RECOMMENDATION ITU-R M.1177*

TECHNIQUES FOR MEASUREMENT OF SPURIOUS EMISSIONS OF MARITIME RADAR SYSTEMS

Question ITU-R 202/8)

(1995)

Summary

Appendix 8 to the Radio Regulations (RR) specifies the maximum values of spurious emissions from radio transmitters in terms of both relative mean power and absolute mean power, but these limits are not applicable to the radiodetermination service until acceptable methods of measurement exist.

This Recommendation provides techniques for the measurement of maritime radar spurious emissions.

The ITU Radiocommunication Assembly,

considering

a) that both fixed and mobile radar stations in the radiodetermination service are widely implemented in bands adjacent to and in harmonic relationship with other services;

b) that stations in other services are vulnerable to interference from radar stations with spurious emissions with high peak power levels;

c) that many services have adopted or are planning to adopt digital modulation systems which are more susceptible to interference from radar spurious emissions;

d) that under the conditions stated in a) through c), interference to stations in other services may be caused by a radar station with spurious emissions with high peak power levels;

e) that RR Appendix 8 specifies the maximum values of spurious emissions from radio transmitters in terms of both relative mean power and absolute mean power, but these limits are not applicable to the radiodetermination service until acceptable methods of measurements exist;

f) that techniques to measure radar spurious emissions to ensure compatibility with other services requires the capability to measure levels of the order of 130 dB below the radar fundamental emission;

g) that it is desirable to have the capability to measure spurious emissions up to 18 GHz,

recommends

1 that measurement techniques as described in Annex 1 be used to quantify spurious emission levels from maritime radar stations.

* This Recommendation should be brought to the attention of the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), the International Maritime Radio Association (CIRM), the World Meteorological Organization (WMO) and Radiocommunication Study Groups 1, 4 and 9.

ANNEX 1

1 Introduction

Techniques have been developed in response to § 1 of Question ITU-R 202/8. Two techniques known as the direct and indirect methods are recommended.

The direct measurement method has the ability to accurately measure spurious emissions from radars that are designed in such a way as to preclude measurements at intermediate points in the radar systems. Such radars include, for example, those which use distributed-transmitter arrays that are built into (or that actually comprise) the antenna structure.

The indirect method is where the components of the radar system are measured separately and then the results combined. The recommended split of the radar is to separate the system after the "rotating joint" (Ro-Jo) and thus to measure the transmitter output spectrum at the output port of the Ro-Jo and to combine it with the measured antenna gain characteristics.

Experience with these techniques has yielded repeatability of ± 2 dB at any given frequency and under the condition of agreed fixed measurement parameters when the spectrum of any particular radar unit is remeasured.

2 Measurement system bandwidth and detector parameters

IF bandwidth	≤	$(1/T)$ for fixed-frequency, non-pulse-coded radars, where T: pulse length. (E.g. if radar pulse length is 1 μs, then the measurement IF bandwidth should be ≤ 1/(1 μs) = 1 MHz.)
	≤	$(1/t)$ for fixed-frequency, phase-coded pulsed radars, where t: phase-chip length. (E.g. if radar transmits 26-μs pulses, each pulse consisting of 13 phase coded chips that are 2-μs in length, then the measurement IF bandwidth should be ≤ 1/(2 μs) = 500 kHz.)
	≤	$(B/T)^{½}$, for swept-frequency (FM, or chirp) radars, where B: range of frequency sweep during each pulse and T: pulse length. (E.g. if radar sweeps (chirps) across frequency range of 1 250-1 280 MHz (= 30 MHz of spectrum) during each pulse, and if the pulse length is 10 μs, then the measurement IF bandwidth should be: $\leq ((30\ \text{MHz})/(10\ \mu\text{s}))^{½} = \sqrt{3} \approx 1.73$ MHz.)
Video bandwidth	≥	measurement system IF bandwidth
Detector:		positive peak

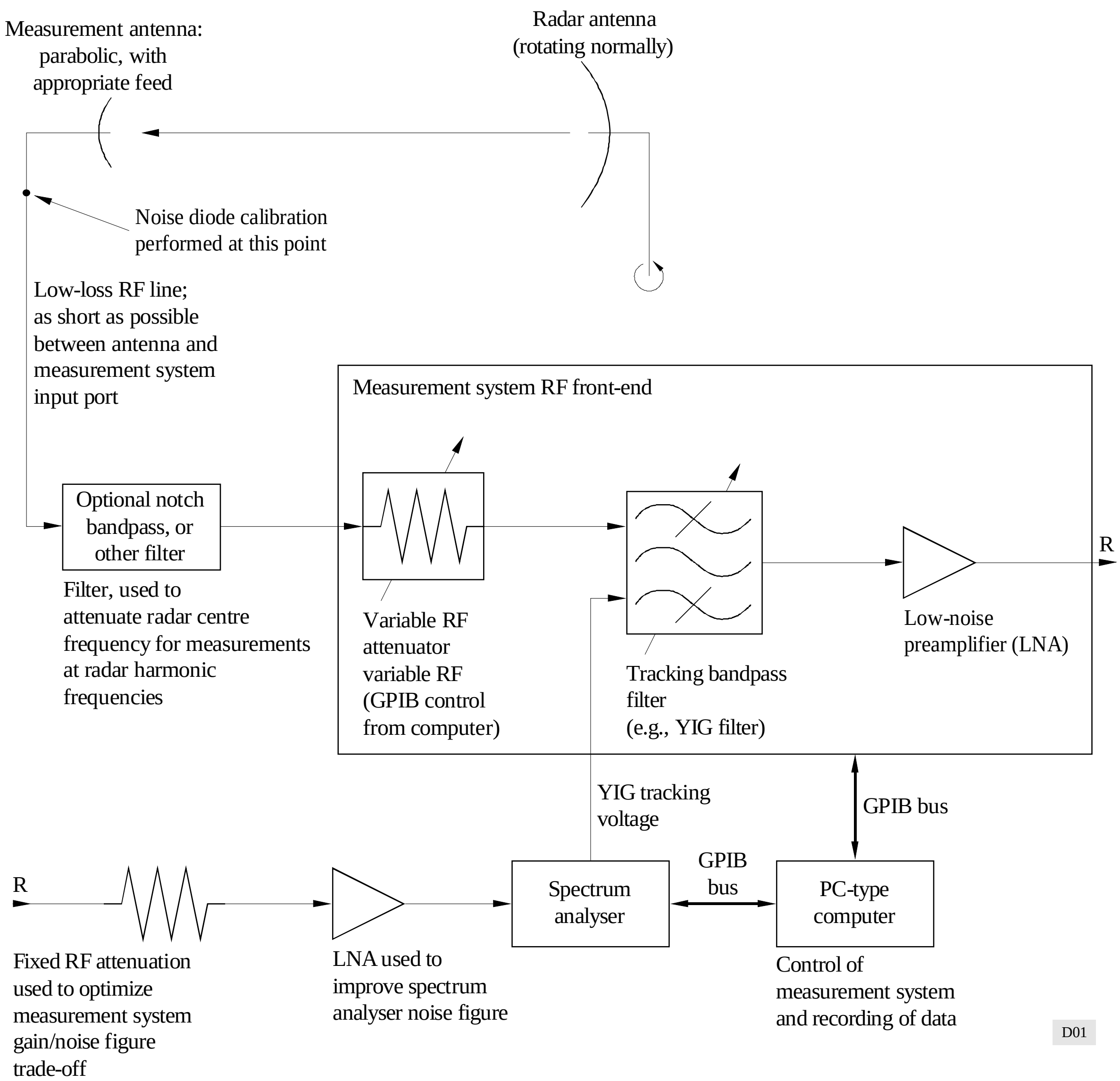
3 Direct method

3.1 Measurement hardware and software

A block diagram of the type of measurement system required for this method is shown in Fig. 1. The first element in the system is the receive antenna. This antenna usually must have a broadband frequency response, at least as wide as the frequency range which is to be measured. A high-gain response (as achieved with a parabolic reflector) is usually also desirable. The high gain value permits greater dynamic range in the resulting measurement, and the narrow antenna beamwidth provides discrimination against other signals in the area. The antenna feed polarization is selected to maximize response to the radar signal. Circular polarization of the feed is a good choice for cases in which the radar polarization is not known *a priori*. A length of low-loss RF cable (which will vary depending upon circumstances of geometry at each measurement site) connects the antenna to the RF front-end of the measurement system. Because losses in this piece of line attenuate the received radar signal, it is desirable to make this line length as short as possible.

FIGURE 1

Block diagram for measurement of radiated spurious emissions from radars using the direct method



The RF front-end consists of three elements: a variable RF attenuator, a frequency-tuneable bandpass filter (referred to here as a preselector), and a low-noise amplifier (LNA). Each of these elements must have a frequency response range at least as wide as the frequency range to be measured. The RF attenuator provides variable attenuation (e.g. 0-70 dB) in fixed increments (e.g. 10 dB/attenuator step). Use of this attenuator during the measurement extends the instantaneous dynamic range of the measurement system by the maximum amount of attenuation available (e.g. 70 dB for a 0-70 dB attenuator). In principle, this attenuator could be manually controlled, but in practice, control via computer is much more practical (see below).

The preselector protects the measurement system from non-linear behaviour due to the high power in the radar signal fundamental frequency when the measurement system is tuned to relatively low-power signals from the radar at extended frequencies in the spurious emission spectrum (e.g. when the radar centre frequency is 3 050 MHz and the measurement system is tuned to 4 800 MHz). This filter could, in principle, be manually tuned. However, as with the attenuator, automatic control, either via computer or an analogue tuned-frequency voltage from the spectrum analyser, is far more practical.

The final element in the RF front-end is an LNA. An LNA installed as the next element in the signal path after the preselector overdrives the noise figure of the rest of the measurement system (e.g. a length of transmission line and a spectrum analyser). Typical spectrum analyser noise figures are 25-45 dB, and transmission line losses may typically be 5-10 dB, depending upon the quality and the length of the line. Use of an LNA after the preselector (and, if required, a cascaded LNA at the spectrum analyser input) can reduce the overall measurement system noise figure to about 10-15 dB.

Any spectrum analyser which can receive signals over the frequency range of interest, and which can be computer-controlled to perform the stepped-frequency algorithm, can be used. As noted above, the high noise figure of currently available spectrum analysers must be overdriven by low-noise preamplification if the measurement is to achieve the necessary sensitivity to observe most spurious emissions.

The measurement system can be controlled via any computer which has a bus interface (GPIB) that is compatible with the equipment being used. In terms of memory and speed, PC-type computers (80386 or higher CPU) are quite adequate. The measurement algorithm (providing for frequency stepping of the spectrum analyser and the preselector, and control of the front-end variable attenuator) must be implemented through software. Some commercially available software may approach fulfilment of this need, but it is likely that the measurement organization will need to write at least a portion of their own measurement software.

Data may be recorded on the computer's hard drive or on a removable disk. Ideally, a data record is made for every 100-200 measurement steps, so as to keep the size of data files manageable, and to prevent the loss of an excessive amount of data if the measurement system computer should fail during the measurement.

3.2 Measurement system calibration

The measurement system is calibrated by disconnecting the antenna from the rest of the system, and attaching a noise diode to the RF line at that point. A 25 dB excess noise ratio (ENR) diode should be more than adequate to perform a satisfactory calibration, assuming that the overall system noise figure is less than 20 dB. The technique is standard Y-factor, with comparative power measurements made across the spectrum, once with the noise diode on and once with the noise diode off.

The noise diode calibration results in a table of noise figure values and gain corrections for the entire spectral range to be measured. The gain corrections may be stored in a look-up table, and are applied to measured data as those data are collected.

The measurement antenna is not normally calibrated in the field. Correction factors for the antenna (if any) are applied in post-measurement analysis.

3.3 Measurement procedure

In addition to the parameters listed in § 2, the spectrum analyser should be set up as follows:

Spectrum analyser centre frequency:		lowest frequency to be measured. (E.g. if radar centre frequency is 3 050 MHz, but the spectrum is to be measured across 2-6 GHz, then initial spectrum analyser centre frequency would be 2 GHz.)
Spectrum analyser frequency span	=	0 Hz. (Analyser is operated as a time-domain instrument.)
Spectrum analyser sweep time	>	radar beam rotation interval. (E.g. if radar rotates at 40 r.p.m., or 1.5 s/rotation, then sweep time should be > 1.5 s; 2 s would be a reasonable selection.)

With the radar antenna beam scanning normally, and with the measurement system set up as described above, the first data point is collected. A data point consists of a pair of numbers: measured power level and the frequency at which the power level was measured. For example, the first data point for the above measurement might be –93 dBm at 2 000 MHz. The data point is collected by monitoring the radar emission at the desired frequency, in a frequency span of 0 Hz, for an interval slightly longer than that of the radar rotation. This time-display of the radar antenna beam rotation will be displayed on the spectrum analyser screen. The highest point on the trace will normally represent the received power when the radar beam was aimed in the direction of the measurement system. That maximum received power value is retrieved (usually by the control computer, although it could be written down manually), corrected for measurement system gain at that frequency, and recorded (usually in a data file on magnetic disk).

The second measurement point is taken by tuning the measurement system to the next frequency to be measured. This frequency is optimally equal to the first measured frequency plus the measurement bandwidth (e.g. if the first measurement was at 2 000 MHz and the measurement bandwidth were 1 MHz, then the second measured frequency would be 2 001 MHz). At this second frequency, the procedure is repeated: measure the maximum power received during the radar beam rotation interval, correct the value for gain factor(s), and record the resulting data point.

This procedure, which consists of stepping (rather than sweeping) across the spectrum, continues until all of the desired emission spectrum has been measured.

The stepped technique also allows the insertion of RF attenuation at the front-end of the measurement system as the frequencies approach the centre frequency (and any other peaks) of the radar spectrum. This ability to add attenuation on a frequency-selective basis makes it possible to extend the dynamic range available for the measurement to as much as about 130 dB, if a 0-70 dB RF attenuator is used with a measurement system having 60 dB of instantaneous dynamic range. This is of great benefit in identifying relatively low-power spurious emissions. To achieve the same effect with a swept-frequency measurement, a notch filter could be inserted at the centre frequency of the radar, but there would be no practical way to insert a notch filter for all the other high-amplitude peaks which might occur in the spectrum.

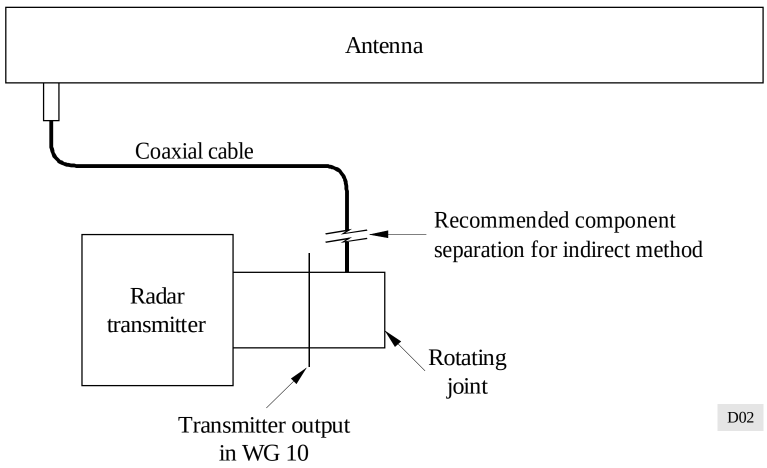
It is ***extremely important*** to provide adequate bandpass filtering at the front-end of the measurement system, so that strong off-frequency signal components do not affect the measurement of low-power spurious components.

4 Indirect method

Figure 2 illustrates a recommended component separation for the indirect method.

FIGURE 2

Typical radar system

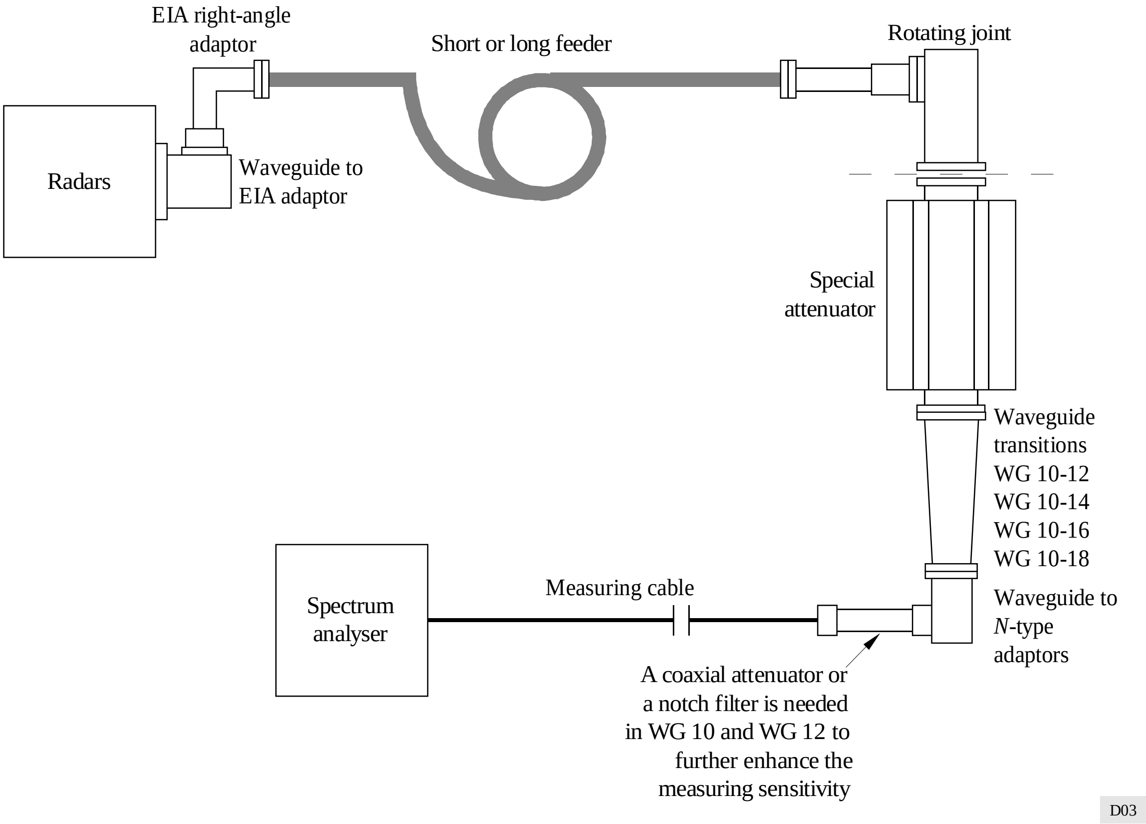


4.1 Transmitter power measurement

The recommended typical arrangement for measuring the transmitter power spectrum is in Fig. 3.

FIGURE 3

Measurement at the rotating-joint port



In order to measure small spurious emission levels in the presence of the main transmitting pulse of perhaps 60 kW peak power, this method uses a fixed notch filter. This comprises a straight WG 10 waveguide with absorbent elements which attenuates the fundamental signal (~ 3.05 GHz) by 17 dB with minimum attenuation to other frequencies. This attenuator is also specifically designed to support only the lowest-order TE_{10} mode. To achieve the required further attenuation to protect the measuring equipment, and to measure the higher frequencies, waveguide linear tapers are employed at the output of the notch filter.

The waveguide taper is a high pass filter and thus rejects, by reflecting back, signals below the cut off frequency. If a taper had been used directly at the output port of a radar transmitter the fundamental would have been reflected back into the transmitter, but with the tapers after the notch filter the reflected signals are absorbed a second time. Thus the return loss at the fundamental frequency is 34 dB which is low enough to avoid frequency pulling of the magnetron. Frequencies above the cutoff are transmitted through the transitions and into the measuring equipment.

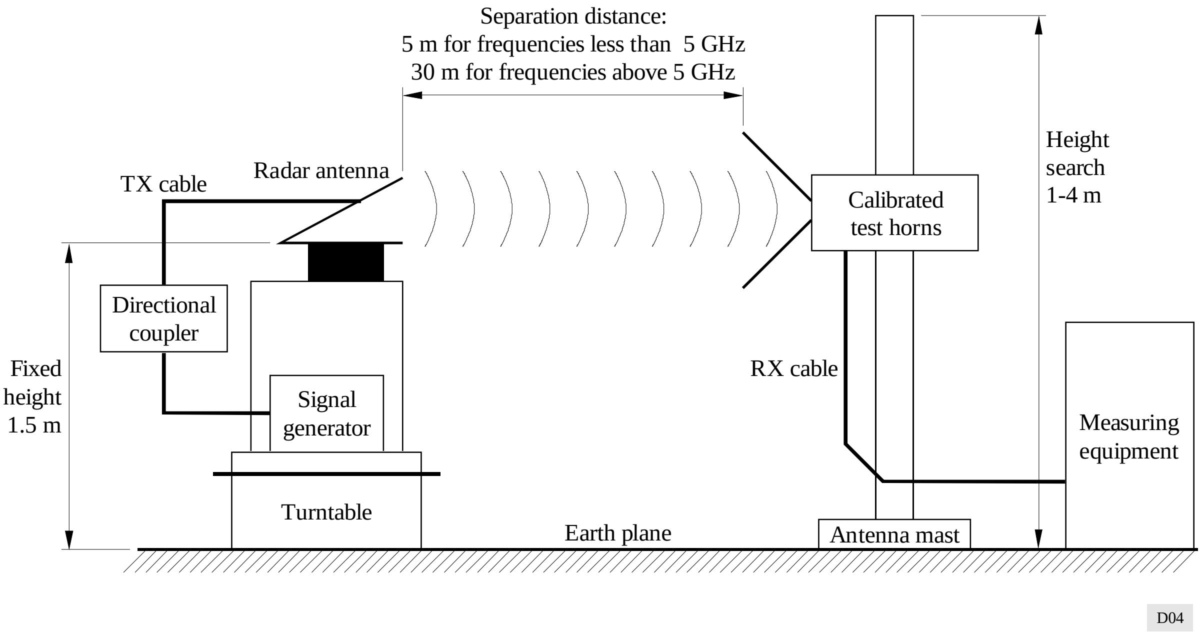
The measurement technique comprises an exploratory search of the frequency band of interest to locate and tag significant spurious outputs by frequency, followed by a revisit to each for detailed measurement of amplitude in a 1 MHz bandwidth and frequency. The measured spectrum is thus not continuous, but comprises a group of transmission spikes at discrete frequencies.

4.2 Antenna gain measurement

The indirect method recommends that near field measurements be made on the antenna on an “open area test site” (OATS) at distances of 5 and 30 m. “Correction factors” are then applied to correct the measurements to an equivalent far field gain. A typical arrangement is shown in Fig. 4.

FIGURE 4

Near field gain measurement arrangement for 5 m and 30 m distances



Measurements are made at typically 0.2 GHz steps over the frequency range 2 to 18 GHz with spot frequency measurements to capture specific harmonics and known modes. At each frequency, the maximum measured gain of the antenna under test (AUT) is found by rotating the antenna in azimuth and moving the test horn up and down.

To obtain acceptable correlation between the far field gain and the near field measurements a distance of 5 m should be used for frequencies below 5 GHz, and 30 m for frequencies above 5 GHz.

The calculations to arrive at the equivalent far field gain (G_a) of the AUT from a measured level (S) is given by:

$$G_a = M - P_i + G_c - G_0$$

with:

$$M = S - G_r + K$$

where:

G_a: far field gain of the AUT (dBi)

M: e.i.r.p. (dBm)

P_i: power input into the AUT (dBm)

G_c: gain correction factor (dB) to correct the spherical wavefront in the near field to a plane wavefront. This is a function of frequency and antenna size. Typical values for a 3.6 m antenna are 15 dB for 5 m distance and frequencies below 5 GHz, and 12 dB for 30 m distance at frequencies above 5 GHz

G_0: factor (dB) to correct for the ground reflected wave of the OATS (6 dB)

S: measured level (dBm)

G_r: gain (dBi) of the test horn receiving antenna

$K =$ 20 log ($4\pi\, d/\lambda$) dB

where:

d: measuring distance (m)

λ: probing wavelength (m).