NO PROBLEM

Transponders in the Radiolocation Service are generally low power transmitter/receivers used in tracking stages of missiles and rockets, or for positive guidance of aircraft. They should pose no problem for the Fixed-Satellite-Service, and their use and frequency assignments within the allocated band are well managed by the area frequency coordinators.

The remaining interactions in this category, as given in the problem matrix of Figure 19, are wholly within the jurisdiction of the FCC or services that operate on a secondary/non-interference basis such as the amateur service or restricted radiation devices. These interactions pose no direct problems to government spectrum management of the 5650-5925 MHz band.

SECTION 6

ELECTROMAGNETIC COMPATIBILITY ANALYSIS

INTRODUCTION:

From a spectrum management standpoint, the major issue of this particular frequency band study is the need to accommodate the Fixed Satellite Service uplink assignment in the 5850-5925 MHz portion. At present the 5650-5925 MHz band is a Government Radiolocation Service occupied by the Army, Navy, Air Force, NASA, and DOE users along with a few manufacturers of equipment and systems used in the band by the Government. The main problem dealt with in this section is the interference potential of high power radars with international communication satellites in Geosynchronous orbit (GEO) of the INTELSAT type which may come into the band in the mid 1980's.

The current proposal calls for two satellite uplink terminals probably one located on each coast within CONUS. As shown in Figure 4 even though the greatest density of assignments is on the coastal areas, there would be many locations where uplink terminals could be located well away from current radar sites. In addition, terrain topology could be utilized to minimize interference potentials between uplink transmitters and radar wide-band receiver front ends.

RADIOLOCATION-AND-FIXED SATELLITE SERVICE SHARING

Radiolocation Transmitter to Satellite Receiver Coupling

Probability of Radar Mainbeam Intercept of Satellite

The problem of terrestrial tracking radar interfering with a geostationary satellite presents the major concern of this study. Although the areas of operation of the terrestrial radiolocation systems are generally known, the pointing angle of the radar antennas will depend upon the relationship of the mission and radar-target geometry. Here the problem of the radar intercepting a geostationary satellite becomes complex enough, it can only be treated by probability for worst case situation

The probability of a tracking radar intercepting a satellite within the hemisphere that can be viewed by the radar has been discussed by H. Ng. et al., (1980). Their analysis of the problem is repeated in Appendix A of this report. From the simplified geometry of Appendix A, the assumption is made that the radar may track a target located at any arbitrary point in the hemisphere above the radar site and that targets are uniformly distributed in that hemisphere zone. From the simplified geometry of Appendix A, the probability of a tracking radar mainbeam intercepting a geostationary satellite is then given by:

$$P = [D_1 - D_2 \cos \phi]/H \qquad \text{(A-5)}$$

where D_1 = radar to satellite distance in Km

D_2 = distance from radar antenna beam 3 dB point on geostationary orbit in Km

ϕ = one-half the 3 dB beam width of the radar antenna.

H = 35,881 km = difference between radar and satellite altitude.

Where D_1 and D_2 may be calculated for various radar elevation angles, θ, and 3 dB beamwidths, 2ϕ, from equation A-4 of the Appendix.

Considering the fact that most tracking radars will have a 3 dB beamwidth of 1° or less, the probability of intercepting a GEO satellite at radar antenna elevation angles between 5° and 15° (the angles from coastal sites that the INTELSAT VI will most likely be visible) is computed from the following parameters:

θ	D_1 (Km)	D_2 (Km)
5°	41,226	41,172
15°	40,167	40,116

Substituting these parameters into equation (A-5) yields

$$P(5°) = 1.5 \times 10^{-3}$$

$$P(15°) = 1.4 \times 10^{-3}$$

based on $2\phi = 1°$.

For coastal and shipborne search radars particularly those with antennas which produce a fan beam such as the AN/SPS-10 where the 3 dB beamwidth is 1.5° in the horizontal plane and 14° in the vertical plane, the beam may scan the satellite once per revolution of the antenna. This is assuming the present planned orbit location of the two INTELSAT VI satellites will make them visible only approximately 5° above the horizon to the West Coast Earth Station and about 10° above the horizon to the East Coast Earth Station. For this situation the satellite will be in the radar 3 dB antenna beamwidth 0.4% of the time.

Note that the model of intercept does not allow for the time of radar mainbeam-satellite intercept. A minimum time of intercept can be estimated from the scan rates of the radars. For example, the AN/FPS-16 is capable of scanning at 25°/sec in elevation, and 45°/sec in azimuth. The respective dwell times are 40 ms and 22 ms when the radar antenna is moving at a maximum rate. The dwell time on the satellite could well be longer than this depending on the radar - transponder target mission geometry and target velocity in a tracking situation. A more detailed analysis of the probability of intercept would require detailed information about past and future test range tracking scenarios which is beyond the scope of this report. There is some difficulty in assessing the mainbeam-to-mainbeam coupling problem since satellite antenna patterns are shaped to receive transmissions from almost every possible terrestrial direction (Fuenzalida et al., 1977).

Radar Mainbeam-to-Satellite Mainbeam Coupling

Another point of difficulty is encountered when attempting to find an agreed upon criteria or an acceptable definition of "harmful radar-to-satellite interference". This is one of the problems being taken up at present by Ad Hoc 183 as mentioned earlier in this report and the outputs from this group should be of great help to studies involving radar/satellite interference. Hernandez (1978) gives some results for low channel voice circuits which have been incorporated into a recent CCIR report (CCIR, 1980) along with those of Wachs and Arroyo (1978) and the analysis of Bryon and Berry (1978). All of these studies are for FDM/FM systems. The INTELSAT V, as an example, permits the use of FDMA/FM, FDMA/PSK, or TDMA/PSK transmission as well, therefore, the results of radar/satellite interaction given in the CCIR report can be used only as a general guideline.

The NASA Measurements reported in a recent CCIR document (CCIR 1980) indicated that the carrier-to-interference ratio (C/I) of 11 to 17 dB is necessary to protect analog FM TV from incoherent interference from radar signals. The COMSAT measurements (Wachs and Arroyo, 1978) indicated that the C/I of -10 dB to 6.5 dB are required to protect FDM/FM Carriers from interfering radar emissions. For analysis purposes in this report based on the types of radars involved, two values of C/I will be used to bound the problem:

C/I = 15 dB for FM/TV

C/I = -7.5 dB for FDM/FM.

Another reference point for the evaluation of interference from radar may be taken as the saturation level at the satellite receiver input. Table 16 gives the saturation flux density for the INTELSAT VI used in this report. For power flux densities which meet or exceed the saturation flux density of the satellite receiver, non-linear regions of the front end may be reached and intermodulation products begin to appear at the receiver output. This nonlinear distortion may appear at frequencies other than that of the interfering signal and be demodulated into unpredictable voice channels (Pawula et al., 1971).

Table 16. INTELSAT VI Communication Satellite Technical Characteristics

Earth station transmitter
Power - 1Kw ERIP 90 dBW
Polarization - Left hand circular
Antenna Gain - 60 dB

Satellite Transponder Receiver
Saturation Power Flux Density

-79 dBW/m^2/80 MHz beam edge

-82.6 dBW/M^2/80 MHz within beam

G/T = -8.5 dB/k beam edge
G/T = -5.5 dB/k within beam
Out-of-band receiver filter response
-30 dB at 5840 MHz
-40 dB at 5830 MHz

The AN/FPS-16 is representative of typical search and tracking radars used in the band and is the most widely used radar at the various tracking ranges in CONUS. The AN/SPS-10 characteristics will be used as representative of typical shipboard radars in the band for analysis purposes. The technical characteristics of these two radars are given in Tables 6 and 11 and will be used in the following analysis. It must be noted that the AN/SPS-10 does not tune into the 5850-5925 MHz portion of the band. However, there is more information and measurements available for analysis than other shipboard radars and most characteristics other than the frequency range are typical. The basic characteristics of this radar will be used here for analysis example only. Peak power transmitted by the radars will be used in all analysis here.

For mainlobe-to-mainlobe coupling

$$C/I = P_T + G_T - P_I - G_I + G_{SE} - G_{SR} - (L_T - L_I) - M + FDR \qquad (1)$$

Where: P_I = Radar transmitter power, dBW

G_I = Radar antenna gain, dBi

P_T = Earth station transmitter power, dBW

G_T = Earth station antenna gain, dBi

G_{SE} = Satellite antenna gain in the direction of the earth station, dBi

G_{SR} = Satellite antenna gain in the direction of the radar, dBi

L_T = Path loss between earth station and satellite, dB

L_I = Path loss between radar transmitter and satellite, dB

M = Path loss margin for the earth station signal, dB (assumed to be equal to 1.2 dB).

FDR = Frequency dependent rejection of receiver, dB.

The maximum differential path loss of two points on the surface of the earth to a satellite is 1.3 dB. $L_T - L_I$ = 1.0 dB will be used in the calculations here as an approximation. For the worst case analysis, it could be assumed that the earth-station is located at the 3-dB satellite beam contour and the radar is located at the beam center. Hence,

$$G_{SE} - G_{SR} = -3.0 \text{ dB} \qquad (2)$$

is a good approximation and will be used in this analysis.

Substituting equations (2) above into (1) gives

$$C/I = P_T + G_T - P_I - G_I + (-3) -(1) -(1.2) + 0$$

$$= P_T + G_T - P_I - G_I -5.2 \qquad (3)$$

(Note, FDR = 0 for cochannel case)

Substituting values from Tables 8 and 15

$$C/I = (30 + 60) - (60 + 47) -5.2$$

$$= -22.2 \text{ dB}$$

For the shipboard AN/SPS-10 type radars with less power and wider beamwidths the calcuation becomes:

$$C/I = 90 - (54.5 + 30) -5.2$$

$$= 0.3 \text{ dB.}$$

Using the C/I criteria as discussed earlier, the AN/FPS-16 radar would then fail to meet the C/I = -7.5 dB criteria by 14.7 dB and 37.2 dB for the C/I = 15 dB criteria. The AN/SPS-10 type radars would have a safe margin of 7.8 dB for the co-channel case using the C/I = -7.5 dB criteria and would fail to meet the C/I = 15 dB criteria by 14.7 dB.

Radar Sidelobe To Satellite Mainbeam Interaction

For the case of the radar sidelobe to satellite mainbeam interactions the worst case will be pursued here which would involve the first sidelobe of the radar. The actual earth station antenna to be used with the INTELSAT VI was not totally specified at this writing but the gain and patterns may be estimated from knowledge given by COMSAT Labs by private communication and ITU recommendations (1982). ITU Appendix 29, Annex III gives a method for calculating radiation patterns as given in Appendix B.

Assuming the earth station antenna has a diameter of 32 m, the gain pattern of the antenna may be calculated by method (a) in Appendix B and is listed in Table 17. In contrast, a typical tracking radar antenna approximately 4.88 m diameter (AN/FPS16) is calculated by method (b) of Appendix B. These results are listed in Table 18.

Table 17. Gain for 32 m Diameter Antenna at Selected Angles Off Boresight

$\phi°$	G(dB)	Remarks
0	60.0	Main lobe
0.12-0.33°	44.1	First Side Lobe
5°	14.5	
10°	7.0	
20°	- 0.5	
40°	- 8.1	
$48° < \phi < 180°$	-10.0	

Table 18. Gain for 4.88 m Diameter Antenna at Selected Angles Off Boresight

$\phi°$	G(dB)	Remarks
0	47.0	Main Lobe
0.84 to 1.07	31.5	First Side Lobe
5	14.8	
10	7.3	
20	-0.2	
40	-7.6	
$48 \leq \phi \leq 180°$	-9.7	

For the radar sidelobe-to-satellite mainbeam coupling case equation (3) can be rewritten in a more convenient form as

$$C/I = P_T + G_T - P_I - G_I\ (\theta) - 5.2 \tag{4}$$

where

$G_I(\theta)$ = radar antenna gain in the direction of the satellite mainlobe as a function of pointing angle, θ.

For the tracking radar case the AN/FPS-16 radar characteristics will be used giving for the first sidelobe from CCIR Annex III

$$G_I = 2 + 15 \log \frac{D}{\lambda} = 31.5 \text{ dBi}$$

$$C/I = 90 - (60 + 31.5) - 5.2 = -6.7 \text{ dB}$$

which fails to meet the C/I criteria of 15 dB by 21.7 dB but is just within the C/I criteria of -7.5 dB by 0.7 dB.

For the minimum angle, θ, that the radar must be pointed away from the geostationary orbit position for C/I = 15 dB

$$P_T + G_T - P_I - G_I\ (\theta) - 5.2 = 15 \tag{5}$$

$$G_I(\theta) = 9.8 \text{ dB}$$

$$52 - 10 \log \frac{D}{\lambda} - 25 \log \theta = 9.8$$

$$\theta = 7.9°$$

Earth Station Transmitter-To-Radar Receiver Coupling

The power at a radar receiver may be calculated using

$$P_r = P_T + G_T + G_I - L_p - FDR \tag{6}$$

where:
- P_r = Power received at the input of the radar receiver, dBW
- P_T = Power transmitted by the earth station, dBW
- G_T = Transmitter antenna gain, dBi
- G_I = Radar receiver antenna gain, dBi
- L_p = Propagation loss between two isotropic antennas, dB
- FDR = Frequency Dependent Rejection, dB

If P_r is set equal to the radar receiver noise level (N_s), then L_p will represent the minimum required propagation loss between the earth station and radar site for permissible operation.

Then

$$L_p = P_T + G_T + G_I - N_s - FDR \qquad (7)$$

and

$$N_s = 10 \text{ Log } KTB_r + F \qquad (8)$$

where: N_s = receiver noise level, dBW

F = radar receiver noise figure, dB

K = Boltzmann's constant (= 1.38×10^{-23} Jules/Kelvin)

T = reference temperature (290° Kelvin)

B_r = radar receiver bandwidth, MHz

N_s = -124 dBW for the AN/FPS 16 radar receiver.

Assuming FDR = 0 for co-channel, equation (7) becomes

$$L_p = P_T + G_T(\phi) + G_I(\phi) + 124 \qquad (9)$$

Using information from Tables 17 and 18, values for L_p were derived for permissible operation of earth station transmitter and radar receiver for various angles off boresight for each antenna and are tabulated in Table 19.

Table 19. Summary of Minimum Required Propagation Loss in dB Between Earth Station Transmitter and Tracking Radar Receiver for Interference Free Operation

EARTH STATION	RADAR RECEIVER						
ANGLE OFF BORESIGHT	MAIN BEAM	FIRST SIDELOBE	5°	10°	20°	40°	48<θ<180°
FIRST SIDELOBE	245	229.6	212.9	205.4	197.9	190.5	188.4
5°	215.5	200	183.3	175.8	168.3	160.9	158.8
10°	208	192.5	175.8	168.3	160.8	153.4	151.3
20°	200.5	185	168.3	160.8	153.3	145.9	143.8
40°	192.5	177.4	160.7	153.2	145.7	138.3	136.2
48°<θ<180°	191	175.5	168.8	151.3	143.8	136.4	134.3

Figure 20 shows the basic transmission loss versus distance using NTIA path-loss model QKAREA (modified Longley, Rice model) where terrain effects are taken into consideration. Four existing COMSAT earth station sites and one planned were used in the model to generate the curves. The sites used and coordinates are:

Andover, ME	44.37.59N, 70.41.52W
Roaring Creek, PA	40.53.35N, 76.26.23W (Planned)
Etam, WV	39.16.50N, 79.44.13W
Jamesburg, CA	36.24.10N, 121.38.48W
Brewster, WA	48.08.49N, 119.41.28W

The five curves of Figure 20 are for five COMSAT earth-stations located as labeled. The distance from each site was extended radially in small steps until an area of 150 km in radius around each site was encompassed. For each area of radius up to the 150 km, the corresponding basic transmission loss curves for 50% of the locations and 50% of the time in the area around the site is shown on the graph. A free space basic transmission loss curve is shown on the graphs for reference. The curves can be used to find the distance that the earth station and radar must be separated to give interference free operation using Table 24. For example; the case of earth station first sidelobe interaction with the radar first sidelobe. The required transmission loss would have to be 229.6 dB for interference free operation. From Figure 20 using the curve for Jamesburg, CA, gives a distance of at least 70 km separation to accomplish interference free operation. The worst case situation would be earth station first sidelobe interaction with the mainbeam of the radar. From the table and the curve for Roaring Creek, PA, the minimum distance of separation would be over 200 km.

However, for many of the sites, there are terrain features such as mountains that would help shield radar sites in the 150 km area. Since a statistical model is used and locations are randomly selected within the 150 km radius from the earth-station transmitter, actual terrain features in the direction of a given radar site are not specifically addressed.

It is highly unlikely that there will ever be earth-station transmitter first sidelobe to radar receiver mainlobe coupling except for ships at sea. It is hard to visualize first sidelobe to first sidelobe coupling for land-based tracking radars and earth-station transmissions as well. For the Jamesburg, CA, site, the Earth-station/radar interactions would seem to be minimal. The Andover, Maine site, with only a cursory look, would seem to be the most promising site of existing COMSAT sites on the East Coast for compatible operation with radiolocation in this band.

Since there would seem to be a manageable problem with earth-station transmission interaction with radar receivers in-band, there would be even less likelihood for interaction if the radars are operated out-of-band (below 5850 MHz). Therefore, out-of-band analysis for this situation will not be given here.

Satellite-Radar Sharing Criteria

The greatest sharing problem as identified in this report is the mainbeam-to-mainbeam coupling between radar transmissions and satellite receivers. In developing a sharing criteria the following analysis is performed:

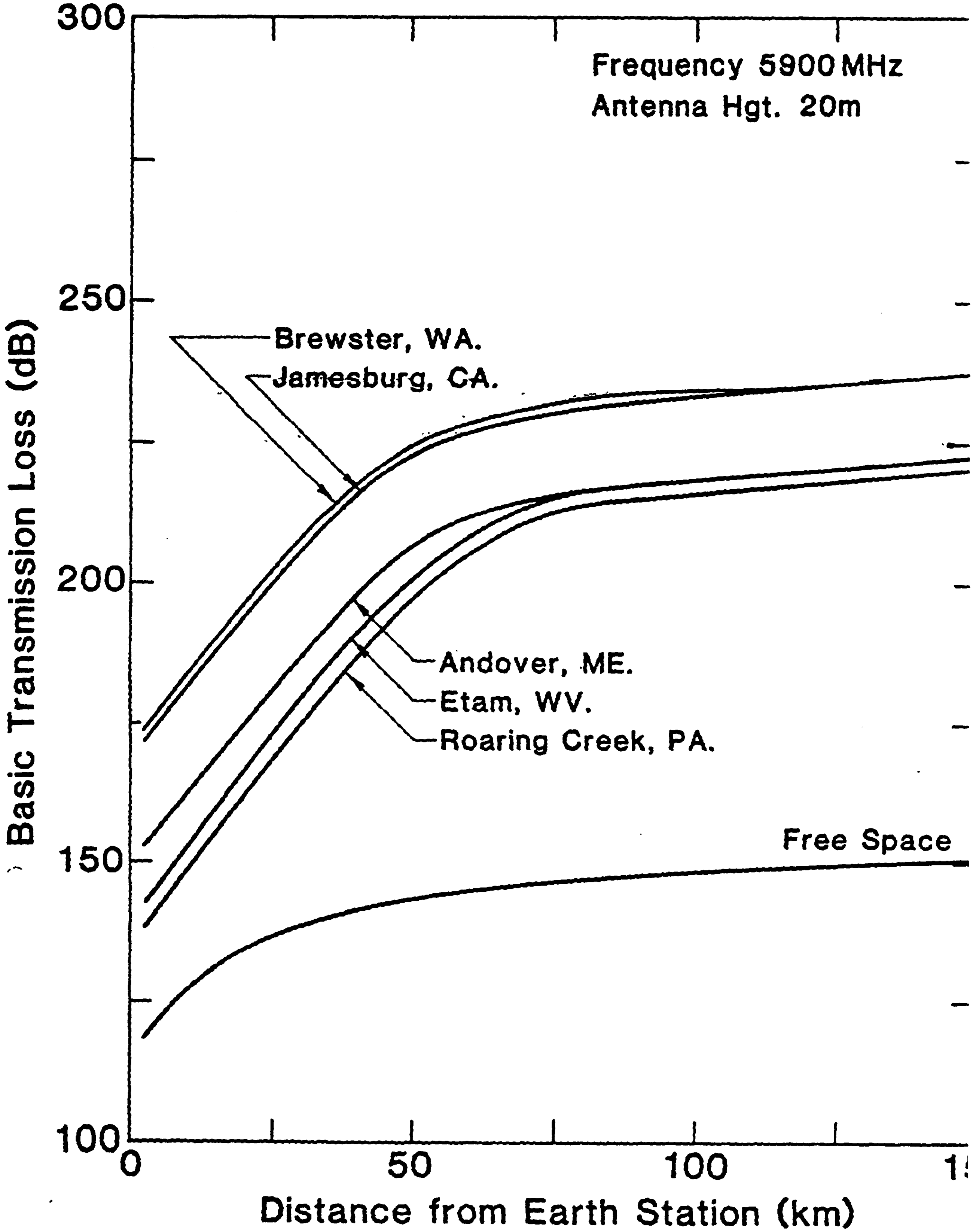

Figure 20. Basic Transmission Loss Versus Distance from Existing COMSAT Transmitter Sites.

The uplink carrier-to-noise ratio is given by

$$C/N = P_T + G_T + G/T_{sat} - L_T - L_m - 10 \log B_r - K \qquad (10)$$

where: P_T = Earth station transmitter power, dBW

G_T - Earth Station Antenna Gain, dBi

G/T_{sat} = Satellite system figure of merit, mid beam, dB/k

L_T = propagation loss between earth station and satellite, dB

L_m = miscellaneous losses assumed to be 1.2 dB

B_r = satellite receiver bandwidth, Hz

K = Boltzmann's constant in dB

$$C/N = 90 - 5.5 - 200 - 1.2 - 79 + 228.6 = 32.9 \text{ dB}$$

Letting $P_{TR} = P_T + G_T$ the Earth Station radiated power and $P_{IR} = P_I + G_I$ the radar radiated power then Equation (4) is rewritten to be

$$P_{TR} = C/I + P_{IR} + 5.2 \qquad (11)$$

Setting $C/I = 15$ dB

$$P_{TR} = P_{IR} + 20.2$$

and $C/I = -7.5$ dB

$$P_{TR} = P_{IR} - 2.3$$

Substituting back into (11)

$$C/N = P_{IR} + 20.2 - 5.5 - 200 - 1.2 - 79 + 228.6$$

$$P_{IR} = C/N + 36.9$$

$$P_{IR} = 32.9 + 36.9 = 69.8 \text{ dBW } (C/I = 15 \text{ dB})$$

and

$$C/N = P_{IR} - 2.3 - 5.5 - 200 - 1.2 - 79 + 228.6$$

$$P_{IR} = C/N + 59.4$$

$$P_{IR} = 32.9 + 59.4 = 92.3 \text{ dBW } (C/I = -7.5 \text{ dB})$$

The maximum radiated power in-band that radars can transmit using the C/I = 15 dB and C/I = -7.5 dB bounds is 69.8 dBW and 92.3 dBW respectively.

The radiated power for the two radars used as typical in the band are: For the AN/FPS-16, P_{IR} = 107 dBW, and for the AN/SPS-10, P_{IR} = 84.5 dBW.

Radar Off-Tune Analysis

Since it is not practical to restrict the power of existing radars in the 5850-5925 MHz band, the other alternative would be to operate the radars out-of-band (below 5850 MHz). Following is the radar out-of-band analysis based on the current receiver filter response characteristics for the INTELSAT VI. Figures 21 and 22 show the received C/I at the INTELSAT VI receiver based on the satellite receiver out-of-band filter response characteristics given in Table 16 and the emission spectra of the AN/FPS-16 and AN/SPS-10 radars used in the example here. The curves were arrived by using a method described by Newhouse (Newhouse, 1969, 1974).

The curve of Figure 21 shows that if the center frequency of the AN/FPS-16 is off-tuned from the satellite receiver frequency by approximately 50 MHz (5840 MHz), the C/I = -7.5 dB criteria can be met. If it is off-tuned approximately 132 MHz (5758 MHz), the C/I = 15 dB criteria can be met. The perturbation around -100 MHz corresponds to the spurious emissions of the AN/FPS-16 measured emission spectrum as shown in Figure 13. If this spurious emission was suppressed by a waveguide filter at the output of the radar transmitter, this would reduce the amount of off-tuning needed to meet the C/I = 15 dB criteria.

For the AN/SPS-10, the curve of Figure 22 shows no frequency offset is needed for the C/I = -7.5 dB criteria since it is met by this radar. If the center frequency of this radar is off-tuned approximately 55 MHz, the C/I = 15 dB criteria can be met. However, the AN/SPS-10 radars normally are not tuned above 5825 MHz which is already 65 MHz away as shown by the vertical line in Figure 22. Thus the AN/SPS-10 radars should meet the C/I criteria bounds as given in this report.

EARTH STATION SIDELOBE-TO-RADIOLOCATION TRANSPONDER COUPLING

Many of the radiolocation scenarios surrounding the missile test ranges involves the tracking of transponders on aircraft, missiles, RPVs, etc. The interaction of earth station sidelobes with the radiolocation transponders would be a very possible situation. For this problem the following situation is assumed;

G_r = 3 dBi (omni directional)

N_s = -74 dBm (transponder receiver)

where: G_r = transponder receiver antenna gain, dB

N_s = transponder receiver noise level

Then the equation for propagation loss, L_p, becomes

$$L_p = P_T + G_T(\theta) + G_r - N_s \qquad (12)$$

Assuming no earth station mainbeam to transponder coupling, the worst case interaction would occur between the first sidelobe of the earth station emitter to radar transponder receiver. The minimum loss for interference free operation becomes

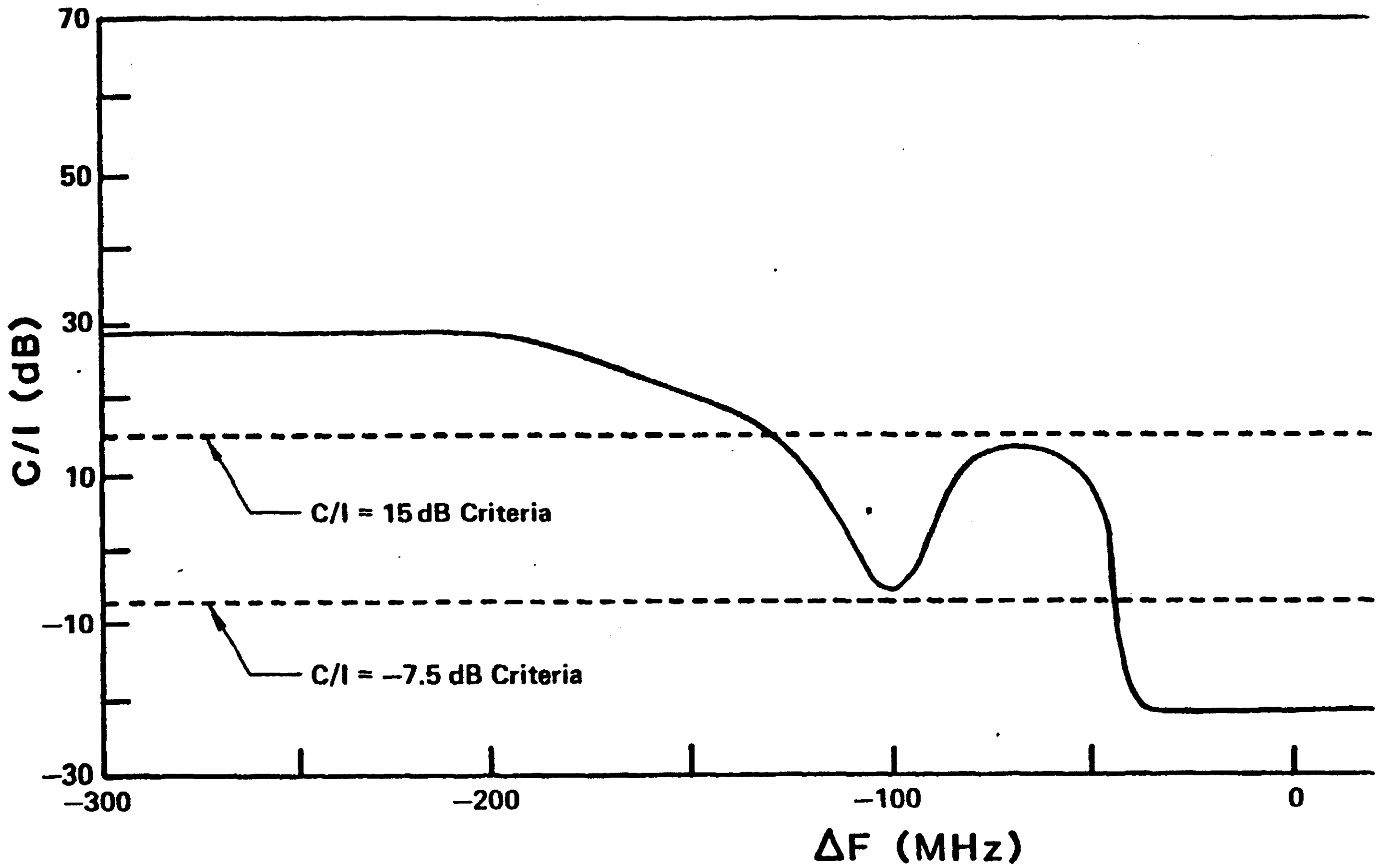

Figure 21. Receiver Carrier-to-Interference Ratio at Satellite for AN/FP

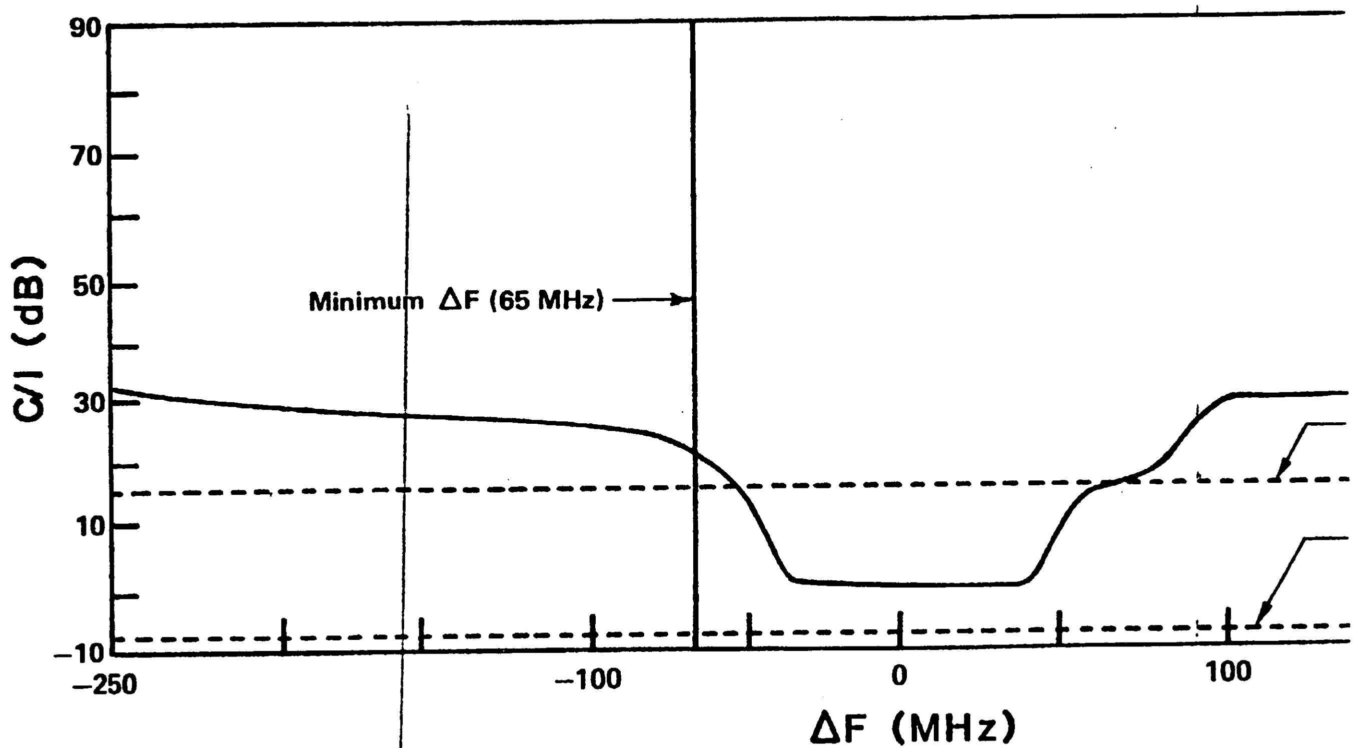

Figure 22. Received Carrier-to-Interference Ratio at Satellite for AN,

$$L_p = 30 + 44.1 + 3 + 74 = 151.1 \text{ dB.}$$

Using the ground-to-air propagation loss curves of Figure 23 [which are computer derived from the Integrated Propagation System, (IPS), Smooth Earth Model] the slant range distance corresponding to transponder altitude for interference free operation is

Transponder Altitude Meters	Slant Range km
300	83
600	105
1500	160
3000	210
6000	280

All other sidelobe conditions give slant range distances of under 10 km for interference free operation which should not pose a problem. Because of the narrow beam of the uplink antenna, the possible intercept with transponders seems unlikely for both the Jamesburg, CA, and Andover, ME sites.

For the case of the radiolocation transponder to satellite receiver interaction, there should be no compatibility problems since the transponder transmitters generally transmit low power (.1 to 1 kW) with an EIRP from 23 to 33 dBW.

ISM AND RESTRICTED RADIATION DEVICES/RADAR INTERACTIONS

Figure 24 gives the separation distances between ISM devices and a radar receiver. Here the AN/FPS-16 radar receiver is used as an example. It is assumed that the ISM devices radiate the maximum allowable out-of-band fields to the AN/FPS-16 receiver for 1.6 MHz and 8.0 MHz radar bandwidth (depending on track mode), and assuming the interfering signal is along the bore sight of the radar antenna (worst case). However, there is no restriction on in-band (5725-5875 MHz) radiated fields for ISM equipment which could pose a problem at some future date if ISM equipment were to use this band in large numbers.

The interactions between ISM and restricted radiation devices with radars was analyzed similar to a method used by Bulawka (1980) in a previous SRA. Given some value of electric field-strength at a specified distance from an ISM device, e.i. 25 μVm at 1000 ft for diathermy equipment, the objective is to calculate the received power level at the radar receiver. The electric field-strength can be calculated using the proportionality relationship of:

$$\frac{E_1}{E_2} = \frac{D_2}{D_1} \qquad (12)$$

where E_1 = electric field-strength at separation distance D_1,

E_2 = electric field-strength at separation distance D_2,

D_1 = separation distance at which electric field-strength is E_1,

D_2 = separation distance at which electric field-strength is E_2.

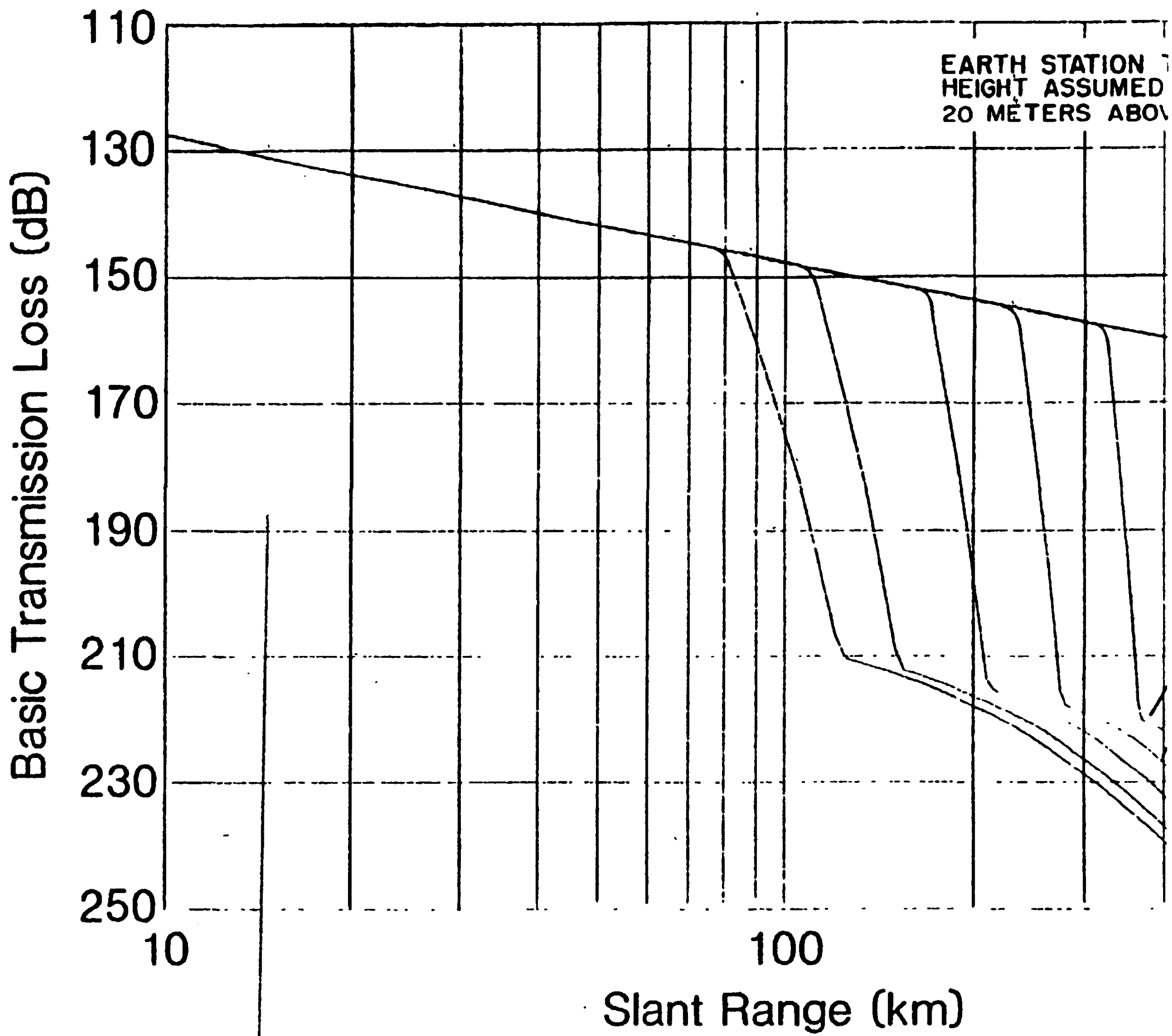

Figure 23. Ground-to-Air Propagation Loss at 5800 MHz.

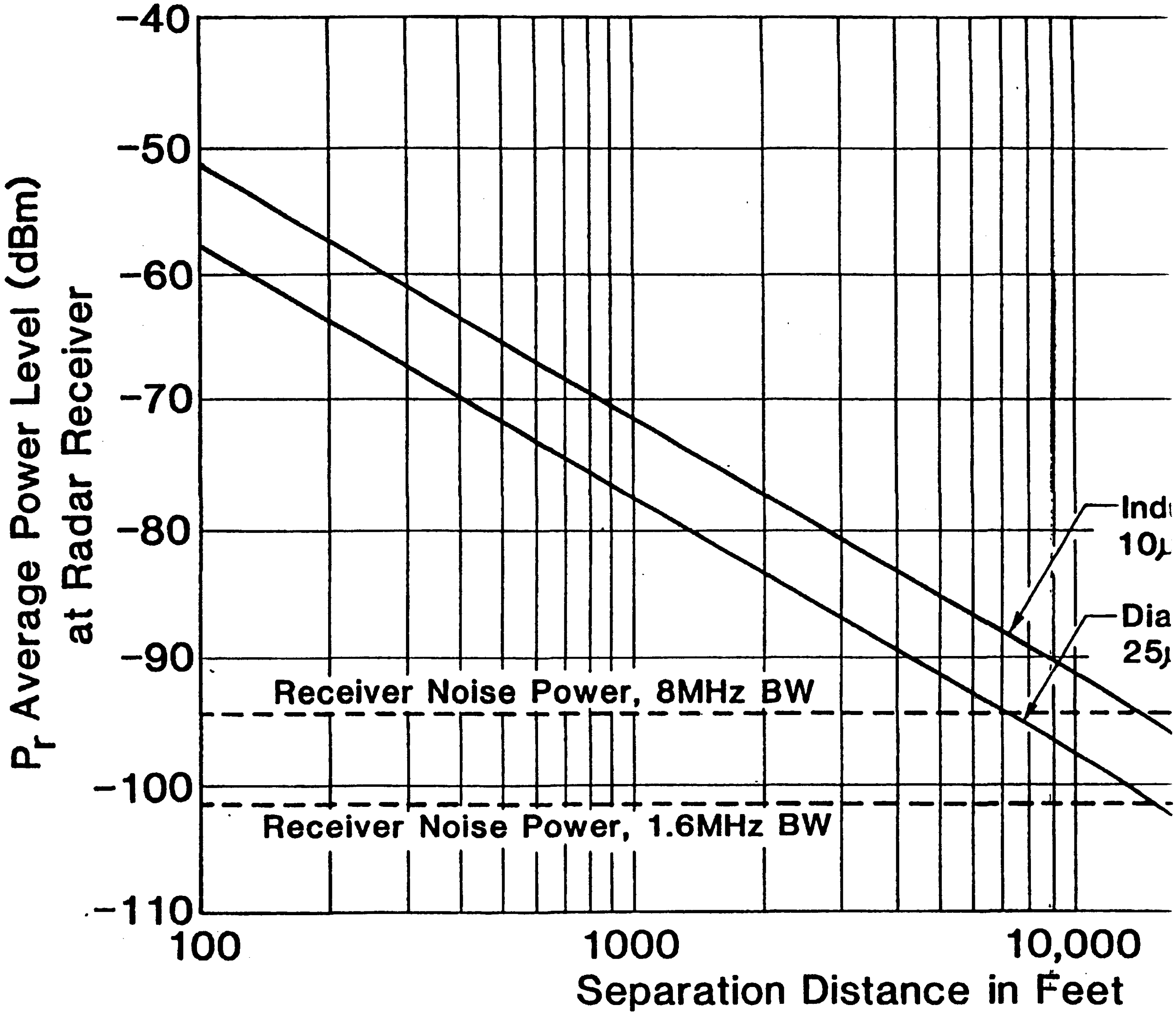

Figure 24. ISM/Radar Receiver Separation Distances Based on Out-of-Ban
Radar Receiver Sensitivity Shown for Two Bandwidths (BW).

For this particular case the received power at the radar receiver as a function of separation distance may be expressed as:

$$P_r = P_d + A_e - OTR \quad (13)$$

where

P_r = radar receiver average power in dBm,

P_d = average power density in dBm/m^2,

A_e = effective antenna aperture in dB,

OTR = on-tune rejection which is 0 in the cases analyzed here where the receiver bandwidth is larger than the interfering signal bandwidth.

The power density may be written as:

$$P_d = \frac{E_2^2 \; D_2^2}{D_1^2 \; R} \quad (2)$$

where P_d is expressed in $watts/m^2$

E_2 is expressed in V/m

R is free space impedance, 377 Ω

Simplifying and rearranging terms

$$P_d = 20 \log (E_2 D_2) - 20 \log (D_1) - 116$$

where

P_d = average power density in dBm/m^2,

E_2 = average electric field strength in μV/m,

D_2 = distance in feet corresponding to E_2,

D_1 = variable separation distance in feet.

The effective antenna aperture is calculated by:

$\frac{G\lambda^2}{4\pi}$, converting wavelength into frequency and taking the logarithm

$$A_e = G - 20 \log (f) + 38.5 \text{ (effective antenna aperture in dB)}$$

$$= 47 - 75.3 + 38.5 = 10.2 \text{ dB.}$$

The receiver noise level (N_s) was calculated for the two receiver bandwidths of the AN/FPS-16 corresponding to two operating modes using equation 8. These levels are shown on the Figures 24 through 26 by the dashed lines.

The average power level P_r at the radar receiver was plotted in Figure 24 for Industrial Heating and Diathermy equipments versus separation distance. From the 10,000 foot separation distance and beyond, the QKAREA path loss model was used to give a more realistic power loss. The radar antenna height was assumed to be 20 meters.

Figure 25 shows the separation distances between Field Disturbance Sensors (FDS), a restricted radiation device, and the AN/FPS-16 radar. This assumes the FDS devices radiate the maximum allowable fields in-band along the bore sight of the radar antenna. As can be seen, distances of 18 to 20 miles would have to be maintained to be below the receiver noise level. Figure 26 shows the separation distances between Low Power Communication (LPC) devices and the AN/FPS-16 radar receiver. These devices are used for measurement of the characteristics of materials. Although no such devices were found operating in the band, the provision for their use is given in Sub-part 15.214 of the FCC Rules and Regulations. Again, the "worst case" condition of the interfering signal along the bore sight of the radar antenna was assumed. The two curves, as labeled, represent the power at the radar receiver versus separation distance for the fundamental and 2nd harmonic.

The FDS and LPC are restricted radiation devices and must not cause harmful interference to systems operating within the band. The devices should be able to operate within the band on a non-interference basis using distance separation as a spectrum management technique.

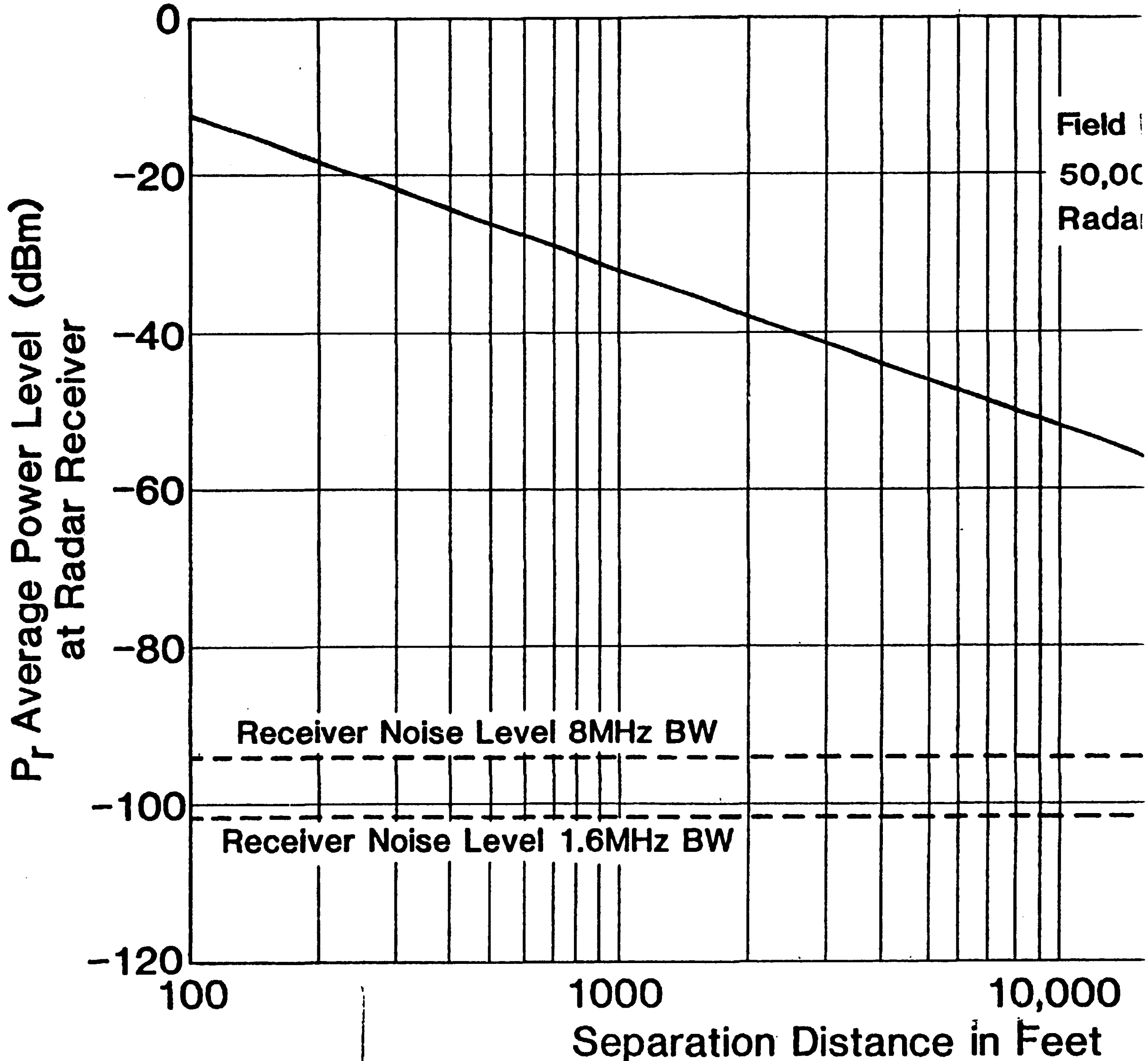

Figure 25. Field Disturbance Sensor/Radar Receiver Separation Based on In-Band Specifications. Radar Receiver Se Shown for Two Bandwidths (BW).