	75,000			M	Y	570-630	0.5		29.3	2.6H, 12.0V
1	AN/BPS-14	8500	9600	75,000	19.5		M	Y	570-630	0.5		29.3	2.6H, 12.0V
1	AN/KPQ-1	8500	9600	140,000		10,000	G	Y	1100	0.8			
1	AN/MSQ-77	8500	9600	250,000	37.5	400,000 YRDS	G	Y	300, 600	0.25			
4	AN/SPG-48	8500	9600	50,000		40,000 YRDS	M	Y	3000	0.1-0.15		37.5	2
1	AN/SPG-50	8500	9600	50,000		34,500 YRDS	M	Y	2000	0.25		36	2.6H, 2.6V
1	AN/TPQ-10*, 10()**	8500	9600	250,000		200,000 METERS	G	Y	1400, 700	0.5, 0.5			1.2H, 2.0V
1	AN/TSQ-81	8500	9600	250,000			G	Y	600, 300	0.25		43	
1	AN/TSQ-96	8500	9600	250,000			G	Y	600, 300			43	
1	AN/APS-67	8530	9600	43,000			A	Y	1200	0.7		27	
1	AN/APN-108	8700	8900			70,000 FT	A	Y					
1	AN/APN-81	8700	8900	35		70,000 FT	A	Y	50000 ppc	0.9			
1	AN/APN-82	8700	8900	35		70,000 FT	A	Y	50000 PPS	0.9			
1	AN/APN-89	8700	8900	35		70,000 FT	A	Y	50000 PPS	0.9			
1	AN/APN-99A	8700	8900	35		70,000 FT	A	Y	50000 PPS	0.9			
1	AN/BPS-1	8740	8890	75E3-110E3			M	Y	540-660	0.5	0-8 RPM		2.0H, 16.0V
1	AN/BPS-1(XN-1)	8740	8890	75E3-110E3			M	Y	54-66	0.5	0-11 RPM		
1	AN/BPS-11	8740	8890	75E3-110E3			M	Y	570-630	0.5		29.3	2.6H, 16V
1	AN/BPS-11A	8740	8890	75E3-110E3			M	Y	570-630	0.5		29.3	2.6H, 16V
1	AN/BPS-5	8740	8890	75E3-110E3	22.5-30		M	Y	570-630	0.5			
1	AN/BPS-5(XN-1)	8740	8890	75E3-110E3	22.5-30		M	Y	570-630	0.5	0-11 RPM		2.6H, 16.0V
1	AN/BPS-5A	8740	8890	75E3-110E3	22.5-30		M	Y	570-630	0.5		29.3	2.6H, 16.0V
1	AN/BPS-9	8740	8890	75E3-110E3			M	Y	540-660	0.5	0-8 RPM		2.6H, 16.0V
1	AN/BPS-9A	8740	8890	75E3-110E3			M	Y	540-660	0.5	0-8 RPM		2.6H, 16.0V
1	AN/BPS-9B	8740	8890	75E3-110E3			M	Y	540-660	0.5			
1, 4	AN/SPG-34	8740	8890	50,000		36,000 YRDS	M	Y	1800	0.3		30	2.4H, 2.4V
1	SS	8740	8890	110,000			M	Y	600	0.5	0-8 RPM	26	2.6H, 16.0V
1	SS-1	8740	8890	110,000			M	Y	600	0.5	0-8 RPM	26	2.6H, 16.0V
1	SS-2	8740	8890	110,000			M	Y	600	0.5	0-8 RPM	26	2.6H, 16.0V

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 25. Radars in the 8500 – 10550 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	SS-A	8740	8890	110,000			M	Y	600	0.5	0-8 RPM	26	2.6H, 16.0V
1	AN/APN-102	8770	8830		10	70,000 FT	A	Y	55000, 80,000-240,000	4.5, 1.04-3.13			
1	AN/APN-144	8770	8830		0.65		A	Y					
1	AN/APN-147(V)	8770	8830		0.5		A	Y					
1	AN/BPS-15	8795	8855	35,000	13		M	Y	1500, 750	0.1, 0.5		29.3	13.0V, 3.0H
1	AN/APN-179	8800	8800		0.5	50,000 FT	A	Y					
1	AN/APX-78	8800	9500				A	Y					
1	AN/UPN-25	8800	9500	400			G	Y	10-2600	0.2-0.4			
1	AN/PPS-4, 41	8900	9400	800			G	Y	5000	0.2			
1	AN/PPS-5, 5A	8900	9400			10,000 METERS	G	Y	5000	0.2			
1	AN/UPN-11	8900	9400	300			M	Y					
1	SU	9000	9000	60,000		80 Mi	M	Y	600, 600	1.0, 0.5			
1	SU-1	9000	9000	60,000		80 Mi	M	Y	600, 600	1.0, 0.5			
1	SU-1A	9000	9000	60,000		80 Mi	M	Y	600, 600	1.0, 0.5			
1	SU-2	9000	9000	50,000		80 Mi	M	Y	600, 600	0.25, 1.0			1.9H, 3.8V
1	AN/CPN-4+	9000	9160			36 NMi	G	Y					
1	AN/CPN-4A+	9000	9160			8 NMi	G	Y					
1	AN/FPN-16, 16A	9000	9160	45,000			G	Y	1883, 5500	0.18, 0.18	60 RPM		
1	AN/FPN-33	9000	9160	50,000			G	Y	1500	0.5		39	0.85V, 2.5H
1	AN/FPN-36	9000	9160	150,000			G	Y	1500	0.5			
1	AN/FPN-40	9000	9160	200,000			G	Y	1500, 1500	0.6, 0.12			
1	AN/FPN-48+	9000	9160			10 NMi	G	Y					
1	AN/FPN-50+	9000	9160			10 NMi	G	Y					
1	AN/FPN-52	9000	9160	35,000	15.8	10 NMi	G	Y	5500	0.16-0.20			
2	AN/FPN-62	9000	9160	45,000	26.7	> 15 NMi	G	Y	3300	0.18			
1	AN/MPN-11B+	9000	9160	45,000		10 Mi	G	Y	5500				
1	AN/MPN-13,A,B,C,D,E+	9000	9160	45,000		10 Mi	G	Y	5500				
1	AN/MPN-14, 14A-14J	9000	9160	45,000			G	Y	1833				
1	AN/TPN-12	9000	9160	150,000	120	40 NMi	G	Y	1500	0.55			
1	AN/TPN-12A	9000	9160	150,000	120	400 NMi	G	Y	1500	0.55			
1	AN/TPN-17	9000	9160	150,000	120	40 NMi	G	Y	1500	0.55			
3	PAR-80	9000	9160	150,000		37 KM	G	Y	3450	0.2		45	1.1H, 0.6V
3	SERIES 52	9000	9160	80,000		20 NMi	G	Y				40.3	
1	SO-12N	9000	9160	50,000		20 Mi	G	Y	465	1	6 RPM		

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 25. Radars in the 8500 – 10550 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (μS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	SO-3	9000	9160	20,000	8	20 Mi	M	Y	400	1	9 RPM		
1	SQ-12-M	9000	9160	50,000		20 Mi	G	Y	465	1	6, 7-10 RPM		
1	AN/FPN-28+	9000	9180	25,000			G	Y	2400	0.5			
1	AN/FPN-28A+	9000	9180	25,000			G	Y	2400	0.5			
1	AN/MPN-5, 5A	9000	9180	25,000		10.0 Mi	G	Y	2400	0.5			
1	AN/SPN-8	9000	9180	60,000		6 NMi	M	Y	4000	0.25		33	1.5H, 6.0V
1	AN/SPN-8A	9000	9180	60,000		6 NMi	M	Y	4000	0.25		33	1.5H, 6.0V
2	AN/GPN-22	9000	9200	300,000	1000	20 NMi	G	Y	3500, 3500, 3500	2, 0.5, 1.0		43.5	0.75H, 1.45V
2	AN/TPN-25	9000	9200	300,000	1000	20 NMi	G	Y	3500, 3500	2.0, 0.5		43.5	0.75H, 1.3V
1	AN/APG-30A	9000	9600	4000	1.6		A	Y	800 CPS	0.3-0.55			
1	AN/APG-56	9000	9600	4000	1.6		A	Y	800PPS	0.5-0.55			
1	AN/APS-88A	9000	9600	65,000			A	Y	2000, 1025, 200	0.35, 0.8, 4.5			
1	AN/SPN-35	9000	9600	175,000			M	Y	1200, 1200	0.2, 0.8	16 RPM	37	
1	AN/SPN-35(XN-2)	9000	9600	200,000			M	Y	1200, 1200	0.2, 0.8	16 RPM		
1	AN/SPN-35A	9000	9600	200,000			M	Y	1200, 1200	0.2, 0.8	10 RPM		
1	AN/TPN-14	9000	9600	175,000		20 Mi	G	Y	1200				
1	AN/TPN-18	9000	9600				G	Y					
1	AN/TPN-8	9000	9600	200,000			G	Y	1200, 1200	0.2, 0.8		37	
1	AN/TPN-13	9000	10000				G	Y	700-1400	0.2-1.0		12.5	
1	AN/FPN-1A+	9010	9150			20 NMi	G	Y	2000	0.5			
3, 4	AN/SPS-55	9050	10000	130,000			M	Y	750, 2250	1.0, 0.12	16 RPM	31	1.5 X 20
1	AN/MPG-1	9090	9090	35,000	35	80,000 YRDS	G	Y	1025, 4097	1.0, 0.25			0.6H, 3.0V
1	AN/APS-94D	9100	9400	45,000			A	Y	700-800	0.2-0.45			0.45H
1	AN/APQ-122(V)2	9100	9500				A	Y					
1	AN/APQ-122(V)5	9100	9500				A	Y					
3	AN/VPS-2	9200	9250	1400	10		G	Y					
1	AN/APG-33	9200	9290	35000		30000 YRDS	A	Y					
1	AN/DPN-78A	9200	9500	200			?	Y					
1	AN/APX-95++	9220	9220				A	Y					
2	AN/FPS-4	9230	9404	250,000		120 NMi	G	Y	539	0.5, 2.0	.33, 0-6 RPM		2.05H, 0.75V
2	AN/FPS-8	9230	9404	250,000		120 NMi	G	Y	539	0.5, 2.0	.33, 0-6 RPM		2.05H, 0.75V
1	AN/TPS-10D	9230	9404	250,000		120 NMi	G	Y	539, 539	0.5, 2.0	0-6 RPM		2.05H, 0.755V
1	AN/MPW-3	9282	9288	800		12 NMi	G	Y					
1	AN/TPW-2, 2A	9283	9287	5,000			G	Y	245-275	1		34	3
1	AN/TPW-3	9283	9287	5,000			G	Y	245-275	1		40	

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 25. Radars in the 8500 – 10550 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APX-27B	9290	9310	110			A	Y					
1	AN/APS-15A, 15B	9300	9415	24,000			A	Y	622, 622, 1155, 300	0.95, 0.5, 0.5, 2.1			
3	AN/MPQ-63	9300	10000	30,000		25 KM	G	Y	1000-10000	1			0.55H, 0.67V
1	AN/APQ-23D+	9307	9313	35000			A	Y	270 PPS	2.25			
1	AN/CPN-6	9307	9313	40,000			GM	Y		0.5			OMNI HORZ
1	AN/MPN-2	9307	9313	40,000			G	Y					
1	AN/MPN-8+	9307	9313	40,000			G	Y					
1	AN/APS-31, 31B	9307	9430	52,000			A	Y	800, 400, 400, 200, 200	0.5, 2.5, 2.25, 5.0, 4.5			
1	AN/APS-31A	9307	9430	52,000			A	Y	800, 400, 200	0.5, 2.25, 4.5			
1	AN/APS-33	9307	9430	52,000			A	Y		0.5, 2.5, 5.0			
1	AN/APS-33A	9307	9430	52,000			A	Y		0.5, 2.5, 5.0			
1	AN/APS-33B	9307	9430	52,000			A	Y	800, 400, 200	0.5, 2.25, 4.5			
1	AN/APS-33C	9307	9430	52,000			A	Y	800, 400, 200	0.5, 2.25, 4.5			
1	AN/APS-33D	9307	9430	52,000			A	Y	800, 400, 200	0.5, 2.25, 4.5			
1	AN/APS-33F	9307	9430	52,000			A	Y		0.5, 2.5, 5.0			
1	AN/ASB-1A	9307	9430	52,000			A	Y					
1	AN/APN-135	9308.5	9311.3	1000			A	Y		0.4-0.6			
1	AN/UPN-4	9308.5	9311.5	500		65 Mi	G	Y		0.5		10	
1	AN/APS-44A	9309	9320	480,000			A	Y					
1	AN/APS-38	9309	9330	50,000			A	Y	800, 400, 200	0.5, 2.25, 4.5			
1	AN/APS-38A	9309	9330	50,000			A	Y	800, 400, 200	0.5, 2.25, 4.5			
1	AN/APS-42	9309	9330	50,000			A	Y	800, 200, 300, 200	0.75, 3.50, 2.25, 5.0			
1	AN/APS-42A	9309	9330	50,000			A	Y	200, 300, 800	3.5, 2.35, 0.75			
1	AN/APS-42A	9309	9330	50,000			A	Y	200, 300, 800	3.5, 2.35, 0.75			
1	AN/APS-44	9309	9420	480,000			A	Y					
1	AN/APN-11	9310	9310		300		A	Y		0.499-0.501			OMNI
1	AN/FPN-13	9310	9310	5,000			?	Y					
1	AN/TPQ-7	9310	9310				G	Y				15	60V 120H
1	AN/APS-27	9310	9330			200 Mi	A	Y	775, 195, 2000, 300				
1	AN/APS-3	9310	9375	25,000			A	Y					
1	AN/APN-132	9310	9400	100			A	Y		0.4-5.52			
1	AN/APS-63	9310	9790			200 Mi	A	Y	775, 195, 300				
1	AN/APN-59B	9315	9395	50000			A	Y					

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 25. Radars in the 8500 – 10550 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APS-23A	9320	9330	25			A	Y			6, 14 RPM		
1	AN/APS-38B	9320	9330	50,000			A	Y	800, 200	0.5, 4.5			
1	AN/APS-45	9320	9330		356	120 NMi	A	Y					
1	AN/APS-45A	9320	9330		356	120 NMi	A	Y					
1	AN/APS-31C	9320	9430	52,000			A	Y	800, 400, 200	0.5, 2.25, 4.5			
1	AN/APS-4A	9320	9430	35,000			A	Y	1000, 600, & 350	0.6, 0.6, &2.1			
1	AN/ASB-1	9320	9430	52,000			A	Y	800, 300, 2400, 400	0.75, 3.0, 0.25, 2.25			
1	AN/ASB-1B	9320	9430	52,000			A	Y					
1	AN/MSN-1	9320	9430				G	Y					
1	AN/MSN-2	9320	9430				G	Y					
1	AN/SPN-11	9320	9430	30,000	12	20 NMi	M	Y	1000	0.4	17 RPM		1.9H, 20.0V
1	AN/SPN-11X	9320	9430	30,000	12	20 NMi	M	Y	1000	0.4	17 RPM		1.9H, 20.0V
1	AN/SPN-11Z	9320	9430	30,000	12	20 NMi	M	Y	1000	0.4	17 RPM		1.9H, 20.0V
1	AN/SPN-18, 18X	9320	9430	40,000	20	40 NMi	M	Y	2000, 800	25.0, 65.0	9 RPM		1.9H, 20.0V
1	AN/SPN-22	9320	9430	7,000		32 NMi	M	Y	2000, 1500, 1100	0.2, 0.2, 0.2	20		1.9H, 20.0V
1	AN/SPN-5	9320	9430	30000	25	81,070 YRDS	M	Y	3000, 750	0.25, 1.0	10 RPM		1.8
1	AN/SPN-5A	9320	9430	30000	25	81,070 YRDS	M	Y	3000, 750	0.25, 1.0	10 RPM		1.8
1	AN/SPN-5X	9320	9430	30000	25	81,070 YRDS	M	Y	3000, 750	0.25, 1.0	10 RPM		1.8
1	AN/SPN-5Y	9320	9430	30000	25	81,070 YRDS	M	Y	3000, 750	0.25, 1.0	10 RPM		1.8
1	AN/SPN-5Z	9320	9430	30000	25	81,070 YRDS	M	Y	3000, 750	0.25, 1.0	10 RPM		1.8
1	AN/SPS-23	9320	9430				M	Y					
1	AN/SPS-23A	9320	9430				M	Y					
1	AN/SPS-23V	9320	9430				M	Y					
1	AN/SPS-23X	9320	9430				M	Y					
1	AN/SPS-23XX	9320	9430				M	Y					
1	AN/SPS-23Z	9320	9430				M	Y					
1	CCXT-303	9320	9480	10,000			M	Y	1000, 1000	0.1, 0.5	20	27.5	1.7H, 22.0V
1	CCXT-404	9320	9480	20,000			M	Y	1000, 1000	0.1, 0.5	20	30	1.2H, 23.0V
1	CCXT-TM909	9320	9480	75,000			M	Y	1000, 1000	0.1, 0.5	20 RPM	30	1.2H, 23.0V
2	MODEL 3900	9325	9425				M	Y	3000, 1500	0.1, 0.67	30 RPM		22.0V, 2.0H
1	AN/SPN-21	9335	9405				M	Y					
1	AN/SPS-35A	9335	9405			32Mi	M	Y	1500, 750	0.2, 0.2	20 RPM		
1	AN/APG-30	9335	9415	5000	1.6		A	Y	800 PPS	0.3-0.55			
1	AN/APN-158A	9335	9415	20000		150 NMi	A	Y	400	3.3			

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 25. Radars in the 8500 – 10550 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APN-59	9335	9415	58000			A	Y	200, 1025, 350, 180	0.35, 0.8, 2.35, 4.5			
1	AN/APQ-23D	9335	9415	35000		100 NMi	A	Y	1350 & 675 PPS	0.5 & 0.75			
1	AN/APQ-50	9335	9415	> 180,000			A	Y		0.5 & 1.75		32	
1	AN/APS-19A	9335	9415	40,000	40		A	Y					
1	AN/APX-26B	9340	9340	60			A	Y		0.4-0.6			
1	AN/APQ-74(XN-1)	9340	9410	135,000		200 Mi	A	Y		0.5		32	
1	AN/AFP-53B	9345	9405	7000		15,000 YRDS	A	Y	3000 & 1500 CPS	0.35			5 DEGREES
1	AN/APB-46	9345	9405				G	Y					
1	AN/APB-53A	9345	9405	7000		0.2-0.4 NMI	A	Y	3000 & 1500 CPS	0.35			5 DEGREES
1	AN/APG-53	9345	9405	7000			A	Y	3000 & 1500 CPS	0.35			
1	AN/APQ-35	9345	9405	200,000	200	120 NMi	A	Y	2450, 550, & 300	0.4, 1.75 & 2.25			
1	AN/APQ-35A	9345	9405	200,000	200	120 NMi	A	Y	2450, 550, & 300	0.4, 1.75 & 2.25			
1	AN/APQ-41	9345	9405			200 Mi	A	Y					
1	AN/FPS-103A	9345	9405	20,000			G	Y		2.5			
1	AN/FPS-103	9345	9405	20,000		20, 50, 150 Mi	G	Y		2.5			
1	AN/SPN-23	9345	9405	10,000		20 NMi	M	Y	1000	0.25, 0.4-0.5	15 RPM		1.8H, 25.0V
1	AN/SPQ-6( )	9345	9405	300,000			M	Y					
1	AN/SPQ-6(XN-1)	9345	9405	200,000		10,000 YRDS	M	Y	1200	1		33	
1, 4	AN/SPS-46, 46X	9345	9405	7,000		32 Mi	M	Y	1500, 750	0.2, 0.4	18 RPM	20	2.2H, 15.0V
1	AN/SPS-53	9345	9405	35,000		32 Mi	M	Y	1500, 750	0.1, 0.5	15 RPM		1.6H, 20.0V
3, 4	AN/SPS-63	9345	9405	20,000		40 NMi	M	Y			25 RPM	28	1.2 X 20
4	AN/SPS-64	9345	9405	20,000, 50,000			M	Y	3600, 1800, 900	0.06, 0.5, 1.0	33 RPM	28	
4	AN/SPS-66A	9345	9405	7,000		32 NMi	M	Y			30 RPM	28	2.0 X 23.0
1	AN/TPS-21	9345	9405	7,000	4	20,000 YRDS	G	Y	1600	0.4	0.66 RPM	25	3 x 10
1	AN/TPS-25, 25A	9345	9405	43,000		18,280 METERS	G	Y	1850	0.5			
1	AN/TPS-33	9345	9405	7,000			G	Y	1600	0.4			
1	CCXT-TM707	9345	9405	20,000			M	Y	1000, 1000	0.1, 0.5	20 RPM		1.2H, 23.0V
1	CRP-1900N	9345	9405	5000			M	Y	2000	0.16	20 RPM		3.0H, 27.0V
1	CRP-1900ND	9345	9405	5000			M	Y	2000	0.16	20 RPM		3.0H, 27.0V
1	CRP-MP-2502	9345	9405	20,000			M	Y	6000, 2000, 1000	0.05, 0.5, 1.0	80 RPM		1.6H, 23.0V
1, 4	AN/SPS-36	9350	9400	10,000		16 Mi	M	Y	1000, 1000	0.15, 0.5	17 RPM	29	28
1	AN/TPS-31	9360	9460	40,000			G	Y			0-20 RPM		
3	RDR-1500	9370	9380	10,000			A	Y					
3	AN/APS-133	9371	9381	65,000		300 NMi	A	Y					

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 25. Radars in the 8500 – 10550 MHz Region (Con't)

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APQ-133	9373	9377	300			A	Y	850 PPS				
1	AN/APN-158	9375	9375	15000			A	Y	380-420 PPS				
3	AN/APS-128D	9375	9375	100,000		120 NMi	A	Y	400, 1200, 1600	(0.5, 2.4) FOR EACH PRR	15, 60 RPM		
1	AN/APS-19	9375	9375	40,000	40		A	Y	480, 660, 2000, 4000	2.1, 1.5, 0.5, 0.25			
1	AN/APS-19B	9375	9375	25,000			A	Y					
1	AN/APS-19C	9375	9375	25,000			A	Y					
1	AN/APS-69	9375	9375				A	Y					
1, 4	AN/SPS-35	9375	9375	7,000		32 Mi	M	Y	1500, 750	0.2, 0.2	20 RPM	28	2.0H, 15.0V
1, 4	AN/SPS-41	9375	9375	10,000		32 NMi	M	Y	1600, 625	0.1, 0.4	21 RPM	27	1.8H, 20.0V
4	AN/SPS-59	9375	9375	75,000			M	Y	500, 2000	1.0, 0.1	22 RPM	30	2.5 X 22.0
1	CCXT-RM314	9380	9440	10,000			M	Y	2000, 1000, 1000	0.05, 0.15, 0.5		27	1.9H, 27.0V
1	CCXT-TM616	9380	9440	10,000			M	Y	2000, 1000, 1000	0.05, 0.15, 0.5		30	1.2H, 18.0V
1	CCXT-TM626	9380	9440	25,000			M	Y	2000, 1000, 10000, 500	0.05, 0.15, 0.5, 1.2	20 RPM	30	1.2H, 18.0V
1	AN/APS-88	9400	9600	65,000			A	Y	2000, 1025, 200	0.35, 0.8, 4.5			
1	CCXT-D202	9415	9475	3000	1.5		M	Y	1000, 1000	0.1, 0.5		26	
1	AN/APQ-111	9500	9600	8,000-10,500	2		A	Y					
3	AN/APS-134(V)	9500	10000	500,000	500		A	Y					2.4H, 4.0V
1	AN/APQ-51	9690	9780	250,000	88 & 120	12,000 YDS	A	Y	1200 & 200	0.42 & 0.66			4 DEGREES
1	AN/APN-105	9790	9810	3		70,000 FT	A	Y					
1	AN/APN-131	9790	9810		3	70,000 FT	A	Y					
1	AN/APN-196	9798	9800	0.333			A	Y	VARIABLE	50% DUTY			
1	AN/APN-501A	9830	9830				A	Y					
1	AN/MSG-1	10000	10000	250		80,000 YRDS	G	Y	1100	0.9, 0.2			5.0H, 5.0V
1	AN/PPS-1	10000	10000			2 Mi	G	Y					
1	ST	10000	10000	30,000	30	30 Mi	M	Y	1500	0.3		15	25.0H, 12.0V
1	AN/SPN-12	10000	10250		20-Oct	2 Mi	M	Y				31	3.3
1	AN/SPN-12(XN-1)	10000	10250		20-Oct	2 Mi	M	Y				31.5	4.25
1	AN/SPN-12(XN-4)	10000	10250		20-Oct	2 Mi	M	Y				31.5	4.25
1	AN/SPN-44	10000	10250		10	4000 YRDS	M	Y					3.3
3	RTVS	10000	10260				G	Y					
3	DR-810 Mk V	10495	10555		3		G	Y					

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

3.14. Band: 13.40 - 14.00 GHz

Almost no radar signals are ever received in this part of the X band. Radars in this band typically employ high gain antennas with a correspondingly low probability of intercept. The probability of seeing any radar in this band within the continental U.S. is extremely low.

3.15. Region: 15.70 - 17.70 GHz

As with the 13.40 - 14.00 GHz band, almost no radar signals are ever received in this region of the spectrum. Radars in this band typically employ high gain antennas with a correspondingly low probability of intercept. {Sanders, 1995) [5]

The Department of Defense has 255 assignments in this band, most all of which are radar type emitters. Table 26 shows the various services located in five bands across this region of the spectrum. Table 27 contains a detailed description of some of the known radars. Typically, radars in this band have a peak power of 30 kW - 250 kW, a pulse repetition rate of 1000 - 8000 pps, and a pulse width of 0.25 - 1.0 Us.

Table 26. Spectrum Allocation in the 15.70 to 17.75 GHz Region

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
15.70-16.60	Radiolocation	Airport surface detection equipment (ASDE) is permitted on a co-equal basis subject to coordination with the military department.	RADIOLOCATION	
16.60-17.10	Radiolocation	Airport surface detection equipment (ASDE) is permitted on a co-equal basis subject to coordination with the military department.	RADIOLOCATION Space Research (deep space) (Earth to space)	
17.10-17.20	Radiolocation	Airport surface detection equipment (ASDE) is permitted on a co-equal basis subject to coordination with the military department.	RADIOLOCATION	
17.20-17.30	Radiolocation Earth-exploration (active) Space-research (active)	Airport surface detection equipment (ASDE) is permitted on a co-equal basis subject to coordination with the military department.	RADIOLOCATION Earth-exploration (active) Space-research (active)	
17.30-17.70	FIXED-SATELLITE (earth to space)	Use for fixed-satellite services is limited to feeder links for the broadcast-satellite services	Radiolocation	Government radiolocation is restricted to operating power of less than 51 dBW E.I.R.P. after feeder link stations are authorized and brought into use

Reference: (NTIA, 1993) [9]

Table 27. Radars in the 15700 – 17700 MHz Region

REF [1]	RADAR NAME	LOWER FREQ (MHz)	UPPER FREQ (MHZ)	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
1	AN/APQ-113	16000	16400	65,000			A	Y					
1	AN/APQ-114	16000	16500				A	Y					
1	AN/APQ-144	16000	16550				A	Y					
2	AN/MPQ-4	16100	16100	80,000	150	10,000 METERS	G	Y	8600	0.25	167 RPM		0.8V, 1.0H
1	AN/APN-136	16278	16282	700			A	Y					
1, 4	AN/SPG-52	16400	16600	50,000		10,000 YRDS	M	Y	1500	0.5		30	5
1	AN/APQ-110	16600	17100	30,000	24.3		A	Y	4045 PPS				
1	AN/APQ-128	16700	17000	30000			A	Y	4045				
1	AN/APQ-134	16700	17000	30,000			A	Y	4045 PPS				
1	AN/APQ-146	16700	17000	30,000			A	Y	4045 PPS				

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 28. X Band Radar (9000 – 12400 MHZ)

REF [1]	RADAR NAME	BAND	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE[2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
3	AN/APG-63	X				A	Y					
3	AN/APG-66	X			40 NMi	A	Y					
3	AN/APG-67	X				A	Y					
3	AN/APG-68	X			160 NMi	A	Y					
3	AN/APG-68(V)	X	1380			A	Y					
1	AN/APQ-102A	X				A	Y					
4	AN/APQ-104	X	160,000			A	Y	1200	0.7		31	4.5
3	AN/APQ-153	X				A	Y					
3	AN/APQ-159	X				A	Y					
3	AN/APQ-164	X			10 NMi	A	Y					
3	AN/APS-115	X				A	Y					
4	AN/BPS-16	X	35,000			M	Y	1500, 750	0.1, 0.5	<=9.5 RPM	29	3 x 13
4	AN/BPS-5	X	110,000		160,000 YRDS	M	Y	600	0.5	0-8 RPM	29	2.6 X 16.0
1	AN/MPN-1A	X	15,000		10 Mi	G	Y	2000	0.5			
1	AN/MPN-1B	X	15,000		10 Mi	G	Y	2000	0.5			
1	AN/MPN-3	X			30 Mi	G	Y	2000	0.5-10.0			
4	AN/SPG-53	X	250,000			M	Y	1000	0.25		39	1.6
3, 4	AN/SPG-60	X	5,500		60 NMi	M	Y	25000-35000 (i,ii,iii)	(i)0.27,(ii)1.0,(iii) 6.0		41.5	1.2 X 1.2
4	AN/SPG-62	X	10,000			M	Y					
3	AN/SPQ-11 COBRA JUDY	X				M	Y					
3, 4	AN/SPQ-9	X	1,200		20 NMi	M	Y	3000	0.3-16.0		37	1.35 X 3.0
4	AN/SPS-57	X	3,000			M	Y	2000, 1000	0.1, 0.2	25 RPM		
3	AN/TPN-22	X				G	Y					
3	AN/TPQ-39(V)+	X				G	Y					
3	AN/UPD-4	X				A	Y					
3	F-5E AIRCRAFT RADAR	X		160	80 NMi	A	Y					
4	HR-76	X	250,000			M	Y	1000-3000	0.25, 0.5, 1.0		32	
2	M33, NIKE-AJAX TTR	X	250,000	62,500	100 NMi	G	Y	1000	0.25			
1	MARK 13 MOD 0	X	50,000		80,000 YRDS	M	Y	1800	0.3			
1	MARK 34 MOD 17	X	50,000		36,000 YRDS	M	Y	1800	0.3			
4	MK-13	X	50,000		50,000 YRDS	M	Y	1800	0.3			0.9 X 3.5
4	MK-25	X	250,000		100,000 YRDS	M	Y	1320	0.25		39	1.6
3	MRSR	X				G	Y					

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

Table 28. X Band Radar (9000 – 12400 MHZ) (Con't)

REF [1]	RADAR NAME	BAND	PEAK POWER (WATTS)	AVG POWER (WATTS)	RANGE	BASE [2]	PULSED?	PULSE REP RATE (PPS)	PULSE WIDTH (mS)	SCAN RATE (RPM)	ANT. GAIN (Db)	BEAM WIDTH (DEGREES)
2	NIKE AJAX MTR	X	140,000	62,500	50 NMi	G	Y	1000	0.25			
2	NIKE AJAX MTR+	X		250,000	140,000	G	Y	4000	0.25			
2	NIKE HERCULES MTR	X	250,000	32,300		G	Y	500	0.25			
2	NIKE HERCULES MTR+	X	200,000	100,000		G	Y	2000	0.25			
2	NIKE HERCULES MTR++	X	140,000	140,000		G	Y	4000	0.25			
2	NIKE HERCULES TTR	X	250,000	32,300		G	Y	500	0.25			
4	PATHFINDER 1500	X	7000			M	Y	750, 1500	0.14, 0.14			2.0 X 20
4	PATHFINDER 1900	X	5000			M	Y	2000	0.16	20 RPM		3.0 X 27
3, 4	R-76	X	250,000			M	Y	1000-3000	0.25, 0.5, 1.0	15 RPM	32	2.7
3, 4	W-120	X	165,000		56 KM	M	Y	1000, 500	0.4, 2.0		34.5	2.8
3	W-160	X	16,000		45 KM	M	Y	1000-14200	1,2,3,4,8	15, 20, 25 RPM	37	

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

3.16. References

[1] United States Radar Equipment: Military Standardization Handbook, Department of Defense Publication, December 1973, Publication No. MIL-HDBK- 162B, Vol I.

[2] Brookner, E. (1977), Radar Technology, (Artech House Inc., Dedham, Massachusetts).

[3] Blake, B. (1988), Janes's Weapon Systems, (Janes's Information Group, Alexandria, Virginia).

[4] Friedman, N. (1989), The Naval Institute Guide to World Naval Weapons Systems, (Naval Institute Press, Annapolis, Maryland).

[5] Sanders, F. (1993), Draft copy of the Equipment Characteristics Handbook, NTIA Report.

[6] Wepman, J.A. (1991), Spectrum Usage Measurements in Potential PCS Frequency Bands, NTIA Report 9 l-279, September,

[7] Hughes, -D., (1989), Relocatable Over-the-Horizon Radar, ***Aviation Week and Space Technology,*** November 27,1989, pp. 69 80.

[8] Defense Electronics (3rd Ed.), PAVE PAWS Sea-Launched Ballistic Missile Detection System, ***C31 Handbook,*** E.W. Communications, Inc., Palo Alto CA. pp. 69-70.

[9] NTIA, (1993), Spectrum Use Summary 137 MHz - 5 GHz, NTIA Report, June 4,1993.

[10] Non-classified radar specifications data sheet.

[1 l] Defense Electronics (3rd Ed.), Over-the-Horizon Radars, ***C I Handbook,*** E.W. Communications, Inc., Palo Alto CA. pp. 66-68.

4. BROADCAST

A radio broadcasting system is one in which a central transmitter radiates a signal for reception at a large number of remote points. The information transmitted is generally speech, music, or television for entertainment purposes. The transmitter needs to radiate considerable power, and uses an antenna, which radiates in all preferred directions. Assuming that the majority of broadcast stations transmit at the maximum allowable power, a summary of the regulations set forth by the Federal Communications Commission (FCC) is provided to reflect the influence broadcast stations have in the respective frequency bands.

4.1. AM (Amplitude Modulation) Broadcast Band

The design of AM broadcast transmitting systems must be in accordance with the principles and specifications established by the FCC. The format utilized in summarizing the FCC guidelines and requirements for AM Broadcast is as follows: 4.1.1. AM Allocation Standards; 4.2.1. Technical Standards for AM Broadcasting; and 4.1.3. Typical AM Broadcast Equipment.

4.1.1. AM Allocation Standards

The band from 535 to 1,605 kHz is used for standard amplitude modulation sound broadcasting. The band is divided into 107x 1 0-kHz channels; carrier frequencies are assigned at 1 0&Hz intervals from 540 to 1,600 kHz. AM radio allocation standards are enforced according to the station's placement in the channel structure. In the U.S. the FCC establishes three classes of channels: clear channels, for high-powered stations; regional, for medium-powered station; and local channels, for low-powered stations. Stations provide signal coverage for three service areas: primary, secondary, and intermittent. The signals necessary to render **primary service** to different types of service areas are displayed in Table 29.

Table 29. Field Intensity Requirements for Primary AM Service

Area	Field-intensity ground wave [mV/m]
City, business, or factory areas	10-50
Residential areas	2-10
Rural areas, all areas during winter, and northern areas during summer	0.1-0.5
Southern areas during summer	0.25-1.0

These values are based on the usual noise levels in the respective areas, assuming no objectionable interference from other broadcast stations. The values apply to both day and night, but fading or interference from other stations usually limits the primary service at night in rural areas to higher values of field intensity than the values given. **Secondary service** is delivered in the areas where the sky wave for 50% or more of the time has a field intensity of 500 uV/m or greater. It is not considered that satisfactory secondary service can be provided to cities unless the sky wave approaches the ground wave value required for primary service. **Intermittent service** is rendered by the ground wave. It begins at the outer boundary of the primary service area and extends to the value of signal that has no service value. This limit may extend down to a few microvolts in certain areas and up to several millivolts in areas of high noise level,

interference from other stations, or objectionable fading at night. Table 28 lists the standard broadcast channels allocated in the United States by the FCC with their service classes. A supplementary outline of the class regulations on permissible power and objectionable interference infringements are given in table 29.

Table 30. Standard AM Broadcast Carrier Frequencies and Service Classes

Channel, kHz	Classification	FCC Class	Channel, kHz	Classification	FCC Class
540	Clear	II	1050	Clear	II
550-630	Regional	IIIA,IIIB	1060-I 140	Clear	I, II
640-680	Clear	I, II	1150	Regional	IIIA, IIIB
690	Clear	II	1160-1210	Clear	I, II
700-720	Clear	I, II	1220	Clear	II
730-740	Clear	II	1230-1240	Local	IV
750-780	Clear	I, II	1250-1330	Regional	IIIA, IIIB
790	Regional	IIIA,IIIB	1340	Local	IV
800	Clear	II	1350-1390	Regional	IIIA, IIIB
810-850	Clear	I, II	1400	Local	IV
860	Clear	II	1410-1440	Regional	IIIA, IIIB
870-890	Clear	I, II	1450	Local	IV
900	Clear	II	1460-1480	Regional	IIIA, IIIB
910-930	Regional	IIIA,IIIB	1490	Local	IV
940	Clear	I, II	1500-1530	Clear	I, II
950-980	Regional	IIIA,IIIB	1540	Clear	II
990	Clear	II	1550-1560	Clear	I, II
1000	Clear	I, II	1570-1580	Clear	II
1010	Clear	II	1590-1600	Regional	IIIA, IIIB
1020-1040	Clear	I, II			

Further information for AM radio-frequency protection radios are given in CCIR Recommendation 560-3 [4].

Table 31. Summary of FCC Regulations for Standard Broadcast Stations

Class of station	Channel used	Permissible Power [kW]		Signal strength contour of areas protected from objectionable interference [uV/m]	
		day	Night	Day	Night
IA	Clear	50	50	SC 100 AC 500	SC 500 (50% skywave) AC 500 GW
IB	Clear	10-50	10-50	SC 100 AC 500	SC 500 (50% skywave) AC 500 GW
IIA	Clear	0.25-50	10-50	500	500
IIB, IID**	Regional	0.25-50	0.25-50	500	2,500
IIIA	Regional	1-5	1-5	500	2,500
IIIB	Regional	0.5-5	0.5-1	500	4,000
IV	Local	0.25- 1	0.25	500	Not prescribed

C = same channel AC = adjacent channel GW = ground-wave
+50 % Skywave = skywave intensity must not exceed maximum for 50% of the time or more
**IID = daytime only

Class I Stations (10 < Power < 50 kW). Class I stations are designed to render service to primary and secondary service over an extended area and at relatively long distances. Only class I stations are assigned on the basis of rendering secondary service and only class I stations are assigned protection from interference from other stations in the intermittent service area. From an engineering point of view, class I stations can be divided into two groups: IA and IB. The power of class IA stations are required to be 50 kW and duplicate nighttime operation on coinciding channels are not permitted. Stations in class IB are those assigned to channels on which duplicate operation is permitted (i.e., other class I or class II stations operating on unlimited time may be assigned to such channels).

Class II Stations (0.25 < Power < 50 kW). Class II stations are secondary stations which operate on clear channels. The primary service area may be relatively large but is limited by, and subject to, interference from class I stations. Directional antennas are employed as a means to avoid causing interference within the protected service areas of class I or other class II stations. It is recommended that class II stations be so located that the interference received from other stations will not limit the service area to greater than the 2.5 mV/m ground wave contour at night and the 0.5 mV/m ground wave contour during the day.

Class III stations (0.5 < Power < 5 kW). Class III stations normally render primary service to the larger cities and to contiguous rural areas.

Class IV Stations (0.25 < Power < 1 kW). Class IV stations operate on local channels, normally rendering primary service only to a city or town and the contiguous suburban or rural area

4.1.2. Technical Standards for AM Broadcasting

4.1.2.1. AM Broadcast Definitions

Amplitude Modulation (AM). A system of modulation in which the envelope of the transmitted wave contains a component similar to the wave form of the signal to be transmitted.

AM broadcast band. The band of frequencies extending from 535 to 1605 kHz.

AM broadcast channel. The band of frequencies occupied by the characteristic carrier and the upper and lower sidebands of an AM broadcast signal with the carrier frequency at the center.

AM broadcast station. A broadcast station licensed for the dissemination of radio communications intended to be received by the public and operated on a channel in the AM broadcast band.

Ground-wave field intensity. That part of the vertical component of the electric field received on the ground which has not been reflected from the ionosphere or the troposphere.

Intermittent service area. The area beyond the primary service area receiving service from the groundwave of a broadcast station. This service area is subject to some interference and fading.

Main channel. The band of audio frequencies from 50 to 10,000 Hz which modulates the AM carrier.

Primary service area. The service area of a broadcast station in which the groundwave is not subject to objectionable interference

Secondary service area. The service area of a broadcast station served by the'skywave and not subject to objectionable interference but is subject to intermittent variations in strength. Suitable secondary service must provide a skywave signal approaching in value the groundwave required for primary service.

4.1.2.2. AM Transmission Standards

Frequency Departure Requirements. Any emission appearing on a frequency removed from the carrier must be attenuated according to Table 32.

Table 32. Out-of-Band Emission

leviation from v_0, Av [kHz]	attenuation requirement [dB]
$15 \le \Delta v \le 30$	25
$30 \le \Delta v \le 75$	35
$75 \le \Delta v$	the lesser of {80} or {43+Power[dBW]}

Polarization. The direction of the electric field as radiated from the transmitting antenna is the polarization of the transmitted signal. AM stations employ an antenna composed of a tower insulated from the ground which cannot support a horizontally polarized groundwave.

Signal Quality. Challenges for AM radio sound quality include the following factors.

1. AM broadcast signals are vulnerable to atmospheric interference and noise.
2. Electronic products (e.g. hair dryers, PC's) emit AM radio waves.
3. Narrow bandwidth (10 kHz) does not allow for high-fidelity.

4. Excess interference created by widespread practice of boosting the higher frequencies of the broadcast signal by AM operators.

U.S./Mexico Border AM Radio Stations. 100-kW AM radio signal transmission from Mexico exists near the common border.

4.1.3. AM Broadcast Equipment

Typical 50 kW AM Transmitter. The MW-50A transmitter (Harris Corporation) is a high-level plate-modulated air-cooled transmitter and uses a pulse-duration modulation scheme. The manufacturer's specifications are shown on Table 33.

Table 33. Specifications of the MW-50A Transmitter

Power Output	50 kW (rated), 60 kW (capable); convenient power reduction to 25 or 10 kW
RF frequency range	535-1620 kHz, supplied to frequency as ordered
RF output impedance	50 Ct unbalanced (higher on special order)
RF frequency stability	*5 Hz
RF harmonics	Exceeds FCC and CCIR specifications
Carrier-amplitude regulation	Less than 2% at 100% modulation
Audio-frequency response	11.5 dB, from 20 to 1,000 Hz, referenced to 1,000 Hz, at 95% modulation
Audio-frequency distortion (unenhanced)	<3w, 20-10,000 Hz at 95% modulation
Compression ratio	4:l dB at 3 dB of enhancement; -95%, +125% modulation
Noise (unweighted)	-57 dB or better below 100% modulation
Audio input	600 Q at +10 dBm + 2 dB, for 100% modulation, unenhanced; +16 dBm with enhancement activated
Power input	480 V +5%, 3-phase, 60 Hz; available for 380 V *5%, 3-phase, 50 Hz
Power consumption	80 kW at On modulation, 87 kW at 30% modulation, 110 kW at 100% modulation
Overall efficiency	Better than 60% at average modulation

4.2. FM (Frequency Modulation) Broadcast Band

Frequency modulation is a system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous amplitude of the modulating signal. The design of FM broadcast transmitting systems must be in accordance with the principles and specifications established by the FCC. The format utilized in summarizing the FCC guidelines and requirements for FM Broadcast is as follows: 4.2.1. FM Allocation Standards; 4.2.2. Technical Standards for FM Broadcasting; and 4.2.3. Typical FM Broadcast Equipment.

4.2.1. FM Allocation Standards

FM channel structure. The FM broadcast band extends from 88 to 108 MHz, divided into 100x200 kHz channels. The channels available (including those assigned to noncommercial educational broadcasting) are given numerical designations by the FCC, from channel 201 (88.1 MHz) to channel 300 (107.9 MHz). The rules and facility requirements applicable to a particular FM station are determined by its class. For the purpose of allotments the U.S. is divided into three zones (I, I-A, II) shown in Figure 22.

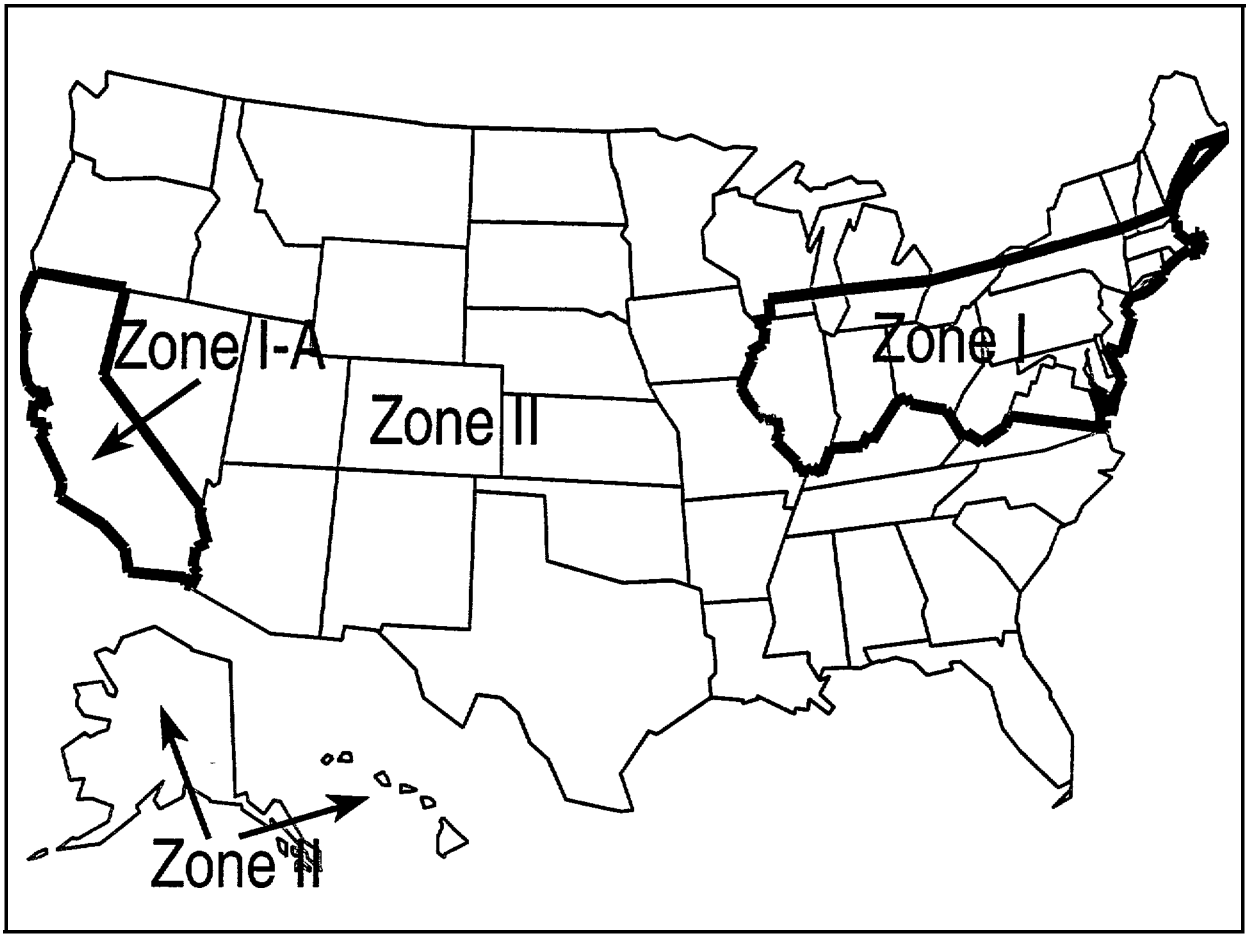


Figure 22. FM broadcast zones.

Possible class designations depend upon the zone in which the station's transmitter is located. Class A, Bl , and B stations may be authorized in zones I and I-A, Class A, C3, C2, Cl, and C stations may be authorized in Zone II.

Table 34. FM Class Structure

Zone I, I-A		Zone II	
Class	rfd range* [km]	Class	rfd range* [km]
A	rfd < 28	A	rfd ≤ 28
B1	28 < rfd < 39	c3	28 < rfd < 39
B	39 < rfd < 52	c2	39 < rfd < 52
		Cl	52 < rfd < 72
		C	72 < rfd < 92

*rfd = reference distance range

The classes are further segregated according to the reference distance (rfd) which equates to the predicted distance to the 1 mV/m contour from the transmitter (see Table 34). The class A FM station is designed to render service to a relatively small community, city, or town. Table 35 lists the numerical designations and frequency limits of class A stations.

Table 35. FM Class A Allocations

Frequency [MHz]	Channel no.	Frequency [MHz]	Channel no	Frequency [MHz]	Channel no
92.1	221	97.7	249	103.1	276
92.7	224	98.3	252	103.9	280
93.5	228	99.3	257	104.9	285
94.3	232	100.1	261	105.5	288
95.3	237	100.9	265	106.3	292
95.9	240	101.7	269	107.1	296
96.7	244	102.3	272		

All channels from 222 through 300 (92.3 through 107.9 MHz) not designated as class A channels are classified as B or C channels. Class B and C stations are designed to provide service to a sizeable community, city, or town and to the surrounding area. The power and antenna height requirements are displayed in Table 36.

Table 36. FM Station Power and Antenna Height Standards

Station Class	Min. ERP [kW]	Min. HAAT [m]	Max. ERP [kW]	Max. HAAT [m]	Contour distance [km]
A	0.1	NP	6	100	28
Bl	6	NP	25	100	39
B	25	NP	50	150	52
c3	6	NP	25	100	39
c2	25	NP	50	150	52
Cl	50	NP	100	299	72
C	100	300	100	600	92

*NP = Not Prescribed
*ERP - The product of the input antennal power and the antenna power gain.

Antenna height above average terrain (HAAT) is calculated by determining the average terrain altitude from 3 to 16 km from the antenna for eight evenly spaced azimuthal directions. The HAAT is the antenna height above this average terrain height. Where circular or elliptieal polarization is used, the HAAT must be based upon the height of the radiation of the antenna that transmits the horizontal component of radiation. If a station has an antenna HAAT greater than the reference HAAT for its class, its ERP must be lower than the class maximum such that the reference distance does not exceed the class contour distance. Additionally, directional antennas are designed for the purpose of obtaining non-circular radiation patterns. Applications for the use of directional antennas that propose a ratio of maximum to minimum radiation in the horizontal plane of more than 15 dB will not be accepted.

<u>Co-channel and adjacent-channel separations</u>. Minimum distance separation requirements are imposed on domestic allotments on the same channel (co-channel) and on adjacent channels relative to the transmitting antenna. Table 37 specifies the station separation restrictions for the co-channel and five pairs of adjacent channels. Additionally, U.S. minimum distance requirements from Canadian and Mexican allotments exist if the transmitter is within 320 km from the common border, and FM radio stations operating in channel 253 (98.5 MHz) must adhere to the restrictions dictating the minimum distance separation from TV channel 6 (82-88 MHz).

Table 37. Co- and Adjacent-channel Separations [km]

Relation	Co-channel	200 kHz	400/600 kHz	10.6/10.8 MHz	Relation	Co-channel	200 kHz	400/600 kHz	10.6/10. MHZ
A-A	115	72	31	10	B-C3	211	145	71	17
A-B	143	96	48	12	B-C2	241	169	74	20
A-B	178	113	69	15	B-Cl	270	195	79	27
A-C3	142	89	42	12	B-C	274	217	105	35
A-C2	166	106	55	15	C3-C3	153	99	43	14
A-Cl	200	133	75	22	C3-C2	177	117	56	17
A-C	226	165	95	29	C3-Cl	211	144	76	24
Bl-Bl	175	114	50	14	C3-C	237	176	96	31
Bl-B	211	145	71	17	C2-C2	190	130	58	20
Bl-C3	175	114	50	14	C2-Cl	224	158	79	27
Bl-C2	200	134	56	17	C2-C	249	188	105	35
B1-Cl	233	161	77	24	Cl-Cl	245	177	82	34
Bl-C	259	193	105	31	Cl-C	270	209	105	41
B-B	241	169	74	20	C - C	290	241	105	48

For further planning standards on FM sound broadcasting, see CCIR recommendation 4 12-5 [2].

Additional Allocations. Supplementary allocations set up by the FCC in the FM band include:

1. Non-commercial educational FM broadcast station (NCE FM) operating on channels 201-220 (87.9 - 91.9 MHz) must comply to requirements similar to those stated above.

2. Channel 206 (89.1 MHz) is revised in the NYC metropolitan area for the use by the United Nations with the equivalent of an antenna height of 150 m HAAT and a power level of 20 kW ERR.

3. In Alaska, stations operating on channels 221-300 (92.1- 107.9 MHz) shall not cause harmful interference and shall accept interference from non-government fixed operations.

4.2.2. Technical Standards for FM Broadcasting

Under FCC regulations, the design of FM broadcast transmitting systems must be in accordance with the principles and standards summarized in this section.

4.2.2.1. FM Technical Definitions

Center frequency. The frequency of the emitted wave without modulation.

FM broadcast band. The band extending from 88 to 108 MHz.

FM broadcast channel. A band 200 kHz wide and designated by its center frequency.

FM broadcast station. A station employing frequency modulation in the FM broadcast band and licensed primarily for the transmission of radio-telephone emissions intended to be received by the general public.

FM stereophonic broadcast. The transmission of a stereophonic program by a single FM broadcast station utilizing the main channel and a stereophonic subchannel.

Frequency departure. The amount of variation of a carrier frequency from its assigned value.

Frequency deviation. The peak difference between modulated wave and the carrier frequency.

Frequency swing. The peak difference between the maximum and the minimum values of the instantaneous frequency of the carrier wave resulting from modulation.

Multiplex transmission. The simultaneous transmission of two or more signals within a single channel. Applied to FM broadcast stations means transmission of facsimile or other signals in addition to the regular broadcast signals.

Percentage modulation. The ratio of the actual frequency deviation to the frequency deviation of 100% modulation (+75 kHz), expressed in percentage.

Left (or right) signal. The electrical output of a microphone or combination of microphones placed so as to convey the intensity, time, and location of sounds originating predominately to the listener's left (or right) of the center of the performance area.

Left (or right) stereophonic channel. the left (or right) signal as electrically reproduced in reception of FM stereophonic broadcasts.

Main channel. The band from 50 to 15,000 Hz which frequency-modulate the main carrier.

Pilot subcarrier. Serves as a control signal for use in the reception of FM stereophonic sound broadcasts.

Stereophonic sound. The audio information carried by plurality of channels arranged to afford the listener a sense of the spatial distribution of sound sources (e.g. biphonic, triphonic, and quadraphonic program service).

Stereophonic sound subcarrier. A subcarrier within the FM broadcast baseband used for transmitting signals for stereophonic sound reception of the main broadcast program service.

Stereophonic subchannel. The band of frequencies from 23 to 53 kHz, containing the stereophonic subcarrier and its associated sidebands.

4.2.2.2. FM Broadcast Equipment Standards

Modulation percentage and bandwidth The transmitter shall operate satisfactorily in the operating power range with a frequency swing of 75 kHz defined as 100% modulation. The transmitting system shall be capable of transmitting a band of frequencies from 50 to 15,000 Hz.

Noise.The transmitting-system output noise level in the band of 50 to 15,000 Hz shall be at least 60 dB below 100% modulation as a reference.

Carrier-frequency control. Automatic means shall be provided in the transmitter to maintain the assigned center frequency within the allowable tolerance of 2,000 Hz.

Frequency Departure Requirements. Any emission appearing on a frequency removed from the carrier must be attenuated according to table 3 8.

Table 38. Out-of-Band Emissions Standards

dev. from v_0, Av [kHz]	attenuation requirement [dB]
120 < Av < 240	25
240 < Av < 600	35
600 <Av	the lesser of (80) or {43+Power[dBW] }

4.2.2.3. Subsidiary FM Communications Authorizations (SCA)

An FM broadcast station may be issued a Subsidiary Communications Authorization to provide limited types of subsidiary services (special interest programs to limited segments of the public wishing to subscribe thereto and signals directly related to the operation of FM broadcast stations) on a multiplex basis. Subsidiary communications multiplex operations are governed by the following engineering standards.

Subcarrier control. The instantaneous frequency of SCA subcarriers must at all times be within the range 20 to 75 kHz, provided, however, that when the station is engaged in stereophonic broadcasting the instantaneous frequency of SCA subcarriers must be within the range 53 to 75 kHz.

Modulation control. The arithmetic sum of the modulation of the main carrier by SCA subcarriers must not exceed 30%, provided, however, that when the station is engaged in stereophonic broadcasting the arithmetic sum of the modulation of the main carrier by the SCA subcarriers must not exceed 10%. Frequency modulation of the main carrier caused by the SCA subcarrier operation, in the frequency range 50 to 15,000 Hz, must be at least 60 dB below 100% modulation, provided, however, that when the station is engaged in stereophonic broadcasting frequency modulation of the main carrier by the SCA subcarrier operation, in the frequency range 50 to 53,000 Hz, must be at least 60 dB below 100% modulation.

4.2.2.4. Stereo Transmission Standards

The modulating signal for the main channel consists of the sum of the left and right signals (see Figure 23). A station engaged in stereophonic broadcasting must comply with the following stereo transmission standards.

Pilot subcarrier. At 19,000 + 2 Hz. the pilot subcarrier frequency modulates the main carrier between the limits 8 and 10%.

Modulation control. The sum of the sidebands resulting from amplitude modulation of the stereophonic subcarrier must not cause a peak deviation of the main carrier in excess of 45% of the total modulation.

Crosstalk into the main channel caused by a signal in the stereophonic subchannel must be attenuated at least 40 dB below 90% modulation, and crosstalk into the stereophonic subchannel caused by a signal in the main channel must be attenuated a like amount.

Further information on stereophonic transmissions standards can be found in the CCIR recommendation 450-l [5]

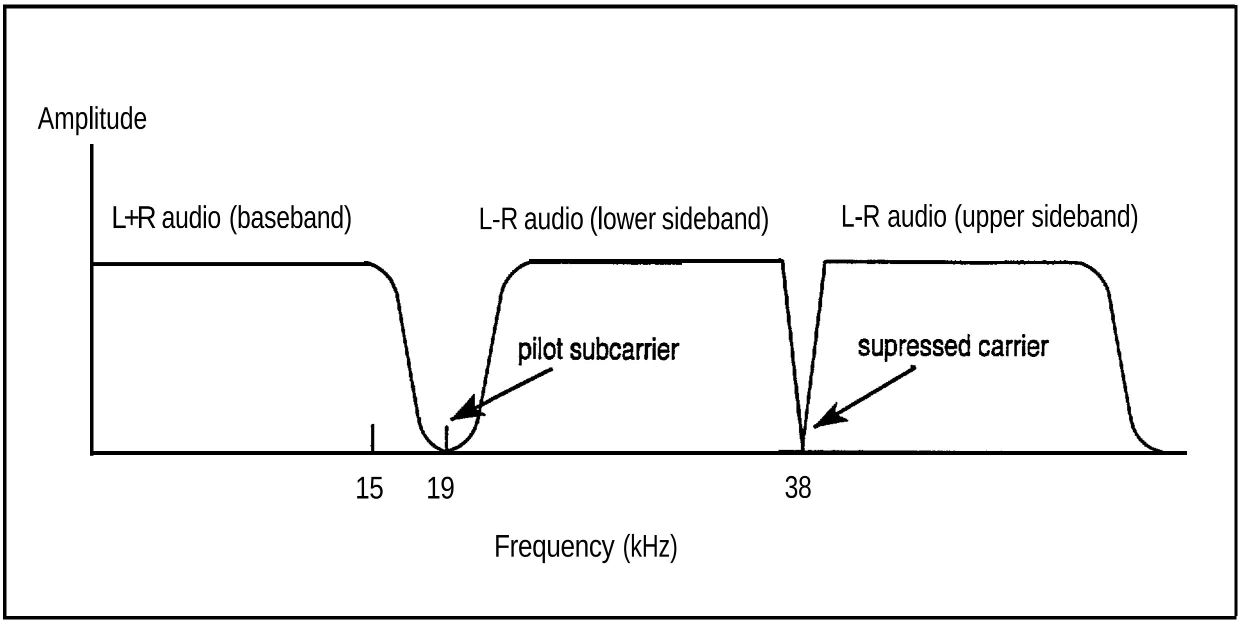


Figure 23. Modulating frequencies for FM stereo transmission.

4.2.3. FM Broadcast Equipment

Typical 40-kW FM Transmitters. Table 39 outlines the manufacturers specifications of a typical 40-kW transmitter (Type FM40K, Harris Corporation). It is made up of two 20-kW transmitters fed by a solid-state exciter, both feeding into a combining network to give the desired 40-kW output.

Table 39 Manufacturer Specifications of the FM40K Transmitter

Power output:	
FM-2.5K	2.5 kW
FM4OK	40 kW
Frequency range	87.5-108 MHz
RF output impedance	500
Frequency stability	0.001% or better
Type of modulation	Direct-carrier FM
Modulation capability	*100kHz
RF harmonics	Suppression meets all FCC requirements
Monaural mode:	
Audio-input impedance	600 0 balanced
Audio-input level	+10 dBm + 2 dB for 100% modulation at 400 Hz
Audio-frequency response	Std. 75, FCC preemphasis curve + 0.5 dB, 30-15,000 Hz
Harmonic distortion	0.2% or less, 30-15,000 Hz
Intermodulation distortion	0.2%, 60-7,000 Hz, 4: 1 ratio
FM noise	68 dB below 100% modulation referred to 400 Hz
AM noise	50 dB below reference carrier AM modulation 100%
Stereophonic mode:	
Pilot oscillator	Crystal-controlled
Pilot stability	19kHz~1Hz
Audio-input impedance	Left and right 600 O balanced
Audio-input level	Left and right +10 dBm + 1 dB for 100% modulation at 400 Hz
Audio-frequency response	Left and right standard 75 FCC pre-emphasis curve +0.5 dB, 50-15,000 Hz
Harmonic distortion	Left or right 0.4% or less, 50-15,000 Hz
FM noise	Left or right 65 dB min below 100% modulation, referred to 400 Hz
Stereo separation	40 dB min, 50-l 5,000 Hz
Subcarrier suppression	dB min, 50-15,000 Hz
Crosstalk (main p subchannel)	45 dB below 90% modulation
SCA mode:	
Modulation	Direct FM
Frequency	4 1 or 67 kHz programmable
Frequency stability	+500 Hz
Modulation capability	+7.5 kHz
Audio-input impedance	600 balanced (ac-coupled) and 2,000 Q unbalanced (dc-coupled)
Audio-input level	+10 dBm + 1dB for l00% modulation at 400 Hz
Audio-frequency response selectable	4 1 kHz and 67 kIIz, 150-us pre-emphasis * 1 dB standard; Flat, 50- or 75-us preemphasis
Distortion	Less than I%, 30-50,000 Hz, +5 kHz deviation
FM noise (main channel not modulated)	55 dB min (ref 100% = +5 kHz deviation at 400 kHz)
Crosstalk (SCA to main or stereo subchannel)	-60 dB or better
Main or stereo subchannel to SCA	50 dB below +5 kHz deviation of SCA, with mono or stereo channels modulated by frequencies 30-15,000 Hz, SCA demodulated with 150-us pre-emphasis
SCA to SAC (4 1 kHz/67 kHz)	50 dB demodulated with 150-us pre-emphasis
Automatic mute level	Variable, 0 to -30 dBm
Mute delay	Adjustable 0.5 to 20 s
Injection level	1 to 30% of composite, adjustable

4.3. Televisions Broadcast

The design of television broadcast transmitting systems must be in accordance with the principles and specifications established by the FCC. The format utilized in summarizing the FCC guidelines and requirements for television is as follows: 4.3.1. Television Broadcast Allocation Standards; 4.3.2. Technical Standards for Television Broadcasting; and 4.2.3. Typical TV Broadcast Equipment.

4.3.1. Television Broadcast Allocations Standards

The FCC has authorized 68x6-MHz channels for commercial and educational television broadcasting in the U.S. A list of the channel numbers and frequency limits of the TV channels are displayed in Table 40. Channels 2 to 6 are known as the low-band VHF channels, 7 to 13 as the high-band VHF channel, and 14-69 as the UHF channels.

Table 40. Television Broadcast Channels

Channel designation	Frequency band, MHz	Channel designation	Frequency band, MHz	Channel designation	Frequency band, MHz
2	54-60	24	530-536	47	668-674
3	60-66	25	536-542	48	674-680
4	66-72	26	542-548	49	680-686
5	76-82	27	548-554	50	686-692
6	82-88	28	554-560	51	692-698
		29	560-566	52	698-704
7	174-180	30	566-572	53	704-710
8	180-186	31	572-578	54	710-716
9	186-192	32	578-584	55	716-722
10	192-198	33	584-590	56	722-728
11	198-204	34	590-596	57	728-734
12	204-210	35	596-602	58	734-740
13	210-216	36	602-608	59	740-746
		37	608-614	60	746-752
14	470-476	38	614-620	61	752-758
15	476-482	39	620-626	62	758-764
16	482-488	40	626-632	63	764-770
17	488-494	41	632-638	64	770-776
18	494-500	42	638-644	65	776-782
19	500-506	43	644-650	66	782-788
20	506-512	44	650-656	67	788-794
21	512-518	45	656-662	68	794-800
22	518-524	46	662-668	69	800-806
23	524-530				

Additional allocations. Supplementary allocations set up by the FCC in the FM band include:

1. The frequency band 470-512 MHz is also allocated for use in the land mobile radio service. In the vicinity of 13 urbanized areas, specific channels are made available for domestic public, public safety, industrial, and land transportation radio services.

2. The frequency bands 54-72 MHz, 76-88 MHz, 174-216 MHz, 470-512 MHz, 512-608 MHz, and 608-806 MHz are also allocated to the Fixed Service to permit subscription television operations.

3. In the band 608-614 MHz (Channel 37) the radio astronomy service shall be protected from extraband radiation. No stations will be authorized to transmit in channel 37.

Co-channel and adjacent-channel separation. Television broadcast stations must meet minimum co-channel separation requirements set up by the FCC. Table 41 displays the minimum separation requirements [km] for each of the television broadcast zones (I,II,and III) and existing in the U.S. (see Figure 24).

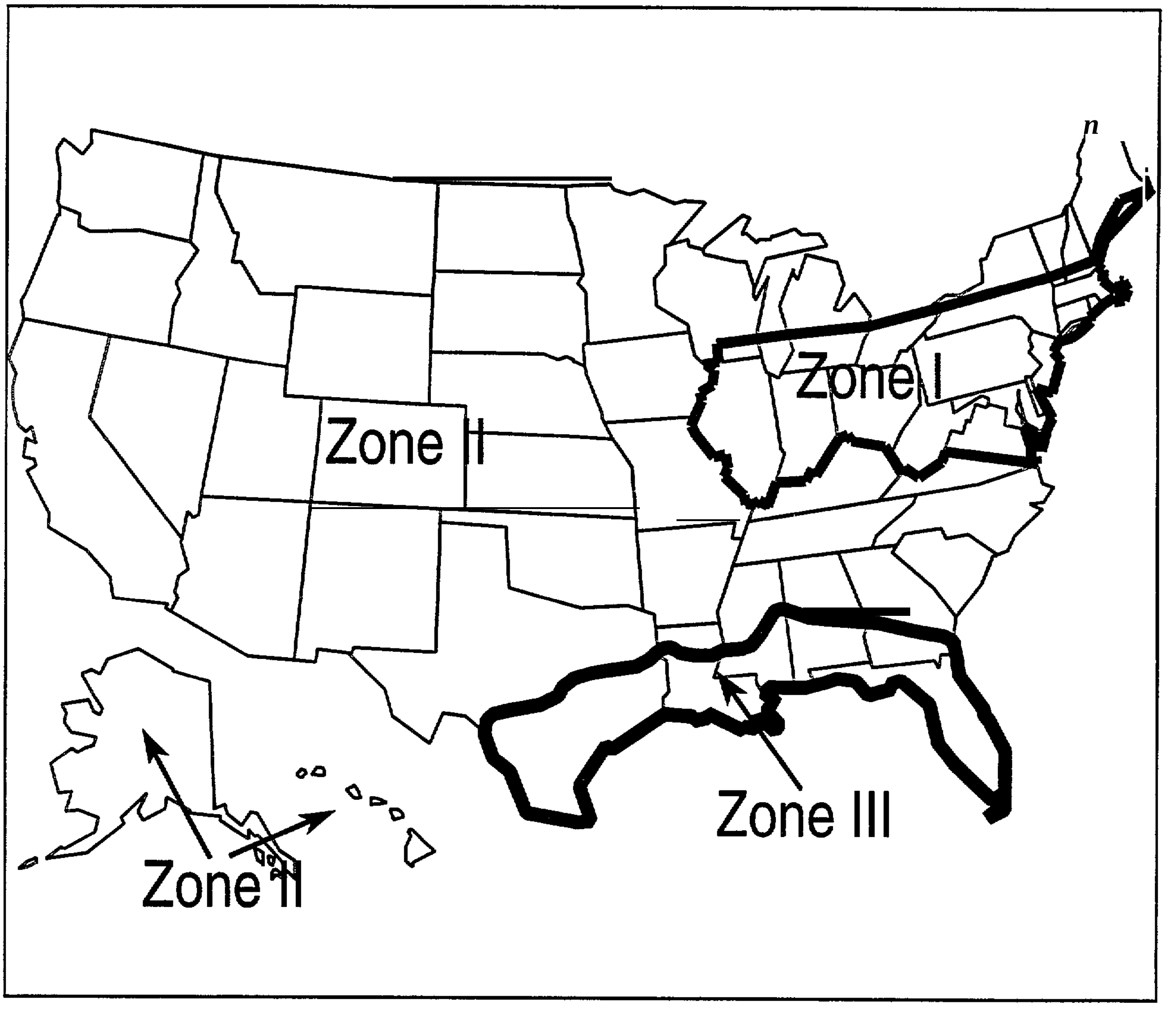


Figure 24. TV broadcast zones.

Table 41. Minimum Co-channel Separation Requirements for Television Stations

Zone	co-channel [km]		adjacent channel [km]	
	Channels 2-13	Channels 14-69	Channels 2- 13	Channels 14-69
I	272.7	248.6	95.7	87.7
II	304.9	280.8	95.7	87.7
III	353.2	329.0	95.7	87.7

Due to frequency spacings channels 4-5, 6-7, and 13-14 shah have no minimum distance requirements imposed upon them. Additionally, TV channel 6 (82-88 MHz) is restricted by a minimum distance requirement (17-41 km) from FM channel 23 (98.5 MHz).

Further information for television radio-frequency protection ratios are given in CCIR recommendation 655- 1 [3].

4.3.2. Technical Standards of TV Broadcast

Under FCC regulations, the design of television broadcast transmitting systems must be in accordance with the principles and standards summarized in this section.

4.3.2.1. TV Broadcast Definitions

Aural center frequency. The frequency of the emitted aural wave without modulation.

Chrominance. The colorimetric difference between any color and a reference color of equal luminance, the reference color having a specific chromaticity.

Chrominance subcarrier. The carrier which is modulated by the chrominance information.

Peak power. The power over a radio frequency cycle corresponding in amplitude to synchronizing peaks.

Percentage modulation. As applied to frequency modulation, the ratio of the actual frequency deviation to the frequency deviation defined as 100% modulation (+25 kHz for aural transmitters of TV broadcast).

Pilot subcarrier. A subcarrier used in the reception of TV stereophonic subchannel broadcasts.

Television broadcast band. The frequencies in the band extending from 54 to 806 MHz which are assignable to television broadcast stations. These frequencies are 54 to 72 MHz (channels 2-4), 76-88 MHz (channels 5,6), 174 to 216 MHz (channels 7-13), and 470 to 806 MHz (channels 14-69).

Television broadcast station. A station in the television broadcast band transmitting simultaneous visual and aural signals intended to be received by the general public.

Television channel. A band of frequencies 6 MHz wide in the television broadcast band and designated either by number or by the extreme lower and upper frequencies.

Visual carrier frequency. The frequency of the carrier which is modulated by the picture information.

Visual transmitter power The peak power output when transmitting a standard television signal.

Vestigial sideband transmission. A system of transmission wherein one of the generated sidebands is partially attenuated at the transmitter and radiated only in part.

4.3.2.2. Television Transmission Standards

Channel standards. Within the 6 MHz bandwidth of the television broadcast channel the visual-carrier frequency is 1.25 MHz above the lower boundary of the channel and the aural center frequency is 4.5 MHz higher than the visual-carrier frequency. Automatic means shall be provided in the visual transmitter to maintain the carrier frequency within + 1 kHz of the authorized frequency and to the aural transmitter to maintain the aural carrier frequency within + 1 kHz The ERP of the aural transmitter must not be less than 10% nor greater than 20% of the peak radiating power of the visual transmitter. The visual-transmission amplitude characteristic is in accordance with Figure 25.

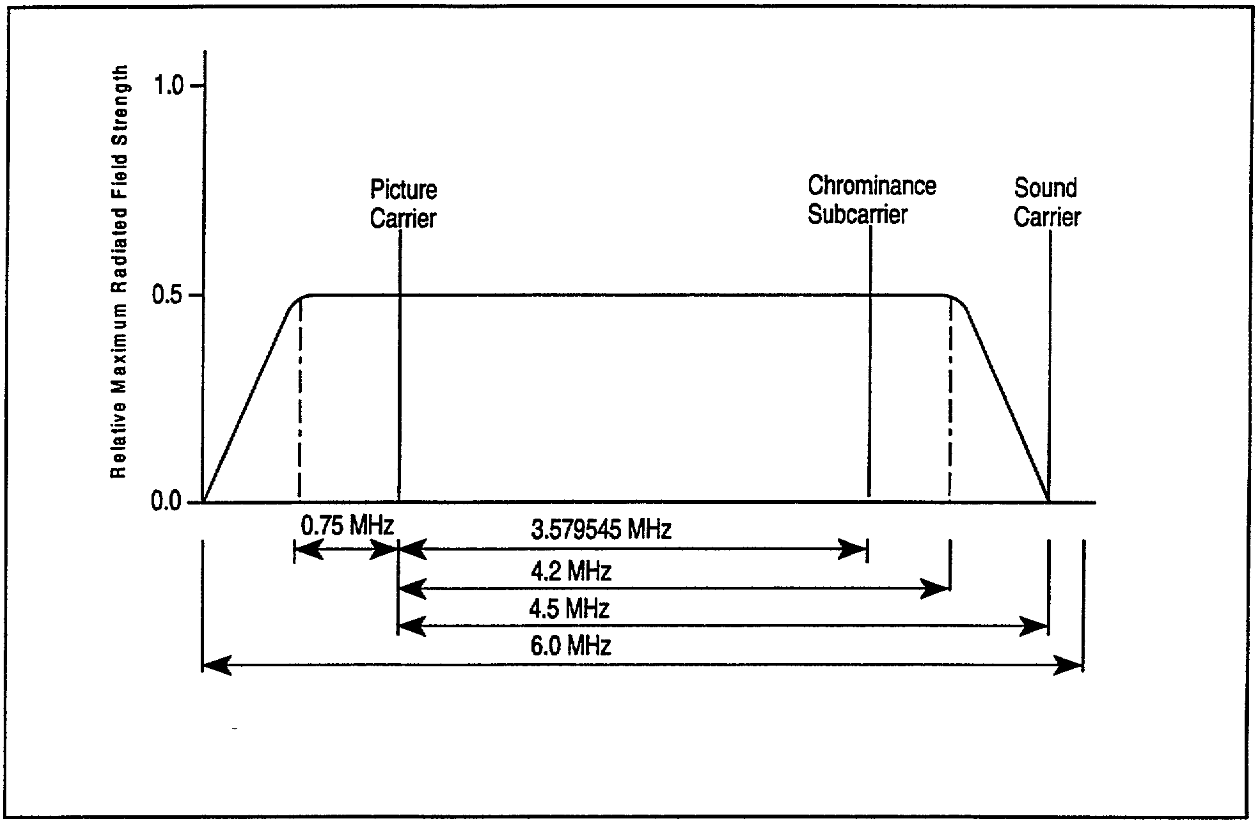


Figure 25. Idealized picture transmission amplitude characteristics.

The chrominance subcarrier frequencies located at 3,579,545.45 ± 10 Hz above the picture carrier is permitted 0.1 Hz/s maximum chrominance rate of frequency drift. For monochrome and color transmissions the number of scanning lines per frame is 525, interlaced two to one in successive fields. The horizontal scanning frequency corresponds to 15,734.264 ± 0.044 Hz and the vertical scanning frequency is at 59.94 Hz. The blanking level frequency has a value of 75 ± 2.5 percent of the peak carrier level and the reference black level is separated from the blanking level by 7.5 ± 2.5 percent of the video range from blanking level to reference white level.

Polarization. Horizontal polarization is standard, however, circular or elliptical polarization is permitted.

Power and Antenna Requirements Transmitter location is chosen so that, on the basis of ERP and HAAT, the minimum field strength (above 1 uV/m [dBu]) is provided over the entire principal community served. Grades of service are designated A and B. To provide the best degree of service to an area the antenna is located at the most central point at the highest elevation available. Television broadcast stations may use directional antennas if the guidelines defined in the table below are followed. Minimum power is 100 kW effective visual radiated power. No minimum antenna height is specified. Except as limited by antenna heights in excess of 1000 feet (2000 feet for channels 14-69) in Zone 1 and antenna heights in excess of 2000 feet in Zones II and III, the maximum visual power above 1 kW [dBk] **is** also demonstrated in Table 42.

Table 42. Power and Antenna Restrictions for Broadcast Television

Channel	Maximum power	Min. field strength 'City'-A-B	Maximum directional antenna min:max ratio
2-6	20 dBk = 100 kW	74 - 68 - 47 dBu	10 dB
7-13 (Zone I)	25 dBk = 316 kW	77 - 71- 56 dBu	15 dB
7- 13 (Zone II)	25 dBk = 316 kW	77 - 71- 56 dBu	15 dB
14-69	37 dBk = 5000 kW	80 - 74 - 64 dBu	NP

Visual Transmitter Requirements. The color picture signal shall correspond to a luminance component transmitted as amplitude modulation of the picture carrier and a simultaneous pair of chrominance components transmitted as the amplitude modulation sidebands of a pair of suppressed subcarriers in quadrature. The strength of the lower sideband of the visual signal shall not be greater than:

-20 dB for a modulating frequency of 1.25 MHz or greater

-42 dB for a modulating frequency of 3.579545 MHz (color subcarrier frequency)

For both monochrome and color, the strength of the upper sideband of the visual signal shall not be greater than:

-20 dB for a modulating frequency of 4.75 MHz or greater

For stations operating on channels 15-69 and employing a transmitter delivering maximum peak visual power output of 1 kW or less, the field strength of the upper and lower sidebands shall depart from the visual amplitude characteristic by no more than the following amounts:

-2 dB at 0.5 MHz below visual carrier frequency

-2 dB at 0.5 MHz above visual carrier frequency

-2 dB at 1.25 MHz above visual carrier frequency

-3 dB at 2.0 MHz above visual carrier frequency

-6 dB at 3.0 MHz above visual carrier frequency

- 12 dB at 3.5 MHz above visual carrier frequency

-8 dB at 3.58 MHz above visual carrier frequency (for color transmission only)

4.3.3. Television Broadcasting Equipment

Typical high-power UHF television transmitter. Table 43 lists the specifications of the BT-55UI (Harris Corporation) transmitter designed for high-power operation in the UHF television band.

Table 43. Specifications of the Model BT-55UI UHF Television Transmitter

Visual performance:	
Power output	55 kW peak
Output impedance, from cabinet	61/4in EIA flanged (channels14-51); waveguide (channels 52-69)
Output to antenna	67/2-in EIA flanged (channels 14-69)
Frequency range	470-806 MHz (channels 14-69)
Carrier stability	+500 Hz (max variation over 30 days)
Regulation of rf output power (black to white picture	3% or less
Variation of output over one frame	<2%
Visual sideband response:	
-3.58 MHz	-42 dB or better
-1.25 MHz and lower	-20 dB or better
Carrier to -0.5 MHz	+0.5 dB, -2.0 dB
Carrier	0 dB reference
Carrier to +4.18 MHz	+0.5 dB, -2.0 dB
+4.75 MHz and higher	-20 dB or better
Frequency response vs. brightness	+0.75 dB
Visual modulation capability	3% or better
Differential gain	0.5 dB or better
Linearity (low frequency)	0.5 dB or better
Differential phase	$+4^{o}$ or better
Signal-to-noise ratio	-50 dB or better (rms) below sync level
K factors	2t, 2%, 12.5t, <10% base-line disturbance
Equivalent envelope delay:	
0.05-2.1 MHz	+40 ns
At 3.58 MHz	+30 ns
At 4.18 MHz	+70 ns
Video input	75-R system
Harmonic Radiation	-80 dB
Aural performance	
Power output	11 kW at diplexer output
Output impedance	50 Q output connector 31/8-in EL4 standard (from cabinet)
Audio input	+10 dBm + 2 dB
Frequency deviation	+25 kHz
Input impedance	600/150 0
Pre-emphasis	75 us
Frequency response	+0.5 dB relative to pre-emphasis (30-I 5.000 Hz)
Distortion	0.5% or less after 75 us de-emphasis with +25 kHz deviation
FM noise	-59 dB or better relative to +25 kHz deviation
AM noise	-55 dB relative to 100% modulation
Frequency stability	+500 Hz
Electrical requirements:	
Power input	440/460/480 V, 3-phase 50/60 Hz
Power consumption (typical):	
Channels 14-51	214 kW
Channels 52-69	269 kW
Power factor	**>90%**

4.4. Shortwave Broadcast Service (Power › 50 kW)

A continental U.S. based international broadcast station’s transmissions are intended to be received directly by the general public in foreign countries. The frequencies assigned by the FCC are shown in Table 44.

Table 44. Frequency Allocations for International Broadcast Bands

Band	Frequencies [MHz]
A	5.950-6.200
B	9.500-9.775
C	11.700- 11.975
D	15.100-15.450
E	17.700-I 7.900
F	21.450-21.750
G	25.600-26.100

Frequencies are assigned only if they will provide a delivered median field-intensity, either measured or calculated, exceeding 150 uV/m for 50% of the time at the distant foreign target area. Transmitters must be equipped with automatic frequency control capable of maintaining the operating frequency within 0.003% of the assigned frequency. Frequency assignments provide a minimum co-channel delivered median field-intensity protection ratio of 40 dB and a protection ratio of 11 dB for adjacent-channel assignments to the transmissions of other broadcasting stations, at reference points in the target areas.

4.5. References

[1] CCIR (International Radio Consultative Committee), "Minimal field strength for which protection may be sought in planning a television service", CCIR Recommendation 4 17-3. International Telecommunications Union, Geneva, Switzerland, 1990.

[2] CCIR (International Radio Consultative Committee), "Planning Standards for FM sound broadcasting at VHF", CCIR Recommendation 412-5, International Telecommunications Union, Geneva' Switzerland, 1990.

[3] CCIR (International Radio Consultative Committee), "Radio-frequency protection ratios for AM vestigial sideband television systems", CCIR Recommendation 655-1, International Telecommunications Union, Geneva, Switzerland, 1990.

[4] CCIR (International Radio Consultative Committee), "Radio-frequency protection ratios in LF, MF, AND HF broadcasting", CCIR Recommendation 560-3, International Telecommunications Union, Geneva, Switzerland, 1990.

[5] CCIR (International Radio Consultative Committee), "Transmission standards for FM sound broadcasting at VHF", CCIR Recommendation 450-1, International Telecommunications Union, Geneva, Switzerland, 1990.

[6] Fink, D.G. and D. Christiansen (1989), *Electronics Engineers' Handbook* (McGraw-Hill Book Co., New York, NY, pp. 21.1-21.40)

[7] National Archives and Records Administration (1 Oct. 1992), *Code of Federal Regulations - Telecommunications, vol. 47,* part O-19, pp. 307-444.

[8] National Archives and Records Administration (1 Oct. 1992), *Code of Federal Regulations - Telecommunications,* vol. 47, part 70-79, pp. l-240.

5. *SUMMARY*

This report has examined the RF roadway environment for various sources of potential electromagnetic interference (EMI). Both intentional and unintentional emitters are considered. Unintentional emitters, as a source of EMI, is examined in section 2 under the title *Roadway Natural and Man-made Noise Environment.* Intentional emitters are examined through a band-by-band description of spectral content. Because a detailed description of all the RF bands is a massive undertaking, only the spectral regions of greatest potential EMI are discussed to any extent. A less detailed description of the spectral content is covered in two papers located in Appendix B and C at the end of this report. The first paper is an OSM spectral usage summary for the frequencies between 137 MHz and 5 GHz. The second paper shows the spectral usage for the frequencies between 2 GHz and 25 GHz Since radar and broadcast signals give some of the highest emission levels, and since their transmitters can be approached in close proximity by vehicles, they are potentially the greatest source of EMI caused by intentional emitters. The radar and broadcast bands are, therefore, covered in greater detail.

A band by band discussion of radar is found in section 3 of this report. This includes a basic description of the characteristics of each band, followed by the number of agency assignments and listings of typical radars (including emission characteristics).

Because the characteristics of the broadcast bands are relatively straightforward and well-behaved according to FCC regulations, these bands are described by summarizing the regulations and recommendations that govern the emissions. This discussion can be found in section 4 of this report.

Besides the radar and broadcast bands, the band 902 - 928 MHz is discussed in greater detail. This band is designated for Automatic Vehicle Identification as well as other assignments. While the band appears quiet in terms of emissions, it has the potential for strong interfering signals. This discussion can be found in section 3 of this report.

In addition to this report, ITS has agreed to provide recommendations for measurement test sites. The primary purpose of these measurements is to assess emissions levels across a large area of the spectrum and in turn, determine the extent of possible EMI secondary to these intentional emitters. Since a worst case scenario is recommended, locations targeted for testing are those with high RF emissions across much of the spectrum. Propagation characteristics are not a consideration, other than the extent that they may contribute to interference. Propagation characteristics are very important of course, in determining what radio services might be available in an area. Therefore, propagation must be considered when evaluating the use of GPS in cities and mountains, cellular and broadcast signals in mountainous areas, and communications of any type in tunnels and enclosed structures.

Recommendations for test sites are based on several factors: 1. Population Density, 2. Proximity to Airports, 3. Proximity to Coastal Areas, and 4. Proximity to Military Bases. High density areas naturally lend themselves to spectral crowding particularly in the broadcast, amateur, and mobile communication bands. In addition, most metropolitan areas have airports and the associated high power radars such as ASR’s, ARSR’s, and weather radars. Coastal areas near Navy shipyards are likely to show marine mobile communications and shipbome radar. Military bases and testing grounds, while often in remote areas, will show emissions from radars and radar simulators, as well as many other RF signals in government designated bands. Remote military bases, however, are less likely to show civilian communications and tend to be transient in nature. Based on this information, seven primary sites have been considered, the first five of which are recommended for testing. These are as follows (listed in order of priority):

1. **San Diego, Los Angeles, and San Francisco California Area:** This area is one of the most heavily congested as far as the spectrum is concerned. There are several military shipyards (Navy and Marine), military airfields, civilian airports, and commercial harbors. There are multiple high powered radars, including ASR’s, ARSR’s, weather radars, and shipbome radars. There is heavy marine mobile communication use particularly on weekends. Because of the high population

density, there are many broadcast signals and heavy land mobile communications use.

2. **Eastern corridor (I-95) between Richmond, VA and Portland, ME: This** is a highly populated area with heavy spectral usage particularly in the broadcast and mobile commutations bands. There are a number of civilian airports along with their associated radars (ASR's, ARSR's and weather).

3. Norfolk, **VA Area:** This area has the largest naval base on the east coast. Emissions in this area include high powered shipbome Naval radar, as well as other military communications. Large commercial container docks are also located in this area, contributing to shipborne radar and marine mobile communications.

4. **El Paso, TX / Juarez and Ft. Bliss Area:** This area is of interest for a couple of reasons. High power and possibly poorly regulated broadcast transmissions can be observed coming from across the Mexican border. In addition, Ft. Bliss, an Army military base in close proximity to El Paso, is noted for numerous high power radar emissions used in military training.

5. **Seattle, WA Area:** This area also has a high population density with naval bases and commercial shipping docks Regions of heavy spectral usage are expected in the radiolocation bands (particularly Navy and commercial shipping), broadcast bands, marine mobile bands, and land mobile bands.

6. **Pittsburgh Area:** This is a high population density area that sits in a valley. However, little is expected in the form of special transmitters not seen in the other locations.

7. **Denver to Grand Junction along I-70:** This area is unique for its mountainous propagation characteristics but most signals are low power and offer little in the way of additional spectral characteristics. This is not an area for obtaining high level emission sources that would make any significant contribution to a worst-case emission environment.

CHAPTER 5

Spectrum Standards

5.0. GENERAL

This chapter contains Radio Frequency Spectrum Standards applicable to Federal radio stations and systems.

A radio frequency spectrum standard is a principle, rule, or criterion that bounds the spectrum-related parameters, and characteristics, of a radio station or system for the purpose of managing the Radio Frequency Spectrum. Application of spectrum standards include:

(a) assisting consideration of telecommunications systems for the National spectrum review process (Chapter 10),

(b) systems planning, design, and procurement.

(c) Consideration of protection devices for the transmission of classified, and/or sensitive but unclassified information, and their spectrum needs.

The standards contained herein are those associated with the potential impact of any system or station on the normal operation of other systems or stations.

If spectrum standards are not specified in this chapter, the appropriate provisions of the ITU Radio Regulations normally shall apply. If spectrum standards are not specified in this chapter or in the ITU Radio Regulations, the appropriate criteria contained in current Recommendations of the CCIR shall be used as guidelines.

Compliance with standards contained in this chapter may not preclude the occurrence of interference. Therefore, compliance with the standards does not obviate the need for cooperation in resolving and implementing engineering solutions to harmful interference problems (see Section 2.3.7)

5.0.1 Consequences of Nonconformance with the Provisions of this Chapter

In any instance of harmful interference caused by nonconformance with the provisions of this chapter, the responsibility for eliminating the harmful interference normally shall rest with the agency operating in nonconformance.

5.0.2 Agency Procurement Specifications

Procurement specifications shall, as a minimum, assure compliance with the appropriate requirements of this chapter. Agencies may promulgate more stringent criteria for their own use.

5.0.3 Measurement Methods

Measurement methods included or referenced in this chapter are provided only for clarification and uniform interpretation of the standards. In cases of harmful interference, the agencies involved are expected to utilize these or equivalent, mutually agreed upon, methods of measurement for resolution of any disagreement concerning compliance with the standards. Agencies may, at their discretion, use these measurement methods as minimum qualification test procedures, e.g., as part of factory test procedures.

5.0.4 Terminology

Definitions of Special Terms, Services, and Stations are contained in Chapter 6.

Desired Relationship of Occupied Bandwidth to Necessary Bandwidth

The emission designator(s) associated in the authorization for any particular frequency assignment specifies the value of the necessary bandwidth of emission for the particular type(s) of transmission permitted. The values of necessary bandwidth are generally idealized. All reasonable effort shall be made in equipment design and operation by Government agencies to maintain the occupied bandwidth of the emission of any authorized transmission as close to the necessary bandwidth as is reasonably practicable. (See Annex J for additional information concerning necessary bandwidth.)

Resolution Bandwidth

Resolution bandwidth is the 3 dB bandwidth of the measurement system used, e.g., in power spectral density measurements. The appropriate resolution bandwidth of the measurement system varies depending on the modulation type and frequency band but should not be greater than the necessary bandwidth of the transmitter being measured.

Power (RR)

Power is designated as:
peak envelope power (PX or pX)
mean power (PY or pY)
carrier power (PZ or pZ)
p denotes power expressed in watts
P denotes power in dB relative to a reference level

Logarithm

In this chapter, Log=Log_{10}

Frequency Tolerances

Transmitter frequency tolerance is the maximum permissible departure from the assigned frequency by the center frequency of the frequency band occupied by an emission.

Receiver frequency tolerance is the maximum permissible departure of the center frequency of the IF passband from the desired center frequency of the IF passband.

The frequency tolerance is expressed in parts per million (ppm).

5.0.5 Specific Standards

Where specific standards are provided in this chapter, the frequency tolerances and levels of unwanted emissions in these specific standards take precedence over the values in the Table in Part 5.1.

5.1 TABLE OF FREQUENCY TOLERANCES AND UNWANTED EMISSIONS

Freauencv Bends and Station Type	Levels of Unwanted Emissions	Frequency Tolerance
BAND: 9 to 535 kHz		
1. Fixed Stations		
1 .1 9-50 kHz	A	100
1.2 50-535 kHz	A	50
BAND: 9 to 635 kHz (continued)		
2. Land Stations		
2.1 Coast Stations	A	100
2.1 .1 Direct printing telegraphy end date	A	10 Hz [aa]
2.2 Aeronautical Stations	A	50
2.3 Base Stations (TIS)	A	100 Hz
3. Mobile Stations		
3.1 Ship Stations	A	200
3.1.1 Direct printing telegraphy and date	A	10 Hz [bb]
3.2 Ship Emergency Transmitters	A	500 [a]
3.3 Survival Craft	A	500
3.4 Aircraft Stations	A	50
3.5 Lend Mobile	A	20
4. Radionavigation Stations	A	100
5. Radiolocation Stations	A	100
BAND: 535 to 1606 kHz		
1. Broadcasting Stations	A	1 0 Hz [b]
BAND: 1605 to 4000 kHz		
1. Fixed Stations		
1 .1 Other than SSB	A	10
1.2 SSB Radiotelephone	B	20 Hz
2. Lend Stations		
2.1 Coast Stations		
2.1 .1 200 W or less, other than SSB	A	100
2.1.2 Above 200 W. other than SSB	A	50
2.1.3 SSB radiotelephone	C	20 Hz
2.1.4 Direct printing telegraphy and date	C	10 Hz [aa]
2.2 Aeronautical Stations		
2.2.1 200 W or less, other then SSB	A	20
2.2.2 Above 200 W, other then SSB	A	10
2.2.3 SSB radiotelephone	C	10 Hz [c]
2.3 Base Stations		
2.3.1 200 W or less, other then SSB	A	20 [d]
2.3.2 Above 200 W, other then SSB	A	10
2.3.3 SSB radiotelephone	C	20 Hz
3. Mobile Stations		
3.1 Ship Stations		
3.1 .1 SSB radiotelephone	C	40 Hz [a]
3.1.2 Other then SSB	A	40 [f][g]
3.1.3 Direct print telegraphy and data	C	40 Hz
3.2 Survival Craft Stations	A	100 [h]
3.2.1 Emergency position indicating radiobeacons	A	100 [i]
3.3 Aircraft Stations		
3.3.1 SSB radiotelephone		
3.3.2 Other then SSB	C	20 Hz [j]
3.4 Lend Mobile Stations	A	20
3.4.1 SSB radiotelephone		
3.4.2 Other then SSB	C	20 Hz
4. Radionavigation Stations	A	50
4.1 Under 200 W		
4.2 200 W and above	A	20
5. Radiolocation Stations	A	10
6. Broadcasting Stations	A	10
	A	10 Hz

Frequency Bands and Station Type	Levels of Unwanted Emissions	Frequency Tolerance
BAND: 4 to 29.7 MHz		
1. Fixed Stations		
1 .1 500 W or less, other than SSB/ISB	A	20 (k)
1.2 Above 500 W, other then SSB/ISB	A	10
1.3 SSB/ISB Radiotelephone	B	20 Hz
1.4 Class F1 B Emissions	A	10 Hz
2. Land Stations		
2.1 Coast Stations		
2.1 .1 500 W or less	A	20Hz (l)(cc)
2.1.2 500 w to 5 kW	A	20Hz (l)(dd)
2.1.3 Above 5 kW	A	20Hz (aa)
2.1 .4 SSB radiotelephone	C	20Hz
2.1 .5 Direct printing telegraphy and data	C	1 0Hz (aa)
2.2 Aeronautical Stations		
2.2.1 500 W or less, other than SSB	A	30
2.2.2 Above 500 W, other than SSB	A	10
2.2.3 SSB radiotelephone	C	10 Hz (c)
2.3 Base Stations		
2.3.1 500 W or less. other than SSB	A	20 (k)
2.3.2 Above 500 W, other than SSB	A	10
2.3.3 SSB radiotelephone	C	20 Hz
3. Mobile Stations		
3.1 Ship Stations		
3.1 .1 Class Al A Emissions	A	10 (g)
3.1.2 Other than Al A Emissions		
3.1.2.1 SSB radiotelephone	C	50 Hz
3.1.2.2 Direct printing radio-telegraphy and data	C	10 Hz (bb)
3.1.2.3 Other than above	A	50 Hz (m)
3.2 Survival Craft Statrons	A	50 (n)
3.3 Aircraft Stations		
3.3.1 SSB radiotelephone	C	20 Hz
3.3.2 Other than above	A	30
3.4 Land Mobile Statrons		
3.4.1 SSB radiotelephone	C	20 Hz
3.4.2 Other than above	A	30
4. Broadcasting Statrons	A	2
5. Earth Statrons	A	20
6. Space Statrons	A	20
BAND: 29.7 to 100 MHz		
1. Fixed Stations		
1 .1 10 W or less	D,E,B	20
1.2 Above 10 W	D,E,C	5
2. Land Stations		
2.1 10 W or less	D,E	20
2.2 Above 10 W	D,E	5
3. Mobile Stations		
3.1 10 w or less	D,E,C	20 (n)
3.2 Above 10 W	D,E,C	5
4. Radionavigation Stations	D	50
5. Broadcasting Stations		
5.1 Other than TV		
5.1.1 10 W or less	D	3000 Hz
5.1.2 Above 10 W	D	2000 Hz
5.2 TV Sound and Vision	D	500 Hz (o)(p)(x)
6. Earth Stations	D	20
7. Space Stations	D	20

Frequency Bands and Station Type	Levels of Unwanted Emissions	Frequency Tolerance
BAND: 100 to 470 MHz		
1. Fixed Statrons		
1 .1 Band 100-406 MHz	D,E	5
1.2 Band 162-174 MHz (Narrow-band)	0	3
1.3 Band 162-l 74 MHz (Splinter channels]		
1.3.1 10 W or less	D,E	5
1.3.2 Above 10 W	D,E	2
1.4 Band 406-470 MHz		
1.4.1 10 W or less	D,E,M	5 (q)
1.4.2 Above 10 W	D,E,M	2.5 (q)
2. Land Stations		
2.1 Coast Stations		
2.1.1 Band 150.8-162.0125 MHz		
2.1 .1.1 Less than 3 W	D,E	1 0 (r)
2.1 .1.2 Less than 100 W but greater than or equal to 3 W	D.E	5 (r)
2.1 .1.3 Greater than or equal to 100 w	D,E	2.5 (r)
2.1.2 Outside band 150.8-162.0125 MHz	D.E	10 (r)
2.2 Aeronautical Stations	D,E	20
2.3 Base Stations		
2.3.1 Band 100-406 MHz	D,E	5
2.3.2 Band 162-174 MHz (Nar-rowband)	0	3
2.3.3 Band 162-174 MHz (Splinter channels)		
2.3.3.1 10 W or less	D.E	5
2.3.3.2 Above 10 W	D,E	2
2.3.4 Band 406-470 MHz		
2.3.4.1 10 W or less	D,E	5
2.3.4.2 Above 10 W	D,E	2.5
3. Mobile Statrons		
3.1 Ship Stations		
3.1.1 Band 156-162 MHz	E	10
3.1.2 Band 406-420 MHz	E	5 I.,
3.1.3 Band 450-470 MHz	D.E	5
3.1.4 Outside above bands	D.E	20 (l)
3.2 Survival Craft Statrons		
3.2.1 Band 156-162 MHz	D.E	10 (r)
3.2.2 Other than above	D.E	20 (u)
3.3 Aircraft Stations		
3.3.1 Bands 156-174 and 406-420 MHz	E	5 (s)
3.3.2 Other than above	D.E	20
3.4 Lend Mobile Stations		
3.4.1 Band 162-l 74 MHz	D.E	5 (n)
3.4.2 Band 162-l 74 MHz (Nar-rowband)	0	3
3.4.2.1 Mobiles	0	5
3.4.2.2 Portables	D.E	2
3.4.3 Band 162-l 74 MHz (Splinter channels)		
3.4.3.1 10 w or less	D.E	5
3.4.3.2 Above 10 W	D.E	2
3.4.4 Band 406-420 MHz	D.E	5
3.4.5 Other than above	D.E	15 (v).
4. Radionevigation Stations		
4.1 Radar	F	50 (w)
4.2 Other than above	D	20

Frequency Bands and Station Type	Levels of Unwanted Emissions	Frequency Tolerance
BAND: 100 to 470 MHz (continued)		
5. Radiolocation Stations		
5.1 Radar	F	50 [w]
5.2 Other than above	D	50
6. Broadcasting Stations		
6.1 Other than TV	D	2000 Hz
6.2 TV Sound and Vision	D	500 Hz [o][p][x]
7. Earth Stations	D	20
8. Space Stations	D	20
BAND: 470 to 960 MHz		
1. Fixed Stations	D,M	5
2. Land Stations	D	5
3. Mobile Stations		
3.1 3 W or less	D	20 [g]
3.2 Above 3 W	D	5
4. Radiolocation Stations		
4.1 Radar	F	400
4.2 Other than above	D	400
5. Broadcasting Stations		
5.1 TV Broadcasting Stations	D	500 Hz [o][p][x]
5.2 TV Broadcasting Translator Stations	D	200
6. Earth Stations	G,H	20
7. Space Stations	G,H	20
BAND: 960 to 1215 MHz		
1. Aeronautical Radionavigation		
1.1 Land and Ship Stations	I	10
1.2 Aircraft Stations	I	50
2. IFF/ATCRBS or Similar Type Stations		
2.1 Interrogators 1030 MHz	I	200 kHz
2.2 Transponders 1090 MHz	I	3 MHz
BAND: 1215 to 2450 MHz		
1. Fixed Stations		
1.1 100 W or less	I,J,M	30
1.2 Above 100 W	I,J,M	10
2. Land Stations	I,J	20 [k]
3. Mobile Stations	I,J	20 [k]
4. Radionavigation Stations		
4.1 Radar	F	500 [y]
4.2 Other than above	I	500 [y]
5. Radiolocation Stations		
5.1 Radar	F	500 [y]
5.2 Other than above	I	500 [y]
6. Earth Stations	N	20
7. Space Stations	N	20
BAND: 2450 to 4000 MHz		
1. Fixed Stations		
1.1 100 W or less	I,M	30
1.2 Above 100 W	I,M	10
2. Land Stations	I	30
3. Mobile Stations	I	30
4. Radionavigation Stations		
4.1 Radar	F	800
4.2 Other than above	I	800
5. Radiolocation Stations		
5.1 Radar	F	800
5.2 Other than above	I	800
6. Earth Stations	N	20
7. Space Stations	N	20

Frequency Bands and Station Type	Levels of Unwanted Emissions	Frequency Tolerance
BAND: 4000 MHz to 10.5 GHz		
1. Fixed Stations		
1.1 100 W or less	I,M	50
1.2 Above 100 W	I,M	10
2. Land Stations	I	50
3. Mobile Stations	I	50
4. Radionavigation Stations		
4.1 Radar	F	1250 [z]
4.2 Other than above	I	1250
5. Radiolocation Stations		
5.1 Radar	F	1250 [z]
5.2 Other than above	I	1250
6. Earth Stations	N	20
7. Space Stations	N	20
BAND: 10.5 to 30 GHz		
1. Fixed Stations		
1.1 Band 21.2-23.6 GHz (See	L	300
Section 5.2.3)	I,M	50
1.2 Other than above	I	100
2. Land Stations	I	100
3. Mobile Stations		
4. Radionavigation Stations	F	2500
4.1 Radar	I	2500
4.2 Other than above		
5. Radiolocation Stations	F	2500
5.1 Radar	I	2500
5.2 Other than above	N	50
6. Earth Stations	N	50
7. Space Stations	K	100
8. Broadcasting Stations		
BAND: 30 to 40 GHz		
1. Fixed Stations	I	75
2. Land Stations	I	150
3. Mobile Stations	I	150
4. Radionavigation Stations		
4.1 Radar	F	5000
4.2 Other than above	I	5000
5. Radiolocation Stations		
5.1 Radar	F	5000
5.2 Other than above	I	5000
6. Earth Stations	N	75
7. Space Stations	N	75
8. Broadcasting Stations	K	100
BAND: Above 40 GHz		
1. Fixed Stations	I	75
2. Land Stations	I	150
3. Mobile Stations	I	150
4. Radionavigation Stations	I	5000
5. Radiolocation Stations	I	5000
6. Earth Stations	N	75
7. Space Stations	N	75

5.1.1 Frequency Tolerances and Unwanted Emissions

The letters A thru K in Section 5.1.3 refer to the levels of unwanted emissions.

Units for frequency tolerance are (±) parts per million (ppm) unless otherwise stated.

The power shown for the various categories of stations is the peak envelope power for single-sideband transmitters and the mean power for all other transmitters, unless otherwise indicated. (RR)

5.1.2 Notes For Frequency Tolerance

(a) If the emergency transmitter is used as the reserve transmitter for the main transmitter, the tolerance for ship station transmitters applies.

(b) In the area covered by the North American Regional Broadcasting Agreement (NARBA) , the tolerance of 20 Hz may continue to be applied.

(c) 20 Hz is applicable to other than Aeronautical Mobile (R) frequencies.

(d) Travelers Information Stations (TIS) have a tolerance of 100 Hz.

(e) The indicated tolerance applies to new equipment after l/1/87. A tolerance of 50 Hz applies to other equipment.

(f) For Al A emissions the tolerance is 50 ppm.

(g) The indicated tolerance applies to new equipment after l/1/87. A tolerance of 50 ppm applies to other equipment.

(h) The indicated tolerance applies to new equipment after l/l/87. A tolerance of 200 ppm applies to other equipment.

(i) The indicated tolerance applies to new equipment after l/1/87. A tolerance of 300 ppm applies to other equipment.

(j) The tolerance for aeronautical stations in the Aeronautical Mobile (R) service is 10 Hz.

(k) The indicated tolerance applies to new equipment after l/1/87. A tolerance of 30 ppm applies to other equipment.

(l) For Al A emissions the tolerance is 10 ppm.

(m) For ship station transmitters in the band 26.175-27.5 MHz, on board small craft, with a carrier power not exceeding 5W operating in or near coastal waters and utilizing A3E or F3E and G3E emissions, the frequency tolerance is 40 ppm. .

(n) 50 ppm applies to wildlife telemetry with mean power output less than 0.5W.

(o) The indicated tolerance applies to new equipment after 1 / l/87. A tolerance of 1000 Hz applies to other equipment.

(p) In the case of television stations of:

(1) 50W (vision peak envelope power) or less in the band 29.7-100 MHz;

(2) 100W (vision peak envelope power) or less in the bank l00-965 MHz;

and which receive their input from other television stations or which serve small isolated communities, it may not, for operational reasons, be possible to maintain this tolerance. For such stations, this tolerance is 1000 Hz.

(q) See Part 5.6.

(r) This tolerance is applicable to all transmitters, including survival craft stations, after Jan 1, 1983.

(s) Except for the RR Appendix 18 Maritime Mobile frequencies, where the tolerance is 20 ppm except for transmitters put in service after January 1, 1973, a tolerance of 10 ppm shall apply, and this tolerance shall be applicable to all transmitters after January 1, 1983.

(t) Outside band 156-174 MHz, for transmitters used by on-board communications stations, a tolerance of 5 ppm shall apply.

(u) For transmitters used by on-board communications stations, a tolerance of 5 ppm applies.

(v) The indicated tolerance applies to new equipment after l/1/87. A tolerance of 20 ppm applies to other equipment.

(w) The indicated tolerance applies to new equipment after l/1/87. A tolerance of 400 ppm applies to other equipment.

(x) For transmitters for system M(NTSC) the tolerance is 1000 Hz. However, for low power transmitters using this system note (p) applies.

(y) The indicated tolerance applies to new equipment after l/1/87. A tolerance of 800 ppm applies to other equipment.

(z) For 10-10.5 GHz, the indicated tolerance applies to new equipment after l/1/87. A tolerance of 2500 ppm applies to other equipment.

(aa) The indicated tolerance applies to new equipment after l/1/92. A tolerance of 15 Hz applies to other equipment.

(bb) The indicated tolerance applies to new equipment after l/1/92. A tolerance of 40 Hz applies to other equipment.

(cc) The indicated tolerance applies to new equipment after l/1/92. A tolerance of 30 applies to other equipment.

(dd) The indicated tolerance applies to new equipment after l/1/92. A tolerance of 20 applies to other equipment.

(ee) The indicated tolerance applies to new equipment after l/1/92. A tolerance of 10 applies to other equipment.

5.1.3 Levels of Unwanted Emissions

For purposes of this Manual, the **term** "authorized bandwidth" is defmed as the necessary bandwidth (bandwidth required for the transmission and reception of intelligence) and does not include allowance for transmitter drift or doppler shift. See, in addition, Chapter 6 for the definitions of special terms including authorized bandwidth and mean power.

A. The mean power of any unwanted emissions supplied to the antenna transmission line, as compared with the mean power of the fundamental, shall be in accordance with the following:

1. On any frequency removed from the assigned frequency by more than 100 percent, up to and including 150 percent of the authorized bandwidth, at least 25 decibels attenuation;

2. On any frequency removed from the assigned frequency by more than 150 percent, up to and including 300 percent of the authorized bandwidth, at least 35 decibels attenuation; and

3. On any frequency removed from the assigned frequency by more than 300 percent of the authorized bandwidth, for transmitters with mean power of 5 kilowatts or greater, at least 80 decibels attenuation; and for transmitters with mean power less than 5 kilowatts, at least 43 plus 10 log,, (mean power of the fundamental in watts) decibels attenuation (i.e., 50 microwatts absolute level), except that

a. For transmitters of mean power of 50 kilowatts or greater and which operate over a frequency range approaching an octave or more, a minimum attenuation of 60 decibels shall be provided and every effort should be made to attain at least 80 decibels attenuation.

b. For hand-portable equipment of mean power less that 5 watts, the attenuation shall be at least 30 decibels, but every effort should be made to attain 43 plus 10 log,, (mean power of the fundamental in watts) decibels attenuation (i .e., 50 microwatts absolute level).

c. For mobile transmitters, any unwanted emissions shall be at least 40 decibels below the fundamental without exceeding the value of 200 milliwatts, but every effort should be made to attain 43 plus 10 log,, (mean power of the fundamental in watts) decibels attenuation (i.e., 50 microwatts absolute level).

d. When AlA, FlB, or similar types of narrowband emissions are generated in an SSB transmitter, the suppressed carrier may fall more than 300 percent of the authorized bandwidth from the assigned frequency. Under these conditions, the suppressed carrier shall be reduced as much as practicable and shall be at least 50 decibels below the power of the fundamental emission.

B. Unwanted emission standards for fixed SSB/ISB stations in the band 2-30 MHz are contained in Section 5.4.1.

C. Unwanted emission standards for mobile SSB stations in the band 2-30 MHz are contained in Section 5.5.1.

D. The mean power of any emission supplied to the antenna transmission line, as compared with the mean power of the fundamental, shall be in accordance with the following:

1. On any frequency removed from the assigned frequency by more than 75 percent, up to and including 150 percent, of the authorized bandwidth, at least 25 decibels attenuation;

2. On any frequency removed from the assigned frequency by more than 150 percent, up to and including 300 percent, of the authorized bandwidth, at least 35 decibels attenuation; and

3. On any frequency removed from the assigned frequency by more than 300 percent of the authorized bandwidth:

a. For transmitters with mean power of 5 kilowatts or greater, attenuation shall be at least 80 decibels.

b. For transmitters with mean power less than 5 kilowatts, spurious output shall not exceed 50 microwatts except for frequency modulated maritime mobile radiotelephone equipment above ***30*** MHz as follows:

(1) The mean power of modulation products falling in any other international maritime mobile channel shall not exceed 10 microwatts for mean transmitter power 20 watts or less.

(2) The mean power of any other unwanted emission on any discrete frequency within the international maritime mobile band shall not exceed 2.5 microwatts for transmitters with mean power of 20 watts or less.

(3) For maritime mobile transmitters of mean power above 20 watts, these 2.5 and 10 microwatt limits may be increased in proportion to the increase of the mean power of the transmitters above this 20 watts.

E. Unwanted emission standards for FM stations are contained in the following parts:

Frequency (MHz)	Part of Manual
29.89-50.00	5.6
150.8-162.0125	5.5
162.0125-174	5.6 5.7
406.1-420	5.6

F. Unwanted emission standards for radionavigation radars and radiolocation radars are found in Part 5.3.

G. For systems with mean power above 25 watts, the unwanted emissions component attenuation shall be at least 60 dB and the absolute mean power level shall not exceed 20 milliwatts.

H. For systems with mean power 25 watts or less, the unwanted emissions component attenuation shall be at least 40 dB and the absolute mean power level shall not exceed 25 microwatts.

I. The mean power of any emission supplied to the antenna transmission line, as compared with the mean power of the fundamental, shall be in accordance with the following (above 40 GHz these are design objectives pending further experience at these orders of frequency):

1. On any frequency removed from the assigned frequency by more than 75 percent, up to and including 150 percent of the authorized bandwidth, at least 25 decibels attenuation;

2. On any frequency removed from the assigned frequency by more than 150 percent, up to and including 300 percent of the authorized bandwidth, at least 35 decibels attenuation; and

3. On any frequency removed from the assigned frequency by more than 300 percent of the authorized bandwidth, for transmitters with mean power of 5 kilowatts or greater, at least 80 decibels attenuation; and for transmitters with mean power less than 5 kilowatts, at least 43 plus 10 log,, (mean power of the fundamental in watts) decibels attenuation (i.e., 50 microwatts absolute level).

J. Unwanted emission standards for telemetering stations, excluding those for space radiocommunication, in the bands 1435-1535, 2200-2290 and 2310-2390 MHz are contained in Part ***5.8.***

K. Development of unwanted emission tolerances is pending.

L. When using transmissions other than those employing digital modulation techniques: the mean power of any emission supplied to the antenna transmission line, as compared with the mean power of the fundamental, shall be in accordance with the following (above 40 GHz these are design objectives pending further experience at these orders of frequency):

1. On any frequency removed from the assigned frequency by more than 50 percent, up to and including 100 percent of the authorized bandwidth, at least 25 decibels attenuation;

2. On any frequency removed from the assigned frequency by more than 100 percent, up to and including 250 percent of the authorized bandwidth, at least 35 decibels attenuation; and

3. On any frequency removed from the assigned frequency by more than 250 percent of the authorized bandwidth, at least 43 plus 10 log,, (mean output power in watts) decibels or 80 decibels, whichever is the lesser attenuation.

M. Standards for unwanted emissions for fixed services in the 406.1-420 MHz band, the 932-935/941-944 MHz bands, and in the 1710 MHz-15.35 GHz frequency range are contained in Section 5.4.2 and Part 5.6.

N. Standards for unwanted emissions for space and earth stations are contained in Part 5.7.

0. Unwanted emission standards for Narrowband fixed and Mobile/Land Mobile stations in the 162-174 MHz band are contained in Section ***5.6.2.***

5.2 SPECIAL PROVISIONS

5.2.1 Low Power Channels and Splinter Channels (162-174 MHz and 406-420 MHz Bands)

The following standard is for the use of low power channels identified in Section 4.3.8 and splinter channels identified in Section 4.3.10.

Transmitter Standards:

1. Frequency tolerance is expressed in parts per million (ppm).

+2 ppm for equipment with greater than 10 watts carrier output power.

+5 ppm for equipment with 10 watts or less carrier output power.

2. Emission--For FM or PM emission the maximum frequency deviation plus the highest audio tone shall not exceed 0.5 times the authorized bandwidth (authorized bandwidth is equal to 2D + 2M).

3. Unwanted emission levels at the equipment antenna terminals on any frequency removed from the center of the authorized bandwidth (BW) by a displacement frequency (fd) shall be attenuated below the mean power (pY) of the unmodulated carrier output as specified by the following:

(fd)	Attenuation in dB
50%BW<fd<100%BW	25
100%BW<fd<250%BW	35
fd>250%BW	43 dB + 10 log (pY)

4. Power output--The maximum mean power of the unmodulated carrier output for operations

on splinter channels in the 406-420 MHz band shall be limited to 30 watts.

5. Equipment designated for low power channels in the 162-174 MHz band as shown in Section 4.3.8 shall comply with the standards for unwanted emissions and frequency tolerances contained in Section 5.6.2.

5.2.2 Distress and Safety Communications

1. Global Maritime Distress and Safety System (GMDSS):

Stations in the maritime and other radio services employing frequencies and techniques used in the GMDSS shall comply with the relevant CCIR recommendations with respect to the technical characteristics of:

a. Digital selective calling (DSC) distress call formats (RR N3112.3 and N3277);

b. DSC on VHF channel 70 (156.525 MHz):

1. Capability of sensing the presence of a signal on channel 70, and

2. Automatic prevention of transmitting a DSC call on channel 70, except for a distress and safety call by DSC, when the channel is occupied by calls (Appendix 19);

c. Other aspects of DSC equipment (RR 4681);

d. Narrowband direct printing (NBDP) message formats (RR 4873) and error correction for distress, urgency, and safety messages (RR N3146, N3212, and N3232, respectively);

e. Transmissions from satellite emergency position-indicating radio beacons (EPIRBs) operating in the bands 406-406.1 MHz and 1645.5-1646.5 MHz (RR 3259A and N3276);

f. Transmissions from search and rescue radar transponders operating in the band 9200-9500 MHz (RR 824A); and

g. Broadcasts on 518 (NAVTEX) and other broadcasts of maritime safety information using NBDP in the bands 4-27.5 MHz (RR N3236).

Additionally, such stations when using DSC shall conform to the calling, acknowledgement, and operating procedures for DSC contained in the Radio Regulations (Article N39) and the relevant CCIR recommendation(s).

2. 121.5/243 MHz EPIRBs:

EPIRBs operating at 12 1.5 MHz and/or 243 MHz shall conform to the requirements of Appendix 37A of the Radio Regulations and Annex 10 to the Convention on International Civil Aviation, to the extent that each provision is applicable.

5.2.3 Low Power ‘Transmit (21.8-22.0 and 23.0-23.2 GHz Band Segments)’

This standard applies to the following four frequency pairs within the above two band segments:

21.825-23.025 GHz
21.875-23.075 GHz
21.925-23.125 GHz
21.975-23.175 GHz

1. Maximum effective radiated power (ERP) shall be 55 dBm.

2. The rated transmitter output power shall not exceed 0.100 watts.

3. Frequency tolerance shall be maintained to within 500 ppm of the assigned frequency.

4. Maximum beamwidth shall not exceed four degrees with a minimum front-to-back ratio of 38 dB.

5. Upon showing need, a maximum bandwidth of 50 MHz may be authorized per frequency assigned.

6. These radio systems shall have no more than five hops in tandem, except upon showing of need, but in any event the maximum tandem length shall not exceed 40 km (25 miles).

7. Interfering signals at the antenna terminals of stations authorized shall not exceed -90 dBm and -70 dBm, respectively, for co-channel and adjacent channel interfering signals.

8. Antennas employing circular polarization may used with these systems.

5.3 Radar Spectrum Engineering Criteria (RSEC)

General

The wide application of radar for various functions makes large demands on the electromagnetic spectrum, and requires the application of effective frequency management measures for the equipment and systems involved. Criteria for certain equipment characteristics are specified herein to ensure an acceptable degree of electromagnetic compatibility among radar systems, and between such systems and those of other radio services sharing the frequency spectrum.

These criteria are concerned with promoting efficient use of the spectrum, and in specifying them there is no intent to require particular numerical values from the standpoint of the radar's mission. For example, characteristics such as power, sensitivity, pulse repetition rate, pulse duration, pulse rise and fall times, and the range of radio frequency emission are closely related to operational requirements. Accordingly, where limits for some of these characteristics are specified herein, the criteria have been chosen to avoid undue degradation of operational effectiveness. Moreover, the specification of these criteria is compatible with the policy of encouraging a free and unrestricted approach in further research looking toward more effective radars. Nevertheless, any proposals for new approaches and new system concepts involving radar must be reviewed from a frequency management viewpoint prior to development of new equipment.

Useful receiver techniques are available for reduction of the susceptibility of radars to low-duty-cycle pulse interference. The applicability of such devices as video integrators, correlators, PRF and pulse width discriminators varies with factors such as cost, availability, and their adaptability to specific equipments and environmental situations. While the mandatory incorporation of such devices is not specified herein, their application is recommended for low-dutycycle radars intended for operation in congested frequency bands and geographic areas.

All primary radars' shall be classified in one of four groups as shown in the following table and then shall come under the criteria indicated for that group.

For radars employing more than a single emitter, including phased array radars, variable PRF radars, radars whose modulation changes from pulse to pulse, and other special types of radars for which any of the following criteria cannot be directly applied, special methods may be required in establishing appropriate criteria. Pending adoption of technical criteria for such radars, values submitted for these parameters shall be accompanied by an explanation of their derivation.

The provisions of Section 5.3.1, Criteria B, are applicable to Class 1 spacebased radar systems3 on a case-by-case basis. The provisions of Section 5.3.1 or Section 5.3.2 (i.e. Criteria B or C as appropriate) are applicable to Class 2 spacebased radar systems4 and active spaceborne sensors' on a case-by-case basis. See Section 8.2.41 for further guidance concerning spacebased radiolocation and active sensor systems.

In the special case where government radionavigation radars operate in the shared govemment/non-government band 9300-9500 MHz, an acceptable degree of electromagnetic compatibility is deemed to be that degree of compatibility associated with the radar equipments commercially available to the non-government community of users. The vast preponderance of the use of this band by non-government domestic and foreign ships and aircraft creates a situation where relatively inexpensive commercial equipment is available "off the shelf' ' and at the same time equipment improvements which might be incorporated unilaterally by small numbers of govemment stations would have little effect on the band as a whole. Accordingly, government radionavigation radars to be operated in this band having a rated peak power of 100 kW or less are placed in Group A with the understanding that government agencies would procure equipments that are acceptable for non-government use and that this exemption will be re-examined should the situation in this band change.

NTIA Report 84-157, Measurement Procedures for the Radar Spectrum Engineering Criteria, August 1984, presents one or more test procedure(s) for each of the equipment parameters covered by the RSEC that will yield adequate measured data for checking against the RSEC. These test procedures are not meant to replace any existing agency radar measurement procedures. NTIA Report 84- 157 is available for purchase from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. (When ordering refer to NTIS Accession No. PB-85-119022.)

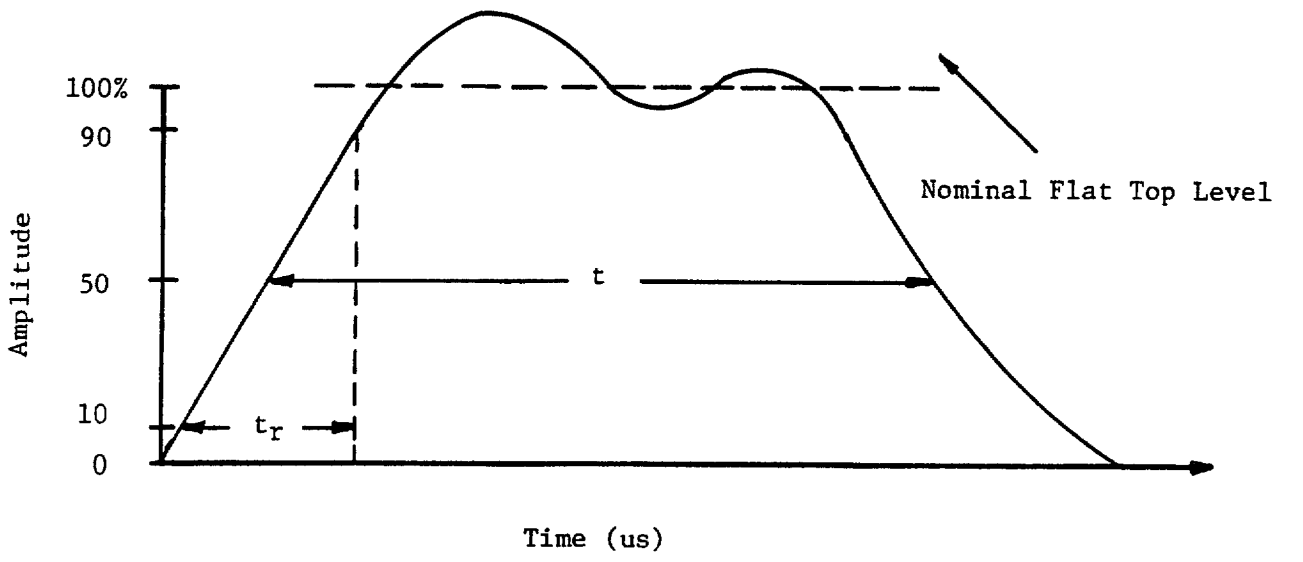


Figure 1. Determination of t and t_r

Applicability of RSEC Criteria[6,7]

Radar Description	Applicable Criteria
Group A Non-pulsed radars of 40 watts or less rated average power; or Pulsed radars of 1 kW or less rated peak power; or Radars with an operating frequency above 40 GHz; or Man-portable[6] radars; or Man-transportable[7] radars; or Radionavigation radars in the band 9300-9500 MHz; as described above; or Expendable, non-recoverable radars on missiles	Criteria A Presently exempt from any RSEC
Group B Radars having a rated peak power of more than 1 kW but not more than 100 kW and operating between 2900 MHz and 40 GHz	Criteria B See 5.3.1
Group C All radars not included in Group A, B or D	Criteria C See 5.3.2
Group D All fixed radars in the 2700-2900 MHz band	Criteria D See 5.3.3

Waivers

Waiver of the requirements herein may be requested when supported by reasonable justification. When technical and engineering data are supplied in support of a request for waiver or in evaluating the performance of equipment, an explanation of the non-conforming parameters and measurement methods employed shall be furnished. Manufacturer's data may be used where deemed appropriate and adequate.

Symbols Used

- B = emission bandwidth, in MHz.
- B_c = bandwidth of the frequency deviation. (The total frequency shift during the pulse duration) in MHz.
- B_d = bandwidth of the frequency deviation (peak difference between instantaneous frequency of the modulated wave and the carrier frequency)--(FM/CW radar systems).
- B_s = maximum range in MHz over which the carrier frequency will be shifted for a frequency hopping radar.
- d = pulse compression ratio = emitted pulse duration/compressed pulsed duration (at 50% amplitude points).
- F_0 = operating frequency in MHz. For non-FM pulse radars the peak of the power spectrum; for FM pulse radars the average of the lowest and highest carrier frequencies during the pulse.
- N = total number of chips (subpulses) contained in the pulse. (N = 1 for non-FM and FM pulse radars.)
- PG = processing gain (dB).
- P_p = peak power (dBm).
- PRR = pulse repetition rate in pulses per second.
- P_t = maximum spectral power density -dBm/kHz.
- t = emitted pulse duration in μ sec. at 50% amplitude (voltage) points. For coded pulses the pulse duration is the interval between 50% amplitude points of one chip (sub-pulse). The 100% amplitude is the nominal flat top level of the pulse (see Fig. 1).
- t_r = emitted pulse rise time in μ sec. from the 10% to the 90% amplitude points on the leading edge. See Fig. 1. For coded pulses it is the rise time of a sub-pulse; if the sub-pulse rise time is not discernible, assume that it is 40% of the time to switch from one phase or sub-pulse to the next.
- t_f = emitted pulse fall time in μ sec from the 90% to the 10% amplitude points on trailing edge. See Fig. 1 and endnote 9.

5.3.1 Criteria B

1. Effective Dates

Technical criteria for new radars shall become effective 1 October 1977 except as noted herein. (New radars are those for which development and subsequent procurement contracts are let after 1 October 1977.)

2. Applicability

These criteria are applicable to radars of Group B, "Radars having a rated peak power of more than 1 kW but not more than 100 kW and operating between 2900 MHz and 40 GHz."

3. Radar Emission Bandwidth

Radars for which development and subsequent procurement contracts are let after 1 October 1977 but before 1 October 1980, shall meet the criteria in Column A below. Radars for which development and subsequent procurement contracts are let after 1 October 1980 shall meet the criteria in Column B below.

All radars procured after 1 October 1986 shall be in compliance with Column B below.

All radars procured subsequent to 1 January 1978 and prior to 1 October 1986 shall be brought into compliance with Column B by 1 October 1991.

All radars procured prior to 1 January 1978 should be brought into compliance with B when undergoing major overhaul.

The emission bandwidth for radars at the antenna input shall not exceed the following limits:

NOTE: There is also the "necessary bandwidth" parameter that is defined for radars. For the method of calculation, see Annex J.

3.1 For Non-FM pulse radars (including spread spectrum or coded pulse radars):[9]

Column A

$$B(-40dB) = \frac{10}{\sqrt{t_r t}} \quad or \quad \frac{64}{t}$$

whichever is less

Column B

$$B(-40dB) = \frac{7.6}{\sqrt{t_r t}} \quad or \quad \frac{64}{t}$$

whichever is less

3.2 For FM-pulse radars (intentional FM):[9]

Column A

$$B(-40dB) = \frac{10}{\sqrt{t_r t}} + 2(B_c + \frac{0.0075}{t_r})$$

Column B

$$B(-40dB) = \frac{7.6}{\sqrt{t_r t}} + 2(B_c + \frac{0.065}{t_r})$$

For FM-pulse radars with pulse rise time, t_r, of less than 0.1 microsecond, an operational justification for the short rise time shall be provided.

3.3 For FM pulse radars (intentional FM) with frequency hopping:[8,9]

Column A

$$B(-40dB) = \frac{10}{\sqrt{t_r t}} + 2(B_c + \frac{0.0075}{t_r}) + B_s$$

Column B

$$B(-40dB) = \frac{7.6}{\sqrt{t_r t}} + 2(B_c + \frac{0.065}{t_r}) + B_s$$

For FM pulse radars (intentional FM) with frequency hopping, but with pulse rise time, t_r, of less than 0.1 microsecond an operational justification for the short rise time shall be provided.

3.4 For frequency hopping radars using non-FM pulses (including spread spectrum or coded pulses):[8,9]

Column A

$$B(-40dB) = \frac{10}{\sqrt{t_r t}} + B_s$$

Column B

$$B(-40dB) = \frac{7.6}{\sqrt{t_r t}} + B_s$$

For this category of radars, an operational justification shall be provided if the pulse rise time, t_r, or fall time, t_f, is less than 0.01 microseconds.

3.5 For CW radars:

Columns A and B

$$B(-40dB) = 0.0003F_o$$

3.6 For FM/CW radars:

Columns A and B

$$B(-40dB) = 0.0003f_0 + 2b_d$$

4. Emission Levels

4.1 With the exception of CW and FM/CW radars, the radar emission level at the antenna input shall be no greater than the values obtainable from the curve in Figure 2. At the frequency + B(-40dB)/2 displaced from F_0, the level shall be at least 40 dB below the maximum value. At and beyond the frequencies + B(-XdB)/2 from F,, the level shall be at least the dB value below the maximum spectral power density given by:

$$X(dB) = 60dB, \text{ or } X(dB) = Pt + 30$$

whichever is the larger value

Between the -40dB and -XdB frequencies the level shall be below the 20dB per decade (S =20) roll-off lines -in Figure 2.

NOTE: Pt ***may be measured or may for the purpose of these criteria be calculated from the following:***

$$Pt = Pp + 20\log_{(N)} + 10\log_{(PRR)} - PG - 90$$

where PG = 0, for non-FM, non-encoded pulse radars

$10\log_{(d)}$, for FM pulse radars

$10\log_{(N)}$, for coded pulse radars

4.2 For CW and FM/CW radars, the levels of all emissions at the antenna input shall be no greater than the values obtainable from the curve in Figure 2. At the frequencies + B(-40 dB)/2 displaced from Fo, the level shall be at least 40 dB below the maximum value. At and beyond the frequencies + B(X dB)/2 from F,, the level shall be at least 60 dB below the maximum level of the signal contained within B(-40 dB). All levels are specified for a 1.0 kHz measurement bandwidth. Between the -40 dB and -X dB frequencies, the level shall be below the 20 dB per decade (S =20) rolloff lines in Figure 2.

5. Antenna Pattern

No requirement is specified at present.

6. Frequency tolerance

Radar transmitters shall meet a frequency tolerance no larger than those noted in the following table:

Frequency Range (MHz)	Tolerance (Parts/Million)
2900-4000	800
4000-10,500	1250
10,500-30,000	2500
30,000-40,000	5000

7. Radar Tunability

Each radar shall be tunable in an essentially continuous manner either over the allocated bands for which it is designed to operate, or over a band which is 10% of the midband frequency. Crystal controlled radars conform to this requirement if operation at essentially any frequency across the band can be achieved with a crystal change.

8. Radar Receivers

The overall receiver selectivity characteristics shall be commensurate with or narrower than the transmitter bandwidth, as portrayed in Figure 2. Rejection of spurious responses, other than image responses, shall be 50 dB or better except where broadband front ends are required operationally. Receivers shall not exhibit any local oscillator radiation greater than -40 dBm at the receiver input terminals. The frequency stability shall be commensurate with, or better than, that of the associated transmitter.

9. Measurement Capability

In order to coordinate radar operations in the field, an accurate measurement of the operating frequency is necessary. An accuracy of +1 part of 10^6 is desirable, although, for most radars + 100 parts in 10^6 is adequate. Of comparable importance is the capability to measure pulse rise time and spectrum occupancy. Accordingly, each Government agency shall have access to the instrumentation necessary to make a frequency measurement to at least + 100 parts in 10^6 and suitable oscilloscopes and spectrum analyzers to measure time and frequency parameters necessary to determine conformance with these criteria. For fast rise time devices, such as magnetrons, oscilloscopes with bandwidths of at least 50 MHz should be used.

5.3.2 **Criteria C**

1. Effective Dates

Technical criteria for new radars shah become effective 1 October 1977 except as noted herein. (New radars are those for which development and subsequent procurement contracts are let after 1 October 1977.)

2. Applicability

These criteria are applicable to radars of Group C, “all radars below 40 GHz not included in Group A, B or D”.

3. Radar Emission Bandwidth

Radars for which development and subsequent procurement contracts are let after 1 October 1977, but before 1 October 1980, shall meet the criteria in Column A below. Radars for which development and subsequent procurement contracts are let after 1 October 1980 shall meet the criteria in Column B below.

All radars procured after 1 October 1986 shall be in compliance with Column B below.

All radars procured subsequent to 1 January 1978 and prior to 1 October 1986 shall be brought into compliance with Column B by 1 October 199 1.

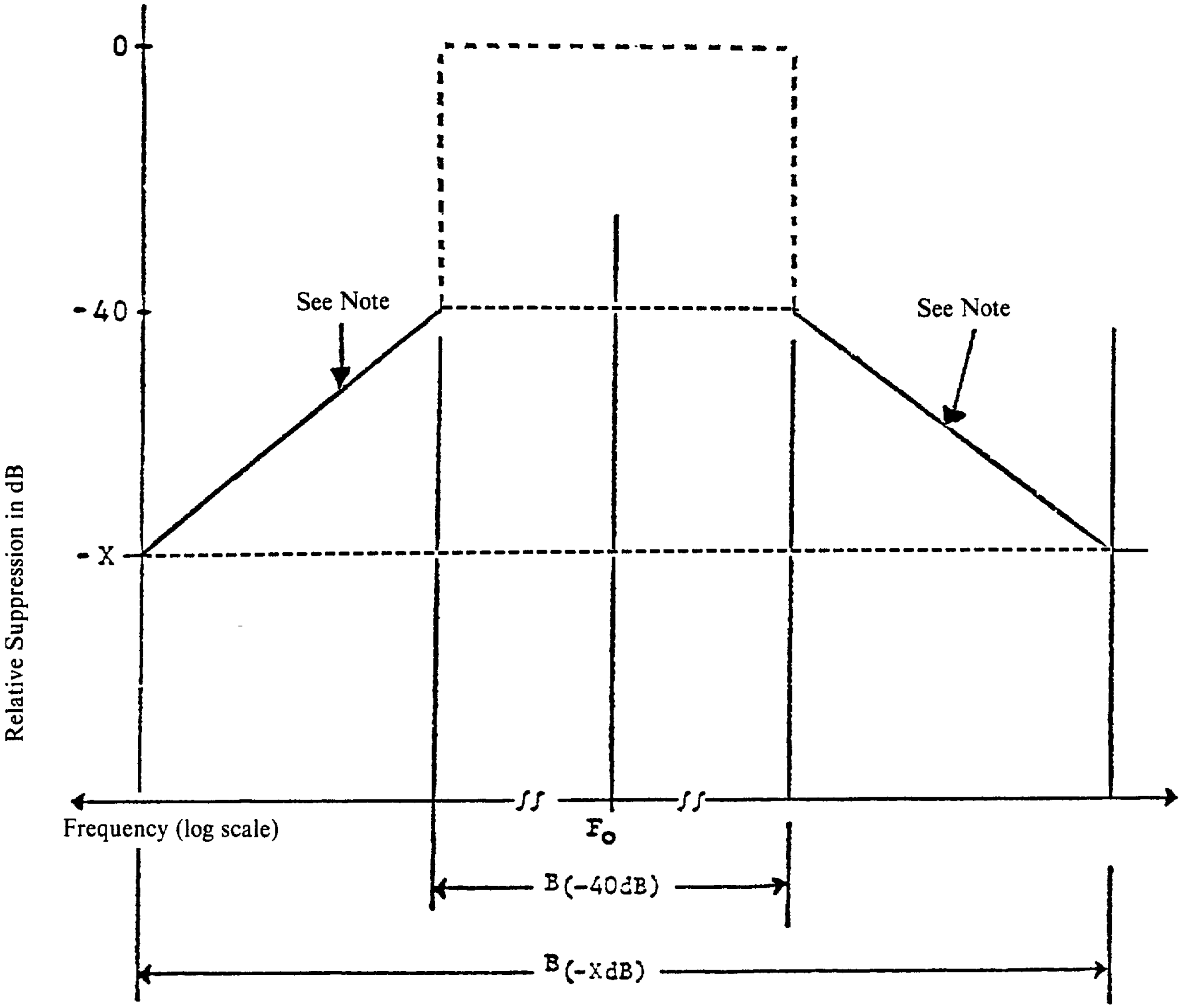
All radars procured prior to 1 January 1978 should be brought into compliance with B when undergoing major overhaul.

The emission bandwidth for radars at the antenna input shall not exceed the following limits:

NOTE: There is also the “necessary bandwidth ” parameter that is defined for radars. For the method of calculation, see Annex J.

3.1 For non-FM pulse radars (including spread spectrum or coded pulse radars):[9]

Figure 2. Radar Emission Bandwidth and Emission Levels



NOTE: The roll-off slope, S, from the -40 dB to -X dB points is at 20 dB per decade for Criteria B and C, and 40 to 80 dB per decade for Criteria D. The maximum emission spectrum level between the -40 dB and -X dB points for S dB per decade slope is described by the formula:

$$Suppression\ (dB) = -S * \log\left|\frac{F - F_o}{\frac{1}{2}B(-40dB)}\right| - 40$$

$$Where:\ \frac{1}{2}B(-40dB) \le |F - F_o| \le \frac{1}{2}B(-XdB)$$

$$and:\ B(-XdB) = (10^{a})\ B(-40dB)$$

$$a = \frac{X-40}{S}$$

Column A

$$B(-40dB) = \frac{7.6}{\sqrt{t_r t}} \quad or \quad \frac{64}{t}$$

whichever is less

Column B

$$B(-40dB) = \frac{6.2}{\sqrt{t_r t}} \quad or \quad \frac{64}{t}$$

whichever is less

3.2 For FM-pulse radars (intentional FM):[9]

Column A

$$B(-40dB) = \frac{7.6}{\sqrt{t_r t}} + 2(B_c + \frac{0.065}{t_r})$$

Column B

$$B(-40dB) = \frac{6.2}{\sqrt{t_r t}} + 2(B_c + \frac{0.105}{t_r})$$

For FM pulse radars with pulse rise time, t_r, or fall time, t_f, of less than 0.1 microsecond, an operational justification for the short rise time shall be provided.

3.3 For FM pulse radars (intentional FM) with frequency hopping:[9, 10]

Column A

$$B(-40dB) = 7.6 + 2(B_c + \frac{0.065}{t_r}) + B_s$$

Column B

$$B(-40dB) = 6.2 + 2(B_c + \frac{0.105}{t_r}) + B_s$$

For FM pulse radars (intentional FM) with frequency hopping, but with pulse rise time, t_r, of less than 0.1 microsecond, an operational justification for the short rise time shall be provided.

3.4 For frequency hopping radars using non-FM pulses (including spread spectrum or coded pulses):[9, 10]

Column A

$$B(-40dB) = \frac{7.6}{\sqrt{t_r t}} + B_s$$

Column B

$$B(-40dB) = \frac{6.2}{\sqrt{t_r t}} + B_s$$

For this category of radars, an operational justification shall be provided if the pulse rise time, t_r, is less than 0.01 microsecond.

3.5 For CW radars:

Columns A and B

$$B(-40dB) = 0.003F_o$$

3.6 For FM/CW radars:

Columns A and B

$$B(-40dB) = 0.003F_o + 2B_d$$

4. Emission Levels

4.1 With the exception of CW and FM/CW radars, the radar emission levels at the antenna input shall be no greater than the values obtainable from the curve in Figure 2. At the frequency $\pm$ B(−40dB)/2 displaced from F_o, the level shall be at least 40 dB below the maximum value. At and beyond the frequencies $\pm$ B(−XdB/2) from F_o, the level shall be at least the dB value below the maximum spectral power density given by:

$$X(dB) = 60dB, \quad or \quad X(dB) = P_t + 30$$

whichever is the larger value

Between the −40dB and −XdB frequencies the level shall be below the 20dB per decade (S=20) roll-off lines in Figure 2.

NOTE: P_t *may be measured or may for the purpose of these criteria be calculated from the following:*

$$P_t = P_p + 20\log_{(N_p)} + 10\log_{(PRR)} - PG - 90$$

where PG = 0, for non-FM, non-encoded pulse radars
$10\log_{(d)}$, for FM pulse radars
$10\log_{(N)}$, for coded pulse radars

4.2 For CW and FM/CW radars, the levels of all emissions at the antenna input shall be no greater than the values obtainable from the curve in Figure 2. At the frequencies + B(-40 dB)/2 displaced from Fo, the level shall be at least 40 dB below the maximum value. At and beyond the frequencies + B(X dB)/2 from F,, the level shall be at least 60 dB below the maximum level of the signal contained within B(-40 dB). All levels are specified for a 1.0 kHz measurement bandwidth. Between the -40 dB and -X dB frequencies, the level shall be below the 20 dB per decade (S =20) rolloff lines in Figure 2.

5. Antenna Pattern

Since electromagnetic compatibility considerations involved phenomena which may occur at any angle, the allowable antenna patterns for many radars may be usefully described by "median gain" relative to an isotropic antenna." Antennas operated by their rotation through 360" of the horizontal plane shall have a "median gain" of – 10 dB or less, as measured on an antenna test range, in the principal horizontal plane. For other antennas, suppression of lobes other than the main antenna beam shall be provided to the following levels, referred to the main beam:

first three sidelobes–17 dB:
all other lobes--26 dB.

6. Frequency Tolerance

Radar transmitters shall meet a frequency tolerance no larger than those noted in the following table:

Frequency Range (MHz)	Tolerance (Parts/Millions)
Below 960	400
960-4000	800
4,000-10,500	1,250
10,500-30,000	2,500
30,000-40,000	5,000

7. Radar Tunability

Each radar shall be tunable in an essentially continuous manner either over the allocated bands for which it is designed to operate, or over a band which is 10% of the midband frequency. Crystal controlled radars conform to this requirement if operation at essentially any frequency across the band can be achieved with a crystal change.

8. Radar Receivers

The overall receiver selectivity characteristics shall be commensurate with the transmitter bandwidth, as portrayed in Figure 2. Receivers shall be capable of switching bandwidth limits to appropriate values -whenever the transmitter bandwidth is switched (pulse shape changed). Receiver image rejection shall be at least 50 dB; rejection of other spurious responses shall be at least 60 dB. Radar receivers shall not exhibit any local oscillator radiation greater than -40 dBm at the receiver input terminals. Frequency stability of receivers shall be commensurate with, or better than, that of the associated transmitters.

9. Measurement Capability

In order to coordinate radar operations in the field, an accurate measurement of the operating frequency is necessary. An accuracy of + 100 parts in 10^6 is adequate. Of comparable importance is the capability to measure pulse rise time and spectrum occupancy. Accordingly, each Government agency shall have access to the instrumentation necessary to make a frequency measurement to at least + 100 parts in 10^6 and suitable oscilloscopes and spectrum analyzers to measure time and frequency parameters necessary to determine conformance with these criteria. For fast rise time devices, such as magnetrons, oscilloscopes with bandwidths of at least 50 MHz should be used.

5.3.3 Criteria D

1. Effective Dates

Technical criteria for new fixed radars in the 2700-2900 MHz band shall become effective on 1 October 1982. (New radars are those for which the initial system procurement contract is let after 1 October 1982.)

2. Applicability

These criteria are applicable to fixed radars in the 2700-2900 MHz band. All radars subject to these criteria shall be designed and constructed to meet the basic minimum electromagnetic compatibility (EMC) requirements stated herein. In addition to the basic minimum EMC requirements, radar systems in the 2700-2900 MHz band which are intended to operate in close proximity to other equipment in the band or operate in areas specified in Annex D shall be designed and constructed to permit, without modification to the basic equipment, field incorporation of EMC enhancement provisions. These additional provisions will improve the electromagnetic compatibility of the radar thus improving the accommodation of the radar system in the band. These provisions are stated in Section 5.3.3, paragraph 9.

3. Radar Emission Bandwidth

The emission bandwidth for radars at the antenna input shall not exceed the following limits:

a. For non-FM pulse radars (including spread spectrum or coded pulse radars):[9]

$$B(-40dB) = \frac{6.2}{\sqrt{t_r t}}$$

For non-FM pulse radars, a pulse rise time, t_r, or fall time, tf,of less than 0.1t shall be justified:

b. For FM-pulse radars (intentional FM):[9]

$$B(-40dB) = \frac{6.2}{\sqrt{t_r t}} + 2(B_c + \frac{0.105}{t_r})$$

For FM pulse radars with pulse rise time, t_r, of less than 0.1 microsecond, a justification for the short rise time shall be provided.

c. For FM pulse radars (intentional FM) with frequency hopping:[9, 12]

$$B(-40dB) = \frac{6.2}{\sqrt{t_r t}} + 2(B_c + \frac{0.105}{t_r}) + B_s$$

For FM pulse radars (intentional FM) with frequency hopping, but with pulse rise time, t_r, of less than 0.1 microsecond, an operational justification for the short rise time shall be provided.

d. For frequency hopping radars using non-FM pulses (including spread spectrum coded pulses):[9,11]

$$B(-40dB) = \frac{6.2}{\sqrt{t_r t}} + B_s$$

For this category of radars, an operational justification shall be provided if the pulse rise time, t_r, is less than 0.01 microsecond.

e. For CW radars:

$$B(-40dB) = 0.0003F_o$$

f. For FM/CW radars:

$$B(-40dB) = 0.0003F_o + 2B_d$$

4. Emission Levels

4.1 With the exception of CW and FM/CW radars, the radar emission levels at the antenna input shall be no greater than the values obtainable from the curve in Figure 2. At the frequency ± B(−40 dB)/2 displaced from F_o the level shall be at least 40 dB below the maximum value. Beyond the frequencies ± B(−40 dB)/2 from F_o, the emission level (s), with the exception of harmonic frequencies, shall be below the 40 dB per decade (S=40) roll-off lines of Figure 2 down to a −X dB level that is 80 dB below the maximum spectral power density. All harmonic frequencies shall be at a level that is at least 60 dB below the maximum spectral power density.

4.2 For CW and FM/CW radars, the levels of all emissions at the antenna input shall be no greater than the values obtainable from the curve in Figure 2. At the frequencies ± B(−40 dB)/2 displaced from F_o, the level shall be at least 40 dB below the maximum value. At and beyond the frequencies B(X dB)/2 from F_o, the level shall be at least 80 dB below the maximum level of the signal contained with B(−40 dB). All levels are specified for a 1.0 kHz measurement bandwidth. Between the −40 dB and −X dB frequencies, the level shall be below the 40 dB per decade (S=40) rolloff lines in Figure 2.

5. Antenna Pattern

Since electromagnetic compatibility considerations involved phenomena which may occur at any angle, the allowable antenna patterns for many radars may be usefully described by "median gain" relative to an isotropic antenna.[13] Antennas operated by their rotation through 360 degrees of the horizontal plane shall have a "median gain" of −10 dB or less, as measured on an antenna test range, in the principal horizontal plane. For other antennas, suppression of lobes other than the main antenna beam shall be provided to the following levels, referred to the main beam:

first three sidelobes--17 dB;
all other lobes--26 dB.

6. Frequency Tolerance

Radar transmitters shall meet a frequency tolerance no greater than 800 parts/million.

7. Radar Tunability

Radar systems shall be tunable over the entire 2700-2900 MHz band.

8. Radar Receiver

The overall receiver selectivity characteristics shall be commensurate with the transmitter bandwidth, as portrayed in Figure 2. Receivers shall be capable of switching bandwidth limits to appropriate values whenever the transmitter bandwidth is switched (pulse shape changed). Receiver image rejection shall be at least 50 dB; rejection of other spurious responses shall be at least 60 dB. Radar receivers shall not exhibit any local oscillator radiation greater than -40 dBm at the antenna input terminals. Frequency stability of receivers shall be commensurate with, or better than, that of the associated transmitters.

9. Additional EMC Provisions

To improve the accommodation of radar systems in the 2700-2900 MHz band which operate in close proximity to other equipment in the band or operate in areas specified in Annex D, the radar shall be designed and constructed to permit, without modification to the basic equipment, field incorporation of system EMC provisions. These provisions include the requirement to meet specifications in accordance with paragraphs a. and b. below and the recommendation to meet guidelines in accordance with paragraph c. below.

a. Emission Levels

The radar emission levels at the antenna input shall be no greater than the values obtainable from the curves in Figure 2. At the frequency +B(-40 dB)/2 displaced from Fo, the level shall be at least 40 dB below the maximum value. Beyond the frequencies + B(-40 dB)/2 from Fo, the equipment shall have the capability to achieve up to 80 dB per decade (S= 80) roll-off lines of Figure 2. The emission levels, with the exception of harmonic frequencies, shall be below the appropriate dB per decade roll-off lines of Figure 2 down to a -X dB level that is 80 dB below the maximum spectral power density. All harmonic frequencies shall be at a level that is at least 60 dB below the maximum spectral power density.

b. Radar System PRF

The radar system shall be designed to operate with an adjustable pulse repetition frequency (s), PRF (s), with a nominal difference of + 1% (minimum). This will permit the selection of PRF's to allow certain types of receiver interference suppression circuitry to be effective.

c. Receiver Interference Suppression Circuitry

Radar systems in this band should have provisions incorporated into the system to suppress pulsed interference. The following information is intended for use as an aid in the design and development of receiver signal processing circuitry or software to suppress asynchronous pulsed interference. A description of the parametric range of the expected environmental signal characteristics at the receiver IF output is:

Peak Interference-to-Noise Ratio: < 50 dB
Pulse width: 0.5 to 4.0 usec
PRF: 100 to 2000 pps

10. Measurement capability

In order to coordinate radar operations in the field, an accurate measurement of the operating frequency is necessary. An accuracy of + 100 parts in 10^6 is adequate. Of comparable importance is the capability to measure pulse rise time and spectrum occupancy. Accordingly, each Government agency shall have access to the instrumentation necessary to make a frequency measurement to at least + 100 parts in 10^6 and suitable oscilloscopes and spectrum analyzers to measure time and frequency parameters necessary to determine conformance with these criteria. For fast rise time devices, such as magnetrons, oscilloscopes with bandwidths of at least 50 MHz should be used.

5.3.4 Criteria E

1. Effective Dates

Technical criteria for new wind profiler radars (WPR) operating on 449 MHz shall become effective on 1 January 1994. (New WPRs are those for which the initial systems procurement contract is let after 1 January 1994.

2. Applicability

These criteria are applicable to WPR's operating on 449 MHz.

3. Emission Bandwidth

The emission bandwidth for WPR's at the antenna input shall not exceed the following limits:

3.1 For non-FM pulse radars (including coded pulse radars):

$B(-40\ dB)=6.2/(t_r t)^{1/2}$ or $64/t$, whichever is less.

3.2 For FM-pulse radars (intentional FM):

$B(-40\ dB)=6.2/(t_r t)^{1/2} + 2(B_c + 0.105/t_r)$

3.3 For wind profiler radars, an operational justification shall be provided if the pulse rise time, t,, is less than 0.01 microsecond.

3.4 For CW radars

$B\ (-40\ dB) = 0.003\ F_o$

3.5 For FM/CW radars

$B\ (-40\ dB) = 0.003\ F_o + 2B_d$

4. Emission Levels

WPR emission levels at the antenna input shall be no greater than the values obtainable from the curve in Figure 3. At the Frequencies + B(-40 dB)/2 displaced from Fo, the level shall be at least 40 dB below the maximum value. At and beyond the frequencies + B(-XdB)/2 from Fo, the level shall be at least the dB value below the maximum spectral power density given by:

X(db) = 60 dB, or
X(dB) =Pt+30,
whichever is the
greater attenuation

Between the -40 dB and -X dB frequencies, the level shall be below the 40 dB per decade (S = 40) roll-off lines in Figure 3. All harmonic frequencies shall be at a level that is at least 60 dB below the maximum spectral power density-

NOTE: Pt may be measured or may for the purpose of these criteria be calculated from the following:

$P_t = P_p + 20\log(N_t) + 10\log(PRR) - PG - 90.$

5. Antenna Gain Characteristics

The center of the antenna main beam generated at any time shall be limited within a cone of half-angels that are 20 degrees from the zenith. The sidelobe levels (excluding the main beam) in all azimuths shall not exceed the following values:

	Median	Maximum
for elevation angle > 45 degrees	0 dBi	12 dBi
for 5 < elevation angle < 45 degrees	-5 dBi	7dBi
for elevation angle < 5 degrees	-20 dBi	-8 dBi

6. Frequency Tolerance

WPR transmitters shall meet a frequency tolerance no greater that 10 parts per million.

7. WPR Receiver

The -3dB receiver bandwidth should be commensurate with the authorized emission bandwidth plus twice the frequency tolerance of the transmitter as specified in paragraph 5.3.4.6. The -60dB receiver bandwidth shall be commensurate with the -60dB emission bandwidth. Receivers shall be capable of switching bandwidth limits to appropriate values whenever the transmitter bandwidth is switched (pulse shape changed). Receiver IF image frequency rejection shall be at least 50dB. Rejection of other spurious responses shall be at least 60dB. WPR receivers shall not exhibit any local oscillator radiation greater than -40dBm at the antenna input terminals. Frequency stability of receivers shall be commensurate with, or better than, that of the associated transmitters.

8. EMC Provision

WPR's shall have the capacity to tolerate incoherent pulsed interference of duty cycles less than 1.5 percent such that peak interfering signal levels 30 d.B greater than WPR receiver noise level at the IF output will not degrade WPR performance.

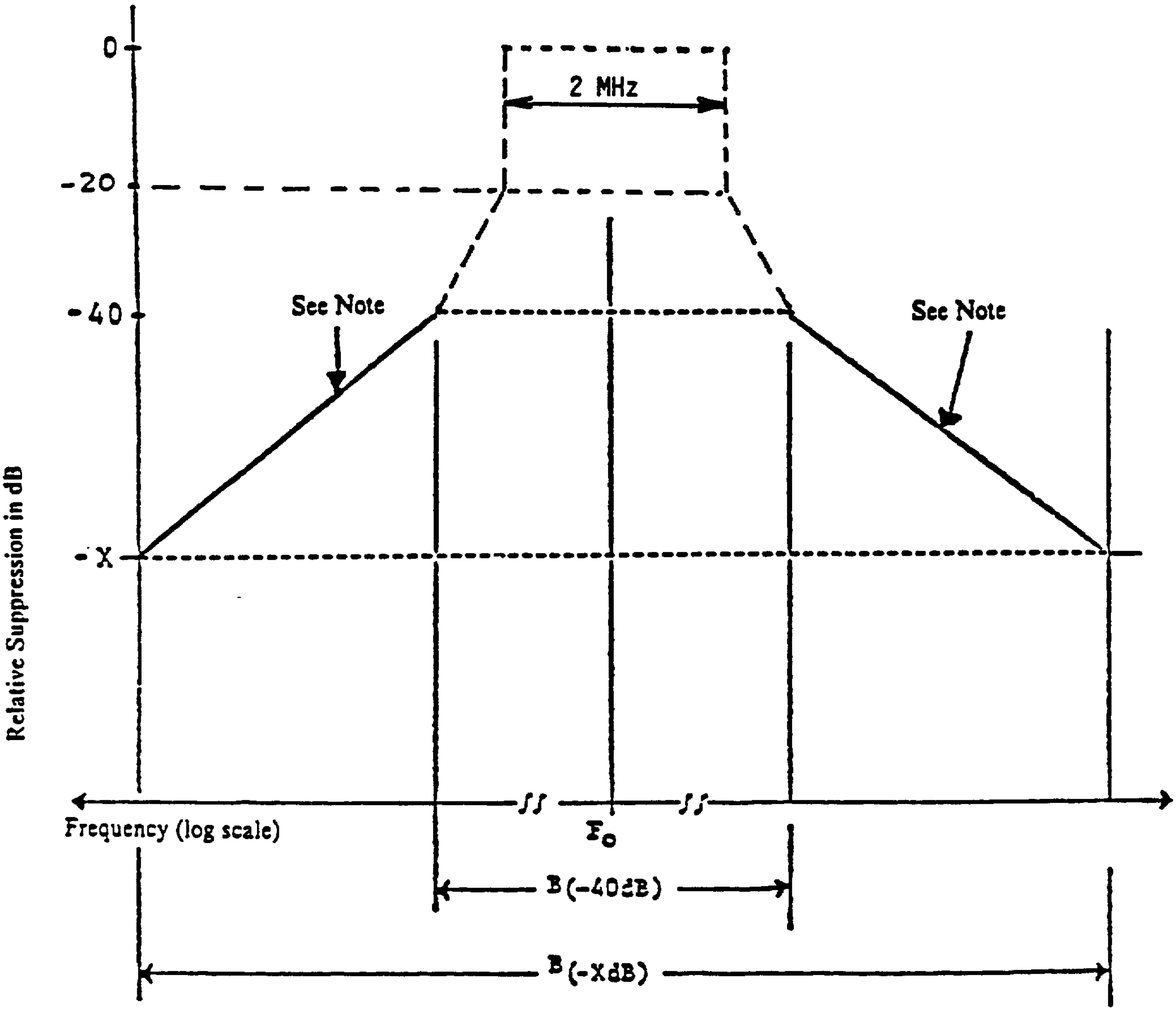
9. Measurement Capability

In order to coordinate radar operations in the field, an accurate measurement of the operating frequency is necessary. An accuracy of 1 .O part per million is adequate. Of comparable importance is the capability to measure pulse rise time and spectrum occupancy. Accordingly, the instrumentation necessary to make a frequency measurement shall have at least 1.0 part per million and suitable oscilloscopes and spectrum analyzers to measure time and frequency parameters necessary to determine conformance with these criteria. Measurement instruments shall have resolution bandwidths of at least 10 kHz to measure close in bandwidth limits, and otherwise 100 kHz bandwidth below 1 GHz and 1 MHz bandwidth at and above 1 GHz should be used.

10. ERP

The peak EIRP of any WPR operating at 449 MHz shall not exceed 110 d.Bm.

Figure 3. Radar Emission Bandwidth and Emission Levels for Wind Profiler Radars at 449 MHz (Criteria E)



Note: The roll-off slope, S, from the -40 dB to -X dB points is at 40 dB per decade for Criteria E. The -20 dB bandwidth is limited to 2 MHz for Wind Profiler radars operating at 449 MHz. The maximum emission spectrum level between the -40 dB and -X db points for S dB per decade slope is described by the formula:

$$Suppression\ (dB) = -S * \log \left| \frac{F - F_o}{\frac{1}{2}B(-40dB)} \right| -40$$

$$Where:\ \frac{1}{2}B(-40dB) \le |F - F_o| \le \frac{1}{2}B(-XdB)$$

$$and:\ B(-XdB) = (10^a)\ B(-40dB)$$

$$a = \frac{X-40}{S}$$

5.4 FIXED SERVICES

5.4.1 Single Sideband and Independent Sideband Equipments. (2-30 MHz)

In using the spectrum standards indicated below, it should be recognized that they do not bar any agency from making improvements thereon.

A. Transmitter Standards

1. The frequency tolerance of transmitters shall be 20 Hz.

2. Unwanted Emissions. The peak power of any emission on any frequency removed from the center of the authorized bandwidth[14] (BW) by a displacement frequency (fd) shall be attenuated below the peak envelope power (pX) of the transmitter in accordance with the following schedule:

fd	Attenuation in dB
50%BW <fd<150% BW	26
150% BW < fd < 250% BW	35
fd > 250% BW	80 or 40 + 10 log (pX) whichever is the lesser attenuation.

3. Where suppressed carrier operation is employed, transmitters shall be capable of operation with the emitted carrier power attenuated at least 40 dB below peak envelope power.

4. Where compatibility with conventional double sideband AM receivers is required single sideband transmitters shall have the capability to transmit the carrier at a level of not more than 6 dB below the peak envelope power.

B. Receiver Standards

1. Selectivity. The passband[15] shall be no greater than the authorized bandwidth of emission and the slope of the selectivity characteristic outside the passband shall be 100 dB/kHz.

2. Tunability. The equipment shall be capable of operation on any frequency within its tuning range. However, where a synthesizer is employed as the frequency controlling element, the receiver shall be capable of operation on any frequency which is an integral multiple of 0.1 kHz.

C. Antenna Standards[16]

1. Directive antennas are not required below 4 MHz. Directive antennas shall be employed above 4 MHz unless in specific cases they are shown to be impracticable.

Minimum forward power gain over an isotropic radiator located at the same height over the same earth as directive antenna shall be 10 dB in the range 4 to 10 MHz and 15 dB[17] in the range 10 to 30 MHz. The gain of any reference antenna used in an actual measurement must be specified relative to an isotropic antenna.

The antenna gain in the desired direction over that of a lobe in any other direction shall be greater than 6 dB.

5.4.2 Fixed Services (406.1-420 MHz Band, the 932-935/941-944 MHz Bands, and the 1710 MHz-15.35 GHz Frequency Range)

The following standard is for Federal Govemment Fixed Services employing: (a) multichannel equipments in the 406.1-420 MHz band, (b) point-to-point and point-to-multipoint equipments in the bands 932-935/941-944 MHz, or (c) point-to-point and transportable type equipments operating between 1710 MHz and 15.35 GHz (except for systems designed to use scatter techniques or where other specific exceptions are stated herein).

This standard became effective on August 28, 1990, for fixed operations (point-to-point and point-to-multipoint) in the bands 932-935/941-944 MHz. These bands were allocated for Govemment and non-Government fixed service usage on a co-primary basis on February 1, 1985. Standards for receivers operating in the bands 932-935/941-944 MHz, are not mandatory and are presented herein to provide guidelines to promote efficient and effective use of these shared frequencies.

This standard became effective on January 1, 1987, for multichannel equipments operating in the 406.1-420 MHz band. Such equipment placed in operation or contracted for prior to January 1, 1987, may continue to operate without regard to the requirements of this standard.

This standard became effective on January 1, 1979, for fixed equipments operating in the 1710-15.35 GHz frequency range. Such equipment placed in operation or contracted for prior to January 1, 1979 may continue to operate without regard to the requirements of this standard until January 1, 1994.

A. Transmitter Standards:

1. The frequency tolerance of transmitters shall be:

406.1-420 MHz . . 2.5 ppm.

932-932.5 **MHz** and
941-941.5 MHz 1.5 ppm (point-to-multipoint)
932.5-935 and
941.5-944 MHz 2.5 ppm (point-to-point)

1.7-4.0 GHz	30 ppm for 10W or less transmitter power	10 ppm for transmitter power above 100W
4.0-10.5 GHz	50 ppm for 100W or less transmitter power	10 ppm for transmitter power above 100W
10.5-15.35 GHz	50 ppm.	

Measurement Method. A sample of the unmodulated carrier at the center frequency should be measured with equipment having an accuracy of at least five times that of the minimum to be measured.

2. Unwanted Emissions. The average power of any emission on any frequency removed from the center of the authorized bandwidth (BW) by a displacement frequency (fd) shall be attenuated below the mean output power (pY) of the transmitter in accordance with the following schedule:

(a) For transmission other than those employing digital modulation techniques:

fd	Attenuation in dB
50%BW < fd<l00% BW	25
l00% BW < fd < 250% BW	35
fd > 250% BW	43 + 10log (pY) or 43

Whichever is the greater attenuation. Attenuation greater than 80 dB is not required.

(b) For transmissions employing digital-modulation techniques: [18]

In any 4 kHz band, the center frequency of which is removed from the assigned frequency by more than 50 percent, up to and including 250 percent, of the authorized bandwidth as specified by the following equation but at least 50 decibels:

A = 35 + 0.8(% -50)+10 log BW

where:

A = attenuation (in decibels) below the mean output power level, % = percent of the authorized bandwidth removed from the assigned frequency.

BW = authorized bandwidth in MHZ.

Attenuation greater than 80 decibels is not required.

In any 4 kHz band, the center frequency of which is removed from the assigned frequency by more than 250 percent of the authorized bandwidth: At least 43 plus 10 log,, (mean output power in watts) decibels, or 80 decibels, whichever is the lesser attenuation.

Measurement Method. A sample of the transmitter output at the interface point with the antenna transmission line shall be measured using a measurement system with 4 kHz resolution bandwidth. The full unmodulated carrier power output is used as the transmitter average power output reference.

Measurement of the unwanted emissions shall be made from the lowest radio frequency generated in the equipment to the third harmonic of the carrier with the transmitter modulated as follows:

(1.) Analog--white noise generator in accordance with EIA Standard RS-252A recommended loading levels.

(2.) Digital--pseudorandom code generator with appropriate loading levels and format.

(3.) When using transmissions employing digital modulation techniques on the 900 MHz multiple address frequencies with a 12.5 kHz bandwidth, the power of any emission shall be attenuated below the unmodulated carrier power of the transmitter (P) in accordance with the following schedule:

(i) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (fd in kHz) of more than 2.5 kHz up to and including 6.25 kHz: At least 53 $\log_{10}$(fd/2.5) decibels;

(ii) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (fd in kHz) of more than 6.25 kHz up to and including 9.5 kHz: At least 103 $\log_{10}$(fd/3.9) decibels;

(iii) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (fd in kHz) of more than 15 kHz: At least 157 $\log_{10}$(fd/5.3) decibels;

(iv) On any frequency removed from the center of the authorized bandwidth by a displacement frequency greater that 15 kHz: At least 50 plus 10 log,,(P) or 70 decibels, whichever is the lesser attenuation.

(4) When using transmissions employing digital modulation techniques on the 900 MHz multiple address frequencies with a bandwidth greater that 12.5 kHz, the power of any emission shall be attenuated below the unmodulated carrier power of the transmitter (P) in accordance with the following schedule;

(i) On any frequency removed from

the center of the authorized bandwidth by a displacement frequency (fd in kHz) of more than 5 kHz up to and including 10 kHz: At least 83 log,, (fd/5) decibels;

(ii) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (fd in kHz) of more than 10 kHz up to and including 250 percent of the authorized bandwidth: At least 116 log,, (fd/6.1) or 50 plus 10 log,,(P) or 70 decibels, whichever is the lesser attenuation;

(iii) On any frequency removed from the center of the authorized bandwidth by more than 250 percent of the authorized bandwidth: At least 43 plus 10 log10(output power in watts) decibels or 80 decibels, whichever is the lesser attenuation.

The maximum equivalent isotropic radiated power (EIRP) shall not exceed the values specified below. However, the additional constraints of Section 8.2.34 of this manual apply.

Frequency Band (MHz)	Maximum Allowable EIRP (dBm)
406.1-420	80
932-932.5	47
932.5-935	70
941-941.5	60
941.5-944	70
17104990	80
7125-15350	85

B. Receiver Standards

1. For the 406.1-420 MHz band, the receiver frequency tolerances shall be maintained within + 10 ppm. For all other systems the receiver Intermediate frequency (IF) shall be maintained at the specified center of the receiver passband within + 2 percent of the -3 dB receiver IF bandwidth when the receiver carrier is at its assigned frequency.

Measurement Method. The Intermediate Frequency (IF) shall be measured with equipment having an accuracy of at least five times greater than the frequency tolerance to be measured. The measurement shall be made with an unmodulated input signal on the assigned frequency coupled to the input of the receiver at a level greater than 20 dB above the receiver ambient noise.

2. The receiver unwanted signals shall be attenuated at least 60 dB relative to the receiver sensitivity at the center of the passband.

Measurement Method. Couple two signal generators to the input of the receiver and connect a spectrum analyzer to the baseband output. The unmodulated output of one signal generator (desired signal) on the assigned frequency shall be adjusted to reduce the baseband noise by 3 dB as observed on the spectrum analyzer. The unmodulated output of the second signal generator (unwanted signals) shall be adjusted to 70 dB above that of the desired signal. The output frequency of the unwanted signals shall be varied over a range of +1 percent of the assigned frequency excluding frequencies within the receiver 60 dB selectivity bandwidth.

At each receiver response of the unwanted frequency, adjust the output of the unwanted signal generator for a 3 dB reduction in baseband noise. The difference, expressed in dB, in the output levels of the two signal generators is the unwanted signal attenuation.

3. Selectivity. Receiver selectivity is the degree to which a receiver is able to discriminate against the effects of undesired signals primarily outside the authorized emission bandwidth that arrive at its RF input terminals.

The -3 dB receiver bandwidth should be commensurate with the authorized emission bandwidth plus twice the frequency tolerance of the transmitter specified in Section 5.4.2 A. The -60 dB receiver bandwidth shall not exceed five times the -3 dB receiver bandwidth.

4. Conducted Undesired Emissions are those undesired signals generated in the receiver and leaving the receiver by way of the receiving transmission line.

Conducted emissions from the receiver on any frequency, as measured at the radio frequency interface point to the antenna system, shall not exceed – 85 dBW. For the bands 406.1-420 MHz and 932-935/941-944 MHz, conducted emissions shall not exceed – 80 dBW.

5. Noise Figure. The noise figure of a receiver is the ratio expressed in dB of (1) the output noise power to (2) the portion of noise power attributable to thermal noise in the input termination at 290 kelvins.

The receiver noise figure including pre-amplifier should be 9 dB or less for frequencies below 4400 MHz, 12 dB or less for frequencies between 4400 MHz, and 10 GHz, and 14 dB or less for higher frequencies (up to 15.35 GHz).

C. Antenna Standards

The following limitations do not apply to transportable antenna systems when used in tactical and training operations. Additionally, the following limitations do not apply to multipoint distribution systems (point-to-multipoint) operating in the bands 406.1-420 MHz and 932-932.5 941-941.5 MHz.

1. Each station shall employ directional antennas with the major lobe of radiation directed toward the receiving station with which it communicates, or toward any passive repeater that may be used.

2. Antenna Radiation Pattern. The antenna radiation pattern is the relative power gain as a function of direction for the specified polarization.

Directional antennas shall meet the performance standards indicated in Table 5.4.2. For assignments in bands shared with satellite-space services, determination on' additional beamwidth limitations shall be made on a case-by-case basis if mutual interference problems are likely to be involved.

TABLE 5.4.2

Frequency Band	Maximum beamwidth (3 dB point)	Minimum suppression at angle in degrees from center line of main beam (dB)						
		5-10°	10-15°	15-20°	20-30°	30-100°	100-140°	140-180°
406.1-420 MHz[1]	80°	-	-	-	-	10	10	10
a) 932.5-935 MHz/941.5-944 MHz[2]	14°	-	6	11	14	17	20	24
b) 932.5-935 MHz/941.5-944 MHz[2]	20°	-	-	6	10	13	15	20
1710-1850 MHz[3]	10°	-	14	16	18	23	24	30
1710-1850 MHz[4]	8°	5	18	20	20	25	28	36
2200-2400 MHz	8.5°	4	12	16	16	24	25	30
4.4-4.99 GHz	4°	13	20	23	24	29	31	31
7.125-8.5 GHz	2.5°	19	23	28	30	34	35	43
14.4-15.35 GHz	1.5°	21	26	31	35	37	41	48

1 - Any secondary lobe.
2 - Stations in this service must employ an antenna that meets the performance standard except that, in areas not subject to frequency congestion antennas meeting standards for category B may be employed. Note, however, the use of a high performance antennas may be required where interference problems can be resolved by the use of such antennas.
3 - These suppression levels could be met, e.g., by a 1.2 meter (4 foot) diameter parabolic antenna.
4 - This standard is applicable to new stations in the 1710-1850 MHz band placed in service after January 1, 1985, except for those located on the military test ranges specified in Section 7.17.1 and those limitations noted in Section 5.4.2.C. These suppression levels could be met, e.g., by a 1.83 meter (6 foot) diameter parabolic antenna.

5.5 MOBILE

5.5.1 Standard for Mobile Service (2-30 MHz Band)

This standard specifies the spectrum standards for single sideband equipments for single channel voice, direct printing telegraphy and data, in the Mobile services between 2 and 30 MHz (Except in the bands allocated exclusively to the Aeronautical Mobile (R) service).[19] In using the spectrum standards indicated below, it should be recognized that they do not prohibit an agency from making improvements thereon.

A. Transmitter Standards

1. The frequency tolerance of transmitters shall be 20 Hz except for ship transmitters which are permitted a tolerance of 50 Hz.

2. Unwanted Emissions. Except for the land mobile service the peak power of any emission on any frequency removed from the center of the authorized bandwidth[20] (BW) by a displacement frequency (fd) shall be attenuated below the peak envelope power (pX) of the transmitter in accordance with the following schedule:

fd	Attenuation in dB
50%BW<fd<150%BW	26
150%BW<fd<250%BW	35
fd>250%BW	40+10 log (pX) or 80 whichever is the lesser attenuation

For the land mobile service, the peak power of any emission on any frequency removed from the center of the authorized bandwidth' (BW) by a displacement frequency (fd) shall be attenuated below the peak envelope power (pX) of the transmitter in accordance with the following schedule:

fd	Attenuation in dB
1.75kHz<fd<5.25kHz	28
5.25kHz<fd<8.75kHz	38
fd>8.75kHZ	43+10 log (px)

3. The equipment shall be capable of operation on any carrier frequency within its tuning range which is an integral multiple of 0.1 kHz.

4. Where suppressed carrier operation is employed, transmitters shall be capable of operation with the emitted carrier power attenuated at least 40 dB below peak envelope power.

Where compatibility with conventional double sideband AM receivers is required, single sideband transmitters shall have the capability to transmit the carrier at a level of no less than 25 percent of the peak envelope power. The upper sideband mode shall be employed where there is need for working among international services.

B. Receiver Standards

1. Selectivity. The passband[21] shall be no greater than the authorized bandwidth of emission.

The slope of the selectivity characteristic outside the passband shall be 100 dB/kHz.

2. Tunability. The equipment shall be capable of operation on any frequency within its tuning range which is an integral multiple of 0.1 kH.z.

C. Antenna Standards

To the extent practicable, land stations shall use antennas designed so as to reduce their radiation and/or their susceptibility to interference in those directions where service is not required.

5.5.2 Mobile, Maritime, FM Operation, (150.8-162.0125 MHz)

The following standard is for mobile operations in the Maritime Mobile service using FM emissions in the band from 150.8 to 162.0125 MHz with necessary bandwidth less than or equal to 16 kHz.

A. Transmitter Standards

The transmitted carrier frequency shall be maintained within the following tolerances:

Transmitter pY (watts)	Station Type	Frequency Tolerance (Ppm)
pY(3	Coast	100
3<pY<50	Coast	50
pY(25	Ship	100

Measurement method to be used is as given in the latest revision of Electronic Industries Association (EIA) Standard RS-152, Minimum Standards for FM or equivalent."

After January 2 1, 1997, ship station transmitters, except portable ship station transmitters, must be capable of automatically reducing power to one watt or less when tuned to the frequency 156.375 MHz or 156.650 MHz. A manual override device must be provided which when held by the operator will permit full carrier power operation on these channels.

5.5.3 Land Mobile, Single Channel NB Operations in the 220-222 MHz Band

The 220-222 MHz band was reallocated on

September 6, 1988 exclusively for shared Government and non-Government land mobile, single channel, narrowband operations with necessary bandwidth less than or equal to 4 kHz. The 2 MHz available in this band are allocated in 400 5 kHz wide-frequencies paired to create 200 narrowband channels. Of these, 10 channels are allocated exclusively for Government nationwide use and 100 channels are for shared Government and non-Government trunked operations.

This standard becomes effective on January 1, 1992 for land mobile, single channel narrowband operations in the 220-222 MHz band.

A. Transmitter Standards

1. The frequency tolerance of transmitters shall be:

Station Class	Frequency Tolerance (ppm)
Base Station	0.1
Mobile	1.5

MEASUREMENT METHOD:

A sample of the unmodulated carrier at the center frequency should be measured with equipment having an accuracy of at least five times that of the minimum to be measured.

2. Bandwidth Limitations: The maximum authorized bandwidth shall be 4 kHz.

3. Unwanted Emissions: On any frequency removed from the center of the authorized bandwidth by a displacement frequency (fd in kHz), the power of any emission shall be attenuated below the peak envelope power (P) watts in accordance with the following schedule:

fd in kHz	Attenuation in dB
$2 < fd < 3.75$	30 + 20(fd-2) 55 + 10log(P) or 65 whichever is the lesser attenuation
$3.75 < fd$	55 + 10log(P) or 65 whichever is the lesser attenuation

4. Resolution Bandwidth: The resolution bandwidth of the instrumentation used to measure the emission power shall be 100 Hz for measuring emissions up to and including 250 kHz from the edge of the authorized bandwidth, and 10 kHz for measuring emissions more than 250 kHz from the edge of the authorized bandwidth. If a video filter is used, its bandwidth shall not be less than the resolution bandwidth. The power level of the highest emission within the channel to which the attenuation is referenced shall be remeasured for each change in resolution bandwidth.

B. Geographic Separation of Sub-Band A Base Station Receivers and Sub-Band B Base Station Transmitters

Base station receivers utilizing channels assigned for sub-band A as designated in Chapter 4 will be geographically separated from those base station transmitters utilizing channels removed 200 kHz or less and assigned from sub-band B as follows:

Separation Distances (Kilometers)	Effective Radiated Power (Watts) *
0.0-0.3	**
0.3-0.5	5
0.5-0.6	10
0.6-0.8	20
0.8-2.0	40
2.0-4.0	50
4.0-5.0	100
5.0-6.0	200
over 6.0	500

* Transmitter peak envelope power shall be used to determine effective radiated power.

** Stations separated by 0.3 km or less shall not be authorized. This table does not apply to the low-power mobile data channels 196-200. (See Section C.)

Except for nationwide assignments, the separation of co-channel base stations shall be 120 kilometers. Shorter separations will be considered on a case-by-case basis upon submission of a technical analysis indicating that at least a 10 dB protection will be provided to an existing station's 39 dBu signal level contour.

C. Limitations on Power and Antenna Height:

1. The permissible effective radiated power (ERP) with respect to antenna heights shall be determined from the follow table. These are maximum values and applications are required to justify power levels requested.

ERP vs Antenna Height Table

Antenna Height above Average Terrain (HAAT) Meters	Effective Radiated Power (ERP) Watts*
Up to 150	500
150 to 225	250
225 to 300	125
300 to 450	60
450 to 600	30
600 to 750	20
750 to 900	15
900 to 1050	10
Above 1050	5

* Transmitter PEP shall be used to determine ERP.

2. The maximum permissible ERP for mobile units is 50 watts. Portable units are considered as mobile units.

3. Channels 196-200 are limited to 2 watts ERP and a maximum antenna height of 20 feet/6.1 meters above ground.

5.6 FIXED AND MOBILE/LAND MOBILE OPERATIONS

5.6.1 Standard for Analog or Digital FM Operations (30-50, 162-174, and 406.1-420 MHz Bands)[23]

Standards in this section related specifically to digital systems become effective on October 1, 1990.

These standards do not apply to:

o Military equipment used for tactical and/or training operations.

o FM wireless microphone systems whose mean output power does not exceed 0.1 watt.

o Equipment operating on splinter channels. (See Section 5.2.1).

o Fixed stations equipment with multi-channel emissions.

The following is for fixed and mobile/land mobile service employing fixed, land, mobile and portable stations using analog or digital FM or PM emissions in the bands 30-50, 162-174, and 406.1-420 MHz. These standards are based upon emissions with analog input and a necessary bandwidth of 16 kHz.[24]

Stations with digital input may require a different necessary bandwidth but still must meet all other standards.

A. Transmitter

1. Frequency tolerance ppm

Station Class	Band (MHz) 30-50	162-174	406.1-420
Land, FX	5	5	2.5
Mobile	5	5	5
Portable	20	5	5

2. Unwanted Emissions: The power of any unwanted emission on any frequency removed from the center of the authorized bandwidth (BW) by a displacement frequency (f_d) shall be attenuated below the unmodulated carrier power (PZ) in accordance with the following and Figure 5.6.1.

f_d	Attenuation in dB
5 kHz < fd ≤ 10 kHz	83log (f_d/5)
10 kHz < fd ≤ 250% BW	30-50 MHz&162-174 MHz: 29log (f_d^2/11) or 50 whichever is the lesser attenuation. 406.1-420 MHz: 116log (f_d/6.1) or 50 + 10log (pZ) or 70 whichever is the lesser attenuation.
fd > 259% BW	Land, Fixed, Mobile 50 + 10log (pZ) (i.e. 10 microwatts absolute) Portable 43 + 10log (pZ) (i.e. 50 microwatts absolute)

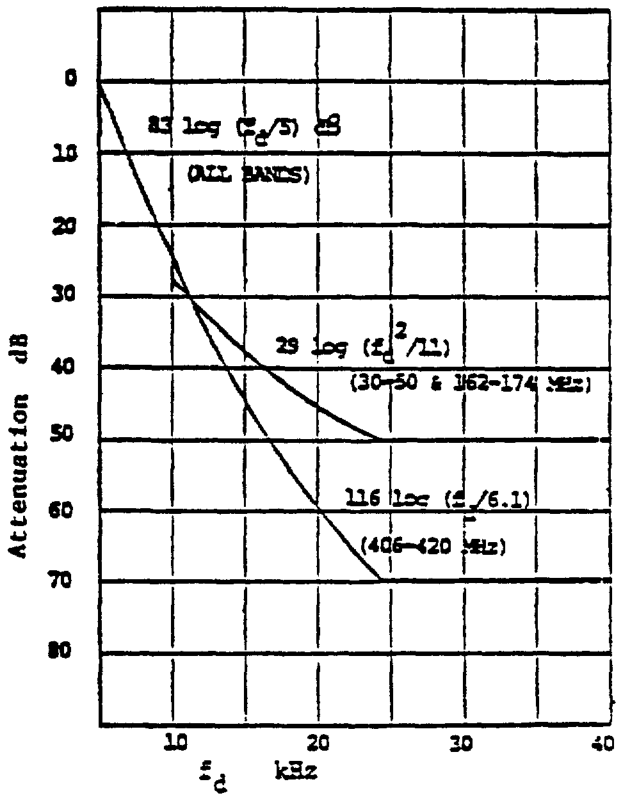


Figure 5.6.1 Levels of Unwanted Emissions

3. Frequency Deviation for all station classes and frequency bands shall not exceed ± 5 kHz.

Measurement Method. The prescribed measurement method to be used is given in the latest revision of Electronic Industries Association (EIA) Standard RS-152, "Minimum Standards for Land Mobile Communications FM or PM Transmitters, 25-866 MHz."[22]

The present EIA measurement methods were written for analog systems. Some of these methods are not appropriate for digital systems. Appropriate analog to digital or digital to analog test sets will have to be used.

B. Receiver

1. Frequency tolerance ppm:[25]

Station Class	Band (MHz)		
	30-50	162-174	406.1-420
Land, FX	5	5	2.5
Mobile	5	5	5
Portable	20	25	5

2. Spurious Response Attenuation:

Station Class	Band (MHz)		
	30-50	162-174	406.1-420
Land, FX, Mobile	85 dB	85 dB	85 dB
Portable	60 dB	60 dB	50 dB

3. Adjacent Channel Selectivity:

ANALOG			
Station Class	Band (MHz)		
	30-50	162-174	406.1-420
Land, FX, Mobile	80 dB	80 dB	80 dB
Portable	50 dB	70 dB	60 dB

DIGITAL			
Station Class	Band (MHz)		
	30-50	162-174	406.1-420
Land, FX, Mobile	50 dB	55 dB	55 dB
Portable	50 dB	50 dB	50 dB

4. Intermodulation Attenuation:

Station Class	Band (MHz)		
	30-50	162-174	406.1-420
Land, FX, Mobile	60 dB	70 dB	70 dB
Portable	50 dB	50 dB	50 dB

5. Conducted Spurious Emissions:

All station classes and all bands −80 dBW

Measurement Method. The prescribed measurement method is given in the latest revision of Electronic Industries Association (EIA) Standard RS-204, "Minimum Standards for Land Mobile Communication FM or PM Receivers, 25-866 MHz."[22]

The present EIA measurement methods were written for analog systems. Some of these methods are not appropriate for digital systems. Appropriate analog to digital or digital to analog test sets will have to be used.

5.6.2 Standard for Narrowband Operations in the 162-174 MHz Band

The standards outlined in this section are designed to replace the wideband standards contained in Section 5.6.1 in accordance with the timetable below and apply to all stations in the 162-174 MHz band. Reference is also made to changes made to the channeling plan and rules of use identified in Section 4.3.7.

These standards do not apply to :

- Military equipment used for tactical and /or training operations.
- FM wireless microphone systems whose mean output power does not exceed 0.1 Watt.
- Equipment operating on channels designated for low power systems as set forth in Sections 4.3.8 and 5.2.1.

- NOAA Weather Radio Transmitters.

Effective Dates

After January 1, 1995, all new equipment, and after January 1, 2005, all equipment in the 162-174 MHz band must conform to these standards.

Waivers

Waivers of the requirements herein may be requested when supported by reasonable justification. Waiver requests should be accompanied by technical data in support of the waiver and an explanation of the non-conforming parameters.

Standard

The following is for fixed and mobile/land mobile service employing fixed, land, mobile, and portable stations in the band 162-174 MHz with a necessary bandwidth of 11 kHz or less. The standard applies to analog and digital transmitters and receivers.

A. Transmitter

1. Frequency tolerance ppm:

Station Class	162-174 MHz
Land, FX	3
Mobile	3
Portable	5

2. Unwanted Emissions: The power of any unwanted emission on any frequency removed from the center of the authorized bandwidth (BW) by a displacement frequency (fd) shall be attenuated below the unmodulated carrier power (PZ) in accordance with the following and the emission mask in Figure 5.6.2.1.

fd	Attenuation
2.5 kHz < fd < 6.25 kHz	53 log(fd/2.5)
6.25 kHz< fd < 9.5 kHz	103 log(fd/3.9)
9.5 kHz < fd < 12.5 kHz	157 log(fd/5.3)
fd > 12.5	60 dB

3. Frequency Deviation for all station classes (FM and PM) shall not -exceed + 2.5 kHz.

Measurement Methods. The prescribed measure method to be used is given in the latest version of Electronics Industries Association (EIA) Standard RS-152, "Minimum Standards for Land Mobile Communications FM or PM Transmitters, 25-866 MHz."

The present EIA measurement methods were written for analog systems. Some of these methods are not appropriate for digital systems. Appropriate digital test sets will have to be used for measurement of digital systems.

B. Receiver

1. Frequency tolerance ppm:

Station Class	162-174 MHz
Land, FX	3
Mobile	3
Portable	5

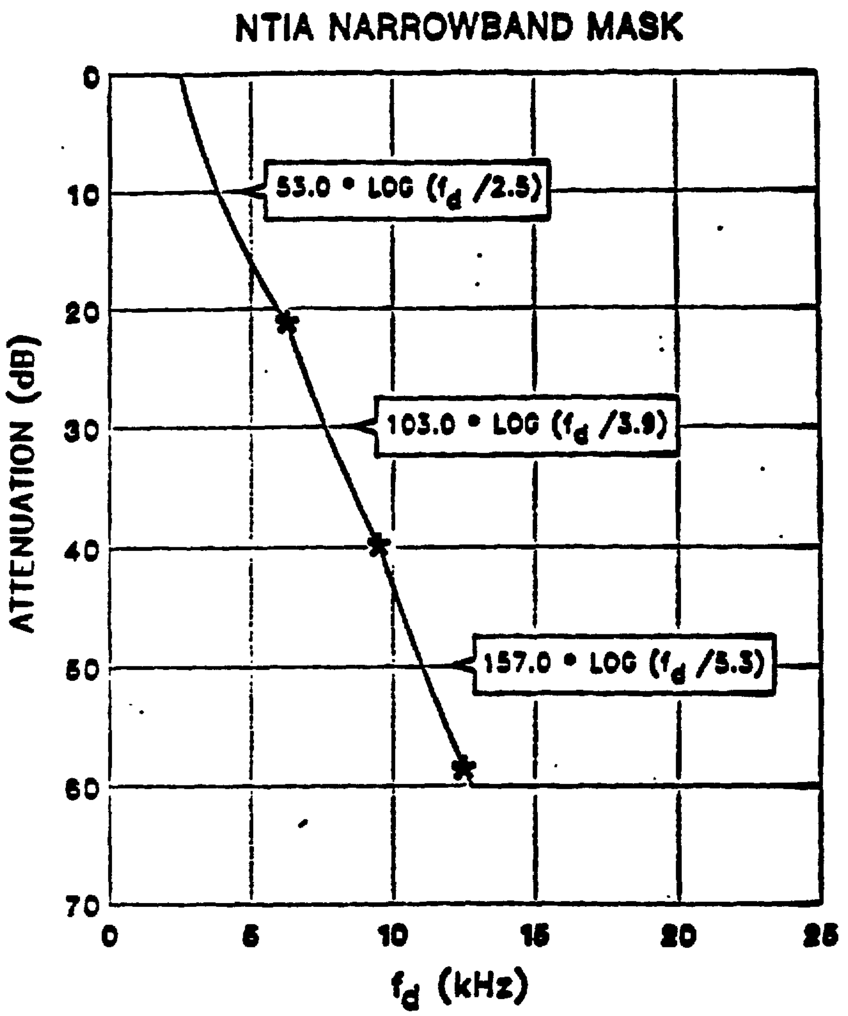


Figure 5.6.2.1 **Levels of Unwanted Emissions**

NOTE: **This emission mask represents existing technology and should provide sufficient protection for adjacent channel systems. As digital systems are developed and introduced into the band, however, this mask may have to be adjusted accordingly.**

2. Spurious Response Attenuation:

Station Class	162-174 MHz
Land, FX	
Mobile	70 dB
Portable	60 dB

3. Adjacent Channel Selectivity:

Station Class	162-174 MHz
Land, FX	
Mobile	60 dB
Portable	60 dB

4. Intermodulation Attenuation:

Station Class	162-174 MHz
Land, FX	
Mobile	70 dB
Portable	50 dB

5. Conducted Spurious Emissions: 70 dB

Measurement Methods. The prescribed measure method to be used is given in the latest version of Electronics Industries Association (EIA) Standard RS-204, "Minimum Standards for Land Mobile Communications FM or PM Receivers, 25-866 MHz."

The present EIA measurement methods were written for analog systems. Some of these methods are not appropriate for digital systems.

Appropriate digital test sets will have to be used for measurement of digital systems.

5.7 SPACE SERVICES

5.7.1 Standard for Unwanted Emissions for the Space Services (Effective 1/1/85)

These standards shall be equalled or exceeded in space systems initially submitted for systems review (Chapter 10) after the effective date.

The requirements in this standard specify the upper bounds on unwanted emissions from space and earth stations associated with the space services. They promote electromagnetic compatibility among space systems and between space systems and systems of other services sharing the spectrum. These requirements simplify the planning and evaluation of system requirements by limiting the envelope of the emitted spectrum to maximum spectral power density (SPD) levels below. (See Figure 5.7.1)

Since this standard cannot be used alone for planning and evaluation purposes, it is emphasized that the modulation type, emission spectrum, power output, frequency tolerance, and maximum expected doppler shift should be considered and provided in accordance with Chapter 10 of this Manual.

These requirements are applicable to U.S. Government space systems including associated earth terminals operating in all portions of the spectrum allocated to the space services above 1 GHz. They do not apply to transmissions from radars on the ground or aboard spacecraft.

A. Transmitter Standard

1. Frequency Tolerance (See Part 5.1).

5.8 TELEMETRY, TERRESTRIAL (1435-1535 MHz, 2200-2290 and 2310-2390 MHz)

These standards are applicable to terrestrial telemetering stations, authorized for operation in the bands 1435-1535, 2200-2290 and 2310-2390 MHz. Part 5.7 contains the standards for space radiocommunication systems.

5.8.1 Standards

A. Transmitter Standards

1. Frequency Tolerance (See Part 5.1).
2. Unwanted Emissions.

a. For Authorized Bandwidths equal to or less than 1 MHZ: (See Figure 5.8.1 a).

On each side of Fo (to determine “A”):

Let A/2=Authorized BW/2 + Authorized BW/2

Then A=2X Authorized’ BW Power Level Limit: In any 3 kHz bandwidth outside bandwidth A, the minimum required attenuation for all emissions is 60 dB below pZ, except that it shall not be necessary in any case to attenuate below a level of -25 dBm.

On each side of Fo (to determine “B”):

Let B/2=A/2+0.5 MHz Then B=(2 X Authorized BW) + 1.0 MHz Power Level Limit: In any 3 kHz bandwidth outside bandwidth B, the minimum attenuation for all emissions must be in accordance with the following formula:

X =60 dB or to -25 dBm, whichever is greater attenuation.

Y (in dB)= -(-5 + 10log BW + 10log pZ)

NOTE: This limits the maximum power level outside B to – 25 dBm. BW = Hz pZ = Watts

EXAMPLE:

Assume an Authorized BW of 0.4 MHz centered on F,:

A =2 X Authorized BW
=2 x 0.4
=0.8 MHz
B =2 X Authorized BW + 1.0 MHz
=2 x 0.4 + 1.0
= 1.8 MHzb. For Authorized Bandwidths Greater than 1 MHz: (See Figure 5.8.1 b).

On each side of Fo (To determine “A”):
Let A/2=Authorized BW/2 + 0.5 MHz
Then A= Authorized BW + 1.0 MHz

Power Level Limit: In any 3 kHz bandwidth outside bandwidth A, the minimum required attenuation for all emissions is 60 dB below pZ, except that it shall not be necessary in any case to attenuate below a level of -25 dBm.

On each side of Fo (to determine “B”):
Let B/2=A/2 + 0.5 MHz
Then B=(Authorized BW) + 2.0 MHz

Power Level Limit: In any 3 kHz bandwidth outside bandwidth B, the minimum attenuation for all emissions must be in accordance with the following formula:

X=60 dB or to −25 dBm, whichever is greater attenuation.
Y (in dB)= -(-5 + 10log BW + 10log pZ)

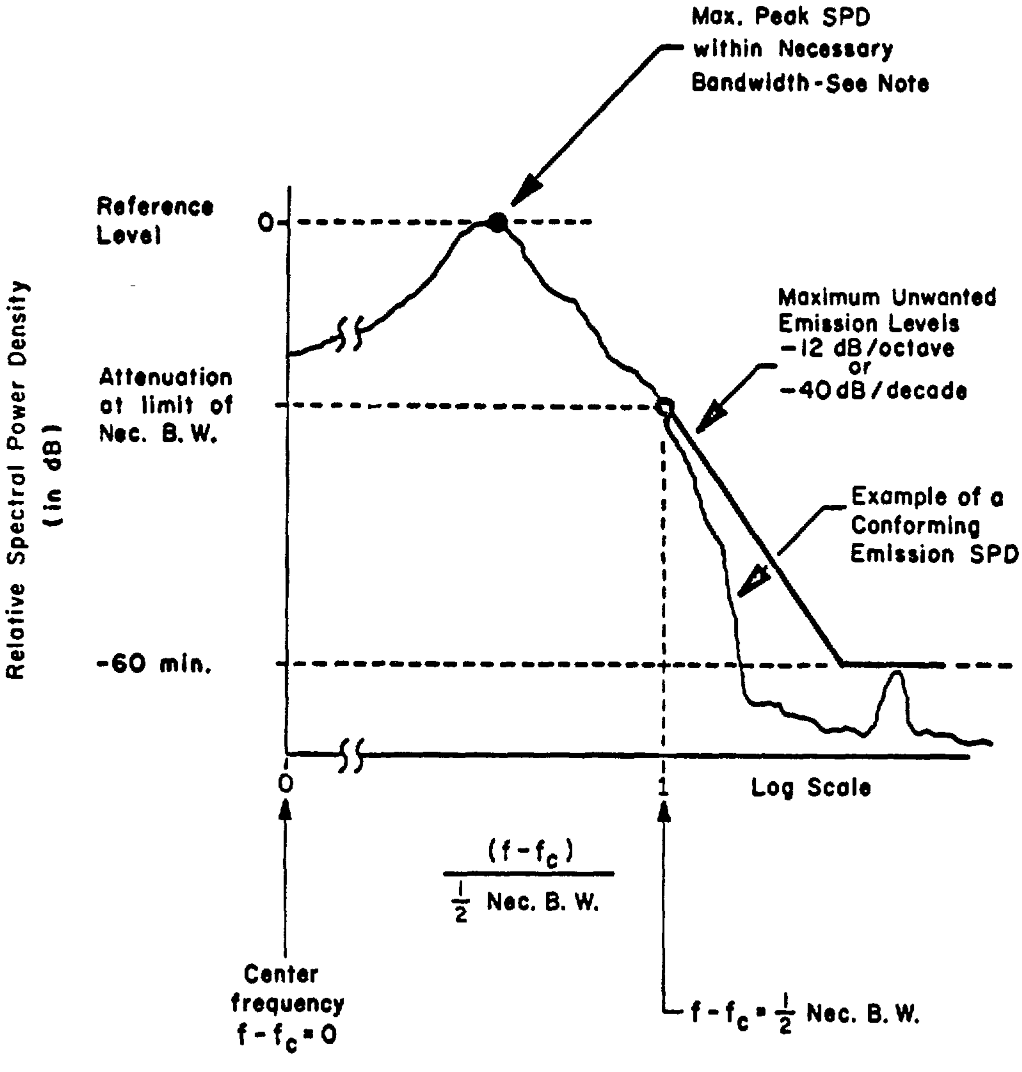
NOTE: This limits the maximum power level outside B to −25 dBm. BW = Hz pZ = Watts

EXAMPLE:
Assume an Authorized BW of 1.5 MHz centered on F_O:

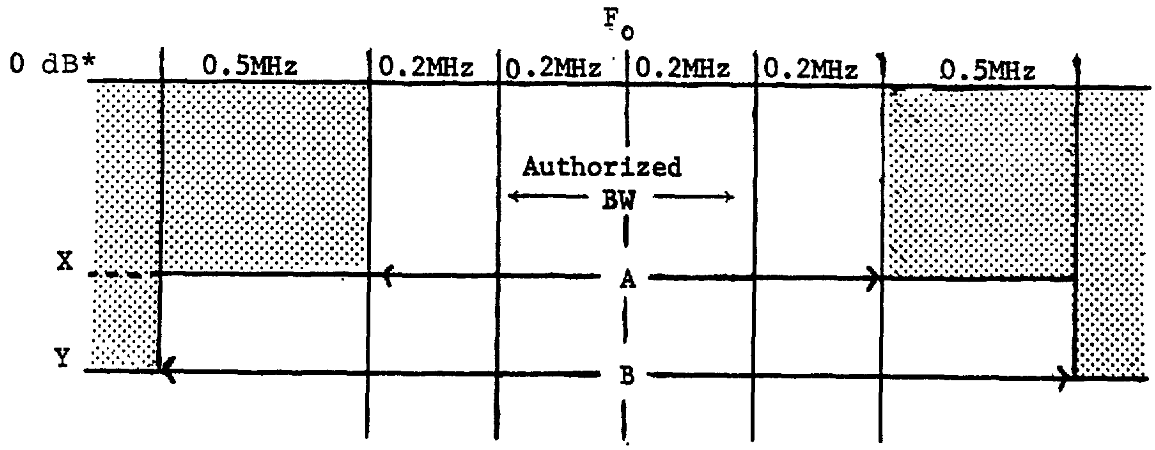
A=Authorized BW+1.0 MHz
=1.5 + 1.0
=2.5 MHz
B=Authorized BW + 2.0 MHz
=1.5 + 2.0
=3.5 MHz

B. Receiver Standards (RESERVED)
C. Antenna Standards (RESERVED)
D. Measurement Methods (RESERVED)

Figure 5.7.1. Maximum Unwanted Emission Levels For Space Services



NOTE: This sample signal spectrum was chosen to emphasize that the reference level is determined by peak SPD wherever it occurs within the necessary bandwidth. The peak does not necessarily occur at the center frequency or the carrier frequency.



*** This 0 dB level is relative to the pZ carrier power in watts.**

Figure 5.8.1 a--Unwanted Emissions for Authorized Bandwidths Less Than or Equal to 1 MHz

b. For Authorized Bandwidths Greater than 1 MHz: (See Figure 5.8.1 b).

On each side of F_o (To determine "A"):
Let A/2=Authorized BW/2 + 0.5 MHz
Then A=Authorized BW + 1.0 MHz

Power Level Limit: In any 3 kHz bandwidth outside bandwidth A, the minimum required attenuation for all emissions is 60 dB below pZ, except that it shall not be necessary in any case to attenuate below a level of −25 dBm.

On each side of F_O (to determine "B"):
Let B/2=A/2 + 0.5 MHz
Then B=(Authorized BW) + 2.0 MHz

Power Level Limit: In any 3 kHz bandwidth outside bandwidth B, the minimum attenuation for all emissions must be in accordance with the following formula:

X=60 dB or to −25 dBm, whichever is greater attenuation.
Y (in dB)= -(-5 + 10log BW + 10log pZ)

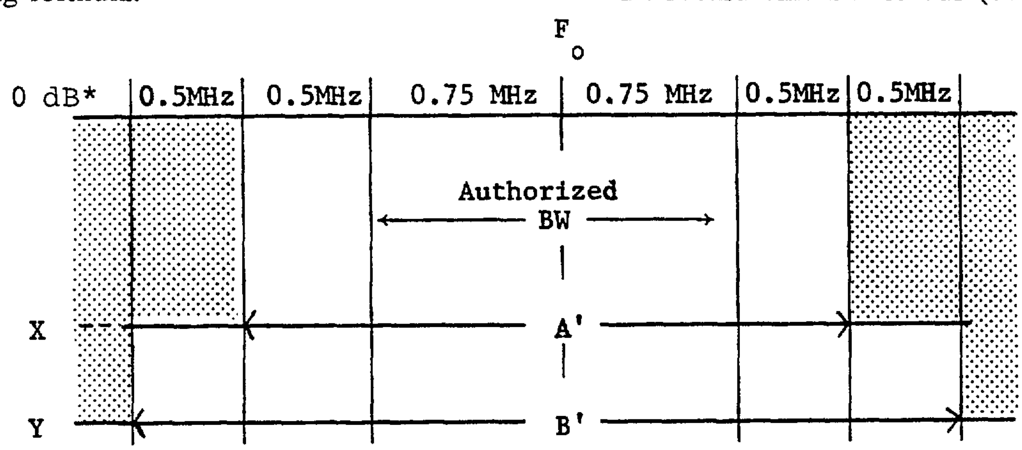
NOTE: This limits the maximum power level outside B to −25 dBm. BW = Hz pZ = Watts

EXAMPLE:

Assume an Authorized BW of 1.5 MHz centered on F_O:

A=Authorized BW+1.0 MHz
=1.5 + 1.0
=2.5 MHz
B=Authorized BW + 2.0 MHz
=1.5 + 2.0
=3.5 MHz

B. Receiver Standards (RESERVED)
C. Antenna Standards (RESERVED)
D. Measurement Methods (RESERVED)



*** This 0 dB level is relative to the pZ carrier power in watts.**

Figure 5.8.1 b--Unwanted Emissions for Authorized Bandwidths Greater than 1 MHz

Endnotes for Chapter 5

1. These frequency pairs are shared between Government and non-Government users. Power constraints placed on the frequency pairs facilitate coordination due to the decreased interference potential.

2. Primary Radar: A radiodetermination system based on the comparison of reference signals with radio signals reflected from the position to be determined. (No. 95 of the ITU Radio Regulations, 1982 Edition.)

3. Spacebased Radiolocation System--Class 1: a radiolocation system in space the primary function of which is the detection and location of objects on or near the surface of the Earth.

4. Spacebased Radiolocation System--Class 2: a radiolocation system installed aboard a spacecraft for the purpose of determinin g the relative positions or velocities of one or more extravehicular objects.

5. Active Spaceborne Sensor--a measuring instrument in the Earth Exploration Service, or in the Space Research Service, by means of which physical measurements of various phenomena are obtained through transmission and reception of radio waves.

6. Man-portable: Items which are designed to be carried as a component part of individual, crew-served or team equipment in conjunction with assigned duties. This items are nominally less than 15 kilograms (32 pounds).

7. Man-transportable: Items which are usually transported on wheeled, tracked or air vehicles but have integral provisions to allow periodic handling by one or more individuals for limited distances (i.e., 100-500 meters). These items are nominally less than 30 kilograms (65 pounds).

8. These formulas yield the total composite B(-40dB) bandwidth of a frequency hoping radar as if all channels included within Bs were operating simultaneously. Individual channels will have a B(-40dB) radar emission bandwidth given by 3.1 or 3.2 above. For frequency hopping radars, the radar spectrum shall not intrude into adjacent spectrum regions on the high or low side of the band, defined by Bs, more than would occur if the radar was fixed tuned at carrier frequencies equivalent to the end values of Bs and was complying with the constraints of 3.1 and 3.2 above.

9. If tf is less that t,, as defined in Part 5.3, tf is to be used in place oft, when performing the emission bandwidth calculations.

10. These formulas yield the total composite B(-40 dB) bandwidth of a frequency hopping radar as if all channels included within B, were operating simultaneously. Individual channels have a B(-40 dB) radar emission bandwidth given by 3.1 or 3.2 above. For frequency hopping radars, the radar spectrum shall not intrude into adjacent spectrum regions on the high or low side of the band, defined by Bs, more than would occur if the radar were fixed tuned at carrier frequencies equivalent to the end values of Bs and was complying with the constraints of 3.1 and 3.2 above.

11. Median gain is defined as that level over an angular region at which the probability is 50% that the observed or measured gain at any position of the antenna will be less than or equal to that level.

12. These formulas yield the total composite B(-40 dB) bandwidth of a frequency hopping radar as if all channels included within Bs were operating simultaneously. Individual channels will have a B(-40 dB) radar emission bandwidth given by a. or b. above. For frequency hopping radars, the radar spectrum shall not intrude into adjacent spectrum regions on the high or low side of the band, defined by Bs, more than would occur if the radar were fixed tuned at carrier frequencies equivalent to the end values of Bs and was complying with the constraints of a. and b. above.

13. Median gain is defined as that level over an angular region at which the probability is 50% that the observed or measure gain at any position of the antenna will be less than or equal to that level.

14. In other than exceptional cases the practice is to authorize 3 kHz as the necessary bandwidth for normal voice intelligibility. This is specified by the emission designator. In the practical case, to meet the minimum performance requirements of this paragraph the roll-off of the emission curve will begin at a value somewhat less than 1.5 kHz form the assigned frequency.

15. Passband. The passband is the band of frequencies limited by the two frequencies for which the voltage is attenuated to one-half of the voltage of the most favored frequency.

16. Applies to both transmitting and receiving antennas, but to the latter only when protection from harmful interference is required.

17. These figures would be approximately 6 dB greater if the gain were to be expressed relative to an isotropic antenna in free space, in order to account for ground reflection.

18. It is recognized that relatively narrowband digital radio systems may be unduly restricted by this standard. Work is in progress to define appropriate limitations for such narrowband systems. This standard will be modified in accordance with the findings and experience with such narrowband systems.

19. Performance standards applicable to aeronautical mobile (R) operations are on pages 24-27 of Appendix 27 Aer2 to the ITU Radio Regulations.

20. In other exceptional cases the practice is to authorize 3 kHz as the necessary bandwidth for normal voice intelligibility. This is specified by the emission designator. In the practical case, to meet the minimum performance requirements of this paragraph the roll-off of the emission curve will begin at a value somewhat less than 1.5 kHz from the assigned frequency.

21. Passband. The passband is the band of frequencies limited by the two frequencies for which the voltage is attenuated to one-half of the voltage of the most favored frequency.

22. Copies of these standards may be obtained from the Electronic Industries Association, 2001 Eye Street, N.W., Washington, D.C. 20006.

23. In the band 406.1-410 MHz, power is limited to a maximum of 7 W/kHz of necessary bandwidth as specified in footnote US 117.

24. The spacing of channels (adjacent channel spacing) is 20 kHz in the 30-50 MHz band and 25 kHz in the 162-174 and 406.1420 MHz bands.

25. Measurement Method -- An unmodulated standard input signal source, adjusted to the standard input frequency as specified in EIA RS-204, shall be connected to the receiver under test and adjusted for an output of 20 dB above the receiver sensitivity. The center frequency of the IF passband shall be measured with equipment having a degree of accuracy of at least five times the minimum tolerance to be measured.

(Last page in Chapter 5)

SPECTRUM USE SUMMARY

2 GHz - 25 GHz

NOTE:

This document represents an overview of non-federal as well as some government spectrum use. In order to serve its purpose as a quick reference, its length has been limited. Therefore, it is not all inclusive in its portrayal of U.S. spectrum requirements or its representation of the allocation table. The table is still in a developmental phase and as more information is obtained, entries are updated.

The allocation tables, presented here, reflect the PRIMARY (uppercase letters), and Secondary (lowercase letters) allocations listed in the national table and footnotes.

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
2.900-3.100	MARITIME-RADIONAVIGATION RADIOLOCATION	1) Maritime radionavigation. Max. power 20 W E.I.R.P. 2) Non-government radiolocation is permitted in this band on the condition that no harmful interference is caused to Government services. Radar is prohibited in (2.900-2.920 GHZz) This band is primarily used for maritime radars and radar beacons (racons) Radars of this type are required on cargo and passenger ships by international treaty (SOLAS) for safety purposes Racons operate in conjunction with maritime radars to provide electronic markers to identify maritime obstructions and navigation points. Typical Bandwidth: 154 KHz - 2.5 MHz (null to null) for tactical search radar and 4 MHz - 20 MHz (null to null) for Navigation Peak Power: l-4 MW for tactical search, 0.005 MW for Navigation (Sanders, 1993)	MARITIME RADIONAVIGATION RADIOLOCATION	1) Maritime radionavigation. Max. power: 20 W E.I.R.P. 2) Meteorological Aids Service limited to Government Next Generation Weather Radar (NEXRAD) on a primary basis. Government radiolocation is primarily for the military service, however, limited secondary use is permitted by government agencies in support of experimental and research programs and for survey operations.. This band is used by a variety of tactical military radars. Whether or not much occupancy is seen in this band depends upon proximity to bases and depots where such radars are repaired or used for training. Usage is highly variable. In coastal areas, a large number of short-range maritime surface search radars will be received in the 3025-3075 MHz range. These radars are used for navigation, and they may produce more occupancy at night or in bad weather. In coastal areas, emissions from the Navy's SPS-48 air search radar are also commonly seen. This is a very common installation on Navy ships. It is a sophisticated, 3-dimensional radar which sweeps in altitude by sweeping in frequency. SPS-48 radars have very broad emission spectra. (Sanders, 1993) Typical Bandwidth: 154 KHz - 2.5 MHz (null to null) for tactical search radar and 4 MHz - 20 MHz (null to null) for Navigation Peak Power: 1-4 MW for tactical search, 0.005 MW for Navigation (Sanders, 1993) NASA performs airborne measurements of rainfall rates over selected ocean areas.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE

General information: 3.10 - 3.70 GHz:

The band is used by a variety of tactical military radars. Whether or not much occupancy is seen in this band depends upon proximity to bases and depots where such radars arerepaired or used for training. Usage lShighly variable.

Typical Bandwidth: I54 KHz - 2.5 MHz (null to null). Peak power: I-4 MW,

(Sanders, 1993)

3.100-3.300	RADIOLOCATION	Radiolocation stations installed on spacecraft may be employed for the earth exploration-satellite and space research services on a secondary basis. See General Information above.	RADIOLOCATION	Government, non-military radiolocation is secondary to military radiolocation. In making assignments to stations of other service, all practicable steps are taken to protect the spectral line observations of the radio astronomy services from harmful interference. This band is primarily used for military radiolocation, including several multi-billion dollar defense radar systems. Use of this band for these systems is considered critical to national defense. The high-power mobile radars include airborne, land-based, and shipbome applications. See General Information above.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
3.300-3.500	AMATEUR RADIOLOCATION	I) Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. 2) Radiolocation survey operations. Max power: 5 W. Secondary to government radiolocation operations (3.3-3.5 GHz). Amateur satellite service is secondary to space, earth and telecommand stations. In making assignments to stations of other service, all practicable steps are taken to protect the spectral line observations of the radio astronomy services from harmful interference in the band 3.3458 - 3.3525 GHz. See General Information above.	RADIOLOCATION	Limited to military radiolocation. This band is primarily used for military radiolocation, including several multi-billion dollar defense radar systems. Use of this band for these systems is considered critical to national defense. The high-power mobile radars include airborne, land-based, and shipbome applications. See General Information above.
3.500-3.600	RADIOLOCATION	See General Information above.	AERONAUTICAL-RADIONAVIGATION (ground-based) RADIOLOCATION	Government, non-military radiolocation is secondary to military radiolocation. This band is primarily used for military radiolocation, including several multi-billion dollar defense radar systems. Use of this band for these systems is considered critical to national defense. The high-power mobile radars include airborne, land-based, and shipbome applications. See General Information above.
3.600-3.700	FIXED-SATELLITE (space-to-earth) RADIOLOCATION	Fixed satellite service is limited to international, inter-continental systems and subject to case-by-case electromagnetic compatibility analysis. INMARSAT and INTELSAT have limited use for fixed satellite service earth stations in this band. Each site must be actively coordinated with the U.S. Government with supporting electromagnetic compatibility analysis. See General Information above.	AERONAUTICAL RADIONAVIGATION (ground-based) RADIOLOCATION	Government, non-military radiolocation is secondary to military radiolocation. The principal Federal Governrnent use of this band is to support a Navy radar used for landing operations on aircraft carriers. This high-power radar is operating on Navy ships and at certain shore locations for training. See General Information above.

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NONGGVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
3.700-4.200	FIXED FIXED-SATELLITE (space-to-earth)	1) Domestic public fixed service. Television STL (studio transmitter link). Bandwidth: 20 MHz. Max. power: 20 W transmitter power. 2) Satellite communication. Bandwidth assigned on a case-by-case basis. This band was the original long-haul microwave band, to provide the first analog transcontinental network to transport television and analog long-distance telephone circuits. Typical user of this band include the telephone companies (local, long distance, and alternative carriers). This band is proposed as an Emerging Technologies migration band and will be rechannelized at 0.4-, 0.8-, 1.6-, 5-, 10-, and 20-MHz bandwidth for private and public services. (Matheson, 1993) This band is also used extensively for satellite downlinks, particular for C-Band television used by cable TV companies and backyard satellite dishes.		
4.200-4.400	AERONAUTICAL-RADIONAVIGATION	1) Aeronautical radionavigation service: used for aircraft radio altimeters exclusively (4.2-4.4 GHz) 2) The standard frequency and time signal satellite service is authorized to use the frequency 4.202 MHz for earth to space transmissions. Bandwidth: 4 MHz. Standard frequency and time signal-satellite is a secondary service. 3) Passive sensing in the earth-exploration satellite and space research services may be authorized on a secondary basis. This band is heavily used (especially near airports) for radar altimeters on board non-government fixed-wing and rotary aircralt. These radars come in two varieties: FM/CW and pulsed. These radars are especially receivable under the approach and departure paths at major airfields. (Sanders, 1993) Typical Bandwidth for pulsed altimeters: 40 KHz - 40 MHz. Peak power is low. (Sanders, 1993)	AERONAUTICAL-RADIONAVIGATION	This band is heavily used (especially near airports) for radar altimeters on board non-government fixed-wing and rotary aircraft. These radars come in two varieties: FM/CW and pulsed. These radars are especially receivable under the approach and departure paths at major airfields. (Sanders, 1993) Typical Bandwidth for pulsed altimeters: 40 KHz - 40 MHz. Peak power is low. (Sanders, 1993) Methods for reducing the bandwidth necessary to perform this function are being studied within the CCIR; however, some altimeter functions may not be able to be provided in reduced beamwidth.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
4.400-4.500			FIXED MOBILE	Military agencies are the primary users of this band. Uses include dual purpose line-of-sight troposcatter links for tactical communications. These systems are transportable point-to-point systems, with sufficient power (greater than I KW) to allow tropospheric scatter communications for beyond-line-of-sight links. In addition, the band is used in drone control, target scoring, and balloon-to-ground data links for tethered balloon surveillance. The average bandwidth for Fixed systems is 8 MHz. (Matheson, 1993) This band is used by the military services for tactical communications, both line-of-sight and troposcatter.
4.500-4.800	FIXED-SATELLITE (space-to-earth)	Assignments held by civilian agencies and by non-government entities are for law enforcement, antenna testing, data links for balloon surveillance, or aircraft data down links. (Matheson, 1993) Fixed-satellite service is limited to international, inter-continental systems.	FIXED MOBILE	Military agencies are the primary users of this band. Uses include dual purpose line-of-sight troposcatter links for tactical communications. These systems are transportable point-to-point systems, with sufficient power (greater than I KW) to allow tropospheric scatter communications for beyond-line-of-sight links. In addition, the band is used in drone control, target scoring, and balloon-to-ground data links for tethered balloon surveillance The average bandwidth for Fixed systems is 8 MHz. (Matheson, 1993) This band is used by the military services for tactical communications, both line-of-sight and troposcatter.

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
4.800-4.990			FIXED MOBILE radio astronomy space-research-and-earth-exploration- satellite	Military agencies are the primary users of this band. Uses include dual purpose line-of-sight troposcatter links for tactical communications. These systems are transportable point-to-point systems, with sufficient power (greater than 1 KW) to allow tropospheric scatter communications for beyond-line-of-sight links. In addition, the band is used in drone control, target scoring, and balloon-to-ground data links for tethered balloon surveillance. The average bandwidth for Fixed systems is 8 MHz. (Matheson, 1993) Allocated for the space research (passive) and earth exploration-satellite (passive) services on a secondary basis (4.950-4.990 GHz). In making assignments to stations of other service, all practicable steps are taken to protect the spectral line observations of the radio astronomy services from harmful interference in the band 4.825 - 4.835 GHZ. No space or airborne allocations permitted in the bands (4.950-4.990 GHz) and (4.825-4.835 Gflz). The National Science Foundation performs some continuum observations in the 4.950-4.990 GHz portion of the band when the 4.990-5.000 GHz band does not provide adequate bandwidth.
4.990-5.000	RADIO-ASTRONOMY spaceresearch		RADIO- ASTRONOMY space-research (passive)	This band is used extensively in the U.S. and other countries for radio astronomy. It is an excellent band for continuum measurement, because the galactic background continuum radiation is low. Observations of galactic and extragalactic radio sources at these frequencies help to define their spectra, which gives information on the physical parameters of the radiating source.

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NGNGGVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
5.000-5.250	AERONAUTICAL-RADIONAVIGATION	I) International microwave landing system for precision approach and landing. 2) Fixed-satellite service (space-to-earth) for feeder links in conjunction with radio determination satellite service (5.150-5.216 GHz). 3) Fixed- and inter-satellite services for connection between earth stations when used in conjunction with the aeronautical radionavigation and/or aeronautical mobile. 4) Radionavigation land test (5031 GHz). Max. power: l W. The international microwave landing system for precision approach and landing takes precedence over any other use in this band. Airborne and space station assignments shall not to cause harmful interference to radio astronomy observations in adjacent bands.	AERONAUTICAL-RADIONAVIGATION	Aeronautical mobile satellite also allocated on a primary basis.

General Information: 5.20 - 5.925 GHz

Varied occupancy occurs in this band. weather radars, maritime surface-search radars, and airborne weather radars are significant in this band.

WSR-74C weather radars and their military equivalents are commonly observed, and may be present in great numbers in areas noted for severe weather. Like their WSR-74s analogues, these units have very extended emission spectra. Typical characteristics are! 4 usec pulse width, 160 pulses per second (not staggered), and 20 second rotation, Sometimes, weather radars are not rotated but are left on a single azimuth, still transmitting, until weather observations are required.

Maritime surface search radars will be seen in great numbers in this band near any busy harbor. Typical characteristics are: less than 1usec pulse width, more than 1000 pulses per second, and 2-4 second rotation rate.

Airborne weather radar signals are highly transient. They usually do not produce much usage.

Typical bandwidth: 400 KHz - 2 MHz (null to null) for weather radar, >2 MHz (null to null) for navigation radar,

Typical power: 0.5 MW for weather radar, 0.005 MW for navigation radar.

(Sanders, 1993)

5.250-5.350	radiolocation	Radiolocation stations installed on spacecraft may also be employed for earth exploration-satellite and space research services on a secondary basis. See General Information above.	RADIOLOCATION	Government, non-military radiolocation shall be secondary to military radiolocation. See General Information above.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
5.350-5.460	AERONAUTICAL-RADIONAVIGATION radiolocation	I) Aeronautical radionavigation service is limited to airborne radars and associated airborne beacons (5.35-5.47 GHz). 2) Radiolocation stations installed on spacecraft may also be employed for earth exploration-satellite and space research services on a secondary basis. See General Information above.	AERONAUTICAL-RADIONAVIGATION RADIOLOCATION	Aeronautical radionavigation service is limited to airborne radars and associated airborne beacons (5.35-5.47 GHz). Government radiolocation is primarily for the military services. Limited secondary use in support of experimentation and research programs (5.35-5.65 GHz). See General Information above.
5.460-5.470	RADIONAVIGATION radiolocation	Non-government radiolocation is secondary to aeronautical and maritime radionavigation and government radiolocation. See General Information above.	RADIONAVlGATION radiolocation	Aeronautical radionavigation service is limited to airborne radars and associated airborne beacons (5.35-5.47 GHz). Government radiolocation is primarily for the military services. Limited secondary use in support of experimentation and research programs (5.35-5.65 GHz). See General Information above.
5.470-5.650	MARITIME-RADIONAVIGATION METEOROLOGICAL-AIDS radiolocation	Maritime radionavigation (5.46-5.65 GHz) is limited to shipbome radars. Max. power: 20 W E.I.R.P. See General Information above. Meteorological ground-based radar (5.60-5.65 GHz) is on equal basis with maritime radionavigation services. Non-government radiolocation is secondary to aeronautical and maritime radionavigation and government radiolocation.	MARITIME-RADIONAVIGATION METEOROLOGICAL-AIDS radiolocation	Maritime radionavigation. Max. power: 20 W E.I.R.P. Government radiolocation is primarily for the military services. Limited secondary use in support ofexperimentation and research programs (5.35-5.65 GHz). See General Information above.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
5.650-5.850	amateur	1) Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. 2) Industrial, scientific and medical (KM) applications are on a primary basis (5.725-5.875 GHz). ISM equipment operating in this band is permitted unlimited radiated energy. 3) Deep space research service (5.600-5.725 GHz) allocated on a co-secondary basis with amateur service. No amateur radio shall interfere with another nation's radiolocation service See General Information above..	RADIOLOCATION	Government radiolocation is primarily for the military services (5.650-5.925 GHz). See General Information above.
5.850-5.925	FIXED-SATELLITE (earth to space) amateur	1) Industrial, scientific and medical (ISM) applications on a primary basis (5.725-5.875 GHz). ISM equipment operating in this band is permitted unlimited radiated energy. 2) Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. Fixed-satellite service is limited to international, intercontinental services. No amateur radio shall interfere with another nation's radiolocation service. See General Information above.	RADIOLOCATION	Government radiolocation is primarily for the military services (5.650-5.925 GHz). See General Information above.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
5.925-6.425	FIXED FIXED-SATELLITE (earth-to-space)	I) Television STL (studio transmitter link) Bandwidth: <30 MHz. Max power: +55 dBW E.I.R.P. 2) Fixed satellite services. Bandwidth assigned on case-by-case basis. Max. power: +40 dBW E.I.R.P. This band is used by the inter-exchange carriers (IXC's) , the local exchange carriers (LEC’s), alternative providers, and the cellular companies. This band provides 30 MHz channelization and is used for the long-haul backbone routes, connections between central offices, and between central offices and customer interface locations. It is also used as backbone by cellular providers, who have built independent networks which by-pass the LEC. This band is shared with large numbers of satellite uplinks, used extensively for TV and data applications. The band has exhibited an average decline over the past four years of 9.3 percent. The decline in 1991 was 22 percent. It will continue to shrink at the overall rate of 6 percent a year. (Matheson, 1993) This band has been designated as an immigration destination band for 2 GHz microwave users displaced by PCS.		
6.425-6.525	FIXED-SATELLITE (earth-to-space)	1) Television pickup and television non-broadcast pickup stations. Bandwidth: <= 25 MHz. Max power +35 dBW E.I.R.P. 2) Broadcast auxiliary station and mobile television pickup (mobile only). Bandwidth: 1 MHz, 8 MHz, and 25 MHz. Max power +35 dBW E.I.R.P. 3) Cable television relay services (CARS). Bandwidth: 1 MHz, 8MHz, and 25 MHz. Max power +35 dBW E.I.R.P. 4) The standard frequency and time signal satellite service is authorized to use the frequency 6.427 MHz for earth to space transmissions. Bandwidth: 4 MHz. Standard frequency and time signal-satellite is a secondary service.		

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
6.525-6.875	FIXED FIXED-SATELLITE (earth-to-space)	I) Operational fixed microwave stations. (6.525-6.875 GHz). Bandwidth: 800 KHz, 1.6 MHz, 5 Mhz, 10 MHz. Max. power: 80 dBm E I.R.P. This band is very heavily used by private business and state and local Government in support of Supervisory Control and Data Acquisition (SCADA) applications for pipelines, power lines, railroads, etc. (6.535, 6.575 GHz) Available only for Emergency restoration, maintenance bypass, or temporary fixed purposes. For 6.425-7.075 GHz, passive microwave sensor measurements are carried out over the ocean.		

General Information: 6.875 - 7.075 GHz

This band is allocated to auxiliary broadcasting, using NTSC frequency-modulated on 25-MHz bandwidth channels. CARS is limited to mobile Cable TV pickup stations (similar to electronic news gathering). This band is the most heavily-used band for studio-to-transmitter links (STL), intercity relays(ICR), and electronic news gathering relay (ENG relays), The band is also used for electronic news gathering (ENG), and for Cable TV pick up stations. TV translator relay stations are also permitted on a secondary basis, There is rapid growth in this band (9.5 percent per year). mainly due to the increased comprehensiveness of support for ENG and coverage of local events. (Matheson, 1993)

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
6.875-7.075	FIXED FIXED-SATELLITE (earth-to-space) MOBILE	1) Mobile television pickup. Bandwidth: <= 20 MHz. Max power: +35 dBW E.1.R P. 2) Cable television relay (CARS). Bandwidth: 25 MHz. Max power: +35 dBW E.I.R.P. Television translator relay stations are authorized to use frequencies in this band on a secondary basis For 6.425-7.075 GHz, passive microwave sensor measurements are carried out over the ocean. See general information above.		

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGGVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
7.075-7.125	FIXED MOBILE	1) Mobile television pickup. Bandwidth: <= 20 MHz. Max power: +35 dBW E.I.R.P. 2) Cable television relay (CARS). Bandwidth: 25 MHz. Max power: +35 dBW E.1.R P. Television translator relay stations are authorized to use frequencies in this band on a secondary basis For 7.075 - 7.250 GHz, passive microwave sensor measurements are carried out. See general information above.		

General Information: 7.125 - 8.500 GHz

This band is allocated exclusively to the Government from 7.125 - 8.450 GHz; from 8.450 - 8.500 GHz, it is shared with a non-Government primary allocation to Space Research. The Government primary allocations are to Fixed, Space Research, Fixed-Satellite, Mobile-Satellite, and Earth Exploration Satellite invarious pottions of the band, Government Fixed allocations are primary, except for secondary status at 7.250 - 7.300 GHz and 7.900 - 8.025 GHz.
The FAA has a nationwide network to tie together the Air Traffic Control System. TVA Bonneville and others control large federal electric power networks. The military has extensive networks on military test and training ranges.
The effective number of non-overlapping channels (probably of varying size) is 68 (giving an average bandwidth of 20 MHz)
Some agency-specific microwave systems will be replaced with commercial alternatives. Although this will not happen on a wholesale basis, there will be a continuing decrease of these links.
Estimated usage in this band indicates a decrease at an average rate of two percent per year over the next five years.
(Matheson, 1993)

7.125-7.190		The band 7.145 - 7.190 GHz is also allocated for earth-to-space transmissions in the space research service, limited to deep space communications. For 7.075 - 7.250 GHz, passive microwave sensor measurements are carried out. See general information above.	FIXED	The band 7. I25 - 7. 155 GHz is also allocated for earth-to-space transmissions in the Space Operations Service at a limited number of sites. See general information above.
7.190--7.235		For 7.075 - 7 250 GHz, passive microwave sensor measurements are carried out. See general information above.	FIXED SPACE RESEARCH (earth-to-space)	See general information above.
7.235-7.250		For 7.075 - 7.250 GHz, passive microwave sensor measurements are carried out. See general information above.	FIXED	See general information above.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
7.250-7.300		See general information above.	FIXED-SATELLITE (space-to-earth) MOBILE-SATELLITE (space-to-earth) fixed	I) MOBILE-SATELLITE (7.250-7.375 GHz). Government fixed- and mobile- satellite services are limited to military systems (7.250-7.750 GHz). See general information above.
7.300-7.450		See general information above.	FIXED FIXED-SATELLITE (space-to-earth) mobile-satellite (space-to-earth)	Government fixed- and mobile- satellite services are limited to military systems (7.250-7.750 GHz). See general information above.
7.450-7.550		See general information above.	FIXED FIXED-SATELLITE (space-to-earth) METEOROLOGICAL-SATELLITE (space-to-earth) mobile-satellite (space-to-earth)	Government fixed- and mobile- satellite services are limited to military systems (7.250-7.750 GHz). Military space radio communication and meteorological satellite services have equal compatibility. See general information above.
7.550-7.750		See general information above.	FIXED FIXED-SATELLITE (space-to-earth) mobile-satellite (space-to-earth)	Government fixed- and mobile- satellite services are limited to military systems (7.250-7.750 GHz). See general information above.
7.750-7.900		See general information above.	FIXED	See general information above.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
7.900-8.025		See general information above.	FIXED-SATELLITE (earth-to-space) MOBILE-SATELLITE (earth-to-space) fixed	See general information above.
8.025-8.175		No airborne transmission (8.025-8.400 GHz). See general information above.	EARTH-EXPLORATION-SATELLITE(space-to-e d) FIXED FIXED-SATELLITE (earth-to-space) mobile-satellite (earth-to-space)	See general information above.
8.175-8.215		No airborne transmission (8.025-8.400 GHz). See general information above.	EARTH-EXPLORATION-SATELLITE(space-to-e d) FIXED FIXED-SATELLITE (earth-to-space) METEOROLOGICAL-SATELLITE(earth-to-space) mobile-satellite (earth-to-space)	See general information above.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
8.215-8.400		No airborne transmission (8.025-8.400 GHz). See general information above.	EARTH-EXPLORATION-SATELLITE (space-to-earth) FIXED FIXED-SATELLITE (earth-to-space) mobile-satellite (earth-to-space)	See general information above.
8.400-8.450		See general information above.	FIXED SPACE-RESEARCH (space to earth) (deep space only)	See general information above.
8.450-8.500	SPACE RESEARCH (space-to-earth)	See general information above.	FIXED SPACE RESEARCH (space-to-earth)	See general information above.

General Information: 8.50 - 10.55 GHz

Except for precision approach radars (PARs) used at airports, this part of X band is occupied by mobile radars: maritime surface search units and airborne search, navigation, mapping and fire control radars.
Typical bandwidth: 2 MHz -20 MHz (null to null) for Navigation, 2 MHZ - 20 MHz (null to null) for Airborne, and 40 MHz (null to null) for Coast Guard Vessel Traffic Service (VTS)
Typical peak power: 0.005 MW for Navigation, 0.005 MW for VTS, and low power for Airborne.
(Sanders, 1993)

8.500-9.000	radiolocation	Secondary doppler radionavigation aids, government and non-government airborne doppler radar are permitted (8.750-8.850 GHz). Radiolocation stations installed on spacecraft may also be employed for earth exploration-satellite and space research services (8.550-8.650 GHz). See General Information above.	RADIOLOCATION	See General Information above.

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NONGGVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
9.000-9.200	AERONAUTICAL-RADIONAVIGATION radiolocation	Aeronautical radionavigation is restricted to ground-based, surveillance radar and to associated airborne transponders which transmit only when actuated by radars operating in the same band. See General Information above.	AERONAUTICAL-RADIONAVIGATION radiolocation	See General Information above.
9.200-9.300	MARITIME-RADIONAVIGATION radiolocation	Maritime radionavigation (9.200-9.225 GHz) is limited to shore-based radars Search and Rescue Transponders (SART) (9.200-9.500 GHz). See General Information above.	MARITIME-RADIONAVIGATION RADIOLOCATION	See General Information above.
9.300-9.500	RADIONAVIGATION meteorological-aids radiolocation	Aeronautical radionavigation ground-based radar beacons are permitted secondary to the maritime radionavigation service (9.300-9.320 GHz). Aeronautical radionavigation is limited to airborne weather radar, associated airborne beacons, and ground-based radar. Response from radar transponders shall not be able to be confused with racons. Ground-based meteorological service radar is primary to radiolocation. Non-government radiolocation is secondary to government radiolocation. See General Information above.	RADIONAVIGATION meteorological aids radiolocation	I) Maritime radar units (usually SPS-66's) (9345 - 9405 GHz) Typical bandwidth: 3.33 MHz - 20 MHz (null to null) 2) Land-based radars used to monitor shipping traffic for the Coast Guard's Vessel Traffic Service (9.30 - 9.50 GHz). Bandwidth: 40 MHz (null to null) 3) Airborne radar (9.30 - 9.40 GHx). Bandwidth: 2 MHz (null to null) (Sanders, 1993) See General Information above.
9.500-10.000	radiolocation	Radiolocation installed in spacecraft can be employed for earth exploration-satellite and space research services on a secondary basis (9.500-9.800 GHz) Meteorological-satellite service is permitted on a secondary basis to weather radar (9.975-10.025 GHz). See General Information above.	RADIOLOCATION	Airborne radar (9.50 - 10.00 GHz). Bandwidth: 2 MHz (null to null) See General Information above.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
10.0-10.45	Amateur Radiolocation	I) Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. 2) Radiolocation is limited to non-pulsed survey operations (not to exceed 5 W into transmitter). Non-government radiolocation is secondary to Amateur. Amateur and radiolocation are secondary to government operations. See General Information above.	RADIOLOCATION	Radiolocation for military use. Also includes radar on meteorological satellites on a secondary basis and government non-pulsed survey operations on a secondary basis. See General Information above.
10.45-10.5	Amateur Amateur-Satellite Radiolocation	I) Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. Amateur also includes amateur-satellite. 2) Radiolocation is limited to non-pulsed survey operations (not to exceed 5 W into transmitter). Non-government radiolocation is secondary to Amateur. Amateur and radiolocation are secondary to government operations. See General Information above.	RADIOLOCATION	Radiolocation for military use. Also includes radar on meteorological satellites on a secondary basis and government non-pulsed survey operations on a secondary basis. See General Information above.
10.5-10.55	RADIOLOCATION	The band 10.5-10.55 is restricted to type NON (AO) emission with a power not to exceed 40 W into the antenna. (Police radar speed guns). Narrow bandwidth CW signals.	RADIOLOCATION	The band 10.5-10.55 is restricted to type NON (AO) emission with a power not to exceed 40 W into the antenna. Narrow bandwidth CW signals.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
10.55-10.60	FIXED	1) Fixed point-to-point microwave radio services. Bandwidth: 2.5 MHz. Max power: 10.0 W transmitter power. 2) Digital Electronic Message Service (DEM). Bandwidth: 2.5 MHz and 5 MHz. Max power: <0.5 W per 250 KHz for nodal transmitter and < 0.4 W per 250 KHz for user transmitter. This band was originally intended for DEM services for which several corporations had intended to construct a large network. This was never fully accomplished and, therefore, the band remains relatively unused. However, the band has been growing rapidly for short range links deployed in support of cellular sites with narrowband channelization. (Matheson, 1993)		
10.60-10.68	EARTH-EXPLORATION-SATELLITE (passive) SPACE-RESEARCH (passive) FIXED	1) Fixed point-to-point microwave. Bandwidth: I .25 MHz, 2.5 MHz, and 3.75 MHz. Max power: 40 dBW E.I.R.P. 2) Digital Electronic Message Services (DEM). Bandwidth: 2.5 MHz and 5 MHz. Max power: <0.5 W per 250 KHz for nodal transmitter and C 0.4 W per 250 KHz for user transmitter. All practical steps are made to protect the radio astronomy services from interference. This band was originally intended for DEM services for which several corporations had intended to construct a large network. This was never fully accomplished and, therefore, the band remains relatively unused. However, the band has been growing rapidly for short range links deployed in support of cellular sites with narrowband channelization. Since the band is shared with radio astronomy, transmitter power levels are limited. (Matheson, 1993)	EARTH-EXPLORATION-SATELLITE(passive) SPACE RESEARCH (passive)	

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
10.68-10.70	EARTH-EXPLORATION-SATELLITE (passive) RADIO-ASTRONOMY SPACE-RESEARCH (passive)	All emissions in this band are prohibited in the U.S.	EARTH-EXPLORATION-SATELLITE (passive) RADIO-ASTRONOMY SPACE RESEARCH (passive)	All emissions in this band are prohibited in the U.S.
10.70-I 1.70	FIXED FIXED-SATELLITE (space to earth)	I) Fixed point-to point microwave services: Bandwidth 40 MHz. Max power: +40 dBW E.I.R.P. Telephone companies have used this band to provide wideband links over short distances. It was used heavily for early analog and digital telephone and analog video. (Matheson, 1993) 2) Television STL (studio transmitter link). Bandwidth 40 MHz. Max power IO W transmitter power. Fixed-satellite in the bands 10.95 - 11.20GHz and II.45 - I 1.70 GHz is limited to international systems (i.e. other than domestic systems) Applications for space station assignments are urged to take all practical steps to protect radio astronomy observations in the adjacent band. This band was one of the bands used heavily by AT&T. It was used especially in urban situations where the 4GHz and 6 GHz band were already crowed, and the higher rain fading at 11 GHz could be tolerated because of a short path length. The common carriers are replacing many of these microwave links with liber. The use of this band will continue to diminish fairly rapidly (7 percent decrease per year) as existing common carrier microwave links are replaced with fiber. (Matheson, 1993)		

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NONGQVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
11.70-12.20	FIXED-SATELLITE (space to earth) Mobile(except aeronautical)	I) Television pickup and television non-broadcast pickup. Bandwidth: 40 MHz. Max power: 10 W into transmitter. 2) Fixed satellite services. Bandwidth assigned on a case by case basis. This frequency band is shared on a secondary basis with stations in the broadcasting-satellite and fixed-satellite services. Transponders on space stations in fixed-satellite services may be used additionally for transmissions in the broadcasting-satellite services, provided that such transmissions do not have a maximum E.I.R.P. greater that 53 dBw per television channel and do not cause greater interference than the coordinated fixed-satellite services frequency assignment.		
12.20-12.70	FIXED BROADCAST-SATELLITE	1) Fixed microwave services. Bandwidth: IO MHz or 20 MHz. Maximum power +50 dBW E.I.R.P. (12.2-12.5 GHz), +45 dBW E.I.R.P. (12.5-12.7 GHz) 2) Direct broadcast satellite services (DBS) Operational fixed stations are required to make any or all adjustments necessary to prevent interference to operating broadcasting-satellite systems. No DBS assignments have been implemented yet in the US, and the band remains relatively unused. Considerable recent worldwide interest in broadcast satellites, including HDTV in Japan and digital audio in Europe, may finally cause the broadcasting satellite service to be offered in this band in the US. (Matheson, 1993)		

General Information: 12.70 - 13.25 GHz

Typical users in the band 12.70-13.25 GHz include Cable TV system operators, along with a few TV broadcasters and networks. The major functions include blocktransmission of NTSC-format TV channels from a central distribution point to a cable head-end site (studio-to-headend link, SHL), studio-to-transmitter links(STL), electronic news gathering (ENG), intercity relay (ICR), and comparable functions by cable and public operators. Public point-to-point stations are allowed in the 12.75-13.25 GHz band. Growth ln this band will reverse in the next five years, giving a net decline for the five years of 5 percent a year.
(Matheson, 1993)

FREQUENCY (GHz)	NONGQVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
12.70- 12.750	FIXED FIXED-SATELLITE (earth to space) MOBILE	I) Broadcast satellite services (fixed services) 2) Cable Television Relay Stations (CARS). Bandwidth: 6 MHz, 12.5 MHz, and 25 MHz. Max power +55 dBW E.I.R.P. 3) Community antenna relay stations. Bandwidth 25 MHz. Max power +55 dBW E.I.R.P. 4) Communications common carrier in the Local Television Transmission Service for television broadcast stations, television broadcast network entities, cable system operations and cable network entities. Bandwidth: 25 MHz. Max power +55 dBW E.I.R.P. This is the most heavily used microwave band, with more than 100,000 assignments. Television pickup stations and CARS pickup stations operate on a secondary basis to fixed stations. Television translator relay stations may be authorized to use frequencies tn this band on a secondary basis. See general information above.		
12.75-13.25	FIXED FIXED SATELLITE (earth to space) MOBILE	Same as 12.5 - 12.75 GHz band with the following additions: 1) Television pickup and television non-broadcast pickup (13.2 - 13.25 GHz). Bandwidth: 25 MHz. Max power IO W transmitter power. 2) Fixed point-to-point microwave (13.2 - 13.25 GHz). Bandwidth: 25 MHz. Max power: IO W transmitter power 3) Television STL (studio transmitter link). Max Bandwidth: 25 MHz.6) Cable television relay services (CARS). Bandwidth: 25 MHz, 12.5 MHz, and 6 MHz Television pickup stations and CARS pickup stations operate on a secondary basis to fixed stations. See general information above.		

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
13.25-13.40	AERONAUTICAL-RADIOLOCATION Space Research (earth to space)	Aeronautical radionavigation services is limited to doppler navigationaids.	AERONAUTICAL-RADIOLOCATION Space Research (earth to space)	Aeronautical radionavigation services is limited to doppler navigation aids.
13.40-14.00	Radiolocation Standard-Frequency and-time-signal-satellite (earth to space) Space Research	Radiolocation stations installed on space craft may be employed for the earth exploration-satellite and space research services on a secondary basis. Almost no radar signals are ever received in this part of the X band. Radars in this band are typically tire-control systems for either aircraft of surface-to-air missile systems, and employ high gain antennas with a correspondingly low probability of intercepts. Typical bandwidth: 2 MHz - 40 MHz (null to null) Typical peak power is low. (Sanders, 1993)	RADIOLOCATION Standard-Frequency and-time-signal-satellite (earth to space) Space Research	Radiolocation stations installed on space craft may be employed for the earth exploration-satellite and space research services on a secondary basis. Almost no radar signals are ever received in this part of the X band. Radars in this band are typically tire-control systems for either aircraft of surface-to-air missile systems, and employ high gain antennas with a correspondingly low probability of intercepts. Typical bandwidth: 2 MHz - 40 MHz (null to null) Typical peak power is low. (Sanders, 1993)
14.00-14.20	RADIONAVIGATION FIXED-SATELLITE (earth to space) Space Research	I) Maritime radiodetermination (radionavigation) assignable to ship and shore stations including ship and shore radar and transponder stations. Bandwidth: 20 MHz (hand held radar only). Max power: 200 mW for ship radar. 2) Land-mobile-satellite services are assigned on a on a secondary basis. 3) Airborne radionavigation devices Radionavigation services operate on a secondary basis to the fixed satellite services.	RADIONAVIGATION Space Research	1) Maritime radiodetermination (radionavigation) assignable to ship and shore stations including ship and shore radar and transponder stations. Bandwidth: 20 MHz (hand held radar only). Max power: 200 mW for ship radar. 2) Land-mobile-satellite services are assigned on a on a secondary basis. 3) Airborne radionavigation devices
14.20-14.30	Fixed-Satellite(Earthto space) Mobile - except aeronautical mobile	I) Television pickup and television non-broadcast pickup stations. 2) Land mobile-satellite services are assigned on a secondary basis. 3) Airborne radionavigation devices Radionavigation services operate on a secondary basis.		

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
14.30-14.40	Fixed-Satellite(Earthto space) Mobile - except aeronautical mobile	1) Television pickup and television non-broadcast pickup stations. 2) Land mobile-satellite services are assigned on a secondary basis. 3) Airborne radionavigation devices Radionavigation services operate on a secondary basis.		
14.40-14.50	FIXED-SATELLITE (earth to space)	All practical steps are made to protect special line observations of the radio astronomy services from harmful interference. Radio astronomy observations in the 14.47 to 14.5 GHz band may be made at certain radio astronomy observations.	Fixed Mobile	All practical steps are made to protect special line observations of the radio astronomy services from harmful interference. Radio astronomy observations in the 14.47 to 14.5 GHz band may be made at certain radio astronomy observations.
l4.5000-14.7145			FIXED Mobile SpaceResearch	Fixed service is primary, while Mobile, and Space Research allocations are secondary, The band is divided into 84 channels, each of which is 2.5 MHz wide. Adjacent channels can be combined to obtain the required bandwidth. (Matheson, 1993)
14.7145-15.1365			MOBILE Fixed SpaceResearch	
l5.1365-15.35			FIXED Mobile SpaceResearch	Radio Astronomy in the adjacent band is protected . Passive Earth Exploration Satellite services is assigned on a secondary basis. The band is divided into 84 channels that are 2.5 MHz wide. Adjacent channels can be combined to obtain the required bandwidth. The average bandwidth is 14 MHz. (Matheson, 1993)
15.35-15.40	EARTH-EXPLORATION-SATELLITE (passive) RADIO-ASTRONOMY SPACE RESEARCH (passive)	All emissions are prohibited in this band.	EARTH-EXPLORATION-SATELLITE(passive) RADIO-ASTRONOMY SPACE RESEARCH (passive)	All emissions are prohibited in this band.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
15.40-15.70	AERONAUTICAL-RADIOLOCATION	1) Aeronautical mobile-satellite 2) Fixed-satellite services and inter-satellite services for connection between one or more earth stations at a specified fixed point on the Earth and space stations when these services are used in conjunction with the aeronautical radionavigation and/or aeronautical mobile services. Action must be taken to protect radio astronomy observation in the adjacent band (15.35 - 15.40 GHz)	AERONAUTICAL-RADIOLOCATION	1) Aeronautical mobile-satellite 2) Fixed-satellite services and inter-satellite services for connection between one or more earth stations at a specified fixed point on the Earth and space stations when these services are used in conjunction with the aeronautical radionavigation and/or aeronautical mobile services. Action is taken to protect radio astronomy observation in the adjacent band (15.35 - 15.40 (GHz)
General Information: 15.70 - 17.70 GHz Almost no radar signals are ever received in this part of the X band. Radars in this band are typically fire-control systems for either aircraft or surface-to-air missile systems, and employ high gain antennas with a correspondingly low probability of intercept. Typical bandwidth: 2 MHz - 40 MHz (null to null) Typical peak power is low. (Sanders, 1993)				
15.70-16.60	Radiolocation	Airport surface detection equipment (ASDE) is permitted on a co-equal basis subject to coordination with the military department. See General Information above.	RADIOLOCATION	See General Information above.
16.60-17.10	Radiolocation	Airport surface detection equipment (ASDE) is permitted on a co-equal basis subject to coordination with the military department. See General Information above.	RADIOLOCATION Space Research (deep space) (Earth to space)	See General Information above.
17.10-17.20	Radiolocation	Airport surface detection equipment (ASDE) is permitted on a co-equal basis subject to coordination with the military department. See General Information above.	RADIOLOCATION	See General Information above.

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
17.20-17.30	Radiolocation Earth-exploration (active) Space-research (active)	Airport surface detection equipment (ASDE) is permitted on a co-equal basis subject to coordination with the military department. See General Information above.	RADIOLOCATION Earth-exploration (active) Space-research (active)	See General Information above.
17.30-17.70	FIXED-SATELLITE (earth to space)	Use for fixed-satellite services is limited to feeder links for the broadcast-satellite services. See General Information above.	Radiolocation	Government radiolocation is restricted to operating power of less than 51 dBW E.I.R.P. after feeder link stations are authorized and brought into use. See General Information above.
17.70-17.80	FIXED-SATELLITE (space to earth) (earth to space) MOBILE FIXED	I) Television STL (studio transmitter link), television relay stations and television translator relay stations. Bandwidth: 10 MHz, 20 MHz, 40 MHz, and 80 MHz. Max power: +55 dBW E.I.R.P. 2) Cable Television relay service (CARS). Bandwidth: 10 MHz, 20 MHz, 40 MHz, and 80 MHz. Max power: +55 dBW E.I.R.P. 3) Digital electronic message service 4) Point-to-point fixed microwave. Bandwidth: 10 MHz, 20 MHz, 40 MHz, and 80 MHz. Max power: I W E.I.R.P. This band is lightly used but is recently being exploited, due partly to the recent availability of equipment for this frequency range. This band will continue growing at an average rate of 20 percent a year for the next five years. (Matheson, 1993)		

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGGVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
17.80-18.60	FIXED FIXED-SATELLITE (space to earth) MOBILE	I) Television STL (studio transmitter link), television relay stations and television translator relay stations. Bandwidth: 2 MHz, 6 MHz, IO MHz, 20 MHz, 40 MHz, and 80 MHz. Max power: +55 dBW E.I.R.P. 2) Cable Television relay service (CARS). Bandwidth. 6 MHz, I0 MHz, 20 MHz, 40 MHz, and 80 MHz. Max power: +55 dBW E.I.R.P. 3) Digital electronic message service 4) Point-to-point fixed microwave. Bandwidth: 5 MHz, 6 MHz, IO MHz, 20 MHz, 40 MHz, and 80 MHz, 220 MHz. Max power: I W E.I.R.P. This band is also allocated to the meteorological-satellite service (earth-to-space) on a primary basis. This use is limited to geostationary satellites. The 220 MHz channelization was made for a very wideband microwave system, which was apparently made obsolete by fiber and never deployed in the US. (Matheson, 1993) This band is lightly used but is recently being exploited, due partly to the recent availability of equipment for this frequency range. This band will continue growing at an average rate of 20 percent a year for the next five years. (Matheson, 1993)		

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
18.60-18.80	EARTH-EXPLORATION-SATELLITE (passive) SPACE-RESEARCH (passive) FIXED FIXED-SATELLITE (space to earth) MOBILE - except aeronautical mobile	I) Aural broadcast STL (studio transmitter link) and intercity relay stations. Bandwidth: 5 MHz. Max power: +35 dBW E.I.R.P. 2) Television STL (studio transmitter link), television relay stations, and television translator relay stations. Bandwidth: 6 MHz 3) Point-to-point microwave services. Bandwidth: IO MHz and 20 MHz. Max power: I W E.I.R.P. Fixed and mobile services are assigned taking into account the passive sensors in earth-exploration satellites and space research. Fixed and mobile services are limited to a maximum E.I.R.P. of +35 dBW. The fixed satellite service is limited to a power flux density at the earth's surface of -101 dBW/m' in a 200 MHz band. This band is lightly used but is recently being exploited, due partly to the recent availability of equipment for this frequency range. This band will continue growing at an average rate of 20 percent a year for the next five years.	EARTH-EXPLORATION-SATELLITE (passive) SPACE-RESEARCH (passive)	

(Matheson, 1993)

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
18.80-19.70	FIXED FIXED-SATELLITE (space to earth) MOBILE	1) Television STL (studio transmitter link), television relay stations, and television translator relay stations. Bandwidth: IO MHz, 20 MHz, 40 MHz, 80 MHz. Max power: +55 dBW E.I.R.P. 2) Aural broadcast STL (studio transmitter link). Bandwidth: 5 MHz. Max power: +35 dBW E.I.R.P. 3) Cable television relay services (CARS). Bandwidth: IO MHz, 20 MHz, 40 MHz, 80 MHz. Max power: +55 dBW E.I.R.P. 4) Point-to-point microwave services. Bandwidth: IO MHz, 20 MHz, 40 MHz, and 80 MHz, 220 MHz. Max power: 1 W E.I.R.P. 5) Digital electronic message service (Digital termination assignments). Bandwidth: 10 MHz. Max power +55 dBW E.I.R.P. The 220 MHz channelization was made for a very wideband microwave system, which was apparently made obsolete by fiber and never deployed in the US. (Matheson, 1993) This band is lightly used but is recently being exploited, due partly to the recent availability of equipment for this frequency range. This band will continue growing at an average rate of 20 percent a year for the next five years. (Matheson, 1993)		
19.70-20.2	FIXED-SATELLITE (space to earth) Mobile-Satellite (space to earth)			
20.20-21.20	Standard Frequency and Time Signal Satellite (space to earth)		FIXED-SATELLITE (space to earth) MOBILE-SATELLITE (space to earth) Standard Frequency and Time Signal Satellite (space to earth)	Government fixed-satellite and mobile-satellite services are limited to military systems.

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
General Information: 21.20 - 23.60 GHz This band is a general-purpose point-to-point band shared by private, public and Government users. The band is ohannelized at 50 MHz, with a maximum bandwidth of 100 MHz, Alternate 600 MHz portions are set aside for common carrier and private operational users, with Government use across the entire 2.4GHz. Typical user of this band include common carrier (492 assignments), privateoperational(6,666), and Government (1,280). Although the huge growth once forecast for this band has not materialized, an average of a 9 percent compounded growth rate is expected for the nextfive years. This will be widely distributed over a number of short-range services. (Matheson, 1993)				
2 1.20-21 .40	EARTH-EXPLORATION-SATELLITE (passive) FIXED MOBILE SPACE-RESEARCH (passive)	1) Television pickup and television non-broadcast pickup stations. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 2) Television STL (studio transmitter link). Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 3) Fixed point-to-point microwave. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. Space research and earth exploration-satellite services to not receive protection from the fixed and mobile services. See general information above.	EARTH-EXPLORATION-SATELLITE(passive) FIXED MOBILE SPACE-RESEARCH (passive)	See general information above.
2 1.40-22.00	FIXED MOBILE	I) Television pickup and television non-broadcast pickup stations. Bandwidth: <l00 MHz. Max power +50 dBW E.I.R.P. 2) Television STL (studio transmitter link). Bandwidth: <100 MHz. Max power +50 dBW E I.R.P. 3) Fixed point-to-point microwave. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. See general information above.	FIXED MOBILE	See general information above.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
22.00-22.21	FIXED MOBILE - except aeronautical mobile	I) Television pickup and television non-broadcast pickup stations. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 2) Television STL (studio transmitter link). Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 3) Fixed point-to-point microwave. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. Efforts are made to protect the spectral line observations at the radio astronomy service in the band 22.01-22.21 GHz from harmful interference. See general information above.	FIXED MOBILE - except aeronautical mobile	See general information above.
22.21-22.50	EARTH-EXPLORATION-SATELLITE (passive) FIXED MOBILE RADIO-ASTRONOMY SPACE-RESEARCH (passive)	I) Television pickup and television non-broadcast pickup stations. Bandwidth: 400 MHz. Max power +50 dBW E.I.R.P. 2) Television STL (studio transmitter link). Bandwidth: 400 MHz. Max power +50 dBW E.I.R.P. 3) Fixed point-to-point microwave. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. Space research and earth exploration do not receive protection from the fixed and mobile services See general information above.	EARTH-EXPLORATION-SATELLITE (passive) FIXED MOBILE RADIO-ASTRONOMY SPACE-RESEARCH (passive)	See general information above.
22.50-22.55	BROADCAST-SATELLITE FIXED MOBILE	1) Television pickup and television non-broadcast pickup stations. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 2) Television STL (studio transmitter link). Bandwidth: 400 MHz. Max power +50 dBW E.I.R.P. 3) Fixed point-to-point microwave. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. All practical steps are taken to protect radio astronomy in the adjacent band from harmful interference. See general information above.	FIXED MOBILE	See general information above.

FREQUENCY (GHz)	NONGOVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
22.55-23.00	BROADCAST-SATELLITE FIXED INTER-SATELLITE MOBILE	I) Television pickup and television non-broadcast pickup stations. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 2) Television STL (studio transmitter link). Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 3) Fixed point-to-point microwave. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. All practical steps are taken to protect the spectral line observations of the radio astronomy service in the bands 22.81 - 22.86 GHz and 23.07 - 23.12 GHz from harmful interference. In the 22.55 - 23.55 GHz band, non-geostationary intersatellite links may operate on a secondary basis to geostationaryintersatellitelinks. See general information above.	FIXED INTER-SATELLITE MOBILE	See general information above.
23.00-23.55	FIXED INTER-SATELLITE MOBILE	I) Television pickup and television non-broadcast pickup stations. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 2) Television STL (studio transmitter link). Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 3) Fixed point-to-point microwave. Bandwidth: 400 MHz. Max power +50 dBW E.I.R.P. All practical steps are taken to protect the spectral line observations of the radio astronomy service in the bands 22.81 - 22.86 GHz and 23.07 - 23.12 GHz from harmful interference. In the 22.55 - 23.55 GHz band, non-geostationary intersatellite links may operate on a secondary basis to geostationaryintersatellitelinks. See general information above.	FIXED INTER-SATELLITE MOBILE	See general information above.

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
23.55-23.60	FIXED MOBILE	I) Television pickup and television non-broadcast pickup stations. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 2) Television STL (studio transmitter link). Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. 3) Fixed point-to-point microwave. Bandwidth: <100 MHz. Max power +50 dBW E.I.R.P. See general information above.	FIXED MOBILE	See general information above.
23.60-24.00	EARTH-EXPLORATION-SATELLITE (passive) RADIO-ASTRONOMY SPACE RESEARCH (passive)	All emissions in this band are prohibited.	EARTH-EXPLORATION-SATELLITE(passive) RADIO-ASTRONOMY SPACE RESEARCH (passive)	All emissions in this band are prohibited.
24.00-24.05	AMATEUR AMATEUR-SATELLITE	Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. All practical steps are taken to protect radio astronomy observations in the adjacent bands from harmful interference. The band 24.00-24.25 GHz is designated for industrial, scientific, and medical (ISM) applications. Radiocommunications services operating within this band must accept harmful interference which may be caused by these applications.		

FREQUENCY (GHz)	NONGGVERNMENT ALLOCATION	NONGOVERNMENT USE	GOVERNMENT ALLOCATION	GOVERNMENT USE
24.05-24.25	Earth-exploration-satellite (active) Amateur Radiolocation	Amateur emission types authorized in this band are MCW (tone-modulated international Morse code telegraphy), phone (speech and other sound emissions), image (facsimile and television emissions), RTTY (narrow-band direct-printing telegraphy), data (telecommand and computer communications), ss (spread spectrum), test, and pulse. The band 24.00-24.25 GHz is designated for industrial, scientitic, and medical (ISM) applications. Radiocommunications services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is permitted unlimited radiated energy. Non government radiolocation is secondary to government radiolocation services. For the frequency 24.125 GHz, unmodulated continuous wave (NON) emissions only shall be employed.	RADIOLOCATION Earth-exploration-satellite (active)	All government non-military radiolocation is secondary to military radiolocation. Non government radiolocation is secondary to government radiolocation services. For the frequency 24.125 GHz, unmodulated continuous wave (NON) emissions only shall be employed. The band 24.00-24.25 GHz is designated for industrial, scientific, and medical (ISM) applications. Radiocommunications services operating within this band must accept harmful interference which may be caused by these applications.
24.25-25.25	RADIONAVIGATION	Airborneradionavigation	RADIONAVIGATION	Airborneradionavigation

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Sanders, F. (1993), Draft copy of the Equipment Characteristics Handbook, NTIA Report.

1. See references at end of this section
2. A = Airborne, G = Ground Based, M = Marine Based

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