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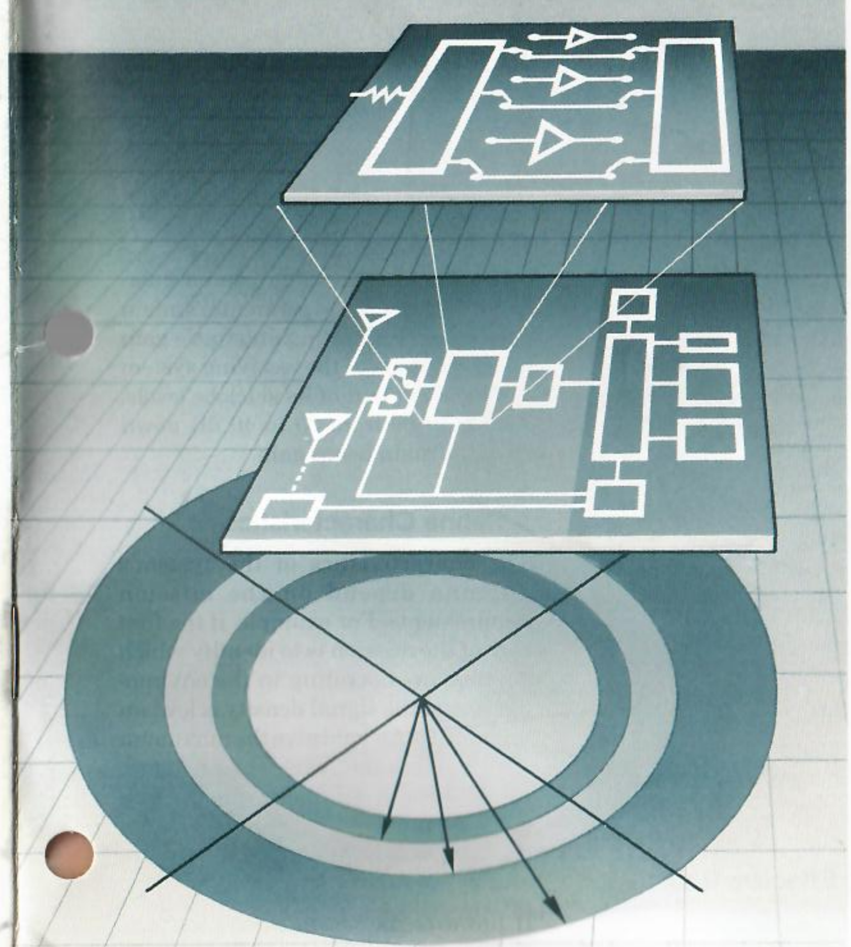
RF Signal Processing Before the Receiver



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Tech-notes

This article analyzes what happens to the rf energy from the time it leaves the transmitting antenna to when it is applied to the tuner input port. It is intended to pinpoint some of the more commonly overlooked areas of signal processing and to give further insight into some of the tradeoffs required to achieve an optimal surveillance receiver system.

The discussion will be limited to microwave surveillance receiver applications that cover the 0.5 to 18.0 GHz frequency range.

Introduction

Any receiving system cannot operate at its peak performance unless all links in the rf path are at their optimum levels. Examples of what should be considered in the design of a receiving system are:

a. Transmitted Effective Radiated Power (ERP)

b. Propagation losses due to free space and atmospheric effects

c. Polarization of the transmitted electromagnetic wave

d. Receiving antenna characteristics; i.e., gain and polarization

e. Processing of the rf energy between the antenna and the receiver

f. Interference due to close-by high power emitters

During this discussion, a typical antenna rf distribution subsystem will be used to illustrate the techniques used.

Transmitted Effective Radiated Power

The ERP (Effective Radiated Power) of an emitter is important to the receiver system designer, since it determines the maximum distance that a receiving system can detect and/or analyze a given emitter.

The ERP of an emitter is the amount of transmitter power multiplied by the gain of the transmitted antenna. ERP is usually expressed in dBw or dBm units. In the following analysis, the units used will be dBm, since this is the common unit used in receiver sensitivity calculations.

Expressed as dBm,

$$\text{ERP (dBm)} = \text{Transmitter Power (dBm)} + \text{Antenna Gain (dB)}$$

Emitters in the microwave region that are subject to ECM surveillance are usually pulsed radars that use directional antennas, as opposed to a transmitting antenna used for communication in the vhf or uhf frequency bands, whose antenna would be broad beamed or omnidirectional.

If the receiving antenna cannot intercept the transmitting antenna's main beam, the transmitting antenna's gain in the direction of the receiving system is reduced to that of its sidelobe levels. This may be from 20 to 40 dB down from the main beam gain.

Antenna Characteristics

The characteristics of the system's antenna depend on the mission requirements. For example, if the first step of the mission is to identify which emitters are operating in the environment, and the signal density is low, an antenna that would give the maximum spatial coverage, such as an omni, would be the optimum choice. The omni antenna provides little gain so the system is at its least sensitive configuration.

If, however, the system must operate in a dense environment, a better choice for an antenna might be one that provides spatial discrimination by the use of a narrow beamwidth. This choice

may necessitate a compromise of having a lower probability of detection for scan-on-scan conditions.

As can be seen by the above examples, each system will have to consider all of the requirements and constraints. The entire system, from antennas to rf distribution networks to receiver types to signal processing, must be considered as a whole to provide the optimal system.

The pattern of an antenna is the same whether that antenna is receiving or transmitting. The major difference between the two antennas is the maximum amount of power that one can handle over the other. Figures 1 and 2 show the pattern of an omni and a direction-finding antenna. Referring to the pattern of the omni antenna, note that it is not a perfect circle, but that the gain varies with respect to the azimuth angle. This is common, and is referred to as the "deviation from omni," which usually runs in the order of ±3 dB. In Figure 2 the DF antenna pattern illustrates some features that are important to the system designer. These are the presence of sidelobes and squint. Sidelobes are present on practical antennas due to imperfect illumination of the reflector by the feed. In Figure 2 the sidelobe levels are about 14 to 15 dB down from the peak of the main beam. Typically, multioctave antennas will have nominal sidelobe levels of 10 dB. The *squint* of an antenna is the dif-

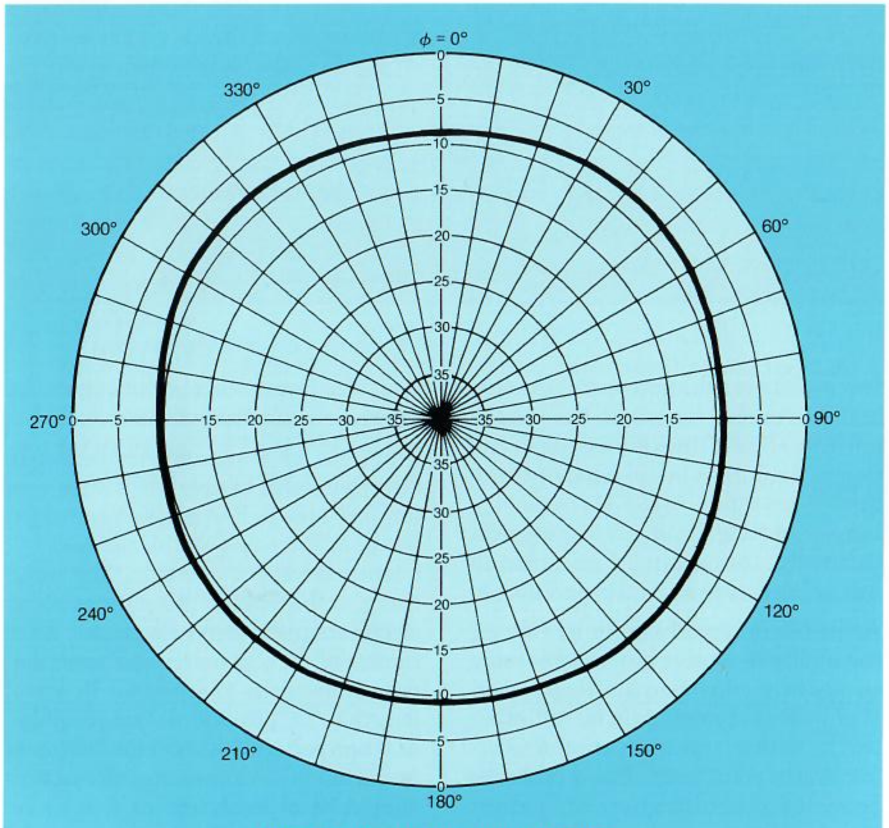

Figure 1. Typical omni antenna pattern.

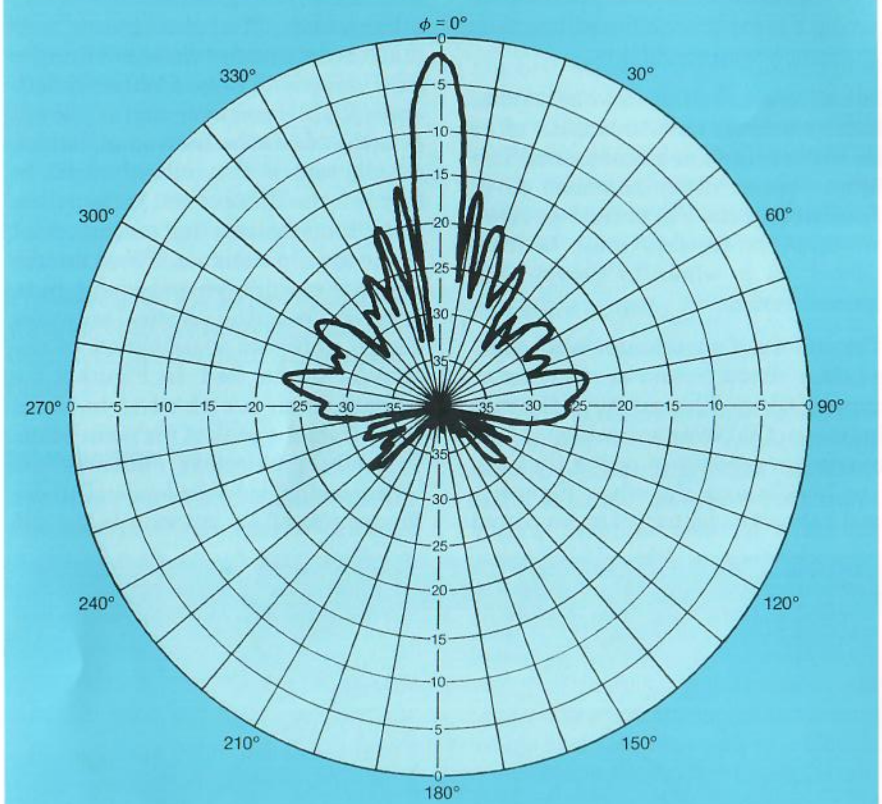

Figure 2. Typical DF antenna pattern.

ference between the antenna's electrical and mechanical boresight. For the DF antenna shown, the squint is about one degree. Squint of a broad-band antenna that covers the 0.5 to 18 GHz frequency range can range from ±5 to 0 degrees. Generally, the squint of an antenna will be ±1 degree at 2 GHz and above.

An antenna provides gain by having the ability to receive or transmit more energy in one direction than in another. It provides apparent gain by collecting energy with a large aperture and focusing it at a point much like a telescope provides magnification of distant objects. Also like a telescope, there is a price that you pay for the magnification. The larger the magnification the narrower is the field of view.

The gain of a parabolic antenna is directly related to aperture size as was implied above. For a given antenna, the gain increases as the received frequency increases, or saying the same thing, as the wavelength of the received electromagnetic wave decreases. As a matter of fact, antenna engineers discuss dimensions of antennas in wavelengths. To provide a "reasonable" antenna pattern that systems designers would like to have, the antenna aperture should be at least four or five wavelengths in width. To give an example, an antenna that works reasonably well

at 500 MHz should have an aperture at least eight feet in diameter. That much space in an airplane is usually impossible to acquire. What will have to happen is for all disciplines involved to make concessions. For an airborne rotating DF system, the trade-off at the lower frequencies is to have lower gain and decreased DF accuracy. For a fixed site, the conditions might dictate that the large diameter disk is feasible, but a radome may be required.

Polarization considerations sometimes will dictate what the antenna characteristics will be in a given system. If the signal that you are trying to collect has vertical polarization and your antenna has horizontal polarization, theoretically the system will not detect it. The relative polarization mismatch loss is presented in Table 1 (1). For any antenna having a single feed of a specific polarization, there is one polarization that it cannot receive. Electromagnetic waves possessing unlike polarizations will result in a loss of power from that level that could have been received from an antenna that had like polarization. An example of this would be the apparent 3-dB loss of the reception by a linearly (either hori-

Antenna Polarization	Wave Polarization: Vertical	Horizontal	Right-Hand Circular	Left-Hand Circular	Right Slant Linear	Left Slant Linear
Vertical	0 dB	∞	3 dB	3 dB	3 dB	3 dB
Horizontal	∞	0 dB	3 dB	3 dB	3 dB	3 dB
Right-Hand Circular	3 dB	3 dB	0 dB	∞	3 dB	3 dB
Left-Hand Circular	3 dB	3 dB	∞	0 dB	3 dB	3 dB
Right Slant Linear	3 dB	3 dB	3 dB	3 dB	0 dB	∞
Left Slant Linear	3 dB	3 dB	3 dB	3 dB	∞	0 dB

Table 1. Relative polarization mismatch.

zontal, vertical or slant) polarized antenna of a wave having circular polarization. The term "like polarization" merely means that the electromagnetic wave and the receiving antenna have the same polarization, or are matched.

Since most radars will transmit a polarization that is either circular or linear (either vertical or horizontal), a general purpose polarization that enjoys wide application is slant linear, either left slant or right slant. The penalty that must be paid is that the antenna has 3 dB less gain than it could have had if the polarization were matched.

Free Space and Atmospheric Propagation Loss

Free space losses are those losses that are dependent on the length of the path the electromagnetic wave travels through, and its wavelength. This loss is equal to:

$$20 \log (4 \pi d/\lambda) \text{ dB}$$

where, d is distance and λ is the wavelength.

This equation can be more conveniently expressed in dB as,

$$L = 97.8 + 20 \log(f \text{ GHz}) + 20 \log(d \text{ nmi})$$

$$L = 96.8 + 20 \log(f \text{ GHz}) + 20 \log(d \text{ mi})$$

$$L = 92.45 + 20 \log(f \text{ GHz}) + 20 \log(d \text{ km})$$

Figure 3 illustrates the free space/propagation loss with range as a variable.

The losses due to the effects of the atmosphere at frequencies below 10 GHz, and that do not traverse the tropospere, can usually be ignored. However, at 10 GHz and above, the absorption losses can be significant. The losses due to rain are difficult to take into account, since it varies so much from one condition to another. For further discussion of the atmospheric losses due to the effects of rain (see references 2 and 3).

For the atmospheric losses due to oxygen and water vapor, an estimate of 0.01 dB per nautical mile at frequencies of 1 to 10 GHz can be used, while at frequencies up to 20 GHz, an estimate of 0.1 dB per nautical mile can be used (3).

Other propagation losses are due to terrain, effects of the radio horizon and multipath. Losses due to the terrain are beyond the scope of this paper, but are discussed in the references.

The radio horizon can be calculated from the following equations (4):

$$\text{Range} = \sqrt{2} \times (H_t^{1/2} + H_r^{1/2})$$

where, the range is in miles and the height is in feet.

$$\text{Range} = 1.23 \; (H_t^{1/2} + H_r^{1/2})$$

where, the range is in nautical miles.

Figure 4 illustrates the effects of antenna height on the radio horizon. If the receiving antenna is at a height of 50 feet, the radio horizon is approximately ten miles. However, if the receiving antenna is at 10,000 feet, the radio horizon is approximately 140 miles (5).

RF Processing Between The Antenna And The Receiver

After the antenna has received the electromagnetic wave, an rf distribution network is usually required for a number of reasons.

a. The antenna frequency characteristics do not match that of the tuners.

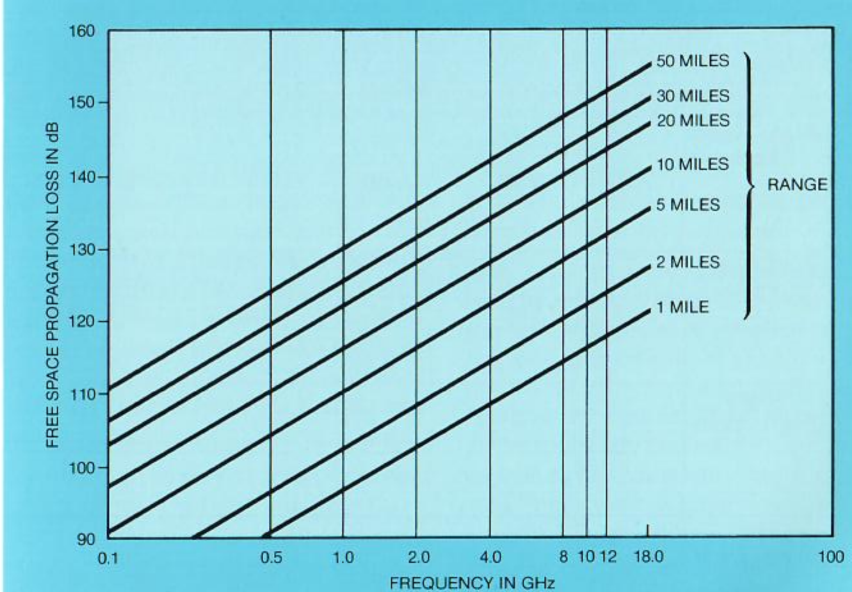

Figure 3. Free space propagation loss vs. frequency.

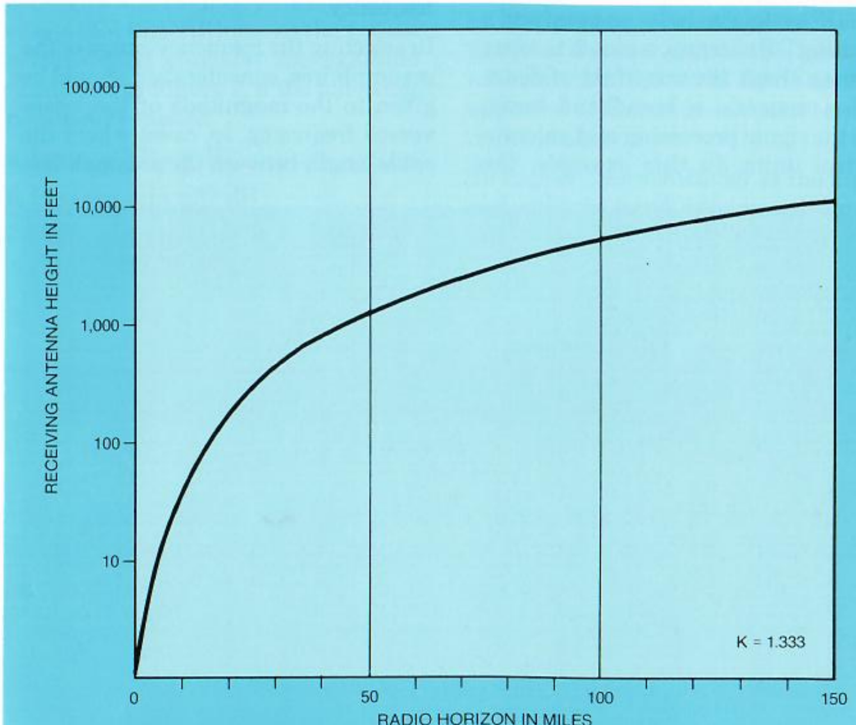

Figure 4. Radio horizon vs. receiving antenna height.

b. Polarization switching may be required.

c. Preamplification is required to meet system sensitivity requirements.

d. Frequency multiplexing of the antenna output is required to divide the output of the antenna into subbands for preamplification.

e. Additional components to extend the receiver's dynamic range are required.

f. Devices that protect the receiver inputs or the preamplifiers from excessive power are necessary.

g. Preamplification is required to overcome long cable runs.

A typical direction finding system is shown in Figure 5, with the distribution network shown in more detail in Figure 6.

The DF system includes an omni and a spinning DF antenna, a switch to select between them, the rest of the rf distribution network, a broadband tuner, and the signal processing and antenna control units. In this example, the frequency range of the antenna is matched to that of the tuner, but to increase the system sensitivity, preamplifiers are required. Practical preamps do not cover the entire 0.5 to 18.0 GHz frequency range, but are capable of multioctave performance. Examples used are preamps covering the 0.5 to 2.0, 2 to 8, and 8 to 18 GHz bands.

Prior to the input to the preamplifiers, the frequency must be divided into the appropriate bands. For minimum insertion loss, this is usually done with a multiplexer, in this case a triplexer. This device will allow continuous frequency scanning of the entire frequency range without having to resort to switching or taking a large insertion-loss penalty if power dividers are used. Multiplexer performance is similar to a 3-dB power divider at the crossover frequency.

In selecting the frequency range of the preamplifires, consideration should be given to the magnitude of the losses versus frequency. In cases where the cable length between the preamplifiers

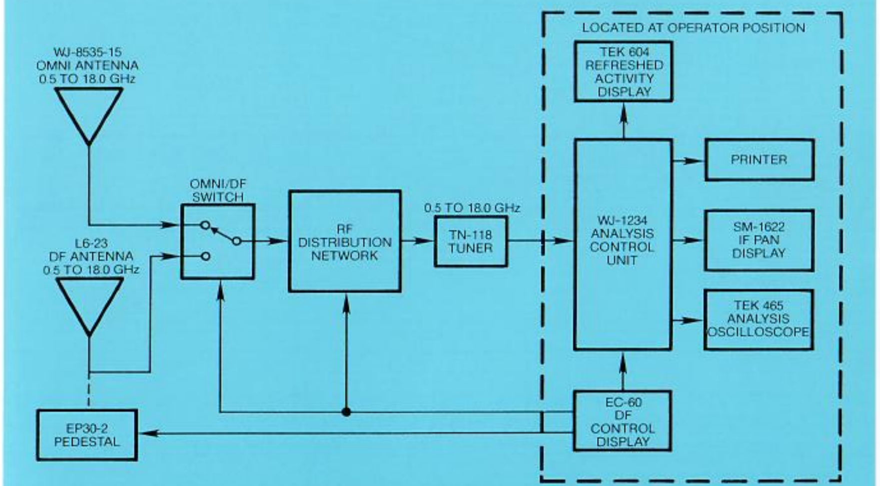

Figure 5. Direction finding system.

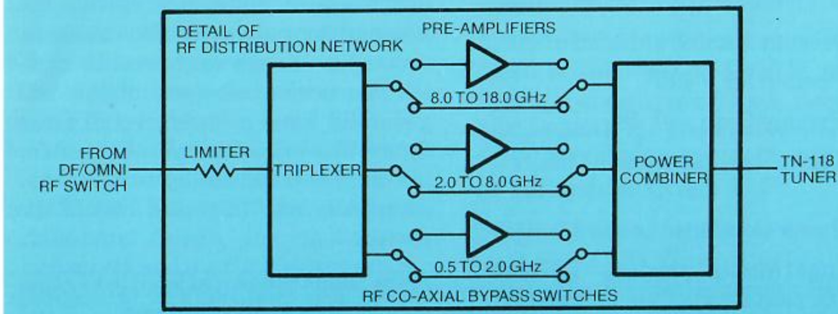

Figure 6. RF distribution detail.

and the tuners is long, the losses at the high end of the frequency band can be significantly higher than those losses at the lower end.

For example, the cable loss of a typical cable can vary as much as 65 percent between 8 and 18 GHz. To illustrate the effects that this will have on the system performance, consider the example illustrated in Figure 7, if the following parameters existed:

a. Preamp NF = 8 dB

b. Preamp gain = 37 dB

c. Preamp output 1-dB compression point = +10 dBm

d. Cable loss (50 feet) = 21 dB at 8 GHz, 34 dB at 18 GHz

e. Tuner NF = 20 dB

f. Tuner input 1-dB compression point = -10 dBm

Note that the dynamic range is limited by the preamplifier. Also, the noise figure at the low end of the band is adequate, but the noise figure at the upper end of the band could stand some improvement.

To improve the sensitivity at the high end, split the band into two subbands of 8 to 12 and 12 to 18 GHz, as shown in Figure 8. Octave-band preamplifiers

Frequency (GHz)	System NF (dB)	Input 1-dB Comp Pt (dBm)	MDS, BW = 1 MHz S/N = 1 (dBm)	Dynamic Range (dB)
8	9.4	-27	-104.6	77.6
18	17.5	-27	-96.5	69.5

Figure 7. 8 to 18 GHz single amplifier example.

are available that will cover these bands. The system parameters are now:

a. Frequency Band 8 to 12 GHz:

1. Preamp NF = 4 dB
2. Preamp Gain = 37 dB
3. Cable Loss = 21 dB at 8 GHz; 26 dB at 12 GHz
4. Power Combiner Loss = 3.5 dB
5. Input Multiplexer Loss = 1 dB over the pass band of the multiplexer

b. Frequency Band 12 to 18 GHz:

1. Preamp NF = 7 dB
2. Preamp Gain = 44 dB
3. Cable Loss = 26 dB at 12 GHz; 34 dB at 18 GHz
4. Power Combiner Loss = 3.5 dB
5. Input Multiplexer Loss = 1 dB

Comparison of the two examples point out the following:

a. The system noise figure is about the same at the low end of the frequency range, but has improved by 2.2 dB over the 12 to 18 GHz frequency band.

b. The overall dynamic range has been degraded by 1 dB at 8 GHz and by 4.1 dB at 18 GHz.

By reducing the frequency range over which a preamplifier must operate, the preamplifier gain can more closely be tailored to the system losses. In addition, the octave band preamplifier will generally have a lower overall noise figure. The price that must be paid for the increased sensitivity is additional complexity and increased cost of the system.

Some points to be considered in locating components in a system are:

a. Antennas are usually not situated close to the operations room that houses the receiver.

b. The tuner is usually placed in close proximity to the antenna to reduce the amount of rf cable run.

c. Cable losses at the IF frequencies are usually insignificant over most practicable cable runs.

Any rf distribution network must consider:

a. Receiver type
b. System sensitivity
c. Dynamic range
d. Location of the components
e. Proximity of high-power emitters
f. Primary purpose of the system

Frequency (GHz)	System NF (dB)	Input 1-dB Comp Pt (dBm)	MDS, BW = 1 MHz S/N = 1 (dBm)	Dynamic Range (dB)
8	10.0	-26.0	-104.6	78.6
12	14.0	-26.0	-100.0	74.0
12	10.3	-33.0	-103.7	70.7
18	15.3	-33.0	-98.6	65.6

*Losses at the diplexer crossover frequency are ignored.

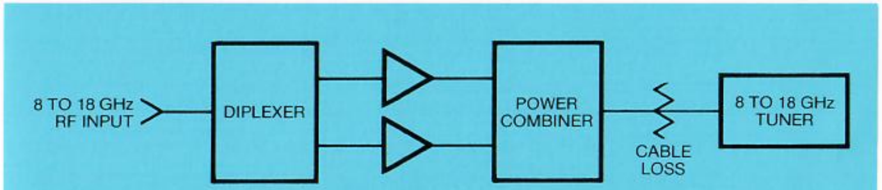

Figure 8. 8 to 18 GHz two amplifier example.

To design an rf distribution system that meets system requirements, each of the components of the system are analyzed. Figure 9 shows typical values of noise figures of devices commonly used in rf distribution networks. Note that the lowest noise figure devices are the octave and multioctave band preamplifiers. These are followed by the octave-band tuners, the multioctave band tuners and the HP-8566 Spectrum Analyzer (6). The spectrum analyzer is shown in this example because of its increased use as a receiver.

When the noise power of a spectrum analyzer is considered in a 1-MHz bandwidth and specified as noise figure, the value of noise figure is quite large. However, using preamplifiers to set the system noise figure, comparable sensitivity to that of a narrow-band receiver can be achieved. The use of preamplifiers can produce intermodulated products that narrow-band receivers reject, but a wide-open front-end device, like a spectrum analyzer operating without preselection, will detect.

Figure 10 presents an example of what length of cable run is feasible, given certain operating conditions. Assume that you wish the preamplifier gain to exceed the cable loss by 10 dB, and that the preamplifier gain is 40 dB.

This requires that the cable loss does not exceed 30 dB. Three cable types are shown. The first is the popular RG214 that has been around for many years. It has a basic frequency limitation in that it is usable only to approximately 10 GHz. After that frequency, it starts to exhibit moding (another way to say it is that above 10 GHz, there are regions of high attenuation).

The next cable to be considered is the type that has loss characteristics similar to the 0.141 semirigid cable. Note that at about 18 GHz, the maximum cable run in this example is about 50 feet.

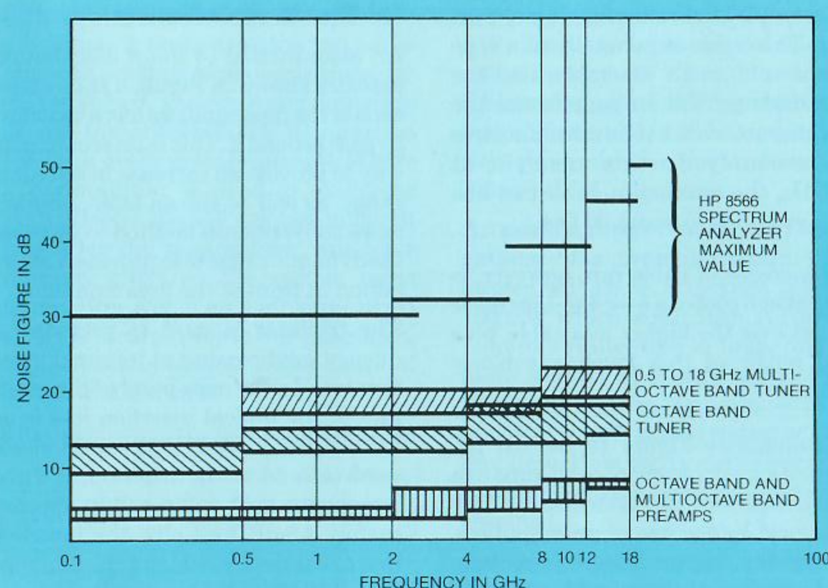

Figure 9. Noise figures of typical devices used in receiving system applications.

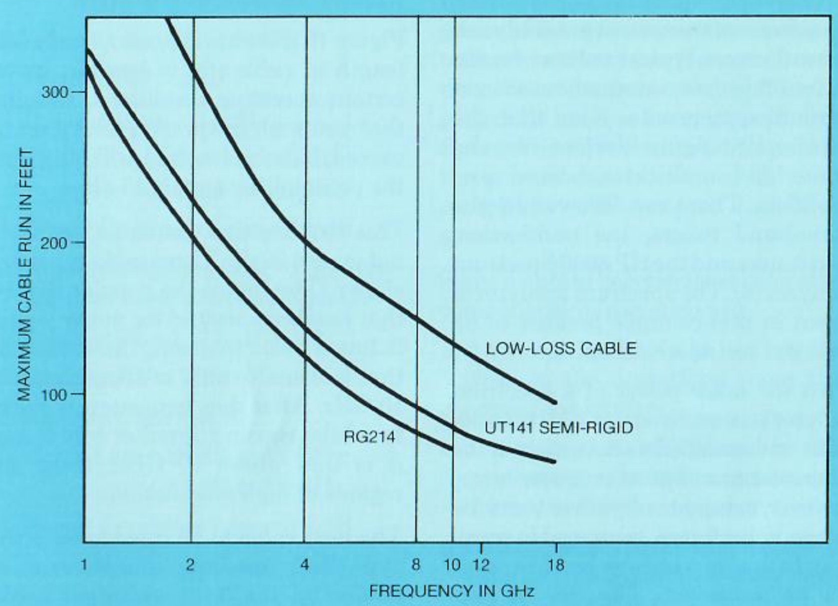

Figure 10. Maximum length of cable if preamplifier gain is 10 dB greater than cable loss. Assumes preamp gain = 40 dB.

An example of a low-loss cable is shown next. This cable is generally of a type that is sold as an assembly, and the manufacturer will only guarantee the loss characteristics if he manufactures the assembly. In this example, at 18 GHz, the maximum cable run has been extended to about 90 feet.

The increase of cable run, however, is bought at a cost of a 4- or 5-to-1 increase in cost over the higher loss cable, plus field repair of this low-loss cable is difficult.

To summarize Figure 10, at low frequencies, most practical cable runs can be accomplished and system sensitivity preserved by the use of preamplifiers, but at the higher frequencies, long cable runs add increased cost and complexity along with higher-cost preamplifiers.

RF Distribution Network

An examination of the rf distribution network shown in Figure 6 shows that each of the preamplifiers has a switched bypass around it. This is an economical way to provide an increase in dynamic range, as will be shown later. Another more conventional method to increase the dynamic range is to provide rf attenuation in front of the preamplifiers.

The triplexer is used to provide frequency multiplexing at minimal insertion loss. In the pass band of the multiplexer, the typical insertion loss is on the order of 1 dB. If a power divider is used instead of the triplexer, a three-way power split will result in approximately 4.8-dB loss plus the insertion loss of the device, which typically runs from 0.5 to 1.0 dB. One disadvantage to the multiplexer is that there is an additional 3.0 to 3.5 dB loss at the crossover frequency, which is in addition to the insertion loss of the pass band. The crossover frequency may be specified at a frequency where no signal activity is anticipated.

After the preamplification takes place, the three outputs of the preamplifiers have to be recombined to match the frequency range of the tuner. A power combiner is used here, but another triplexer or a diode switch may be used in its place.

The use of a power combiner may have detrimental effects if the higher frequency band preamplifiers provide gain and, hence, noise power at the lower frequencies. Any noise added at this point in the circuit will degrade the signal-to-noise ratio at video, resulting in degraded system operation. This condition can be alleviated by the inclusion of a high-pass filter at the output of the offending preamplifier.

The use of a second multiplexer to recombine the frequencies is a viable choice, but adds to the cost of the rf distribution network. One possible disadvantage is that unless the two multiplexers have their crossover frequencies (f_{co}) matched, the crossover loss may exceed the anticipated 6-dB insertion loss by a much greater amount. Where a preamplifier is used to overcome system losses, a small increase in circuit loss after the preamplifier will have minimal effect on the system noise figure. However, if an additional 10 dB of loss is incurred due to this mismatch, an increase in system noise figure of 3.5 dB would result.

This is shown in the following example:

	Matched f_{co} (dB)	Mismatched f_{co} (dB)
Tuner NF	20.0	20.0
Preamp to tuner loss	10.0	20.0
Preamp gain	30.0	30.0
Preamp NF	8.0	8.0
System NF at preamp	8.6	12.1

If the preamplifier's excess gain is only 10 dB then:

	Matched f_{co} (dB)	Mismatched f_{co} (dB)
Tuner NF	20.0	20.0
Preamp to tuner loss	10.0	20.0
Preamp gain	20.0	20.0
Preamp NF	8.0	8.0
System NF at preamp	12.1	20.2

This shows an increase of over 8 dB in system noise figure.

One item that has not yet been examined is the limiter that is placed in front of the triplexer. This device is meant to protect the more sensitive active devices from the affects of high-power emitters. These can be from nearby "friendly" radars or from the near pass of a target emitter. A limiter is a device that shunts rf energy to ground by the use of parallel diodes. Specifications important to the design engineer pertaining to these devices are maximum input power expressed in both cw and pulsed terms and the amount of leakage power.

A typical solid-state GaS FET amplifier will survive an input cw power level of +20 dBm and +27 dBm pulsed power without degradation. The pulsed power is specified to be of a maximum duration of one microsecond at a maximum duty cycle of 0.1 percent.

An examination of the leakage specifications of a typical medium-power limiter will show a leakage power of 150 mW, which is +23 dBm. All limiters require a finite time to limit, and will allow a spike of energy to be passed. This spike of energy is measured in ergs of power, which is the product of power and time. How many ergs a particular preamplifier can take is not generally specified.

One further point should be made about limiters. The maximum power input specification given in the literature is that which the limiter itself can handle.

Some limiters will take more power without burnout, but after a certain input power will exhibit a linear transfer function with a reduced slope, i.e., a 10-dB increase in input power will result in a 3 or 4 dB increase in the output power. The resultant output power level can cause damage if the input power is great enough, and the limiter does not fail. This is another reason that anticipated power levels be considered early in the system design.

System Sensitivity

The noise figure of two cascaded amplifiers is:

$$f_{pa} = f_1 + (f_2 - 1)/g_1$$

$$F_{pa} = 10 \log f_{pa} \text{ expressed in dB}$$

where, f_1 is the noise figure of the preamplifiers, g_1 is the gain of the preamplifier minus the losses from the preamplifier to the tuner, and f_2 is the noise figure of the tuner. This formula is repeated for successive stages of amplifier pairs from the tuner back to the antenna output port.

To calculate the system noise figure referenced to the antenna output port, the sum of the losses of the components from the antenna output port to the input of the preamplifier is added to F_{pa}.

$$F_{sys} = \text{Losses} + F_{pa}$$

To determine the minimum system noise floor at the antenna port, the effects of processing bandwidth and signal-to-noise ratio must now be addressed.

The theoretical noise contributed by a passive device that is at room temperature is

$$f = kTB_r$$

where T = temperature in degrees Kelvin

K = Boltzmann's constant = 1.38054×10^{-23} watts/Hz/degrees Kelvin

B_r = receiver IF bandwidth in Hz

A more convenient working term is that the noise power of a passive device at room temperature and with a bandwidth of 1 MHz is -114 dBm. To change the bandwidth to another value, you must find the ratio of the new bandwidth in dB referenced to 1 MHz. For example, if the actual processing bandwidth were 10 MHz then,

$$\Delta B_r = 10 \log (10 \text{ MHz}/1 \text{ MHz}) = 10 \log(10) = 10 \text{ dB}$$

In addition, allowances must be made for the minimum processing bandwidth necessary to provide specified probability of detection (P_d) and false alarm (P_{fa}). Generally, a 14-dB S/N ratio is adequate to provide a 97 percent P_d and a P_{fa} of 10^{-6} on a single-pulse basis. Incidently, the P_{fa} value can more realistically be related to time between false alarms by the equation shown below (7).

$$\text{time(sec)} = M \times \text{pulse duration}/P_{fa}$$

where, M is the number of pulses integrated.

To calculate the power level of an incoming signal that is required at the antenna port,

$$P_r(\text{dBm}) = -114(\text{dBm}) + B_r(\text{dB}) + F_{sys}(\text{dB}) + S/N(\text{dB})$$

As an example, assume that the resultant noise figure at the preamplifier was 8 dB and there were 7 dB of component losses between the preamplifier and the antenna. Then the system noise figure would be 8 + 7 = 15 dB. The IF bandwidth is 10 MHz and the required signal possessing S/N ratio is 14 dB, as before.

	Band 1		Band 2		Band 3	
Frequency (GHz)	0.5	2.0	2.0	8.0	8.0	18.0
Tuner Noise Figure, max. (dB)	20.0	20.0	20.0	20.0	23.0	23.0
Component Losses, Preamplifiers to Tuner, Including Cable Loss (dB)	8.0	11.0	11.0	19.0	19.0	28.0
Preamplifier Gain (dB)	30.0	30.0	41.0	41.0	44.0	44.0
Preamplifier NF (dB)	3.5	3.5	5.5	5.5	7.5	7.5
Noise Figure at Preamp (dB)	4.7	5.0	6.0	6.0	8.0	10.0
Component Loss Antenna Port to Preamplifier (dB)	4.3	5.0	4.0	7.0	7.0	8.0
System NF at Antenna Port (dB)[1]	9.0	10.0	10.0	13.0	15.0	18.0

NOTE:
1. Add 3.5 dB to system NF to allow for additional loss at the triplexer's crossover frequencies.

Table 2. Sensitivity budget for sample system, antenna output to tuner input.

The required power at the antenna output port would then be:

$$P_r = -114 + 10 + 15 + 14$$

$$P_r = -75 \text{ dBm}$$

Note that this figure does not include the effects of antenna gain.

Table 2 tabulates the sensitivity budget for the sample system.

The next step is to calculate the amount of power that satisfies these system conditions at the antenna aperture. That is done by subtracting the antenna's gain from the value of P_r. In our example, let us assume that there is an omni antenna and a DF antenna with gains of +1 dBi and +17 dBi, respectively.

$$P_{OM} \text{ ant} = -75 - 1 = -76 \text{ dBm}$$

$$P_{DF} \text{ ant} = -75 - 17 = -92 \text{ dBm}$$

This example also points out an advantage of the gain of a directional antenna. Note that by processing with the DF antenna, the system is 16 dB more sensitive than with the omni antenna. In addition, the DF antenna provides spatial discrimination by virtue of its directivity. These advantages may be offset, however, under spatial and frequency-search conditions by decreased probability of intercept. These results are tabulated in Table 3.

To convert the power at the antenna aperture into watts per square meter, use the expression,

$$P_o = 139.6 f^2 (\text{Papt})$$

where P_o = power density in watts/square meter

f = frequency in GHz

Papt = power at the antenna aperture in watts

System Performance

Figure 11 illustrates the required energy in dBm at the antenna aperture to satisfy the NF, bandwidth, and S/N ratio requirements. It plots the sensitivity for both the DF antenna and the omni antenna. Note the omni antenna curve. It increases in sensitivity to about 2 GHz, at which time it begins to decrease. This is the point at which the system losses overtake the increase in antenna gain. Note that the omni antenna does have an increase in gain from -6 dB at 0.5 GHz to +1 at 2 GHz.

	Band 1		Band 2		Band 3	
Frequency (GHz)	0.5	2.0	2.0	8.0	8.0	18.0
System NF at Antenna Port (dB)	9.0	10.0	10.0	13.0	15.0	18.0
Processing S/N Ratio[1]	14.0	14.0	14.0	14.0	14.0	14.0
Antenna Gain (dB)[2]						
DF	-3	7	7	17	17	22
Omni	-6	1	1	1	1	1
Power Required at Antenna Aperture						
DF	-78	-87	-87	-94	-92	-94
Omni	-75	-81	-81	-78	-76	-73

NOTES:
1. Processing bandwidth assumed to be 10 MHz.
2. Antenna gain corrected for vertical or horizontal emitter.

Table 3. Received energy required to provide video processing level of 14 dB S/N (BW = 10 MHz, horizontally or vertically polarized).

From 2 to 18 GHz, the gain remains relatively constant at 1 dB.

For the case of the DF antenna, the system losses never overtake the increase in antenna gain, but the change in slope at the higher frequencies indicates that they are narrowing the gap. The discontinuities at the triplexers crossover frequencies is due to the difference in the preamplifier gains. Note also that none of the tables or curves take into account the crossover losses of the triplexer. The sensitivities at those points will be about 3.5 dB worse.

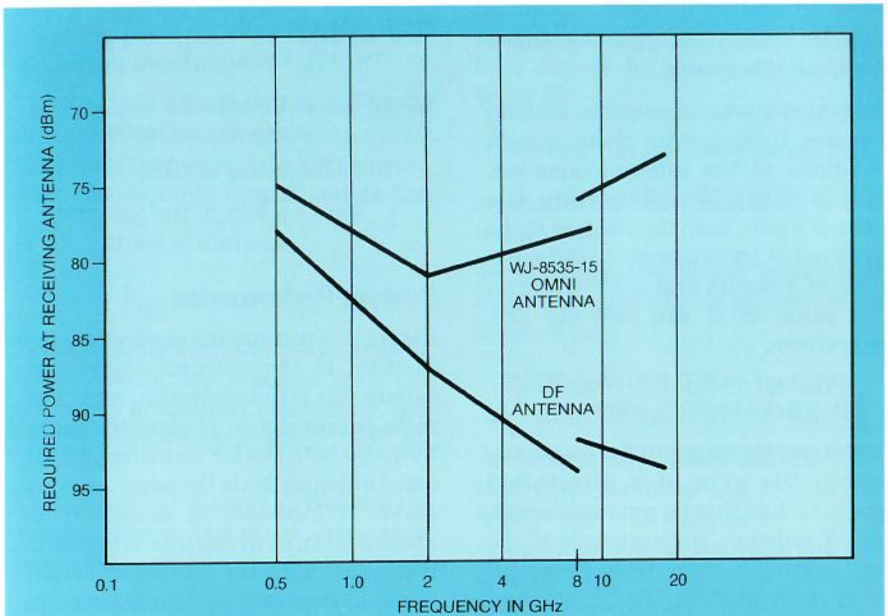

Figure 11. Received energy required for video processing level of 14 dB S/N in 10 MHz bandwidth using omni and DF antennas.

Figure 12 presents the same data in the different manner. The graph shows the required ERP versus frequency, with range as a variable. It shows what ERP the emitter must have in order that the system will have sufficient power to process it. In this figure, only free-space propagation losses were included.

Until this point, we have only mentioned dynamic range but have not considered it. A commonly used definition of dynamic range is the difference between the value of a system's minimum discernible signal level (MDS) in a 1-MHz rf bandwidth and its 1-dB compression point. As an example, the 1-dB compression point of our system at 18 GHz is -34 dBm at the antenna aperture, while the MDS value would be -96 dBm. This is the point at which the signal power equals the noise power. The dynamic range of the system is therefore -34 - (-96) = 62 dB. However, a signal at the same level as the noise cannot be detected or processed since the P_d and P_{fa} criteria are radically different under those power conditions. To continue talking in the same terms that our system sensitivity has been defined, the same rf bandwidth and signal-to-noise ratio must be used. In this example, the "processing" dynamic range is now computed to be,

$$\text{Dynamic Range} = (1\ \text{dB pt}) - B_r - S/N - \text{MDS dB}$$

$$\text{Dynamic Range} = -34\ \text{dBm} - 10\ \text{dB} - 15\ \text{dB} - (-96\ \text{dBm}) = 37\ \text{dB}$$

This is a much smaller processing dynamic range than expected, and illus-

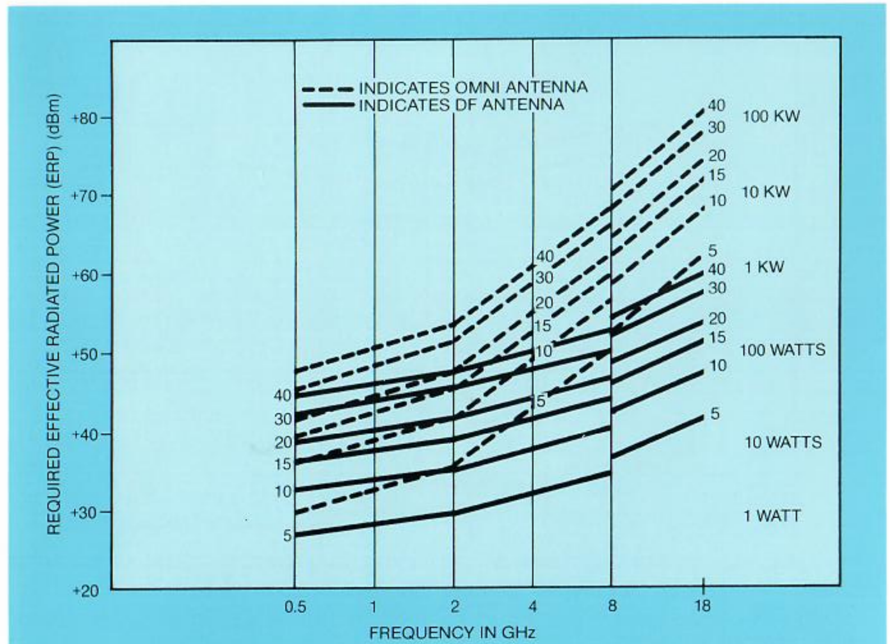

Figure 12. Required ERP vs. frequency with range as a variable (all ranges in miles).

trates the need for some means to extend it. Figure 13 shows the effects of providing preamplifier bypass switching to extend the dynamic range. At 18 GHz the difference between the bypassed and unbypassed conditions is 48 dB. Therefore, by this simple means, the full dynamic range of the system is 37 + 48 = 85 dB considering processing rf bandwidth and signal-to-noise ratio.

Figure 13 also has a number of signals shown with respect to their anticipated received power levels. The power received from each emitter varies due to the distance that the emitter is from the receiving antenna, and ranges from 2 to 40 miles.

Four of the five signals can cause nonlinear operation in the unbypassed preamplifier example. By bypassing the preamplifiers, all but one of the emitters are operating within the linear region of the system. This emitter would be within the linear region at a range of greater than five miles. Bypassing the preamplifiers will degrade the system sensitivity, but extends the dynamic range. A more controlled method to extend the dynamic range would be to use an rf step attenuator, but this adds more cost and complexity to the system.

Table 4 shows some of the variations to the received signal power that can occur. Note that any combination of these changes in power could occur in a given environment.

In the previous example, it was shown how the dynamic range was critical under certain conditions. The importance of system sensitivity will now be considered with respect to geographical coverage.

Figure 14 is a graphical depiction illustrating the increase in geographical coverage that can result when a given system sensitivity is improved.

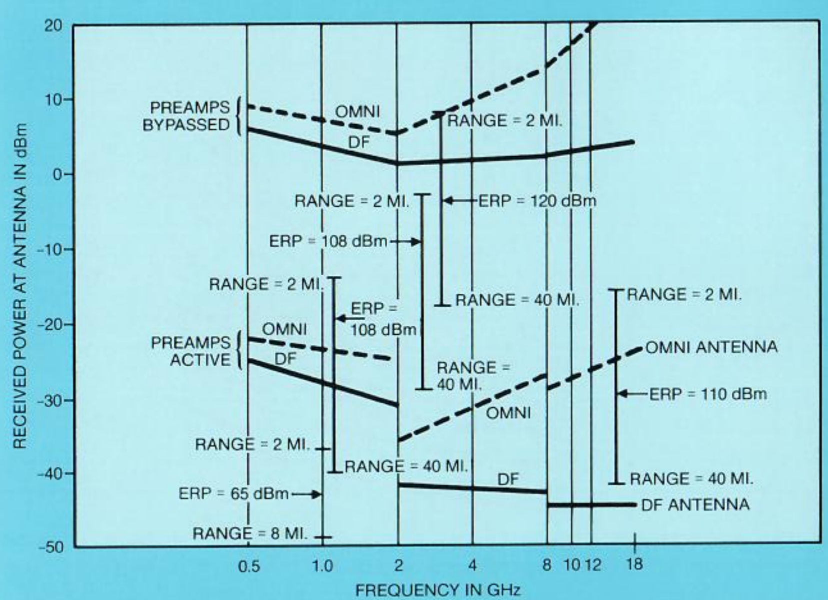

Figure 13. Received power at antenna aperture vs. maximum allowable power for linear operation.

Variable	Range	Change in Power (dB)
Distance to Emitter	2 to 40 miles	26
Transmit Antenna (main lobe to minor lobe)	Depends on beamwidth; 20 to 40 dB	40
Two Emitters within the same narrow frequency range	Example: 2.5 GHz at +108 dBm and 3.0 GHz at +120 dBm	12

Table 4. Typical variations of received signal power.

If the system sensitivity can be increased by 6 dB, the effective range at which an emitter can be detected will be doubled and the area will increase by 300 percent.

The dynamic range of a system can be extended by the addition of *some* components, but the increase of the system sensitivity can only be increased by eliminating components, using lower loss or lower noise figure components, providing higher preamplifier gain (at the further expense of dynamic range) or providing increased antenna gain.

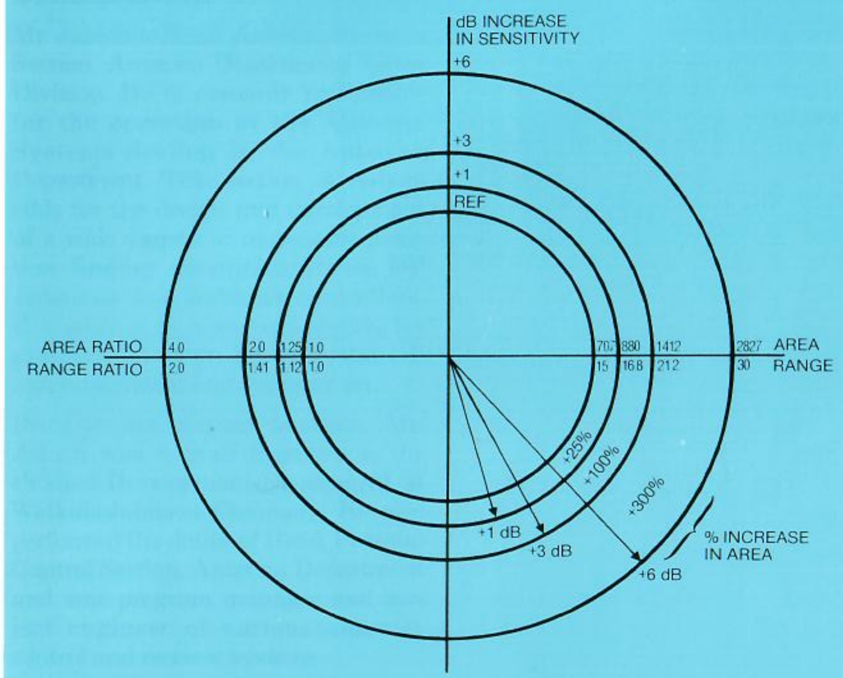

Figure 14. Increase in range and area due to increase of system sensitivity.

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