## SECTION 6

## RADAR SPECTRUM ENGINEERING CRITERIA

### INTRODUCTION

This section contains recommended changes to the Radar Spectrum Engineering Criteria (RSEC) for radars which operate in the 2700-2900 MHz band. The appropriateness of the current RSEC is reviewed in light of present and future usage trends and radar deployment patterns in the 2700-2900 MHz band. Transmitter output emission spectrum characteristics are examined for several types of transmitter output tube devices and waveguide filters. Transmitter and receiver performance guidelines are identified which will improve the accommodation of new radar systems in the band. The identified performance guidelines are incorporated into proposed changes to the present RSEC.

### REQUIRED TRANSMITTER EMISSION SPECTRUM BOUNDS

An investigation was made to determine if the emission spectrum bounds in the current RSEC are appropriate in light of present and future usage trends and radar deployment patterns in the 2700-2900 MHz band. Frequency-distance separation requirements were developed for the current RSEC and other more stringent emission spectrum bound levels based on characteristics of future planned systems. The frequency-distance separation requirements were then analyzed to determine whether or not the current RSEC is adequate to ensure an acceptable degree of electromagnetic compatibility among radars presently in the band and planned for the band.

#### Radar Spectrum Engineering Criteria

All radar systems presently operating in the 2700-2900 MHz band are subject to Criteria C of the current RSEC. (See Part 5.3.2 of the Manual of Regulations and Procedures for Federal Radio Frequency Management, NTIA 1980). Since new radar systems planned for the band procured after October, 1986 will have to meet the Column B Criteria of the current RSEC, the Column B Criteria were used in this investigation. The characteristics of the future planned systems used to determine the current RSEC emission spectrum bounds and more stringent emission spectrum bounds are shown in TABLE 14 in Section 4. The system characteristics given in TABLE 14 are representative of the ASR-9 and NEXRAD radars planned for the band.

Both the ASR-9 and NEXRAD radars are non-FM pulsed radars. Therefore the RSEC -40 dB bandwidth, B (-40 dB), is given by:

$$B(-40\ dB) = \frac{6.2}{\sqrt{t_r t}} \quad \text{or} \quad \frac{64}{t} \qquad (1)$$

whichever is less

where: B = Emission bandwidth, in MHz.
t = Emitted pulse duration in µs at 50% amplitude

$t_r$ = Emitted pulse risetime in μs from the 10% to 90% amplitude points on the leveling edge.

For nominal pulse width ( t ) of 1.0 μs and risetime ($t_r$) of 0.1 μs (measured ASR-8 risetime), the -40 dB bandwidth is 19.6 MHz. From the -40 dB bandwidth, the emission spectrum fall off is given by:

$$\text{Suppression (dB)} = -20 \log \left| \frac{F - F_o}{\frac{1}{2}B(-40dB)} \right| -40 \qquad (2)$$

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

and: $F_o$ = 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.

The emission spectrum floor level (XdB) is given by:

$$X\ (dB) = 60\ dB, \text{ or}$$
$$X\ (dB) = P_t + 30 \qquad (3)$$

whichever is the larger value.

The parameter $P_t$ may be calculated from the following:

$$P_t = P_p + 20 \log (Nt) + 10 \log (PRR) - PG - 90 \qquad (4)$$

where: $P_t$ = Maximum spectral level in dBm/kHz.
$P_p$ = Peak power (dBm)
N = Total number of chips (subpulses) contained in the pulse. (N = 1 for non-FM and FM pulse radars).
t = Emitted pulse duration in u sec. at 50% amplitude (voltage) points.
PRR = Pulse repetition rate in pulses per second.
PG = Processing gain (dB) = 0 for non-FM (non-encoded) pulse radars, 10 log (d), for FM pulse radars; 10 log (N), for coded pulse radars.
and: d = Pulse compression ratio = emitted pulse duration compressed pulsed duration (at 50% amplitude points).

Using the nominal characteristics of future planned systems for the 2700-2900 MHz band ($P_p$ = 90, t = 1.0, PRR = 1200, PG = 0), the value for $P_t$ is 30.76. Therefore, the emission spectrum floor level (XdB) is 60.76 dB. Figure 22 shows plot of the current RSEC calculated for nominal characteristics of future planned systems. Also shown in Figure 22 are more stringent emission spectrum bounds for 40, 60 and 80 dB per decade fall-off from the -40 dB RSEC bandwidth. The more stringent emission spectrum bound curves are labeled RSEC -40, RSEC -60, and RSEC -80 for the 40, 60, and 80 dB per decade fall-offs respectively. The more stringent emission spectrum bound curves are used in developing frequency-distance separation curves for determining appropriate emission spectrum bounds for 2700-2900 MHz band radars.

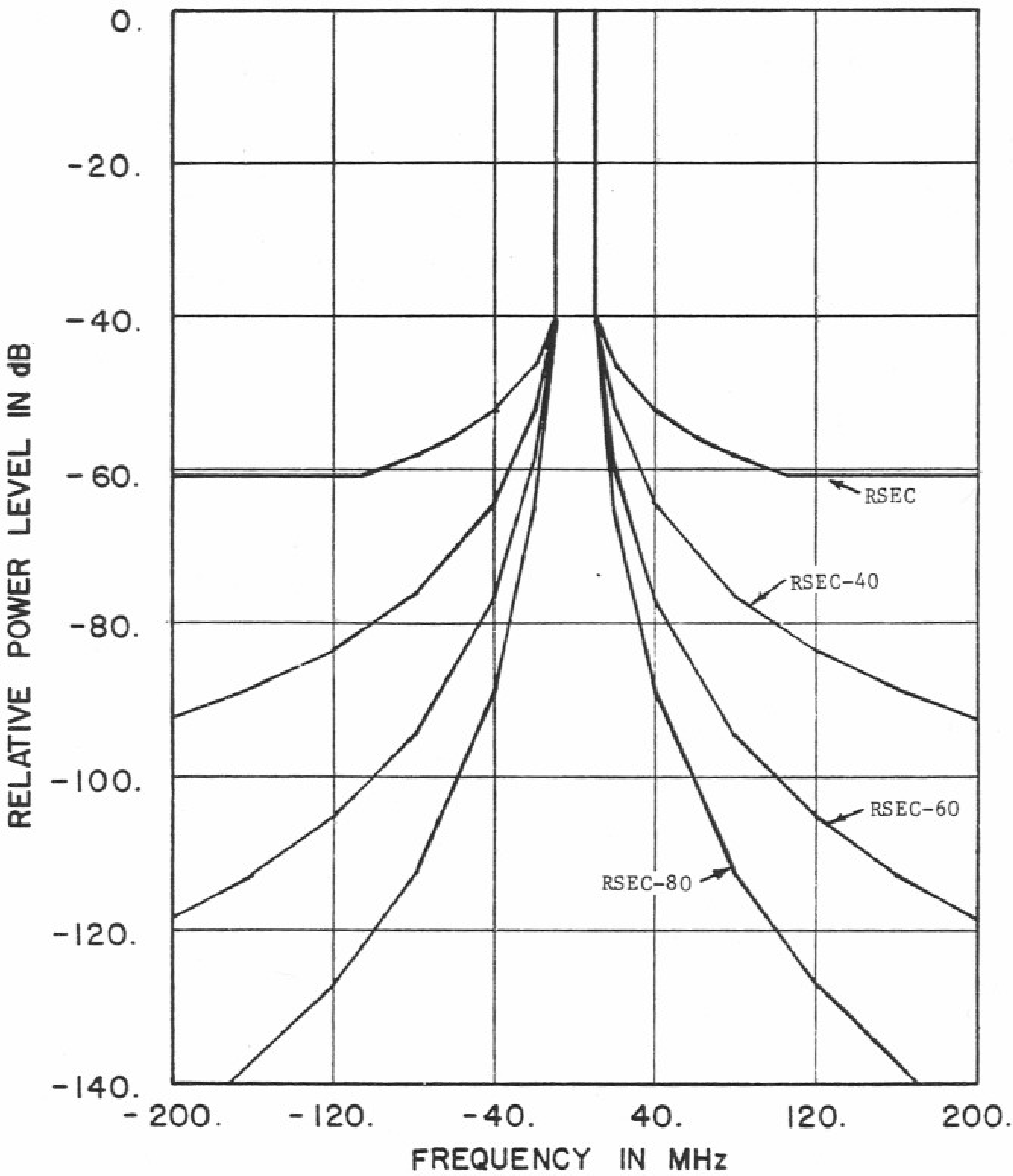



Figure 22. Emission Spectrum Bounds for RSEC and more Stringent Fall-Off Rates of 40, 60 and 80 dB per Decade from the RSEC 40 dB Bandwidth

## Frequency-Distance Separation Requirements

Frequency-distance separation curves were calculated for the four emission spectrum bound curves shown in Figure 22. The frequency-distance curves were then examined to determine if the current RSEC is appropriate in light of present and future usage trends and radar deployment patterns in the 2700-2900 MHz band. The frequency-distance curves show graphically the relationship between the distance separation (d), and off-tuning or frequency separation ($\Delta F$) necessary to limit the interference level at the receiver IF output to some specified value. The frequency-distance curves do not take into account signal processing circuitry, such as pulse integrators or sliding window detectors. Post processing may suppress asynchronous pulsed interference and permit closer frequency-distance separations than those given here. Appendix A contains information on receiver interference suppression circuitry. The frequency-distance separation relationships were obtained using the OFRCAL program (CCIR Report 654) which implements the following algorithm:

$$L(d) + FDR(\Delta F) = P_t + G_t + G_r - I_1 - INR - N \qquad (5)$$

where: $L(d)$ = Median propagation path loss between receiving and interfering

$FDR(\Delta F)$ = Frequency-dependent-reflection, in dB

$P_t$ = The peak transmitter power of the potential interfering radar, in dBm

$G_t$ = The nominal mainbeam gain of the potential interfering radar minus correction for antenna tilt angle, in dBi

$G_r$ = Receiving antenna median backlobe level, -13 dBi

$I_1$ = Waveguide and coupler insertion losses of both receiving and interfering radars. A 2 dB insertion loss was used at both ends (Offi and Herget, 1968).

INR = Maximum allowable peak Interference-to-Noise Ratio at the receiver input to preclude performance degradation, INR=0

N = Receiver), inherent noise level referred to the RF input, ($N = -114 + 10 \log B(\text{MHz}) + NF$), in dBm.

B = Receiving radar 3 dB IF bandwidth, in MHz, 1.1 MHz

NF = Receiving radar noise figure, 4 dB.

The principle of the frequency-distance computer model is that the parameters on the right hand side of Equation 5 are considered as constants and the parameters on the left hand side as variables. That is, the propagation loss, L(d), is a function of distance separation and frequency-dependent-rejection, $FDR(\Delta F)$ is a function of frequency separation between receiving and interfering radars. The left hand side of Equation 5 is essentially the required loss to obtain a specified INR at the receiver IF output.

The input parameters to the OFRCAL model include: transmitter emission spectrum, receiver IF selectivity, propagation model parameters, and required loss (Equation 5). The transmitter emission spectrum characteristics used were the RSEC and more stringent emission spectrum bounds of 40, 60 and 80 dB per decade fall-off from the -40 dB RSEC bandwidth (see Figure 22). The receiver selectivity characteristics used were similar to the specifications for the FAA ASR-9 radar. Since both the ASR-9 and NEXRAD radar may have approximately a 1.0 μs pulse width, the IF selectivity of both future planned systems should be similar. Figure 23 shows the receiver IF selectivity curve used in the OFRCAL model. The propagation model used in the OFRCAL program is the Integrated Propagation System (IPS) model (Baker, 1980). Figure 24 shows the propagation loss versus distance curve used in the OFRCAL model. The propagation parameters used in the IPS model are also shown in Figure 24.

Frequency-distance curves for two coupling conditions: 1) NEXRAD mainbeam coupled to ASR-9 backlobe, and 2) ASR-9 mainbeam coupled to NEXRAD backlobe are shown in Figures 25 and 26, respectively. Also shown in each figure are the parameter values for Equation 5, and statistics on separation distance occurrences discussed in Section 5 of this report. Since the frequency-distance curve shown in Figure 25 is for NEXRAD mainbeam coupling, the separation distance statistics are for Commerce NWS radars in the 2700-2900 MHz band and are taken from TABLE 18 in Section 5. The separation distance statistics shown in Figure 26 are for all radars operating in the 2700-2900 MHz band, and are taken from TABLE 16 in Section 5.

For the coupling conditions shown in Figures 25 and 26, the minimum radar separation distance for the present RSEC is 19.3 and 12.9 statute miles respectively. From the radar separation distance data given in Section 5 and Appendix B, approximately 55 percent of the radars in the 2700-2900 MHz band have at least one radar within 15 statute miles, and 25 percent of the radars in the band have at least one radar within two statute miles (collocated condition). It should be stated that this does not imply that 55 percent of the radars in the band presently have interference on the PPI display. It is shown later (see Figures 27 and 28) that even the sideband emission level of conventional magnetrons are 10-15 dB below the RSEC floor level.

Considering the frequency-distance separation curves and radar separation distance statistics shown in Figures 25 and 26, it was the consensus of the TSC Working Group 1 that the present RSEC is adequate in some situations, but is not adequate for approximately 55 percent of the assignments. These difficulties occur in heavily used areas and under collocated conditions. It should be noted that this does not imply that 55 percent of the radars in the band are presently receiving interference. This finding is based on the RSEC emissions spectrum bounds, and an INR=0 criterion (No Interference). As a result of this finding, it was the opinion of the Working Group that a few changes to the present RSEC would enhance the accommodation of new radar systems in the 2700-2900 MHz band.

Figures 25 and 26 were used to identify more appropriate emission spectrum bounds to be incorporated in the RSEC for radars in the 2700-2900 MHz band. It was the consensus of the Working Group that all new fixed radars in the band should have an emission spectrum level which, from the present RSEC 40 dB bandwidth, falls-off at 40 dB per decade to a fixed noise floor level of 80 dB. Also the new radars planned for the band should be designed and constructed to permit, without modification to the basic equipment, field incorporation of the

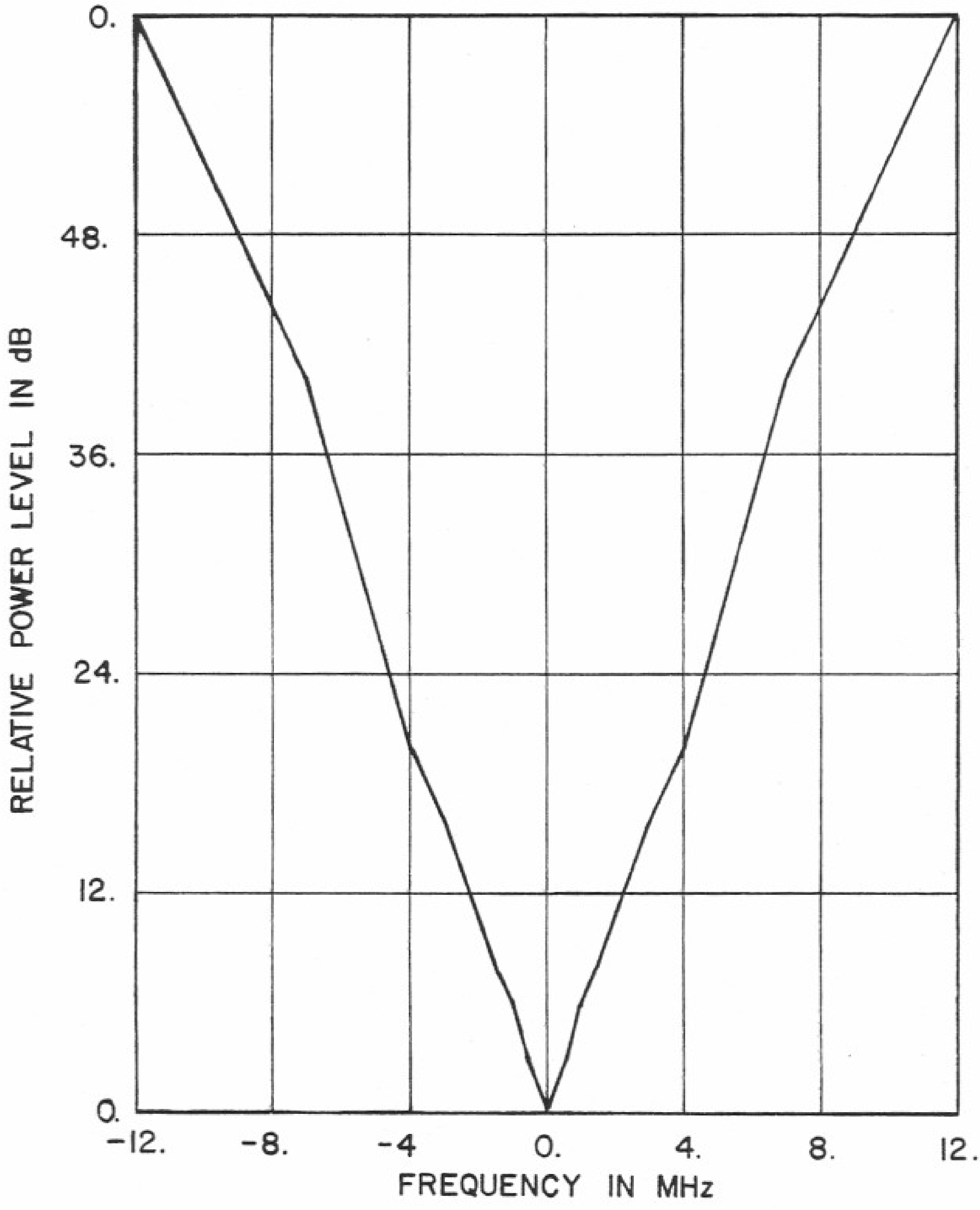



Figure 23. Modeled IF Selectivity

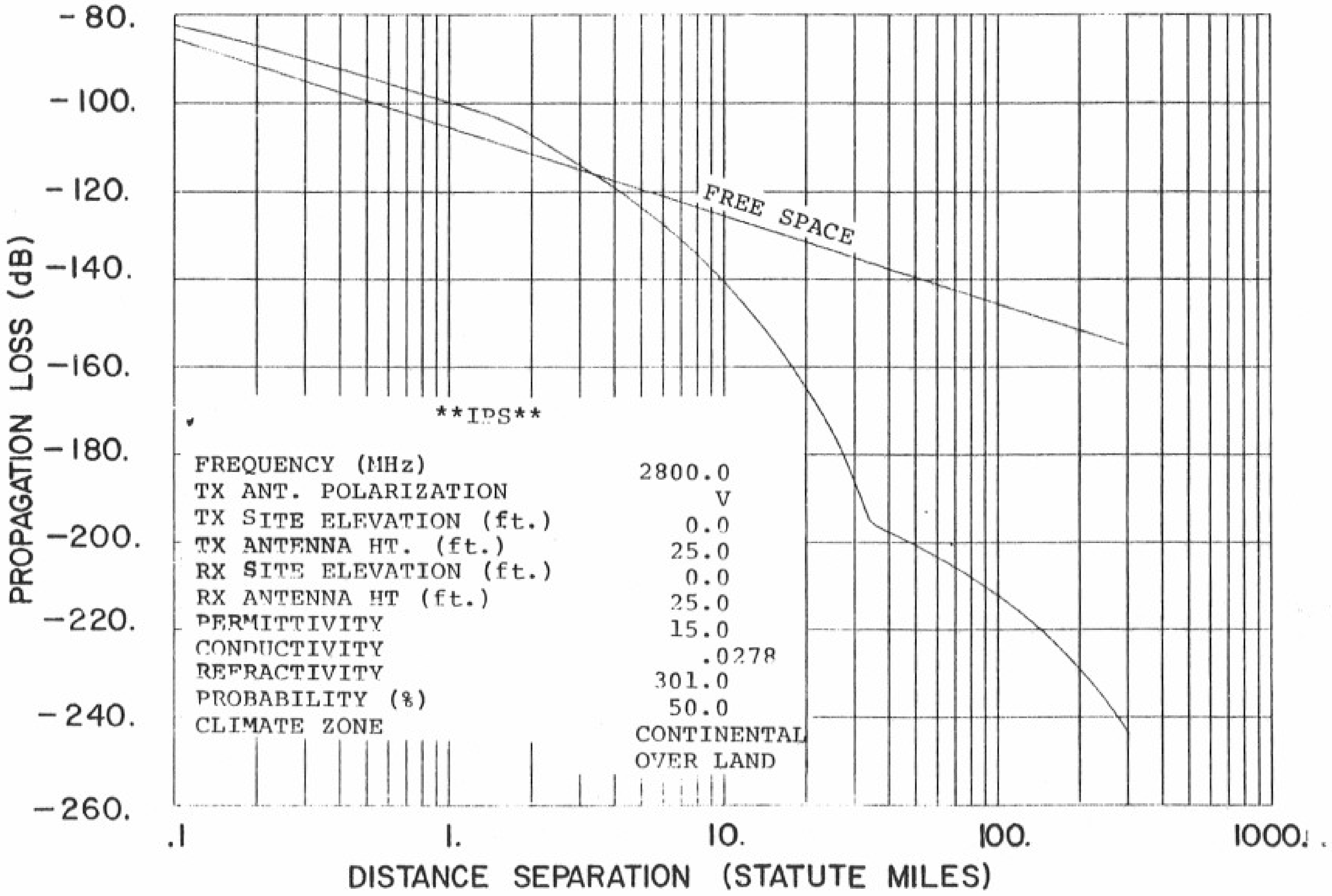
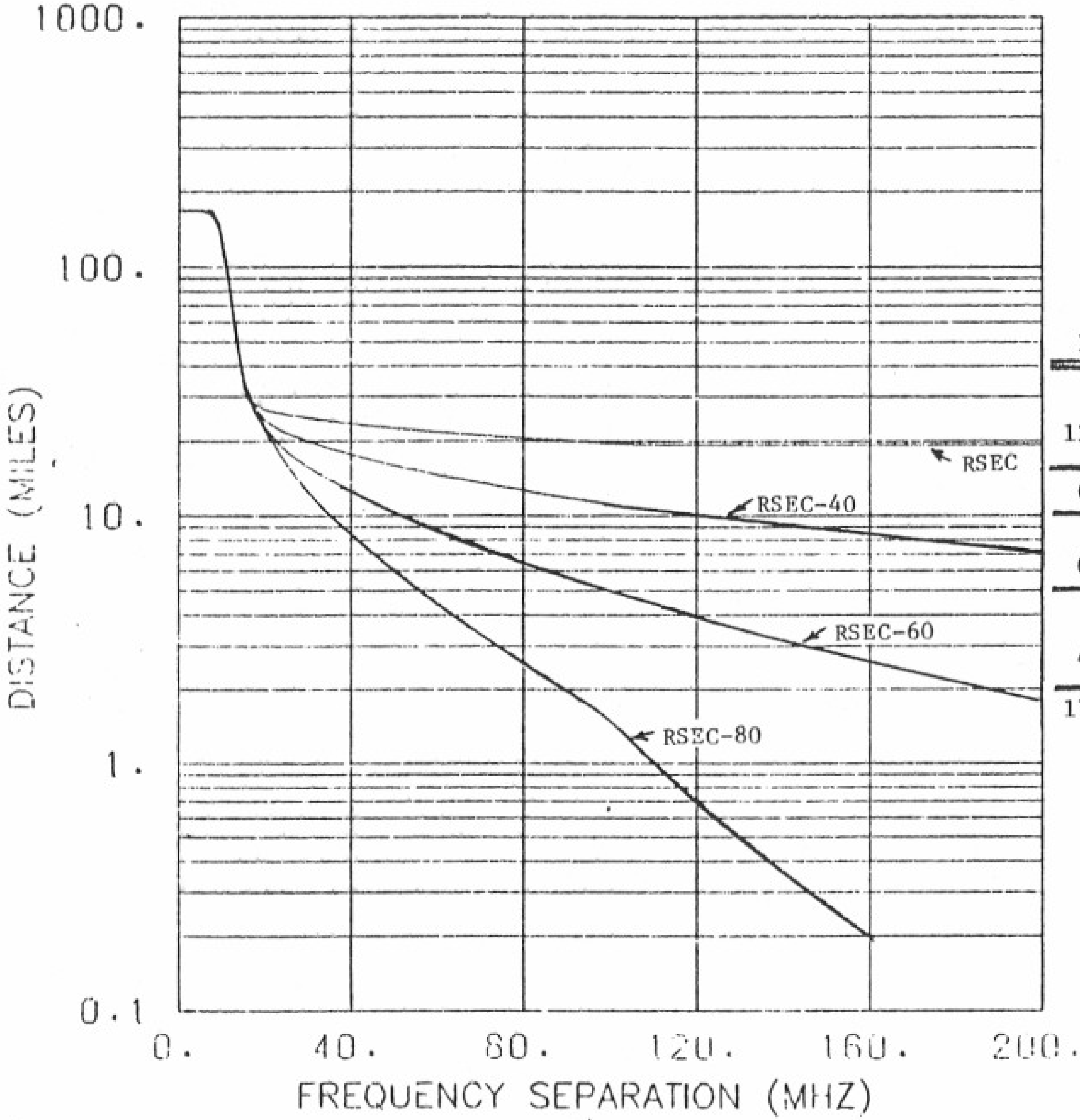



Figure 24. Propagation Loss Versus Distance Separation




NUMBER OF RADARS WITHIN SPECIFIED SEPARATION DISTANCES

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| 13 | 6 | 0 | 1 | 1 | 0 | 0 | 0 |
| 6 | 4 | 0 | 0 | 1 | 1 | 0 | 0 |
| 6 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 2 | 3 | 0 | 0 | 0 | 0 | 0 |

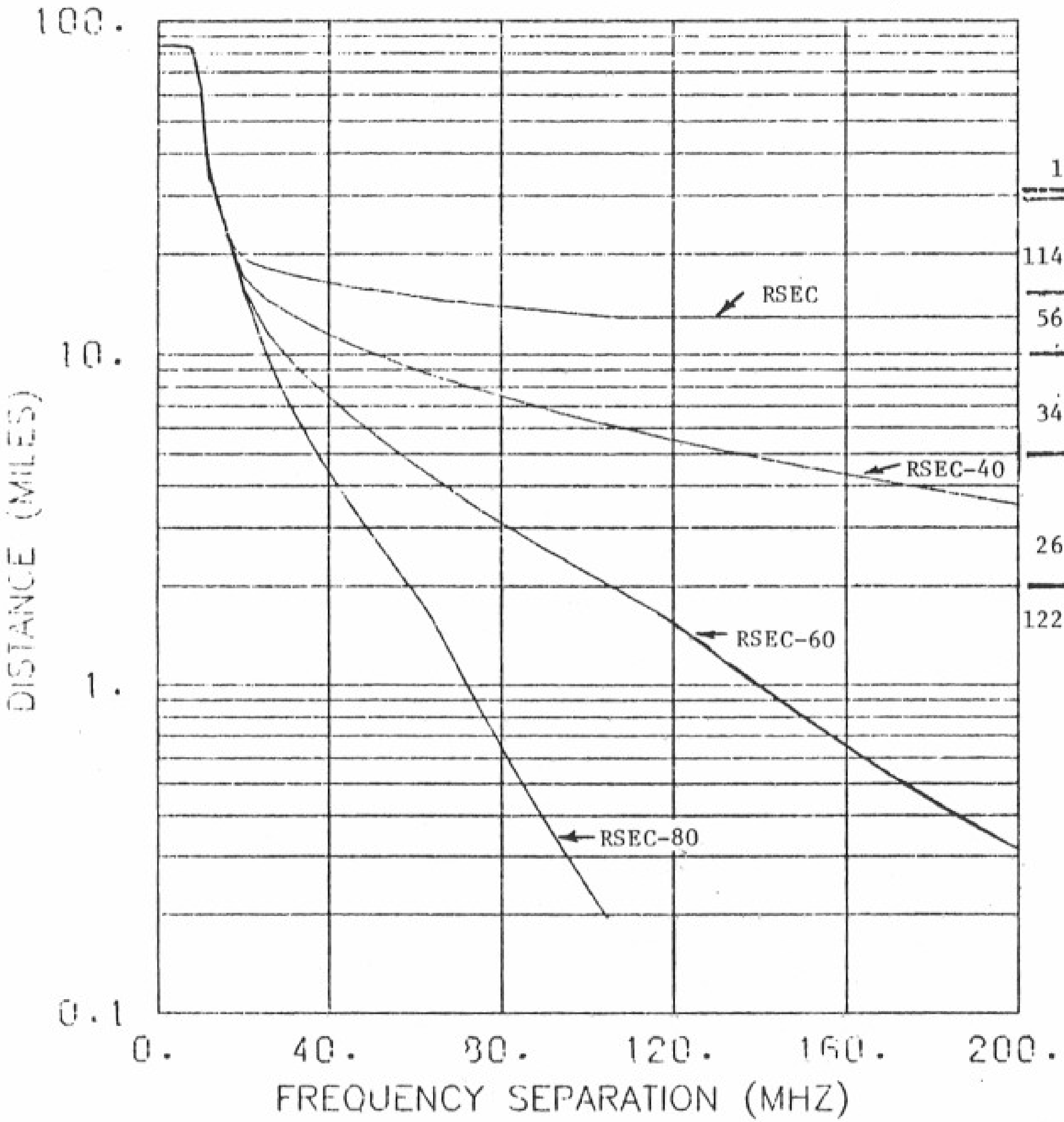
Parameter Values:

$P_p$ = 90 dBm

$G_t$ = 42 dBi (Mainbeam gain minus tilt angle)

L(d) = 225 dB

Figure 25. Frequency Distance Separation Requirements for NEXRAD Mainbeam to ASR-9 Backlobe




NUMBER OF RADARS WITHIN SPECIFIED SEPARATION DISTANCES

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| 114 | 46 | 16 | 16 | 5 | 0 | 0 | 0 |
| 56 | 18 | 13 | 3 | 2 | 4 | 0 | 1 |
| 34 | 14 | 4 | 1 | 0 | 0 | 0 | 0 |
| 26 | 5 | 4 | 1 | 0 | 0 | 0 | 0 |
| 122 | 26 | 24 | 0 | 0 | 0 | 0 | 0 |

Parameters Values:

$P_p$ = 90 dBm

$G_t$ = 27 dBi (Mainbeam gain minus tilt angle)

L(d) = 210 dB

Figure 26. Frequency Distance Separation Requirements for ASR-9 Mainbeam to NEXRAD Backlobe

capability to meet an 80 dB per decade fall-off from the RSEC 40 dB bandwidth down to a noise floor level of 80 dB. The latter more stringent emission spectrum bounds would be used in designated congested areas (See Figure 8 and TABLE 22) and for collocated radar sites when required. It is shown later that the 80 dB per decade fall-off will require the use of waveguide filters which will result in the emission spectrum noise floor level to be over 100 dB down.

## TRANSMITTER EMISSION SPECTRUM CHARACTERISTICS

In order to assure that the recommended changes to the present RSEC emission spectrum bounds are appropriate, transmitter emission spectrum characteristics for various transmitter output tube devices and waveguide filters were investigated. The objectives of this investigation were to:

1. Determine the emission spectrum characteristics relative to the present RSEC of various transmitter output tube devices with and without waveguide filters.

2. Identify the state-of-the-art in radar emission spectrum control so that recommended changes to the present RSEC emission spectrum bounds would be achievable with current off-the-shelf hardware.

The emission spectrum characteristics of several radars presently operating in the 2700-2900 MHz band were measured using the NTIA RSMS van, and the state-of-the-art in radar transmitter emission spectrum control was identified through discussions with various manufacturers of transmitter output tube devices and waveguide filters.

The emission spectrum of a pulse radar is determined by the modulating pulse shape and width, transmitter RF tube, and RF output tube load. The transmission waveguide, rotary couplers, and antennas also affect the emission spectra but to a lesser degree. At the present time, there are only three types of transmitter output tube devices used in radars in the 2700-2900 MHz band. They are conventional magnetrons, coaxial magnetrons, and klystrons. The following is a discussion on the emission spectrum characteristics of these output tubes.

### Conventional Magnetron

Most of the radars presently operating in the 2700-2900 MHz band employ conventional magnetron output tubes listed in TABLE 25. The tuning range and nominal operating characteristics of the tubes are listed in the table. Typical emission spectrum characteristics of conventional magnetrons are documented in a report by Hinkle, Pratt and Matheson (1976).

Figures 27 and 28 show measured emission spectrum of an ASR-5 and ASR-6 radar respectively which use conventional magnetrons. Figure 27 is an extended (300 MHz) measured emission spectrum. Also shown in Figure 27 and 28 are the emission spectrum bound curves for the RSEC and fall-off rates of 40, 60 and 80 dB per decade from the RSEC 40 dB bandwidth, and the radar system parameters used to determine the RSEC emission spectrum bound curves. Both Figures 27 and 28 show that the conventional magnetron does not meet the present RSEC 40 dB bandwidth because of the inherent frequency pulling of the conventional magnetron during the risetime of the modulating pulse. However, the noise

TABLE 25

MAGNETRON TUBE TYPES

| TUBE* TYPE | FREQ. RANGE IN MHz | TUNABLE | PEAK POWER (KW/dBm) | PEAK CURRENT (A) | PEAK VOLTAGE (KV) | PULSE WIDTH (μsec) | DUTY CYCLE |
|---|---|---|---|---|---|---|---|
| 5586 | 2700-2900 | YES | 800/89.0 | 70 | 29.5 | 1.0 | .0005 |
| 8789 (QK1463) | 2700-2900 | YES | 450/86.5 | 70 | 30 | 1.0 | .001 |
| 4J31 | 2860-2900 | NO | 800/89.0 | 70 | 28 | 1.0 | .0005 |
| (DX276) | 2700-2900 | YES | 450/86.5 | 50 | 32 | 1.5 | .001 |
| (QK729) | 2860-2900 | NO | 480/86.8 | 50 | 26 | 4.0 | .0007 |

*Tube types listed in brackets are manufacturer designators. Those tube types not listed in brackets are Joint Electron Device Engineering Council (JEDEC) designators.

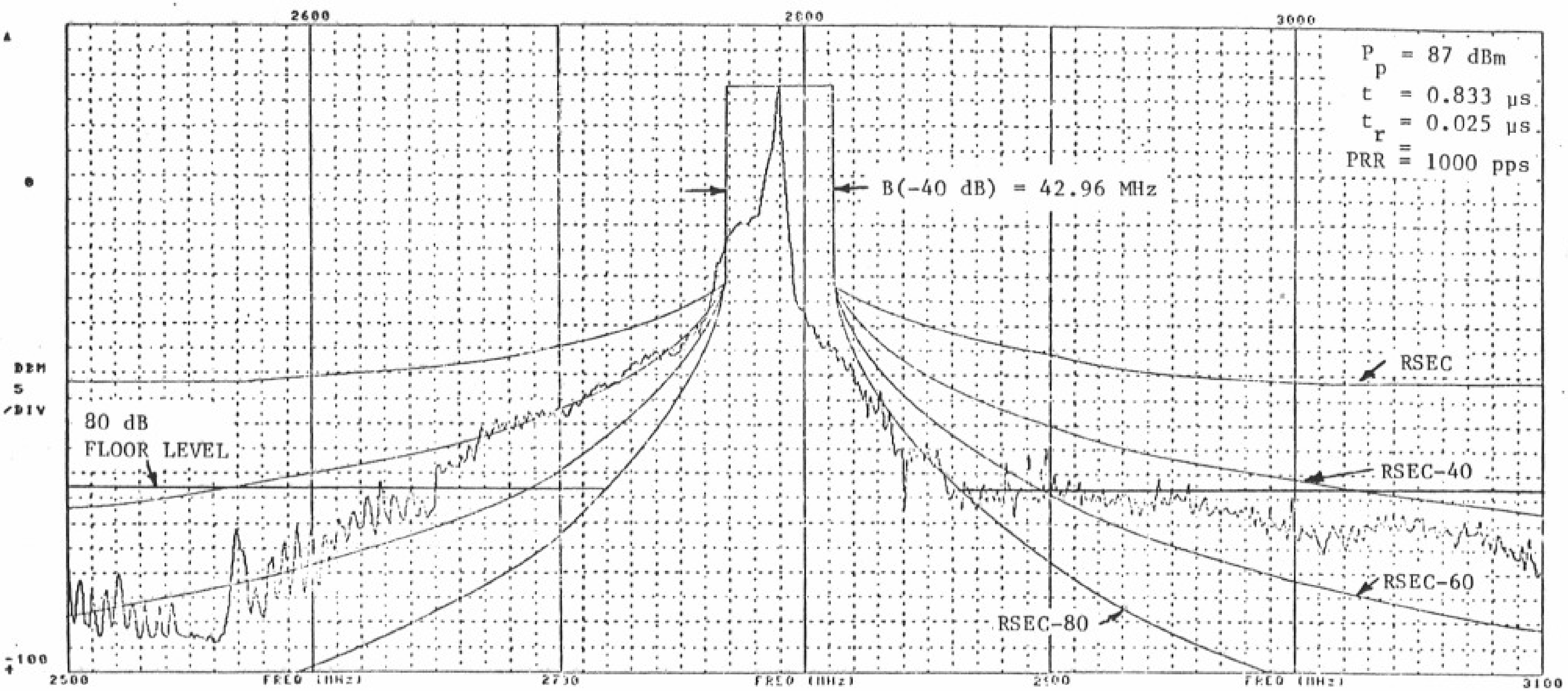



Figure 27. Measured ASR-5 Emission Spectrum (Conventional Magnetron).

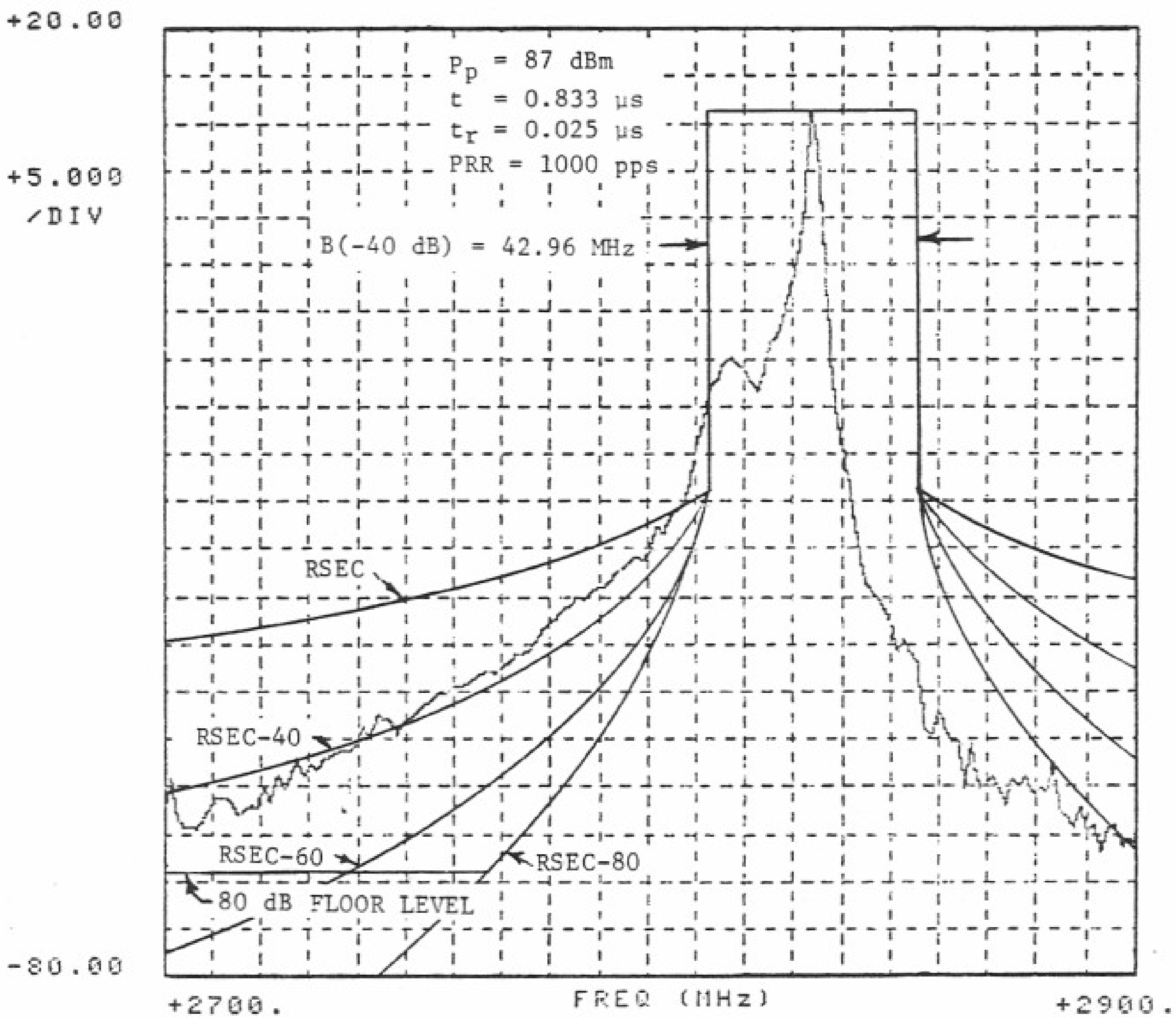



Figure 28. Measured ASR-6 Emission Spectrum (Conventional Magnetron)

level of the conventional magnetron is approximately 70-75 dB down from the fundamental. It is generally characteristic of conventional magnetrons to have relatively high harmonic and non-harmonic spurious emission levels. Major factors which contribute to variations in conventional magnetron noise floor levels are:

1. Magnetron age
2. Modulating pulse shape
3. Magnetron tube type
4. Magnetron anode voltage and current (Peak Power) setting
5. Magnetron load

The above factors are listed in their suspected order of significance. Even though the conventional magnetron has a relatively high noise floor level, it is shown in Figure 28 that the conventional magnetron noise floor is lower than the present RSEC floor level by 10-15 dB. Therefore, the present RSEC floor level appears to be somewhat conservative.

Conventional magnetron emission spectrum characteristics can be made significantly cleaner by using a waveguide filter. The AN/GPN-20 radar uses a conventional magnetron tube (8789, See TABLE 24) and a 5 section bandpass waveguide filter. Figure 29 shows a measured emission spectrum of an AN/GPN-20 with emission spectrum bound curves for the RSEC and fall-off rates of 40, 60, and 80 dB per decade from the RSEC 40 dB bandwidth. As seen in Figure 29, the use of a waveguide filter significantly lowers the sideband emission of a conventional magnetron. Figure 29 shows that by using a waveguide filter the sideband spurious emissions of a conventional magnetron can be suppressed to meet a 60 dB per decade fall-off from the RSEC 40 dB bandwidth. The measured emission spectrum shown in Figure 29 does not quite meet the 80 dB per decade emission spectrum bounds curve, however, proper design of the waveguide bandpass filter would even permit the conventional magnetron tube to meet the 80 dB per decade emission spectrum bound curve.

Coaxial Magnetron

Three radar nomenclatures in the 2700-2900 MHz band use coaxial magnetron output tubes. The NWS WSR-74S weather radar uses a VSM-1197 output tube. The height-finder radars (AN/FPS-6 and AN/FPS-90) which are being updated to AN/FPS-116 use a VSM-1143A or VSM-1143B output tube. Emission Spectrum measurements have been made on the WSR-74S at Volens, Virginia, and also on several height-finder radars.

The WSR-74S radar has the capability to transmit on two different pulse widths, 1.0 and 4.0 μs. Measured emission spectrums for the short pulse (1.0 μs) and long pulse (4.0 μs) are shown in Figures 30 and 31 respectively. Also shown in the figures are the emission spectrum bounds for the RSEC and fall-off rates of 40, 60, and 80 dB per decade from the RSEC 40 dB bandwidth. The coaxial magnetron has a very sharp fall-off around the fundamental frequency which is a big improvement over the conventional magnetron. The emission spectrum floor level of coaxial magnetrons is approximately 70-75 dB down from the fundamental which is similar to the conventional magnetron. In addition to the cleaner emission spectrum around the fundamental, the coaxial magnetron also has a significantly greater life span than the conventional magnetron. It is shown in Figures 30 and 31 that the coaxial magnetron does meet the present RSEC. Like the conventional magnetron, however, the coaxial magnetron can not

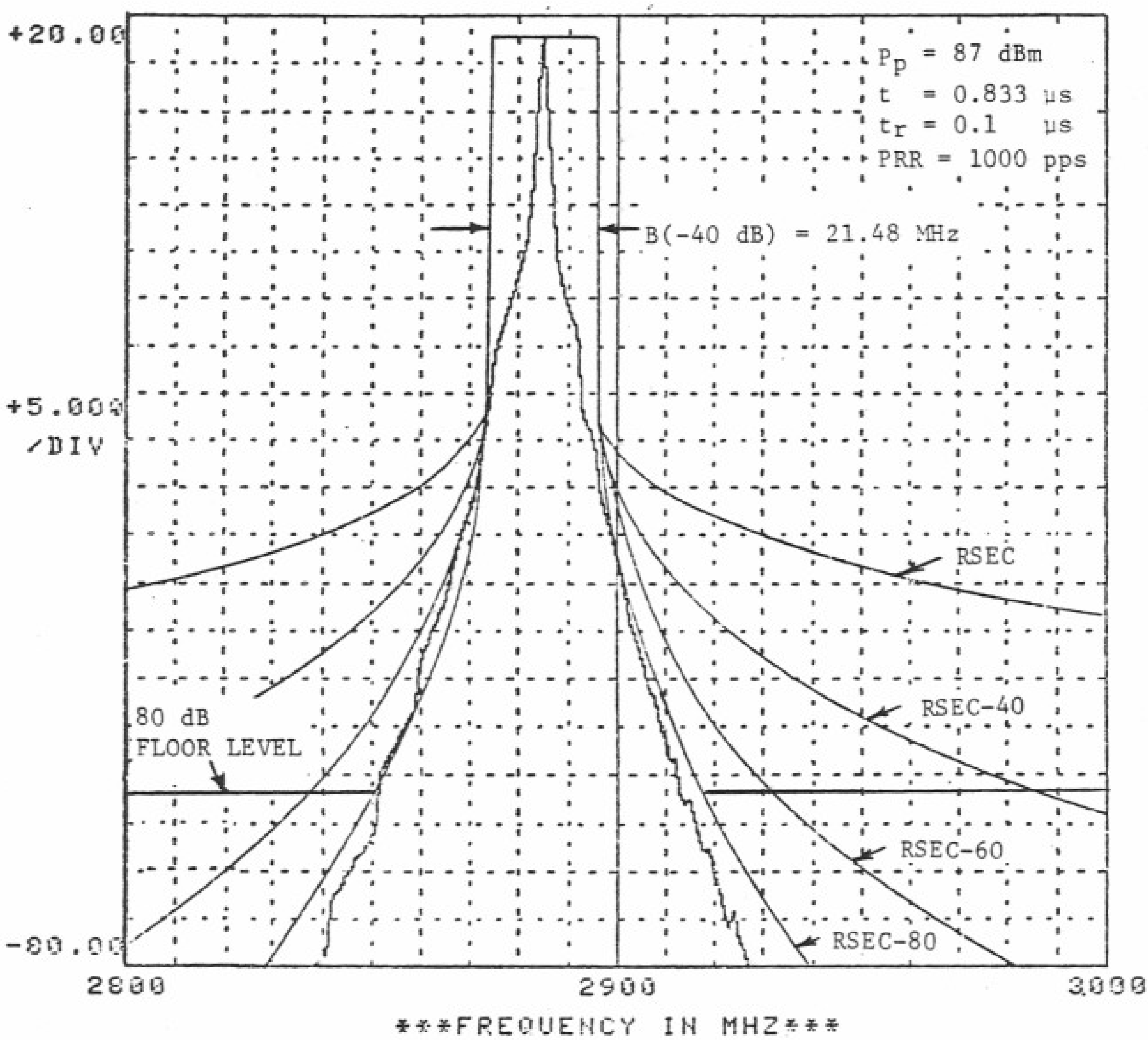



Figure 29. Measured AN/GPN-20 Emission Spectrum (Conventional Magnetron with Waveguide Filter)

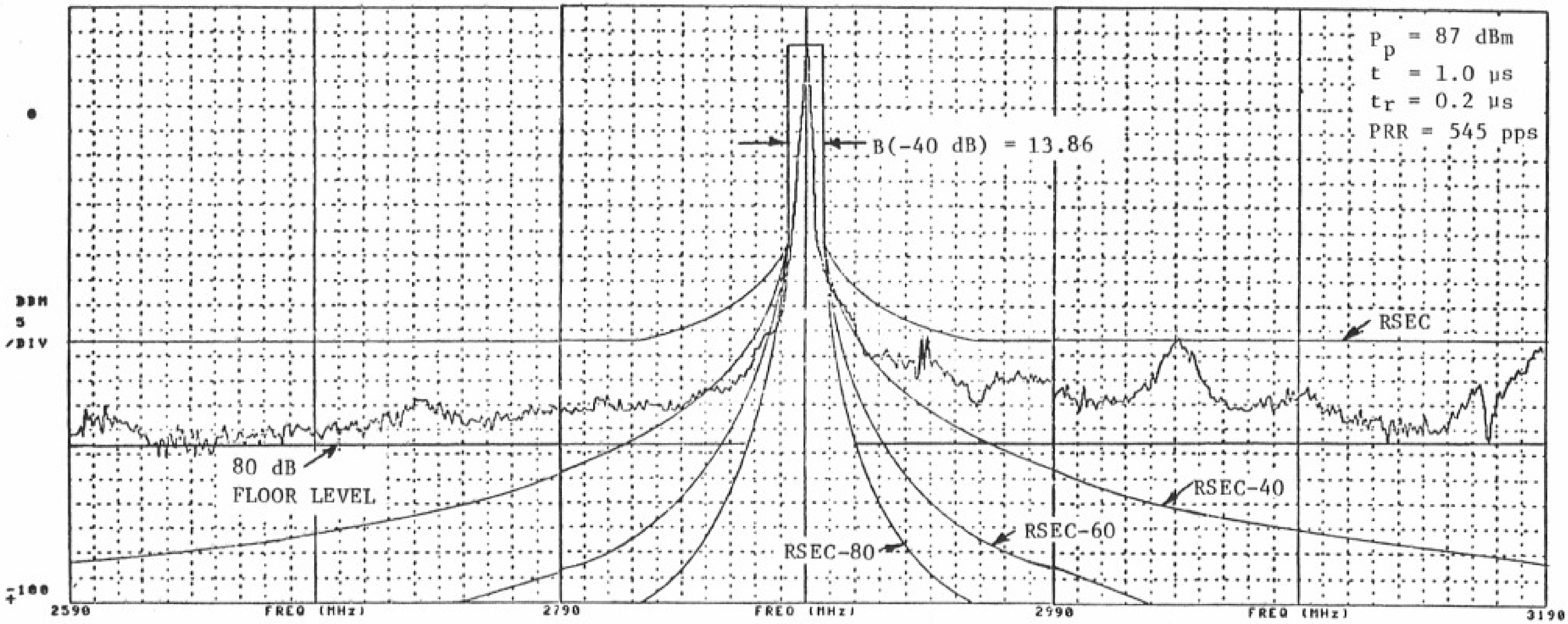



Figure 30. Measured WSR-74S Emission Spectrum, 1.0 μs Pulse (Coaxial Magnetron)

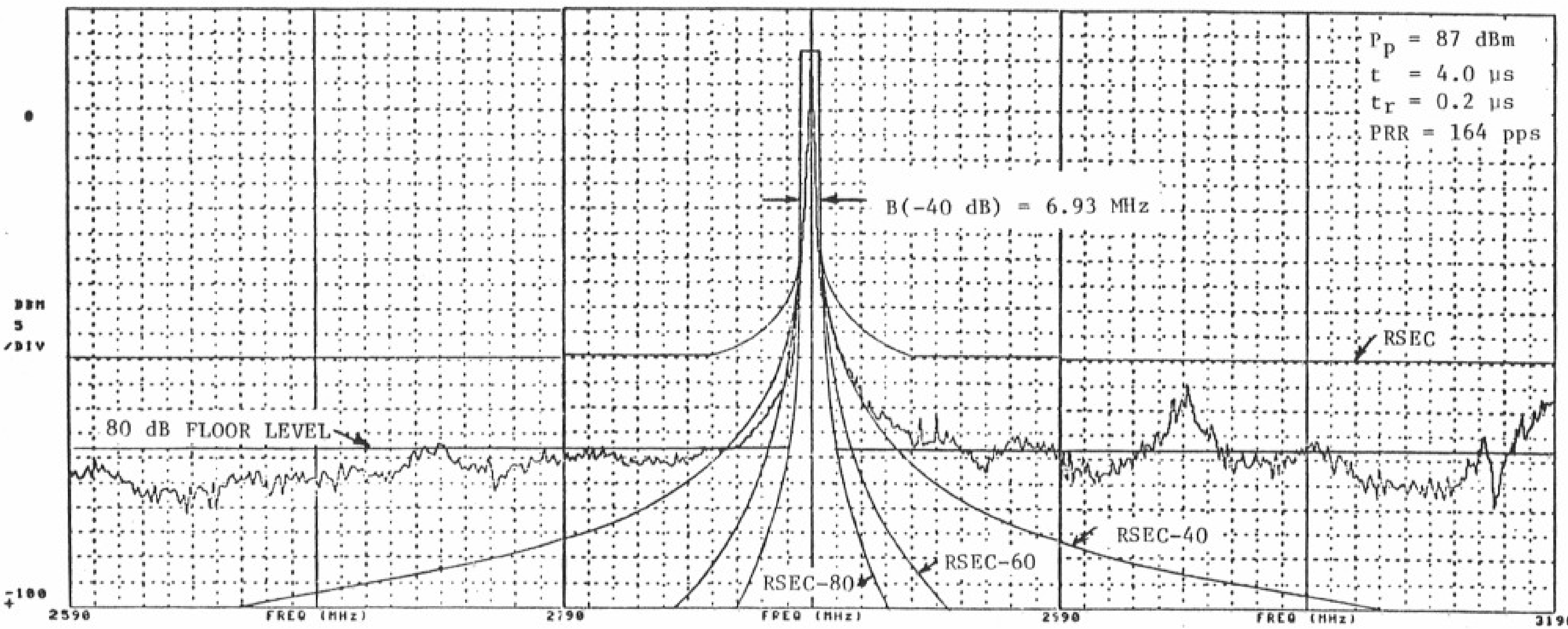



Figure 31. Measured WSR-74S Emission Spectrum, 4.0 µs Pulse (Coaxial Magnetron)

meet the more stringent 40, 60, or 80 dB per decade fall-offs emission spectrum bound unless a waveguide filter is used. At present, there are no radars in the 2700-2900 MHz band which use both a coaxial magnetron and waveguide bandpass filter. However, with the proper designed waveguide filter, the coaxial magnetron should be capable of meeting the 80 dB per decade fall off rate from the RSEC 40 dB bandwidth.

Figure 32 shows the measured emission spectrum of an AN/FPS-90 at San Pedro Hill, California. The figure shows the sharp emission spectrum fall-off around the fundamental typical of coaxial magnetrons and the emission spectrum is below the present RSEC emission spectrum bound level. Emission spectrum measurements have been made on several height-finder radars. Some of these radars had a spurious mode ($TE_{121}$) approximately 70-80 MHz above the fundamental frequency which is approximately 55 dB down. Figure 33 shows measured emission spectrum of the height-finder at North Truro with the $TE_{121}$ mode emission. There is also a spurious emission sometimes on the lower side of the fundamental.

## KLYSTRON

At present, the FAA ASR-8 radar system is the only radar system in the 2700-2900 MHz band which uses a klystron output tube. It uses a Varian VA-87E transmitter output tube, and also has a waveguide bandpass filter for frequency diversity operations. Closed system measurements were made on an ASR-8 radar before and after the waveguide filter.

Figures 34 and 35 show measured emission spectrum before the waveguide filter of the Long Beach ASR-8 A and B channels respectively. In general, klystron emission spectrums are characterized by a very sharp fall-off around the fundamental frequency generally following the theoretical emission spectrum fall-off of the modulating pulse. At approximately 70 to 80 dB down there is a "porch". The fall-off from the "porch" is determined by the selectivity of the cavities in the klystron. The noise floor of the klystron is approximately 110 to 115 dB down from the fundamental. Some factors which contribute to the level (spectral impurities) of the "porch" are:

1. Klystron being operated near or at the saturation level.
2. Incidental phase modulation on the RF drive pulse, and
3. Ripple on the beam voltage.

Careful consideration of the above factors in design of the associated klystron circuitry can significantly reduce the spectral impurities of the "porch".

Figures 34 and 35 show that the klystron can meet the present RSEC. Also channel A (Figure 34) meets the 40 dB per decade fall-off emission spectrum bounds. However, channel B (Figure 35) does not meet the 40 dB per decade emission spectrum bounds. It is believed that with consideration of the previously mentioned factors in the design of the associated klystron circuitry, the klystron can meet the 40 dB per decade fall-off from the RSEC 40 dB bandwidth.

Figures 36 and 37 show the measured emission spectrum after the waveguide filter of the Long Beach ASR-8 A and B channels respectively. The Figures show that with a waveguide filter the radar emission spectrum level is below the 80 dB per decade fall-off line.

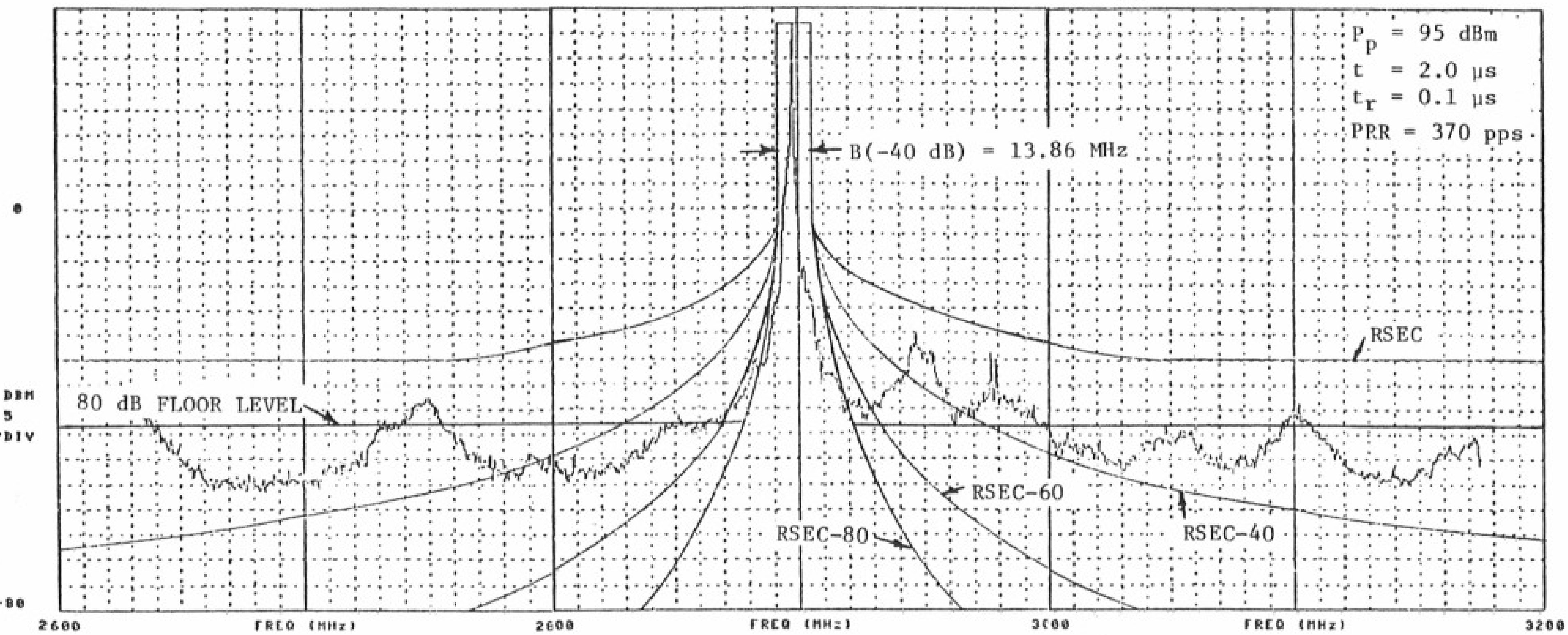



Figure 32. Measured AN/FPS-90 Emission Spectrum (Coaxial Magnetron)

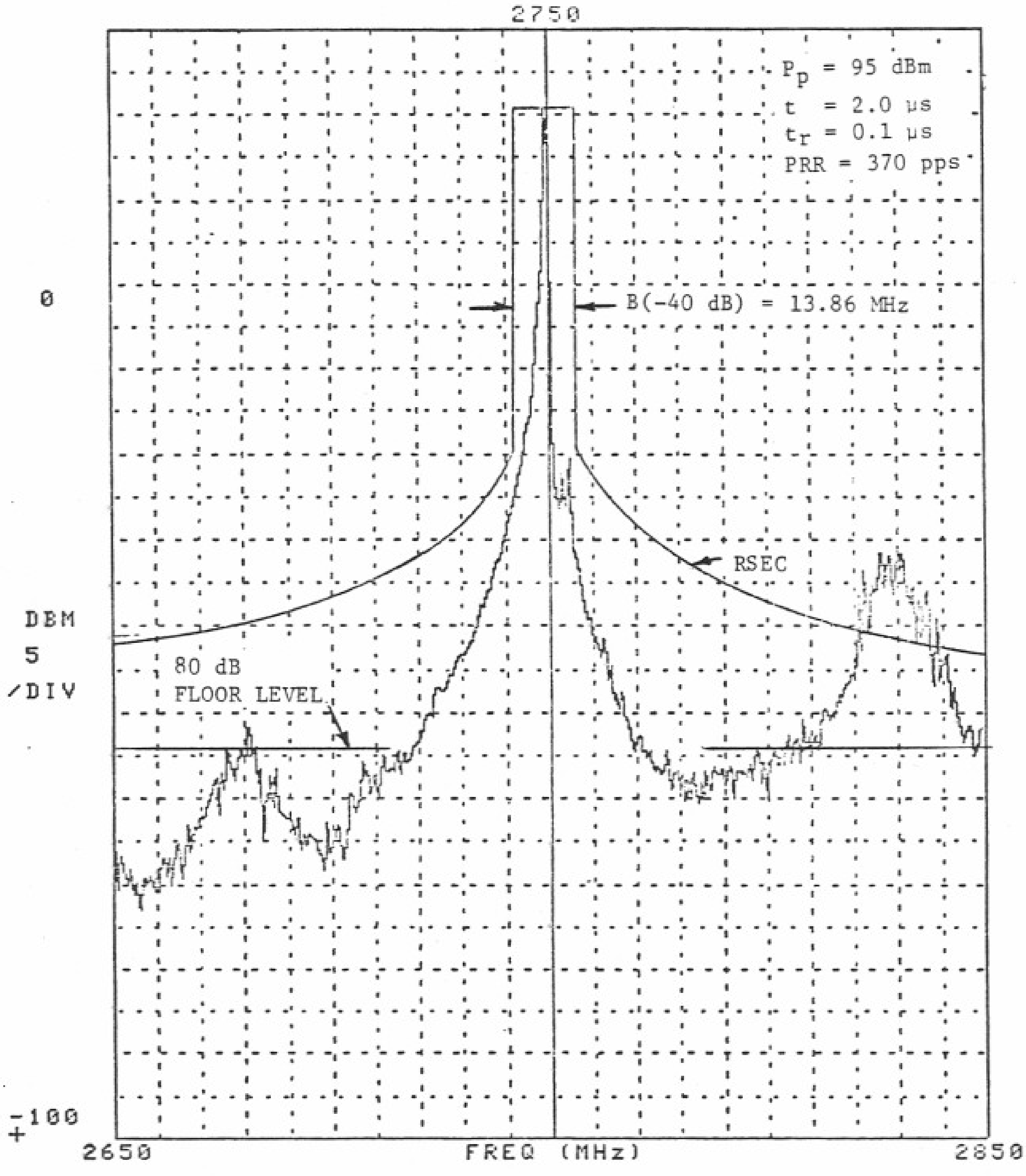



Figure 33. Measured AN/FPS-6 Emission Spectrum (Coaxial Magnetron).

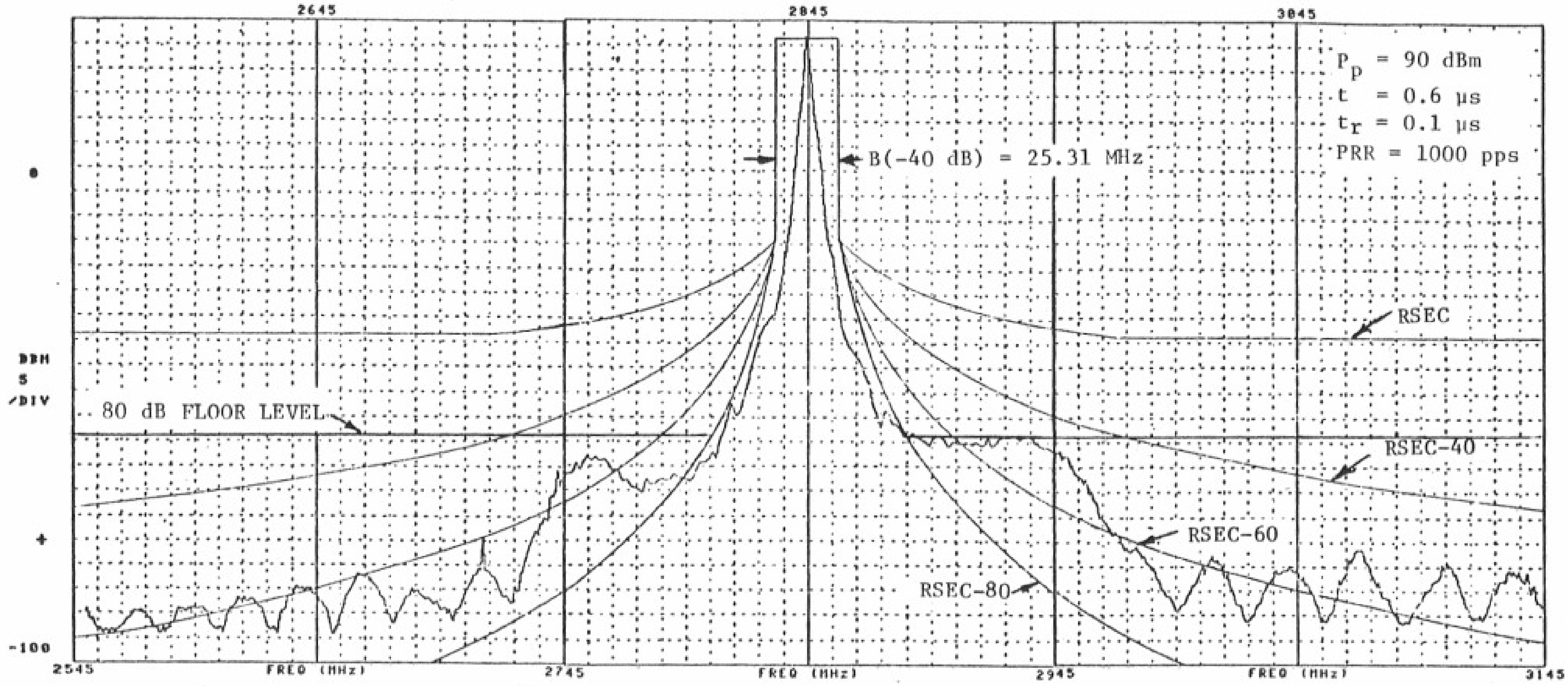



Figure 34. Measured ASR-8 Emission Spectrum, Channel A (Klystron Before Waveguide Filter)

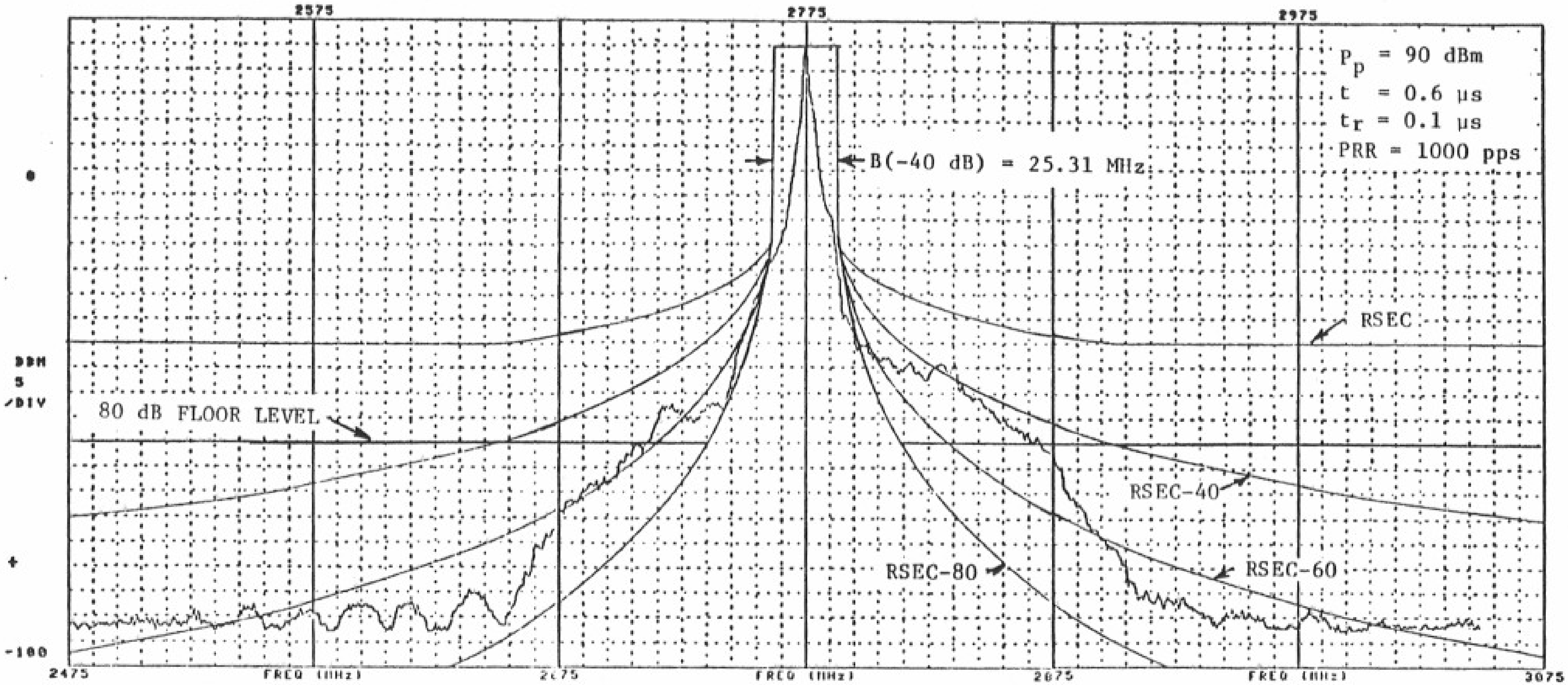



Figure 35. Measured ASR-8 Emission Spectrum, Channel B (Klystron Before Waveguide Filter)

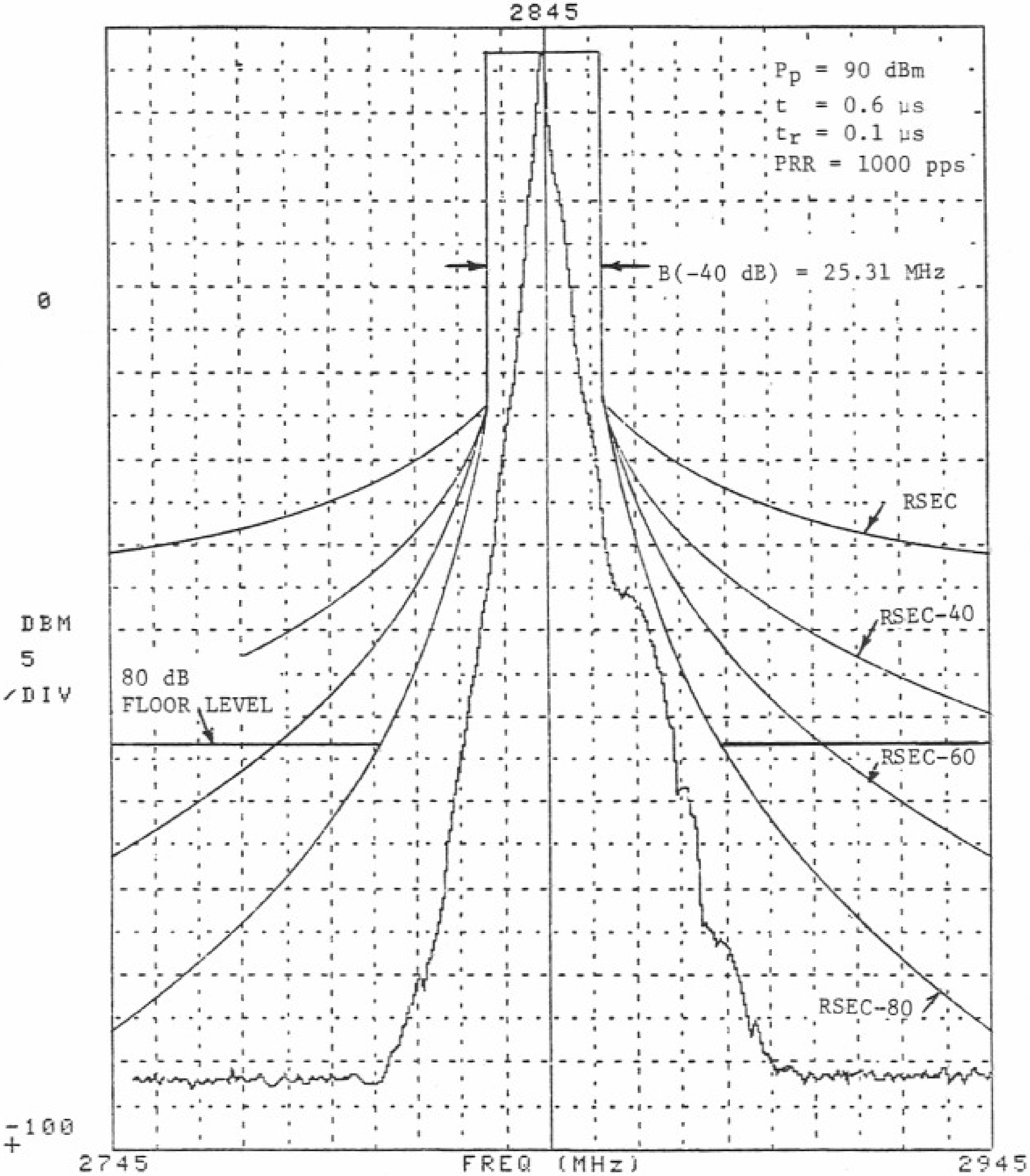



Figure 36. Measured ASR-8 Emission Spectrum Channel A (Klystron After Waveguide Filter)

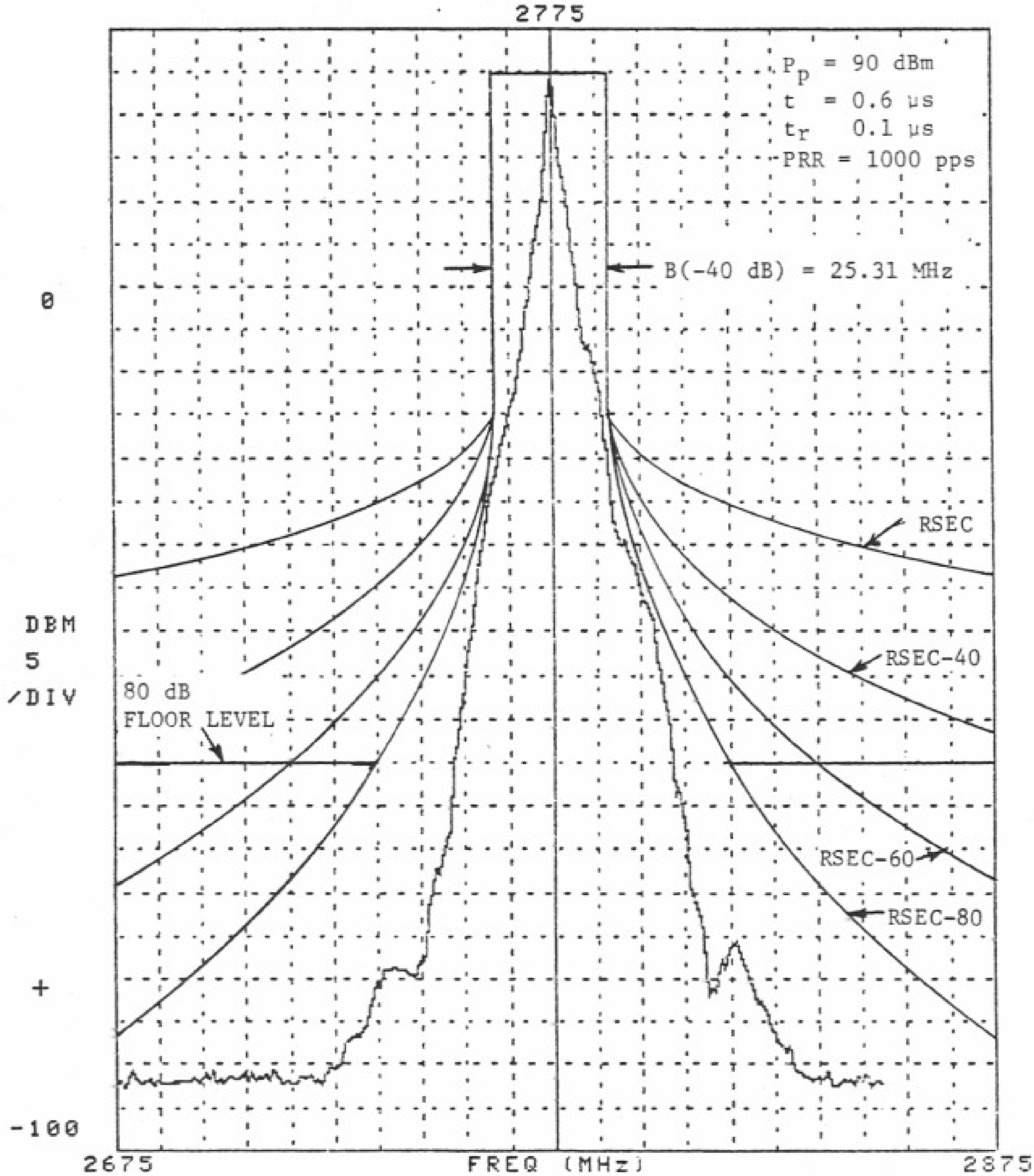



Figure 37. Measured ASR-8 Emission Spectrum, Channel B (Klystron After Waveguide Filter)

## Summary of Transmitter Emission Spectrum Characteristics

As a result of the emission spectrum measurements and analysis made on radars in the 2700-2900 MHz band, it was determined that:

1. The conventional magnetron tube without using a waveguide filter does not meet the present RSEC Column B criteria due to the inherent frequency pulling characteristics of the tube during the risetime of the modulation pulse.

2. The coaxial magnetron and klystron do meet the present RSEC column B criteria.

3. The noise floor level specified in the RSEC is approximately 60 dB down for typical parameters of radars in the 2700-2900 MHz band. The measured noise floor level of conventional and coaxial magnetrons is approximately 70-75 dB down from the fundamental level, and the noise floor level of klystrons is approximately 110-115 dB down from the fundamental level. Therefore, for radars in the 2700-2900 MHz band the present RSEC noise floor level of 60 dB is somewhat conservative.

4. Emission spectrum levels much more stringent than the present RSEC can be achieved by the use of bandpass waveguide filters.

TABLE 26 summarizes the capability of conventional magnetron, coaxial magnetron and klystron tubes to meet the present RSEC and the proposed changes to the RSEC. It is recommended that all new fixed radars in the 2700-2900 MHz band have an emission spectrum level which from the present RSEC 40 dB bandwidth falls-off at 40 dB per decade to a fixed floor level of 80 dB. Also the new radars planned for the band should be designed and constructured to permit without modification to the basic equipment, field incorporation of, the capability to meet an 80 dB per decade fall-off from the RSEC 40 dB bandwidth down to a floor level of 80 dB. The later more stringent emission spectrum bounds would be used in designated heavily used areas (See Figure 8 and TABLE 22) and for collocated radar sites when required. Only the klystron tube can meet the recommended RSEC emission spectrum bound for non-heavily used areas without the use of a waveguide filter. The conventional and coaxial magnetrons both will require the use of a waveguide filter to meet the 40 dB per decade fall-off and 80 dB noise floor level for non-heavily used areas. For the recommended emission spectrum bounds for heavily used areas and collocated operation, the conventional magnetron, coaxial magnetron and klystron will require the use of a waveguide filter.

The cost of waveguide filters was obtained from several manufacturers. It was found that fixed-tuned five section filter costs approximately five to seven thousand dollars each, and tunable waveguide filters cost approximately twenty to thirty thousand dollars each.

Figures 34 and 35 indicates that the ASR-9 and NEXRAD radar systems can be collocated (less than two mile separation distance) if klystrons are used with at least 130 MHz of frequency separation. However, the ASR-9 and NEXRAD systems can be collocated with only approximately 60 MHz of frequency separation if a klystron and waveguide filter or used (See Figure 36 and 37).

TABLE 26

TRANSMITTER OUTPUT TUBE COMPLIANCE
WITH PRESENT AND PROPOSED RSEC

| TRANSMITTER OUTPUT | PRESENT RSEC COLUMN B | PROPOSED RSEC | |
|---|---|---|---|
| | | NON-HEAVILY USED AREAS | HEAVILY USED AREAS |
| CONVENTIONAL MAGNETRON | NO | NO | NO |
| CONVENTIONAL MAGNETRON WITH WAVEGUIDE FILTER | YES | YES | YES |
| COAXIAL MAGNETRON | YES | NO | NO |
| COAXIAL MAGNETRON WITH WAVEGUIDE FILTER | YES | YES | YES |
| KLYSTRON | YES | YES | NO |
| KLYSTRON WITH WAVEGUIDE FILTER | YES | YES | YES |

YES - Implies Tube Will Meet Criteria
NO - Implies Tube Will Not Meet Criteria

Also the ASR-9 and NEXRAD systems can be collocated with only approximately 60 MHz of frequency separation if a magnetron and waveguide filter is used (See Figure 29).

TRANSMITTER OUTPUT POWER LEVEL

Many of the Ground Control Approach (GCA) radars deployed by the Military have control areas of less than 60 nautical miles. The air traffic control areas of the GCA radars are typically between 10 and 30 nautical miles, and therefore do not require the same transmitter output power as do the 60 nautical mile radars for a specified probability of detection. For cost benefit reasons, recent Military radar procurements in the 2700-2900 MHz band have been from FAA developed radars which are designed for operation out to 60 nautical miles. More efficient utilization of the band could be achieved if radars were designed to have the capability to vary the transmitter output power level. However, Trade-off in track continuity must be considered.

The transmitter output power level of klystron tubes can be readily varied up to 12 dB (change in radar detection range by factor of two) by changing the RF drive pulse level or beam voltage. In general, it is more desirable to change the beam voltage since the prime system power can be reduced and should result in the life of the tube being increased. The beam voltage can be readily changed by putting taps on the power transformer. However, there may be a slight drop in tube efficiency as the beam voltage is changed.

The output power of crossed-field tubes (conventional magnetrons and coaxial magnetrons) can not be as readily changed as klytron tubes. The output power level of crossed-field tubes can be changed from 3-6 dB. However, to change the transmitter output power by 12 dB would require the development of a family of tubes designed for the radar. It was believed that two crossed-field tubes would be adequate to cover a 12 dB range in transmitter output power level. It was the consensus of the TSC Working Group that the feature of variable transmitter output power level was desirable from a spectrum conservative viewpoint. However, the requirement of variable transmitter output power level did not appear to be viable requirement because of the difficulty in implementing in radar systems which use cross-field device output tubes.

RECEIVER INTERFERENCE SUPPRESSION CIRCUITRY

In addition to clearer transmitter emission spectrum characteristics, more efficient use of the 2700-2900 MHz band can also be achieved by use of receiver signal processing techniques. Many of the new radar systems planned for deployment in the band will have to operate in heavily used areas where many of the old radar system will have relatively high tranmitter spurious emission levels. Therefore, many of the new radar systems may be subjected to asynchronous pulsed interference in performing their missions.

In order to assure that the performance of new radar systems in the 2700-2900 MHz band are not degraded in heavily used areas, it is imperative that emphasis be placed on interference vulnerability when defining design specifications of new equipment procurements to ensure that system performance requirements can be satisfied in the type of asynchronous pulsed interference environment anticipated. Radar procurement design specifications of systems planned for deployment in the 2700-2900 MHz band in heavily used areas should include Radio Frequency (RF) preselector filter characceristics and

Intermediate Frequency (IF) filter characteristics which minimize the inband energy of undesired signals. Also the system should be designed and constructed to permit, without modification to the basic equipment, the ability to incorporate signal processing circuitry or software to suppress asynchronous pulsed interference. Many of the radars presently in the band have interference suppression circuitry or software. Appendix A contains a compendium of interference suppression techniques used by aeronautical radionavigational radars.

In order to design and develop signal processing circuitry or software to suppress asynchronous pulsed interference, it is necessary to be cognizant of the characteristics of the interfering signals encountered in the operational environment. One of the tasks the IRAC assigned to the TSC was to describe the theoretical environmental signal characteristics (pulse width, pulse repetition frequency, and expected signal levels) which new radars in the 2700-2900 MHz band may be subjected to in performing their operational requirement.

## ENVIRONMENTAL SIGNAL CHARACTERISTICS

The following environmental signal characteristics description was developed as an aid in the design and development of receiver signal processing circuitry or software to suppress asynchronous pulsed interference. The environmental signal characteristics were developed by taking into consideration the nominal radar system characteristics of existing and planned radars for the band, field observations of Plan Position Indicator (PPI) scopes (Hinkle, Pratt, Matheson, 1976) and measurements of radar pulsed densities in the Los Angeles and San Francisco areas (Matheson, Smilley, and Lawrence, 1981). Nominal system characteristics of radars in the 2700-2900 MHz band were discussed in Section 4 and summarized in TABLES 13 and 14. Expected pulse densities in heavily used areas were discussed in Section 5.

In heavily used areas, new radar deployments may receive interference from one or two radars. The probability of receiving interference from two radars in the same time interval (i.e., victim radar mainbeam pointing at bearing or one interfering radar while second interfering radar mainbeam is pointing at bearing of victim radar) is low, but finite. The pulse width of the demodulated interfering signal will be a function of the interfering radar pulse width and receiver bandwidth characteristics. The detected pulse characteristics will also be affected by frequency separation. The total number of interfering pulses detected and peak Interference-to-Noise Ratio (INR) at the victim receiver IF output is a function of the frequency and distance separation as well as siting and terrain topography around and between the radar sites, and will vary as a function of time. The time variation of the peak INR is also influenced by the antenna pattern sidelobe and mainbeam characteristics and antenna scan characteristics of the interfering and victim radars. TABLE 27 summarizes the range of environmental signal characteristics that a radar operating in a heavily used area may be subjected to in performing its operational requirements.

TABLE 27

ENVIRONMENTAL SIGNAL CHARACTERISTICS THAT HAVE A BEARING ON RECEIVER PERFORMANCE

Pulse Width: 0.5 to 4.0 us
Pulse Repetition Frequency (PRF): 100 to 2000 pps
Interference-to-Noise Ratio (INR) at IF Output: $\leq$50 dB

PROPOSED RSEC CHANGES

After examining frequency-distance curves for characteristics of future planned systems, present radar deployment patterns, and projected growth in the 2700–2900 MHz band, it was the opinion of the TSC Working Group 1 that some changes should be made to the present Radar Spectrum Engineering Criteria (RSEC) for new fixed radars which operate in the 2700–2900 MHz band. The following is a summary of the proposed changes recommended by TSC Working Group 1 for the RSEC contained in Part 5.3 of the NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management (NTIA, 1979). Presently radars in the 2700–2900 MHz band are subject to RSEC Criteria C. Appendix C of this report contains a complete copy of the proposed RSEC for new fixed radars in the 2700–2900 MHz band.

The following is a summary of the major changes to the present RSEC Criteria C proposed for new fixed radars in the 2700–2900 MHz band:

1. For non-FM pulse radars, a pulse risetime of less than 0.1t should be justified. This changes the formula for the B(-40 dB) bandwidth (Paragraph 3.1).

2. The emission levels beyond the frequencies B(-40 dB)/2 from $F_o$ were changed to 40 dB per decade roll-off and an 80 dB floor level, X (dB)=80 dB (Paragraph 4).

3. 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 designated heavily used areas, 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 $F_o$, the level shall be at least 40 dB below the maximum value. Beyond the frequencies B(-40 dB)/2 from $F_o$, the equipment shall have the capability to achieve up to 80 dB per decade (S=80) roll-off lines of Figure 2 to a maximum spectral power density of X(dB) = 80 dB.

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 $\pm$ 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: $\leq$ 50 dB
Pulse width: 0.5 to 4.0 us
PRF: 100 to 2000 pps