

## APPENDIX: RADAR SPECTRUM ENGINEERING CRITERIA (RSEC) CALCULATIONS

The RSEC to be applied to each radar spectrum is defined in section 5.3 of the NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management. Several radar parameters--operating frequency, peak power, transmitting pulse shape, type of radar, and procurement or overhaul date--determine the RSEC emission bandwidth and levels to be applied to the radar spectra. Based on these parameters, some of the radars presented in this report were in a different RSEC category at the time the measurements were made; however, for purposes of technical comparability, the same RSEC is applied to all of the spectra. The criteria we selected do apply to non-FM pulse radars having a rated peak power of more than one kilowatt and operating at less than 40 GHz, and do properly apply to many of the radars included in this report.

The RSEC is concerned with the difference between spectral energy measured at  $f_0$  and at sideband frequencies. As long as the measurement system is handling the spectral energy at  $f_0$  and at sideband frequencies identically, the RSEC may be compared directly to the measurements. As noted before, Figure 5 for example, the RSEC limit often starts several decibels above the peak response of the radar. This difference is caused by a correction factor that must be added when the spectrum is measured with a bandwidth larger than  $1/t$ , where  $t$  is the pulse width of the radar being measured. For measurement bandwidths greater than  $1/t$ , but smaller than  $1/t_r$ , where  $t_r$  is the radar pulse rise time, the measurement system responds accurately to the emission at  $f_0$  but sees an impulse at sideband frequencies. As bandwidth,  $B$ , is increased, the measured value of signal at  $f_0$  will remain constant while the signal at sideband frequencies will increase at a  $20 \log B$  rate. For measurement bandwidths less than  $1/t$ , the sideband spectra fall below system noise. For measurement bandwidths outside the range between  $1/t$  and  $1/t_r$ , no correction is necessary. However, use of measurement bandwidths greater than  $1/t$  offer advantages in measurement system sensitivity in the sideband areas of the radar and allow accurate measurement of received radar peak power and pulse width.

For a measurement bandwidth between  $1/t$  and  $1/t_r$ , the correction factor may be computed from some well-known relationships between impulse bandwidth and peak response.

From the RSEC:

$$P_t = P_p + 20 \log (Nt) + 10 \log (PRR) - PG - 90 \quad (1)$$

where,  $P_p$  = peak transmitted power (dBm)  
 $t$  = emitted pulse duration (us)  
 PRR = pulse repetition rate (pulses per second)  
 $P_t$  = maximum spectral level (dBm/kHz)  
 PG = processing gain (dB)  
 $N$  = total number of chips (subpulses) contained  
 in the pulse.

assuming that the processing gain is 0 and the number of chips is 1 (for radars in this report) we can convert to:

$$P_t = P_p + 20 \log t + 10 \log (PRR) - 90 \quad (2)$$

If  $t$  is expressed in s instead of us and  $P_t$  is expressed in dBm/Hz instead of dBm/kHz, this becomes:

$$P_t = P_p + 20 \log t + 10 \log (PRR).$$

Converting from dBm to absolute units gives:

$$P_t = P_p \times t^2 \times PRR, \quad (3)$$

where  $P_t$  is in mW/Hz,  $P_p$  is transmitted power in mW,  $t$  is pulse width in s, and PRR is in pulses/s.

Another equation relates impulse bandwidth and system responses to  $P_t$  at a frequency in the sidebands of the radar:

$$P_t \times b_p = p_i \times 1/b_i \times PRR,$$

where  $b_p$  is the power bandwidth of the system;  $p_i$  is the peak response from an impulse, and  $b_i$  is the impulse bandwidth.

This can be solved to give:

$$P_t = 1/b_p \times 1/b_i \times p_i \times PRR \quad (4)$$

Equations (3) and (4) can be combined by assuming that the  $P_t$  is equal for measurements made at  $f_0$  and the sidebands, then comparing the value of  $P_p$  and  $p_i$ . From (3) and (4):

$$P_p \times PRR^2 \times t^2 \times 1/PRR = 1/b_p \times 1/b_i \times p_i \times PRR$$

simplifying:  $P_p \times t^2 = 1/b_p \times 1/b_i \times P_i$

$$P_i / P_p = t^2 \times b_p \times b_i. \tag{5}$$

The above calculations assume that the measurements are made with a bandwidth larger than  $1/t$ , so that the measured value for  $p_p$  is actually the peak power of the radar. They also assume that the measurement bandwidth is less than  $1/t_r$ , because equation (4) assumes that the signal looks impulsive in the measurement bandpass. These equations work for the asymptotic cases; they give no correct answers when near  $f_0$  or when using bandwidths near  $1/t$ . Careful calibration of the RSMS has not been performed to determine the exact power bandwidth  $b_p$  and impulse bandwidth  $b_i$  for the measurements. However, a general rule of thumb lets us say that  $b_i = 1.25 b_p$ .

From Table 4, measured values for the WSR-57 radar were:  $t = 4.1 \mu s$ ;  $t_r = 50 \text{ ns}$ . Then  $1/t = 244 \text{ kHz}$  and  $1/t_r = 20 \text{ MHz}$ , and for a measurement bandwidth,  $b_p = 1 \text{ MHz}$ , the above equation (5) for  $p_i/p_p$  applies.

$$\begin{aligned} P_i/P_p &= (4.1 \times 10^{-6})^2 \times 1 \times 10^6 \times 1.25 \times 10^6 \\ &= 21 \text{ correction factor} \\ &= 13 \text{ dB correction} \end{aligned}$$

This means that the power at the sidebands ( $p_i$ ) is being measured 13 dB too high, compared to the value measured at the fundamental ( $P_p$ ).

This correction could have been applied by either: a) drawing a dashed line 13 dB below the measured sideband spectra and using the dashed line values to compare with the RSEC for sideband suppression below the peak value, or b) adding 13 dB to the peak value at the fundamental frequency and start the RSEC comparison 13 dB above the fundamental frequency. The latter method was chosen because of the simpler graphical procedure involved.

The current RSEC stipulates that the emission levels at the antenna input must be at least 40 dB below the maximum value (emission level at the fundamental frequency,  $f_0$ ) at frequencies  $f_0 +$  or  $- 1/2 B_{-40 \text{ dB}}$ , and at frequencies,  $f$ , displaced by more than  $1/2 B_{-40 \text{ dB}}$  from  $f_0$ , the suppression (dB) shall be at least

$$-20 \log \left| \frac{f - f_o}{\frac{1}{2} B_{-40 \text{ dB}}} \right| -40,$$

where B = emission bandwidth in MHz. This latter suppression is to continue until the ultimate value of 60 dB or  $P_t + 30$ , whichever is the larger value, is attained, where  $p_t$  may be measured or calculated from:

$$p_t = P_p + 20 \log (Nt) + 10 \log (PRR) - PG -90.$$

Using the same WSR-57 as an example, the allowable emission bandwidth at 40 dB below the level at the fundamental frequency is:

$$B_{(-40 \text{ dB})} = \frac{7.6}{\sqrt{t} t_r}, \text{ or } 64/t$$

whichever is less.

$$B_{(-40 \text{ dB})} = \frac{7.6}{\sqrt{4.1 \times 10^{-6}} \times .05 \times 10^{-6}} = 16.8 \text{ MHz}$$

$$B_{(-40 \text{ dB})} = 64/t = 15.6 \text{ MHz}$$

Thus, at  $f_o +$  or  $- 7.8$  MHz, the emission level must be at least 40 dB below the peak level (peak received signal plus 13 dB correction).

The roll-off from the -40 dB points must be at the 20 dB per decade rate, so that at the required level of 60 dB below the peak, the bandwidth is

$$B_{(-60 \text{ dB})} = B_{(-40 \text{ dB})} \times 10^{\frac{60-40}{20}} = 156 \text{ MHz.}$$