



Recommendation ITU-R M.1177-4
(04/2011)

**Techniques for measurement of unwanted
emissions of radar systems**

M Series
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Note: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.

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RECOMMENDATION ITU-R M.1177-4*

Techniques for measurement of unwanted emissions of radar systems

(Question ITU-R 202/5)

(1995-1997-2000-2003-2011)

Scope

This Recommendation provides two techniques for the measurement of radiated radar unwanted emissions. It should be used to measure the spurious domain emissions and to check emission power against limits specified in Appendix 3 (Section II) of the Radio Regulations (RR), or to measure the level of unwanted emissions falling within the out-of-band domain.

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 unwanted 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 unwanted emissions;
- d) that under the conditions stated in *considering* a) through c), interference to stations in other services may be caused by a radar station with unwanted emissions with high peak power levels;
- e) that Recommendation ITU-R SM.329 specifies the maximum values of unwanted emissions in the spurious emission domain from radio transmitters;
- f) that Recommendation ITU-R SM.1541 specifies the generic limits for unwanted emissions in the out-of-band domain,

recommends

- 1 that measurement techniques as described in Annex 1 should be used to provide guidance in quantifying radiated unwanted emission levels from radar stations operating above 400 MHz;
- 2 that measurement techniques as described in either Annex 1 or Annex 2 should be used, as appropriate based upon radar design, to provide guidance in measuring radiated unwanted emission levels for radar stations operating between 50 MHz and 400 MHz;
- 3 that measurement techniques described in Annex 2 should be used to provide guidance in quantifying radiated unwanted emission levels from radar stations operating below 50 MHz.

* 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 and 4.

Annex 1

Measurement of unwanted emissions of radar systems as detailed in *recommends 1 and 2*

1 Introduction

Two measurement techniques known as the direct and indirect methods are described.

The direct measurement method is recommended and measures unwanted emissions from all radars including those that preclude measurements at intermediate points within the radar transmitters. Examples include those which use distributed-transmitter arrays built into (or comprising) the antenna structure.

The indirect method separately measures the components of the radar and then combines the results. 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.

2 Reference bandwidth

For radar systems, the reference bandwidth, B_{ref} , used to define unwanted emission limits (Recommendations ITU-R SM.329 and ITU-R SM.1541, and RR Appendix 3) should be calculated for each particular radar system. For the four general types of radar pulse modulation utilized for radionavigation, radiolocation, acquisition, tracking and other radiodetermination functions, the reference bandwidth values are determined using the following formulas:

- for fixed-frequency, non-pulse-coded radar, one divided by the radar pulse length (e.g. if the radar pulse length is 1 μ s, then the reference bandwidth is 1/1 μ s = 1 MHz);
- for fixed-frequency, phase-coded pulsed radar, one divided by the phase chip length (e.g. if the phase coded chip is 2 μ s long, then the reference bandwidth is 1/2 μ s = 500 kHz);
- for FM or chirped radar, the square root of the quantity obtained by dividing the chirp bandwidth (MHz) by the pulse length (μ s) (e.g. if the FM is from 1 250 MHz to 1 280 MHz or 30 MHz during the pulse of 10 μ s, then the reference bandwidth is $(30 \text{ MHz}/10 \mu\text{s})^{1/2} = 1.73 \text{ MHz}$);
- for radars operating with multiple waveforms the reference bandwidth is determined empirically from observations of the radar emission. The empirical observation is performed as follows: the measurement system receiver is tuned to one of the fundamental frequencies of the radar, or is tuned to the centre frequency within the chirp range of the radar. The measurement system bandwidth is set to the widest available value, and the received power level from the radar in this bandwidth is recorded. The measurement bandwidth is then progressively narrowed, and the received power level is recorded as a function of the bandwidth. The end result is a graph or table showing measured power as a function of measurement system bandwidth. The required bandwidth is the smallest bandwidth in which the full power level is still observed and the reference bandwidth can be calculated from a knowledge of the impulse response of the measurement receiver using the factor, measurement bandwidth ratio (MBR), as described below. If a reduction in power level is observed immediately, then the widest available bandwidth should be used.

In all cases, where the bandwidths above are greater than 1 MHz, then a reference bandwidth, B_{ref} , of 1 MHz should be used.

3 Measurement bandwidth and detector parameters

The measurement bandwidth, B_m , is defined as the impulse bandwidth of the receiver and is greater than the IF bandwidth, B_{if} , (sometimes referred to as resolution bandwidth for spectrum analyzers). The measurement bandwidth, B_m , may be derived from the following equation:

$$B_m = B_{if} \times MBR$$

The MBR needs to be determined for the measurement receiver being used. MBR is approximately 3/2 for a –3 dB IF bandwidth Gaussian filter as typically used in many commercial spectrum analyzer receivers (in some instruments the IF bandwidth is defined at the –6 dB point).

An appropriate receiver IF bandwidth should be selected to give one of the following recommended measurement bandwidths.

- Measurement bandwidth B_m ¹
- ≤ $(1/T)$ for fixed-frequency, non-pulse-coded radars, where T is the pulse length (e.g. if the radar pulse length is 1 μs, then the measurement bandwidth should be $\leq 1/(1 \mu s) = 1 \text{ MHz}$).
 - ≤ $(1/t)$ for fixed-frequency, phase-coded pulsed radars, where t is the phase-chip length (e.g. if the radar transmits 26 μs pulses, each pulse consisting of 13 phase coded chips that are 2 μs in length, then the measurement bandwidth should be $\leq 1/(2 \mu s) = 500 \text{ kHz}$).
 - ≤ $(B_c/T)^{1/2}$ for swept-frequency (FM, or chirp) radars, where B_c is the range of frequency sweep during each pulse and T is the pulse length (e.g. if radar sweeps (chirps) across the 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 bandwidth should be $\leq ((30 \text{ MHz})/(10 \mu s))^{1/2} = \sqrt{3} \text{ MHz} \approx 1.73 \text{ MHz}$. In accordance with footnote ¹ a measurement bandwidth close to but less than or equal to 1 MHz should be used in this example).
 - ≤ the result of a measurement is as follows: for radars operating with multiple waveforms the measurement bandwidth is determined empirically from observations of the radar emission. The empirical observation is performed as follows: the measurement system receiver is tuned to one of the fundamental frequencies of the radar, or is tuned to the centre frequency within the chirp range of the radar. The measurement system bandwidth is set to the widest available value, and the received power level from the radar in this bandwidth is recorded. The measurement bandwidth is then progressively narrowed, and the received power level is recorded as a function of the bandwidth. The end result is a graph or table showing measured power as a function of measurement system bandwidth. The appropriate measurement bandwidth will be the bandwidth where the first reduction of the full power level is observed. If a reduction in power level is observed immediately, then the widest available measurement bandwidth should be used.

¹ In all cases, if the above derived measurement bandwidth is greater than 1 MHz, then the corrections described in § 3.2 should be used.

Video bandwidth $\geq$ measurement system bandwidth.

Detector positive peak.

3.1 Measurements within the out-of-band domain

Within the out-of-band (OoB) domain, the limits given in Recommendation ITU-R SM.1541 are defined in dBpp. This is a relative power measurement and an IF bandwidth leading to a measurement bandwidth less than the reference bandwidth should be used. Even if the measurement bandwidth is less than the reference bandwidth no correction needs to be done, since both the peak of the spectrum and the data points within the OoB domain are measured using the same measurement bandwidth B_m .

Measurements should generally be made using a bandwidth that is close to but less than the specified reference bandwidth. This approach will minimize the measurement time but it also causes some broadening of the measured spectrum. Thus in marginal situations, where measurement of the true close in spectrum shape may be important, it is recommended that the close-in region within the OoB domain should be re-measured using a maximum bandwidth of $0.2/T$ or $0.2/t$ as appropriate.

3.2 Measurements within the spurious domain

3.2.1 Correction of the measurement within the spurious domain

Where the measurement bandwidth, B_m , differs from the reference bandwidth, B_{ref} , a correction factor needs to be applied to the measurements conducted within the spurious domain to express the results in the reference bandwidth. Then the following correction factor should be applied:

$$\text{Spurious level, } B_{ref} = \text{Spurious level (measured in } B_m) + 10 \times \log(B_{ref}/B_m)$$

NOTE 1 – This correction factor should be used except where it is known that the spurious is not noise-like, where a factor between 10 and $20 \log(B_{ref}/B_m)$ may apply and may be derived by measurements in more than one bandwidth. In all cases the most precise result will be obtained using a measurement bandwidth (B_m) equal to the reference bandwidth. For radars operating above 1 GHz the reference bandwidth (B_{ref}) is 1 MHz.

3.2.2 Correction of the measurement data to the peak envelope power

Within the spurious domain, the limits given in RR Appendix 3 are defined in a reference bandwidth, B_{ref} , with respect to the peak envelope power (PEP). Data recorded in dBpp within the spurious domain must be referenced to the PEP (and not the spectrum peak observed in dBpp).

The PEP is approximated using the following correction formulae:

For continuous wave (CW) and phase coded pulses:

$$PEP = P_{meas} + 20 \times \log(B_{pep}/B_m) \quad \text{for } B_{pep} > B_m$$

For swept-frequency (FM or chirp) pulsed radars:

$$PEP = P_{mes} + 10 \times \log(B_c / (B_m^2 \times T)) \quad \text{for } (B_m^2 T) / B_c < 1$$

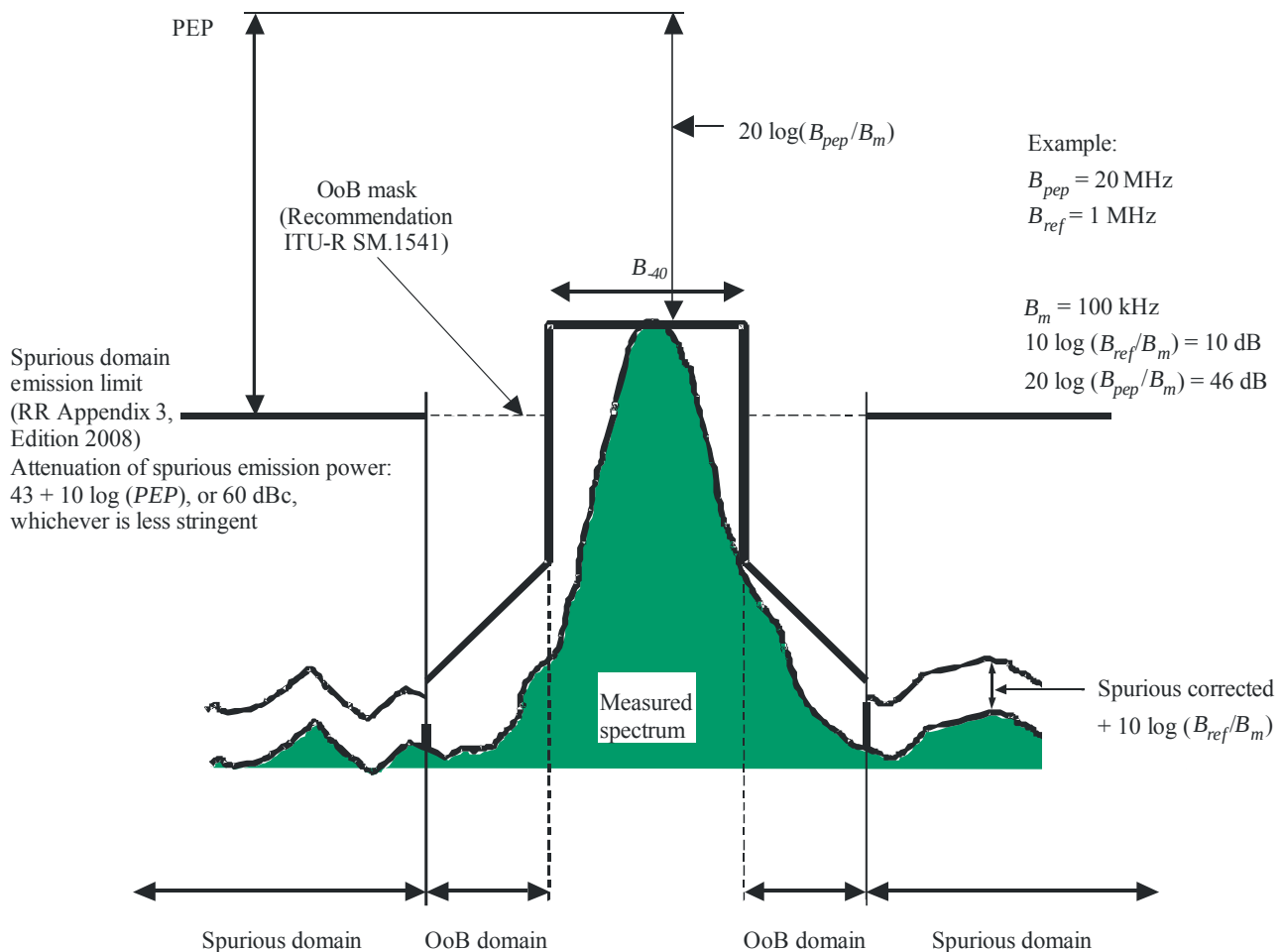
where:

- PEP*: peak envelope power;
- P_{meas}*: spectrum peak power (*B_m*);
- B_{pep}*: bandwidth calculated according to the following:
- for fixed-frequency, non-pulse-coded radar, one divided by the radar pulse length (s) (e.g. if the radar pulse length is 1 μs, then *B_{pep}* is 1/1 μs = 1 MHz);
 - for fixed-frequency, phase coded pulsed radar, one divided by the phase chip length (s) (e.g. if the phase coded chip is 2 μs long, then *B_{pep}* is 1/2 μs = 500 kHz);
 - for FM or chirped radar, the square root of the quantity obtained by dividing the chirp bandwidth in MHz by the pulse length (μs) (e.g. if the FM is from 1 250 MHz to 1 280 MHz or 30 MHz during the pulse of 10 μs, then *B_{pep}* is $(30 \text{ MHz}/10 \text{ μs})^{1/2} = 1.73 \text{ MHz}$);
 - for radars operating with multiple waveforms *B_{pep}* is determined empirically from observations of the radar emission. The empirical observation is performed as follows: the measurement system receiver is tuned to one of the fundamental frequencies of the radar, or is tuned to the centre frequency within the chirp range of the radar. The measurement system bandwidth is set to the widest available value, and the received power level from the radar in this bandwidth is recorded. The measurement bandwidth is then progressively narrowed, and the received power level is recorded as a function of the bandwidth. The end result is a graph or table showing measured power as a function of measurement system bandwidth. The required bandwidth is the smallest bandwidth in which the full power level is still observed and *B_{pep}* can be calculated from a knowledge of the impulse response of the measurement receiver using the criteria described below. If a reduction in power level is observed immediately, then the widest available bandwidth should be used. The corrections described in § 3.2 are illustrated graphically in Fig. 1.

As can be seen in Fig. 1, the OoB mask and the measured spectrum have been referenced to the equivalent PEP level by using the factor $20 \log(B_{pep}/B_m)$. The Figure shows that the measured spurious is shifted upwards by an amount equal to the correction factor described in § 3.2.1 (here taken as $10 \log(B_{ref}/B_m)$). In this example, a measurement bandwidth of 100 kHz was chosen only for illustrative purposes, even though a bandwidth close to 1 MHz is recommended in this case. Also for illustrative purposes, the mask is shown offset in frequency as permitted in Recommendation ITU-R SM.1541.

FIGURE 1

Graphical illustration of the correction described in § 3.2



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4 Measurements for multiple pulse or multimode radars

For radars with multiple pulse waveforms, the B_{40} dB bandwidth should be calculated for each individual pulse type and the maximum B_{40} dB bandwidth obtained shall be used to establish the shape of the emission mask (see Recommendation ITU-R SM.1541, Annex 8).

For radars with multiple pulse width settings, that can be selected individually, the setting which results in the widest calculated B_{40} dB bandwidth (see Recommendation ITU-R SM.1541, Annex 8) should be used. Emission measurements only need to be carried out for this pulse width setting.

For radars using elevation beam scanning, measurements normally need only be made in the azimuth plane.

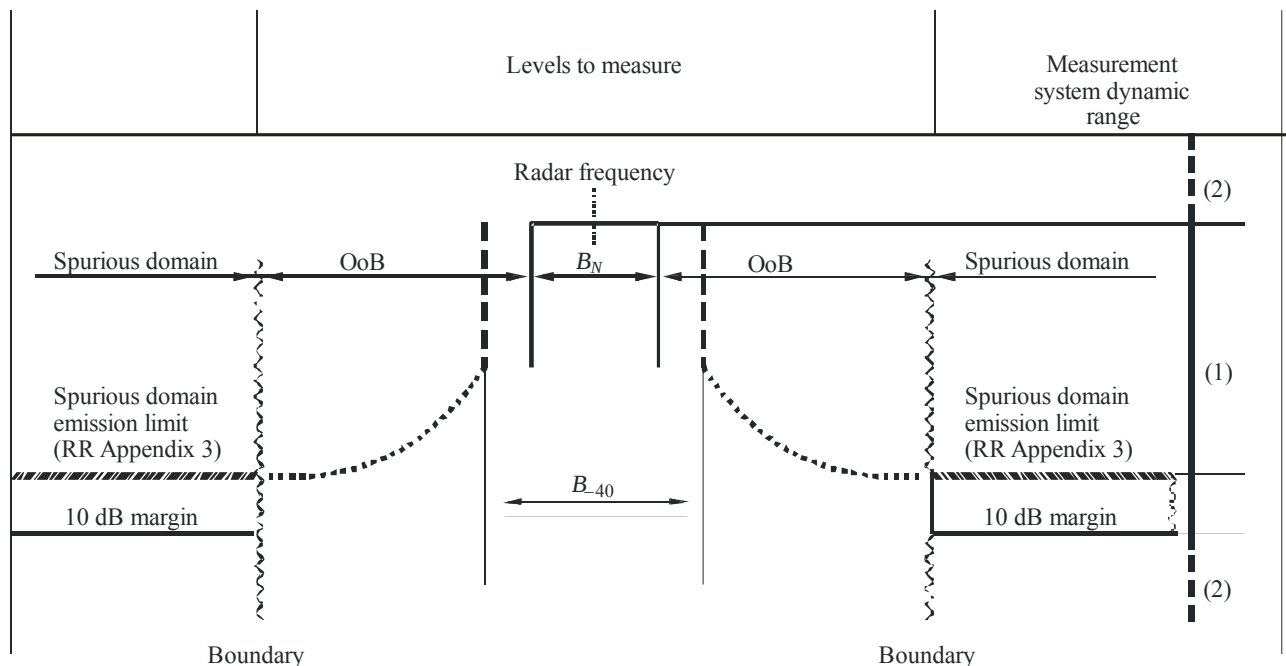
5 Dynamic range of the measurement system

The measurement system should be able to measure levels of unwanted emissions as given in RR Appendix 3. To obtain a complete picture of the spectrum especially in the spurious emissions domain, it is recommended to be able to measure levels of emissions 10 dB below the levels given in RR Appendix 3.

For a high level of confidence in the results, the measurement dynamic range of the system should be significantly higher than the required range of measurement (margin (2) in Fig. 2).

The link between the required range of measurement and the recommended dynamic range of the measurement system is given in Fig. 2.

FIGURE 2
Relation between the required range of measurement and the recommended
dynamic range of the measurement system



(1): Recommended range of measurement
(2): Margin

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NOTE 1 – It should be noted that Recommendation ITU-R SM.329 recommends, under category B limits, more stringent limits than those given within RR Appendix 3 in some cases. This should be taken into account when evaluating the required range of measurement and the recommended dynamic range of the measurement system.

6 Direct methods

Two direct methods described below can be used to measure unwanted emissions (OoB and spurious) from radar systems. The first method is manually controlled and the second method is automatically controlled. These two methods have been used to measure the emission characteristics of radar systems operating at frequencies up to 24 GHz, transmitter output powers of several megawatts, and e.i.r.p. levels in the gigawatt range. Taking safety aspects into account, these methods may also be carried out in an anechoic chamber.

6.1 Measurement environment conditions

Regarding the measurement distance, either near field or far field measurements can be made. Variation of the peak received signal should be made less than 3 dB using the absorber when the receiving antenna is moved $\lambda D/2H$ horizontally or vertically away from the point where maximum signal is received (H : height of the transmitting point, D : measurement distance, λ : transmitting wave length).

Regarding the measurement site, it is preferable to locate the transmitting and receiving antennas in a fairly high position such as on towers. Note that the height should be determined considering the vertical beam width of the radar and measurement antennas, and no reflective objects should be between the antennas.

6.2 Measurement hardware and software

Block diagram of the type of measurement system required for the two direct methods are shown in Fig. 3 (manual method) and Fig. 4 (automatic method). The first element to be considered in the system is the receive antenna. The receive antenna should have a broadband frequency response, at least as wide as the frequency range 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 measurement; the narrow antenna beamwidth provides discrimination against other signals in the area; the narrow beamwidth minimizes problems with multipath propagation from the radar under measurement; and spectrum data collected with a parabolic antenna require a minimum of post-measurement correction, as discussed in the next paragraph. 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*. The antenna polarization may be tested by rotating the feed (if linear polarization is used) or by exchanging left and right-hand polarized feeds, if circular polarization is being used.

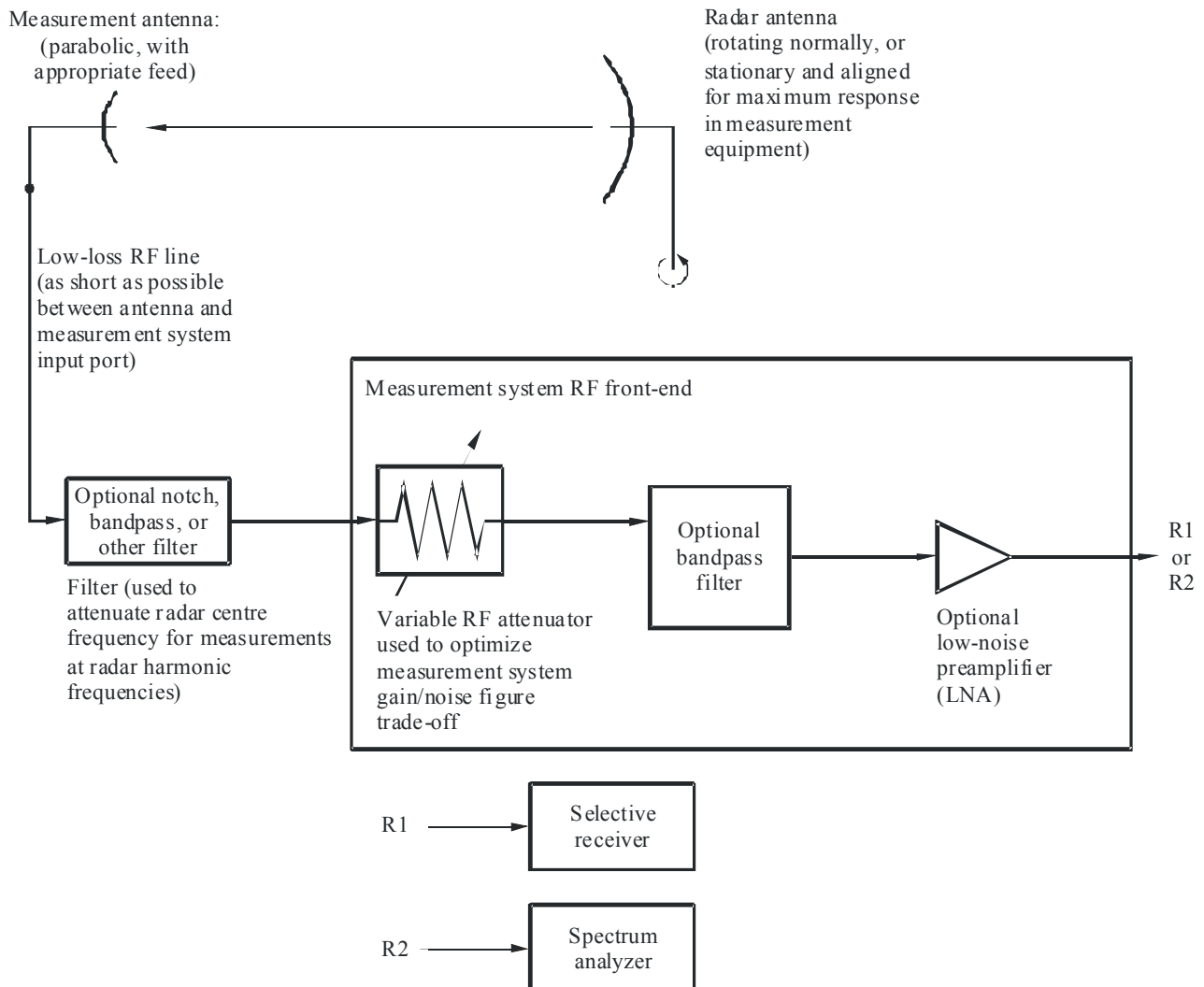
Corrections for variable antenna gain as a function of frequency should be considered. Antenna gain levels are usually specified relative to that of a theoretically perfect isotropic antenna (dBi). The effective aperture of an isotropic antenna decreases as $20 \log(f)$, where f is the frequency being measured. This means that, if the measurement antenna has a constant effective aperture (that is, has an isotropic gain that increases as $20 \log(f)$), no corrections for variable antenna gain need be performed. This requirement is met by a theoretically perfect parabolic reflector antenna, and is one of the reasons that such an antenna is preferred for a broadband radar spectrum measurement.

Conversely, to the extent to which the gain of the measurement antenna deviates from a $20 \log(f)$ curve (including a less-than-ideal parabolic antenna), the resulting measurements must be corrected for such deviation.

The cable connecting the measurement antenna to the measurement system should also be considered. A length of low-loss RF cable (which will vary depending upon the circumstances of measurement system geometry at each measurement radar site) connects the antenna to the RF front-end of the measurement system. As losses in this piece of line attenuate the received radar signal, it is desirable to make this line length as short, and as low-loss, as possible.

FIGURE 3

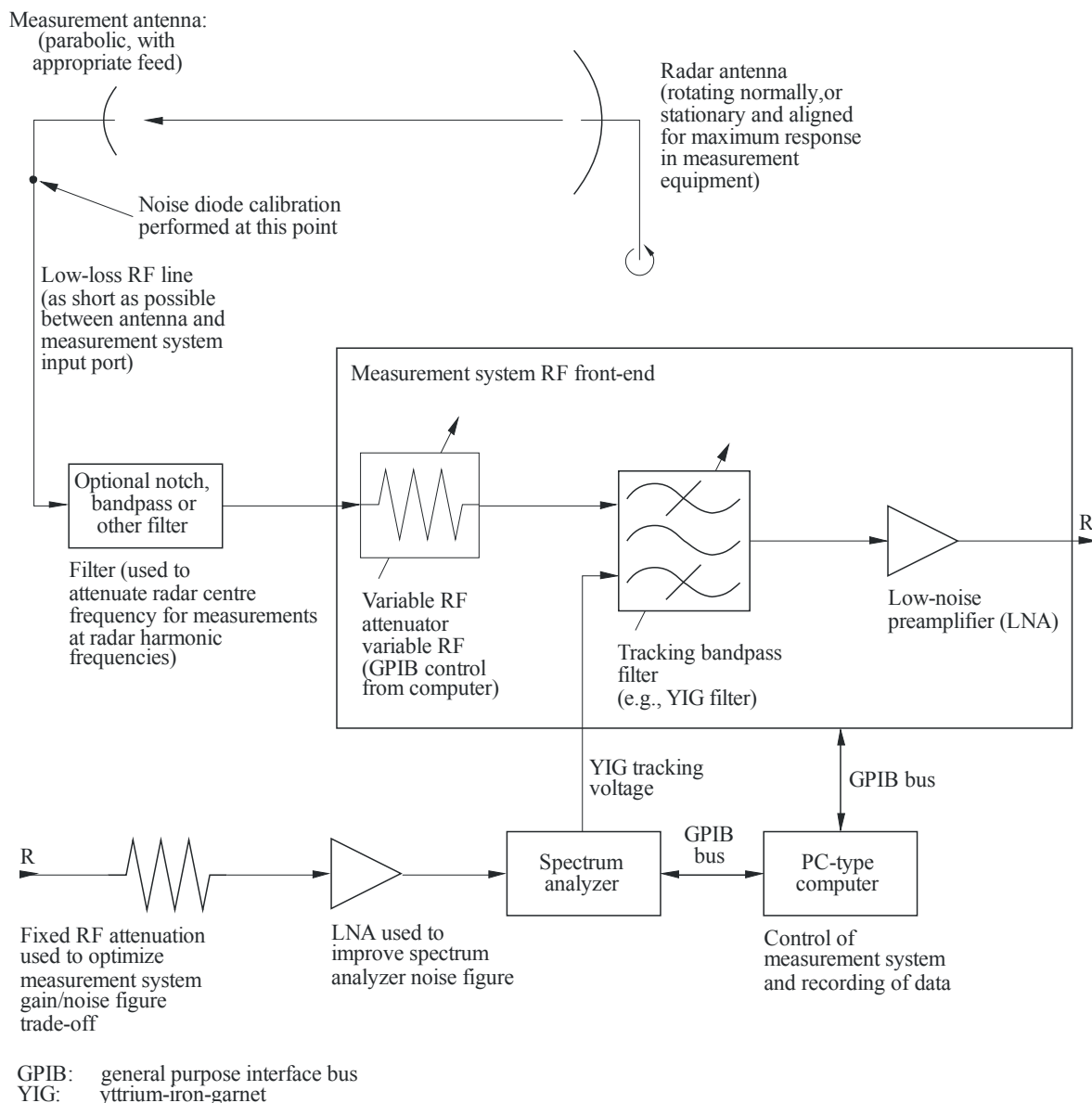
Block diagram for measurement of radiated unwanted emissions from radars using the manually controlled direct method



M.1177-03

FIGURE 4

Block diagram from measurement of radiated unwanted emissions from radars using the automatically controlled direct method



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The RF front-end is one of the most critical parts of the entire measurement system. It performs three vital functions. The first is control and extension of measurement system dynamic range through the use of variable RF attenuation. The second is bandpass filtering (preselection) to prevent overload of amplifiers by high-amplitude signals that are not at the tuned frequency of the measurement system. The third is low-noise preamplification to provide the maximum sensitivity to emissions that may be as much as 130 dB below the peak measured level at the radar fundamental.

Each of these sections in the RF front-end is considered below.

The RF attenuator is the first element in the front-end. It 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 dynamic range of the measurement system by the maximum amount of attenuation available (e.g. 70 dB for a 0-70 dB attenuator).