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Dependence of Radar Emission Spectra on Measurement Bandwidth and Implications for Compliance with Emission Mask Criteria

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Abstract. *Radar transmitter emission criteria normally include the specification of frequency-dependent emission masks. These masks specify the amount by which unwanted radar emissions (both out-of-band and spurious) must be suppressed relative to the power levels emitted at the radars' fundamental frequencies. Compliance with emission masks is determined through measurements of emission spectra. The measured levels of radar unwanted emissions and fundamental-frequency emissions both vary as a function of measurement system bandwidth, B_m. But the variation with B_m differs between the unwanted emissions and the fundamental-frequency emissions. Moreover, the variation of unwanted emission levels varies as a function of frequency as well as B_m. This creates a problem for radar emission mask-compliance measurements.*

The National Telecommunications and Information Administration (NTIA) Institute for Telecommunication Sciences (ITS) has explored this problem by performing emission spectrum measurements on a maritime surface search (navigation) radar. In the spectrum data that are presented, the radar unwanted emission levels are found to vary between 12 log(B_m) and 20 log(B_m), depending upon frequency. But the measured power of the radar fundamental frequency is found to vary as 20 log(B_m) for all bandwidths that are less than or equal to 1/(radar pulse width). The result is that the level offset between the unwanted emissions and the fundamental-frequency emission level depends upon the measurement bandwidth and the frequency of the unwanted emissions. This result implies, at a minimum, that measurement personnel must take the effect of B_m into account when performing radar emission spectrum measurements for the purpose of determining emission mask compliance. Based upon the results of these maritime radar spectrum data, some technical strategies for measuring radar emission spectra for emission mask compliance are proposed. Possible technical implications for future development of radar emission masks are also discussed.

1. Introduction

Pulsed radar transmitters produce broadband spurious emissions at relatively high levels compared to emissions from narrowband communication systems. As documented in [1], radar spurious emission levels are typically tens of decibels higher than theoretically predicted sinc^2 spectra of pulsed emissions. These emissions in the frequency domain probably correspond to short-term transient behavior in the time domain characteristics of the rising and falling edges of the radar pulses.

For spectrum management purposes, radar out-of-band and spurious emissions are limited in the U.S. by Government regulations such as the radar spectrum emission criteria (RSEC). RSEC spurious emission masks are specified in terms of amplitude suppression relative to the power produced at radars' fundamental frequencies [2]. (E.g., suppression might be required to be at least 60 dB below the fundamental at frequencies of 100 MHz or more away from the fundamental.) Mask-compliance limits are computed on the basis of a theoretically perfect pulsed emission plus a margin that allows for realistic performance of an economical transmitter design.

Compliance with emission masks is determined through measurements of emission spectra. The measured levels of radar unwanted emissions and fundamental-frequency emissions both vary as a function of measurement system bandwidth, B_m. But the variation with B_m differs between unwanted emissions and the fundamental-frequency emissions. Moreover, the variation of unwanted emission levels varies as a function of frequency as well as B_m. This presents a problem for radar emission mask-compliance measurements.

In a peak-detected power measurement, completely non-coherent (noise-like) emissions should vary as $10\log(B_m)$, while coherent emissions should vary as $20\log(B_m)$. Since the bandwidth progression coefficients of 10 and 20 represent limiting cases, radar spurious emissions should have a coefficient somewhere between these two values. But no study is known to have been undertaken to determine the actual coefficient for radars.

The National Telecommunications and Information Administration (NTIA) Institute for Telecommunication Sciences (ITS) has begun to address this problem by performing emission spectrum measurements on a maritime surface search (navigation) radar. The purpose of the measurements has been to determine the actual variation of spurious emission levels of a radar relative to the measured fundamental level as a function of the measurement bandwidth, B_m. With this value known, NTIA will be better able to specify appropriate bandwidths for RSEC-compliance measurements, as well as any post-measurement correction factors that might be required.

2. Approach

A magnetron-based X-band maritime surface search radar was set up with an antenna height of approximately 4 m on a mast at a prairie location free of local obstructions. A measurement system contained in the RF-shielded enclosure of the NTIA Radio Spectrum Measurement System (RSMS) was positioned at a distance of 105 m from the radar. The RSMS received radar emissions via a 1-meter diameter parabolic dish antenna with a linear, matched-polarization log-periodic feed. Figure 1 shows the radar transmitter and the RSMS during the measurement.

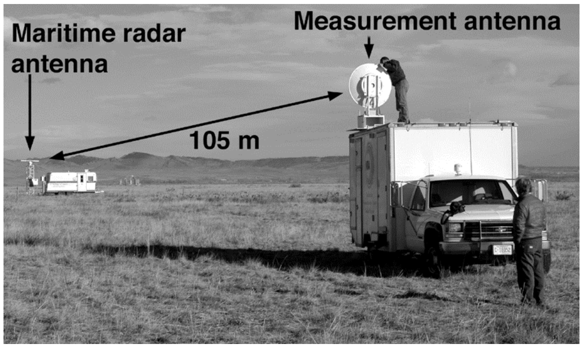

Figure 1. Maritime radar and measurement system.

The measurement system is shown in block-diagram form in Figure 2. Following the antenna, a variable (0-70 dB) attenuator was adjusted on a frequency-dependent basis to keep the received signal level from the radar within the dynamic range of the measurement system. That is, the attenuation level was zero when radar emissions were close to measurement system noise, but was gradually increased (in 10-dB steps) to as much as 70 dB as the measured frequency approached the radar fundamental. The attenuation was gradually decreased at frequencies above the radar fundamental, being finally reduced to zero at the upper end of the measured spectrum.

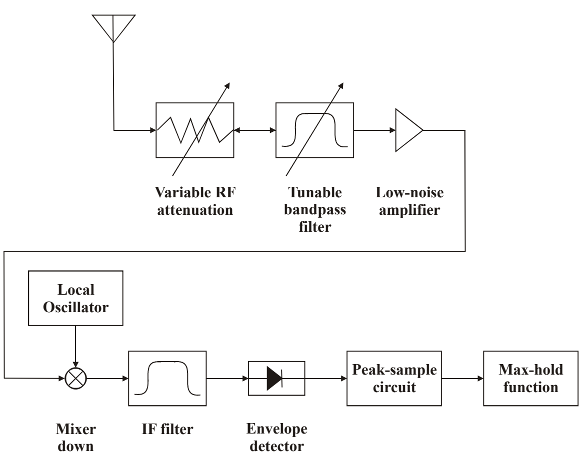

Figure 2. Measurement system functional block diagram.

Following the attenuator, a tunable bandpass filter based on yttrium-iron-garnet (YIG) technology isolated the system's broadband low-noise filter (LNA) from the high-power radar fundamental energy as the spectrum measurement progressed. The LNA provided the sensitivity required to measure out-of-band and spurious emission levels as much as 100 dB below the measured fundamental power level.

The LNA output was fed into a spectrum analyzer. The critical spectrum analyzer stages are shown in Figure 2, including frequency downconversion; intermediate frequency (IF) filtering; envelope and peak detection; analog-to-digital conversion; and final output to a data-recording computer.

As noted above, the requisite dynamic range of the measurement (about 100 dB) demanded that the RF attenuator setting be varied as a function of frequency. Therefore, the measurement system could not be operated in a swept-frequency mode. Instead, the measurement system was fixed-tuned to a single frequency with a single attenuator setting. A peak-detector circuit was operated at the single frequency for a period of time (3 sec) slightly in excess of the radar's antenna rotation period (2.7 sec). This ensured that the radar beam maximum output would be sampled at each measured frequency.

With the emission amplitude measured at a single frequency, the measurement system was tuned to another frequency, the RF attenuator was adjusted (if necessary) and the measurement process was repeated for another 3 sec. This stepped-frequency measurement process was used to acquire all data presented in this paper.

With 100 dB dynamic range available in the measurement, the radar spectrum was measurable across 4.2 GHz of spectrum, from 7300 MHz to 11500 MHz. Because the out-of-band and spurious emissions are a continuum, lacking discrete carrier frequencies, those emissions could be sampled at arbitrary spacings between frequency steps. For this measurement, the step interval was set at 6 MHz, for a total of 700 steps (and 701 measured frequencies) across the range 7300-11500 MHz. Each spectrum run therefore required about 35 minutes for completion.

Because the 6-MHz step spacing could result in the omission of the radar fundamental frequency from the measured spectrum, a supplemental measurement was made at the radar fundamental for each spectrum. This ensured that radar peak power was accurately included in each spectrum output.

The radar can transmit multiple pulse widths, ranging from 80 nsec to 800 nsec. The radar spectrum was measured in two pulse modes (80 nsec and 800 nsec) in four IF bandwidths (where B_m=300 kHz, 1 MHz, 3 MHz, and 8 MHz). Thus a total of eight spectrum measurements were performed.

3. Results

The measured emission spectra for short-pulse and long-pulse radar modes are shown in Figures 3 and 4. Measurement system internal noise occurs as a flat floor at frequencies between 7300-8000 MHz, and as a flat area between 11000-11200 MHz. It is observed that the spurious emission levels are changing with a progression that is somewhere between 10 log and 20 log bandwidth, depending upon frequency.

Figure 5 shows measured power at the radar fundamental frequency (approximately 9410 MHz) as a function of measurement IF bandwidth. The data in this figure confirm that the radar fundamental power follows a 20 log(B_m) rule for values of B_m that are equal to or less than (1/pulse width).

In the short-pulse mode, the 80-nsec pulse width results in a predicted fundamental-frequency 3-dB emission bandwidth of 12.5 MHz, which is wider than the maximum measurement IF bandwidth of 8 MHz. Consequently, the measured power increases as 20 log(B_m) for all points. But in the long-pulse mode of 800-nsec pulse width, the 3-dB emission bandwidth is predicted to be 1.25 MHz. As a result, the 20 log(B_m) progression breaks down for 3 MHz and 8 MHz B_m values.

Figures 6a through 6f quantify the decibel differences between spectra measured in successive values of B_m. These are shown as deviations from a 20 log progression, computed as follows:

$$\Delta = \left[\frac{P_x - P_y}{\log\left(B_x / B_y\right)} \right] - 20 \qquad \text{(unitless)}$$

where:

Δ = deviation from 20 log(B_m) progression;
$P_{[x,y]}$ = log power measured in B_x and B_y;
$B_{[x,y]}$ = measurement bandwidth;
[x,y] are subscripts for successive measurement IF bandwidths (e.g., 3 MHz and 1 MHz).

The differences should lie between –10 (corresponding to a noise-like 10 log progression) and 0 (for the 20 log rule that coherent emissions should follow). Some points lie outside these bounds. Deviations outside this range could result from the interaction of spectrum peaks and valleys with a particular measurement bandwidth; uncertainty in measured values; or variation in shape factors between filters.

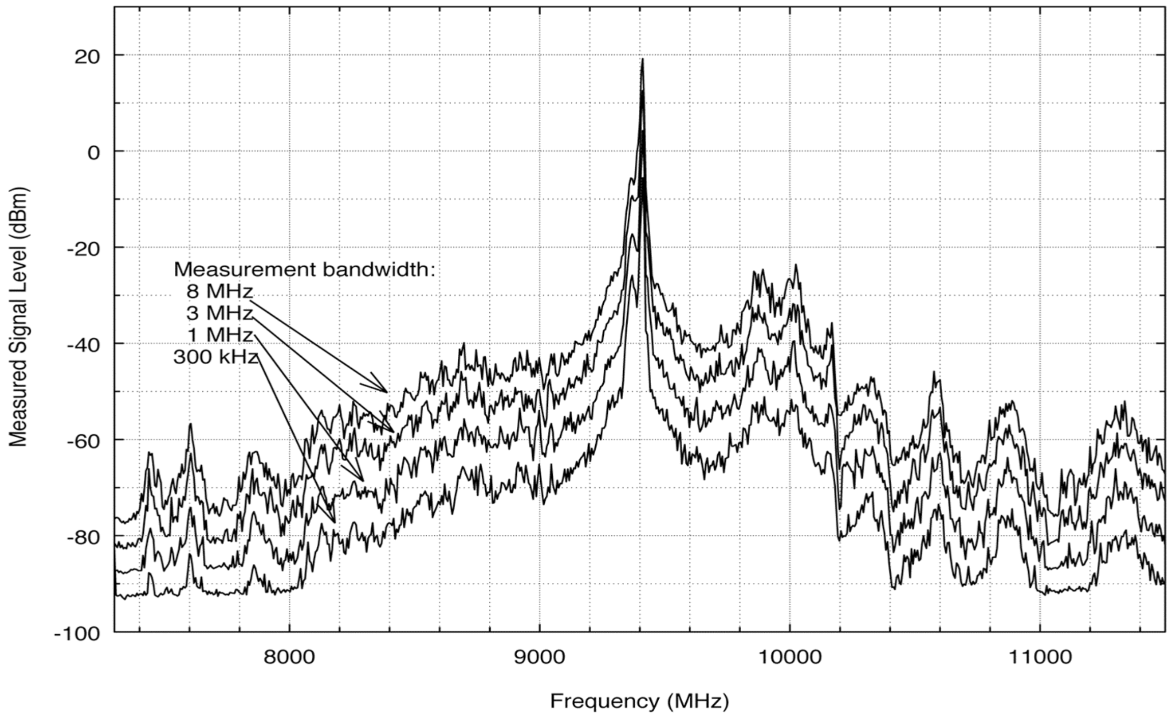

Figure 3. Maritime radar emission spectrum measured in four bandwidths with transmitter operating in short-pulse mode.

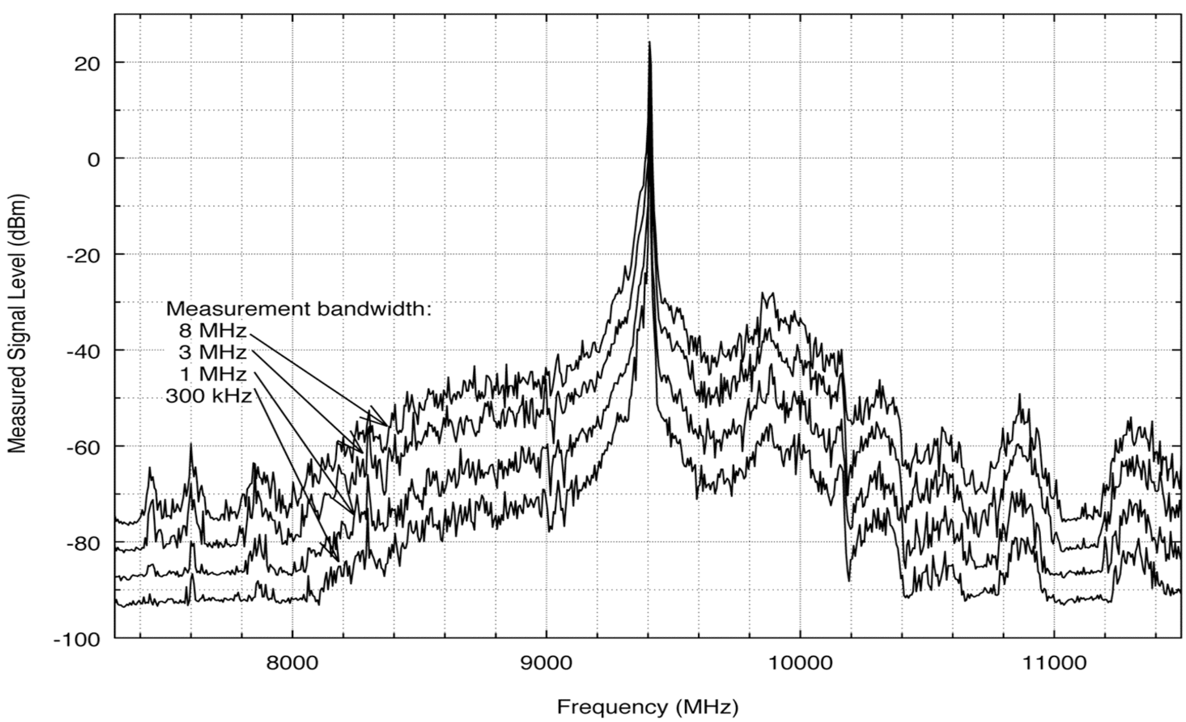

Figure 4. Maritime radar emission spectrum measured in four bandwidths with transmitter operating in long-pulse mode.

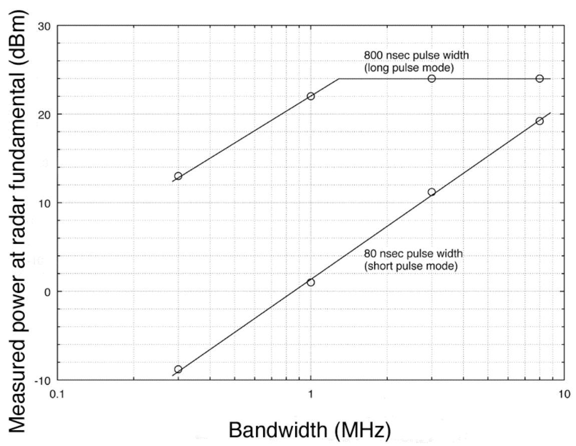

Figure 5. Variation in measured power at the radar fundamental as a function of measurement bandwidth and pulse mode.

Some trends are clearly observed in the values for the curves in Figure 6. The values of the deviation curves typically range between −4 and −2, corresponding to variation coefficients between 16 and 18. Neglecting the points that exceed zero, the extreme values range between −8 and 0, corresponding to variation coefficients between 12 and 20, respectively.

4. Summary and Conclusions

In summary, spurious and out-of-band emissions measured from a maritime navigation radar were found to typically vary at a value between $16 \log(B_m)$ and $18 \log(B_m)$. Extreme values ranged from a low of $12 \log(B_m)$ to a high of $20 \log(B_m)$.

These results indicate that the radar spurious emissions did not vary as would be predicted for thermal noise (10 log progression). Thus radar spurious emissions should not be characterized as "noise-like," at least for the radar measured in this study.

Radar emission spectrum measurements that are performed for the purpose of determining the suppression of out-of-band and spurious emissions relative to radar fundamental-frequency power will show a bandwidth dependent variation. Measurement of spectra in multiple bandwidths is recommended until this phenomenon is better understood.

It may be desirable for future emission masks to accommodate this effect. Such masks might include a recommended IF measurement bandwidth, and possibly a method for computing correction factors for measurements made in other bandwidths.

5. References

[1] R.J. Matheson, J.D. Smilley, G.D. Falcon, V.S. Lawrence, "Output tube emission characteristics of operational radars," NTIA Report 82-92, Jan. 1982.

[2] *Manual of Regulations and Procedures for Federal Radio Frequency Management*, revised Jan. 2000, Revisions Jan./May/Sep. 2001, NTIA Office of Spectrum Management, U.S. Government Printing Office, Stock No. 903-008-00000-8.

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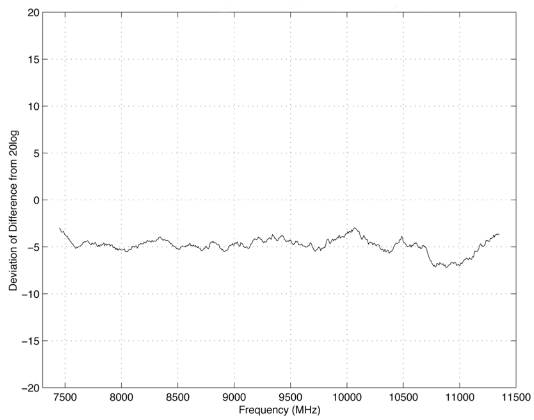

Figure 6a. 8 MHz – 3 MHz smoothed difference, short pulse radar mode.

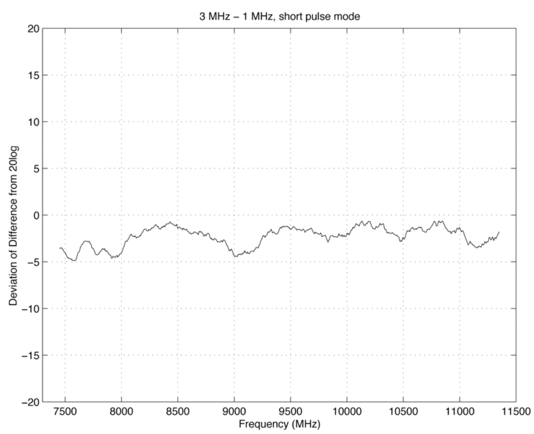

Figure 6b. 3 MHz – 1 MHz smoothed difference, short pulse radar mode.

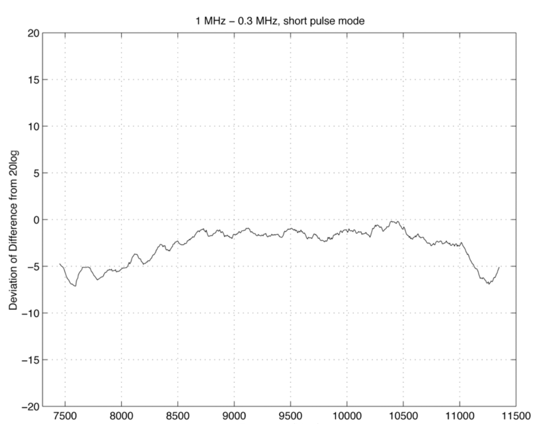

Figure 6c. 1 MHz – 300 kHz smoothed difference, short pulse radar mode.

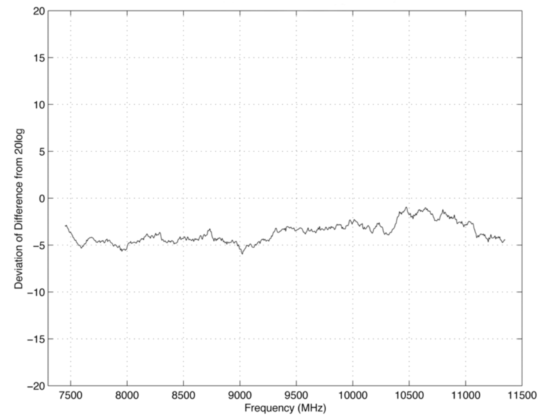

Figure 6d. 8 MHz – 3 MHz smoothed difference, long pulse radar mode.

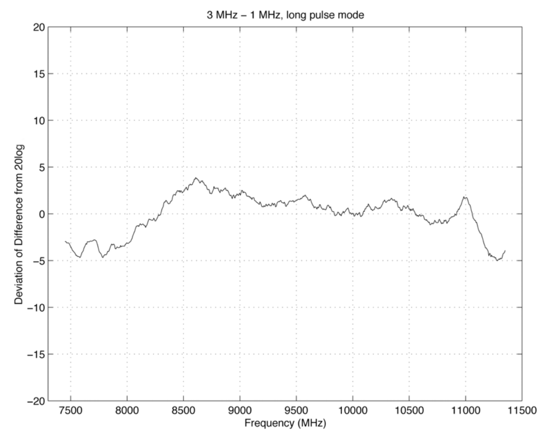

Figure 6e. 3 MHz – 1 MHz smoothed difference, long pulse radar mode.

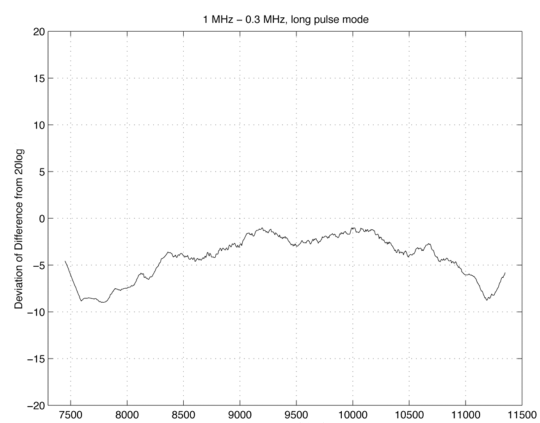

Figure 6f. 1 MHz – 300 kHz smoothed difference, long pulse radar mode.