RCG-8

PRELIMINARY DRAFT REVISION OF
RECOMMENDATION ITU-R M.1461*

Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services

(Question ITU-R 226/8)

(2000)

The ITU Radiocommunication Assembly,

considering

a) that antenna, signal propagation, target detection, and large necessary bandwidth characteristics of radar to achieve their functions are optimum in certain frequency bands;

b) that the technical characteristics of radars operating in the radiodetermination service are determined by the mission of the system and vary widely even within a band;

c) that the radionavigation service is a safety service as specified by RR No. S4.10 and harmful interference to it cannot be accepted;

d) that considerable radiolocation and radionavigation spectrum allocations (amounting to about 1 GHz) have been removed or downgraded since WARC-79;

e) that some ITU-R technical groups are considering the potential for the introduction of new types of systems (e.g., fixed wireless access and high-density fixed and mobile systems) or services in bands between 420 MHz and 34 GHz used by radars in the radiodetermination service;

f) that representative technical and operational characteristics of systems operating in bands allocated to the radiodetermination service are required to determine the feasibility of introducing new types of systems;

g) that procedures and methodologies are needed to analyse compatibility between radars operating in the radiodetermination service and systems in other services,

recommends

1 that the procedures in Annex 1 provide guidance for determining the potential for interference between radars operating in the radiodetermination service and systems in other services;

2 that those radar characteristics contained in appropriate ITU-R Recommendations be used for the frequency band under study.

NOTE 1 – This Recommendation will be revised as more detailed information becomes available. It should be noted that work is already in progress within ITU-R addressing specifically the compatibility between radars in the band 2 700-2 900 MHz and IMT-2000 systems.

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[*] This Recommendation should be brought to the attention of the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), the International Maritime Radio Committee (CIRM) and the World Meteorological Organization (WMO).

ANNEX 1

Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services

1 Introduction

Analysis procedures have been developed. Because of the high transmitter output power (50 kW to several MW) and antenna gain (30 to 45 dBi) of radars operating in the radiodetermination service (hereafter simply referred to as radars), compatibility between radars and systems in other services is largely determined by analysing the effects of the emissions from radars on receiving functions of other services. Therefore, this analysis procedure primarily addresses the methods to assess the potential for interference from radars. In addition, potential desensitization of radar receivers by emissions from modulated continuous-wave (CW) systems in other services is briefly discussed.

By the nature of the missions of radars, many are mobile and cannot be constrained to prescribed areas of operation. Also, the mission of radars often requires frequency agility and utilize the entire allocated band. But when radars are anticipated to operate in certain areas in proximity to other systems, the potential for interference can be assessed using the procedures contained in this Recommendation.

2 Interference from radars to systems of other services

Investigations of several interference cases have identified two primary electro-magnetic interference coupling mechanisms between high power radar systems and other services. These interference coupling mechanisms are receiver front-end overload and radar transmitter emissions coupled through the receiver IF passband. Discussion of the interference mechanisms are provided below.

2.1 Receiver front-end overload

This interference mechanism occurs when energy from the fundamental frequency (necessary emissions) of an undesired signal saturates the victim receiver front-end (low noise amplifier (LNA) in some systems), resulting in gain compression of the desired signal sufficient to degrade receiver performance. Receiver front-end overload is typically a result of inadequate RF selectivity in the front-end of the victim receiver.

2.1.1 Assessing the potential for receiver front-end overload

The input threshold at which receiver front-end overload occurs is a function of the 1 dB gain compression (saturation) level and the gain of the receiver front-end or LNA. Specifically:

$$T = C - G \qquad (1)$$

where:

T: input threshold at which receiver front-end overload occurs (dBm)

C: output 1 dB gain compression (saturation) level of the receiver front-end or LNA (dBm)

G: gain of the receiver front-end or LNA at the radar fundamental frequency (dB).

For example, if the receivers use LNAs with gains of 50 to 65 dB and they have an output 1 dB compression level of +10 dBm, the range of values for T is –55 dBm to –40 dBm, depending on the gain of the LNA.

A potential for interference from receiver front-end overload will exist whenever:

$$I_T = T - FDR_{RF} \tag{2}$$

where:

I_T: peak radar signal level at the antenna output or receiver input that causes receiver front-end overload (dBm)

T: input threshold at which receiver front-end overload occurs (dBm)

FDR_{RF}: frequency dependent rejection of the radar fundamental from any RF selectivity that may be ahead of the receiver RF amplifier (LNA) or that may be inherent in the RF amplifier (LNA) itself.

Equation (3) can be used to determine whether receiver front-end overload is likely when radars operate within particular distances of other stations and are separated in frequency by certain amounts:

$$I = P_T + G_T + G_R - L_T - L_R - L_P \tag{3}$$

where:

I: peak power of radar pulses, at the radar's fundamental frequency, at the receiving antenna output or receiver input (dBm)

P_T: peak power of the radar transmitter (dBm)

G_T: main beam antenna gain of the radar (see Note 1) (dBi)

G_R: receiver antenna gain in the direction of the radar station under analysis (dBi)

L_T: insertion loss in the radar station transmitter (dB) (2 dB assumed)

L_R: insertion loss in the victim receiver (dB)

L_P: propagation path loss between transmitting and receiving antennas (dB).

In determining the propagation path loss, appropriate propagation models and possible indirect coupling should be used taking into consideration antenna heights and terrain when appropriate. If the calculated peak power of the radar pulses, at the fundamental frequency, I, exceed the threshold at which receiver front-end overload occurs, I_T, necessary steps to ensure compatibility need to be taken.

NOTE 1 – Interference cases of radar transmitter emissions causing receiver front-end overload for radar mainbeam coupling have been documented. Therefore, it is recommended that the radar mainbeam gain be used in assessing the maximum potential for interference caused by receiver front-end overload.

2.2 Radar transmitter emission coupling

This interference mechanism occurs when energy emitted from the radar transmitter falls within the IF passband of the receiver. This energy then passes through the receiver chain with little or no attenuation. When the radar emission levels in the receiver passband are high relative to the desired signal level, performance degradation to the receiver can occur.

2.2.1 Assessing the potential for radar transmitter emission interference

The initial step in assessing compatibility is the determination of the signal level at which the receiver performance starts to degrade, I_T.

$$I_T = I/N + N \tag{4}$$

where:

I/N: interference-to-noise ratio at the detector input (IF output) necessary to maintain acceptable performance criteria (dB)

N: receiver inherent noise level (dBm)
($N = -144$ dBm + 10 log B_{IF} (kHz) + NF
or
$N = -168.6$ dBm + 10 log B_{IF} (kHz) + 10 log T)
where:

B_{IF}: receiver IF bandwidth (kHz)

NF: receiver noise figure (dB)

T: system noise temperature (K).

Also, the signal level at which a receiver starts to degrade, $I_{T,}$ can be calculated using equation (5):

I_T~~IT~~ $= C - (C/I)$ (5)

where:

C: desired carrier signal level at the antenna output (receiver input) (dBm)

C/I: carrier-to-interference ratio at the predetector input (IF output) necessary to maintain acceptable performance criteria (dB).

Equation (6) can be used to determine whether radar transmitter emission interference is likely when radars operate within particular distances of other stations and are separated in frequency by certain amounts.

$$I = P_T + G_T + G_R - L_T - L_R - L_P - FDR_{IF} \quad (6)$$

where:

I: peak power of the radar pulses at the receiver (dBm)

P_T: peak power of the radar transmitter under analysis (dBm)

G_T: main beam antenna gain of the radar under analysis (see Note 1) (dBi)

G_R: receiver antenna gain in the direction of the radar station under analysis (dBi)

L_T: insertion loss in the radar station transmitter (dB)

L_R: insertion loss in the victim receiver (dB)

L_P: propagation path loss between transmitting and receiving antennas (dB)

FDR_{IF}: frequency-dependent rejection produced by the receiver IF selectivity curve on an unwanted transmitter emission spectra (dB).

The FDR value to be used in equation (6) can be determined from Recommendation ITU-R SM.337. The FDR can be divided into two terms, the on-tune rejection (OTR) and the off-frequency rejection (OFR), the additional rejection which results from off-tuning the radar and the receiver.

$$FDR_{IF}(\Delta f) = OTR + OFR(\Delta f) \quad (7)$$

For CW and phase-coded pulsed signals, the OTR factor is given by:

$$OTR = 0 \qquad \text{for } B_R \geq B_T \quad (8)$$

$$OTR = 20 \log (B_T / B_R) \qquad \text{for } B_R < B_T \quad (9)$$

where:

B_R: receiver 3 dB bandwidth (Hz)
B_T: transmitter 3 dB bandwidth (Hz).

For chirped pulsed signals, the OTR factor is given by:

$$OTR = 0 \quad \text{for } B_C / (B_R^2\, T) \le 1 \tag{10}$$

$$OTR = 10 \log (B_C / (B_R^2\, T)) \text{ for } B_C / (B_R^2\, T) > 1 \tag{11}$$

where:

T: chirped pulse width (s)
B_C: transmitter chirped bandwidth during the pulsewidth, T, (Hz).

Calculation of the OFR requires the IF response and the emission spectrum characteristics of the radar transmitter. The ITU-R has provided methods for calculating the emission spectrum characteristics of CW pulsed and chirped pulsed radars. If information is not available for radar transmitter rise and fall time characteristics, the radar emission envelops should be calculated for nominal rise and fall times of 0.1 µs. The spurious emission levels from radar transmitters are a function of the transmitter output device. Representative spurious emission levels for various radar output devices are contained in Recommendation ITU-R M.1314. Since many radars have high transmitter power and antenna gains, large frequency separations, guardbands, may be required to ensure compatibility.

In determining the propagation path loss, appropriate propagation models and possible indirect coupling should be used taking into consideration antenna heights and terrain when appropriate. If the calculated peak power of the radar pulses, at the receiver input, I, exceed the threshold at which at which receiver performance degrades, I_T, necessary steps to ensure compatibility need to be taken.

NOTE 1 – Interference cases of radar transmitter emissions causing receiver degradation for radar mainbeam coupling have been documented. Therefore, it is recommended that the radar mainbeam gain be used in assessing the maximum potential for interference caused by radar transmitter emissions in the receiver IF passband.

3 Interference to radars from systems in other services

Introduction

Two primary electro-magnetic interference coupling mechanisms between the radar system and interfering signals from other services exist. The first mechanism is caused by front-end overload causing saturation [, and the generation of intermodulation products]. The second is interfering emissions within the receiver IF passband leading to desensitization and degradation of performance resulting in an overall lowered quality radar data output.

3.1 Receiver front-end overload

3.1.1 Front-end saturation

This interference mechanism occurs when energy from an undesired signal saturates the LNA of the radar receiver front-end resulting in gain compression of the desired signal which is sufficient to degrade receiver performance. The input threshold at which receiver front-end overload occurs is a function of the 1 dB gain compression (saturation) level and the gain of the receiver front-end. Given a radar receiver with front-end RF bandwidth, B_{RF}, and 1 dB compression input power $P_{1dB,\ in}$ dBm, the total interference power inside B_{RF} entering the radar receiver must not exceed:

$$P_{I,\ RF\ max} = P_{1dB,\ in}\ [+\ k_{sat}] = C - G\ [+\ k_{sat}]\ \mathrm{dBm} \qquad (12)$$

where:

$P_{I,\ RF\ max}$ is the maximum allowed total interference power inside the RF-bandwidth (dBm)

[k_{sat} is the saturation margin (dB), to be determined individually for each radar and interference type (k_{sat} is generally negative)]

$P_{1dB,in}$ is defined as the 1dB-input power compression point (dBm), i.e. when the gain of the whole receiver chain has decreased by 1dB

C is the output 1 dB gain compression (saturation) level of the receiver front-end or LNA (dBm)

G is the gain of the receiver front-end at the fundamental frequency of the potential interference source (dB)

For example, if the receivers use LNAs with gain of [X] dB and they have an output 1 dB compression level of [Y] dBm, the value for $P_{1dB,in}$ is [Y-X] dBm.

Fulfilment of equation (12) is essential in order to avoid driving the receiver close to or into saturation and thereby to maintain sufficient dynamic range for the radar echo signal itself. Moreover, the fraction of interference power falling into the radar receiver's IF bandwidth must also fulfil the requirements laid down in relevant ITU recommendations.

A potential for receiver front-end overload from interference will exist whenever:

$$I_T > P_{I,\ RF\ max} - FDR_{RF} \qquad (13)$$

where:

I_T: interference signal level at the receiver input that causes receiver front-end overload (dBm)

FDR_{RF}: frequency dependent rejection of the interference source by any RF selectivity that may be ahead of the receiver RF amplifier (LNA) or that may be inherent in the RF amplifier (LNA) itself

Received interference power, aggregated over the full RF bandwidth, must not be higher than the level which causes output power of that particular element in the receiver chain which first goes into saturation to retain a sufficient separation below the 1 dB compression point. This is to limit the reduction in dynamic range and to prevent 3rd order intermodulation products exceeding the acceptable I/N in the receiver's IF bandwidth.

Equation (13) can be used to determine the interference signal level at the input of the first amplifier stage of the receiver chain when interference sources operate within particular distances of other stations and are separated in frequency by certain amounts, but are within the receiver RF-bandwidth:

$$I = P_T + G_T + G_R - Lt - L_R - L_P \qquad (14)$$

where:

I: peak power of interference signal at the receiver input (dBm)

P_T: peak power of the interference source transmitter (dBm)

G_T: antenna gain of the interference source in the direction of the radar under analysis (dBi)

G_R: receiver antenna gain in the direction of the interference source (dBi)

Lt: insertion loss in the transmitter (dB)

L_R: insertion loss in the radar receiver (dB)

L_P: propagation path loss between transmitting and receiving antennas (dB)

In determining the propagation path loss, appropriate propagation models and possible indirect coupling should be used taking into consideration antenna heights and terrain when appropriate (refer to section 3.3). If the calculated power of the aggregated interference sources exceed the threshold at which receiver front-end overload occurs, I_T, necessary steps to ensure compatibility need to be taken.

[3.1.2 Intermodulation

For a radar receiver with large RF front-end bandwidth B_{RF} (as defined in section 3.1.1) and with usually much narrower IF bandwidth, the mechanism of 3rd-order intermodulation, with the effect of transferring signal energy from outside the IF band (but inside the RF bandwidth) to inside the IF bandwidth, must be taken into account.

Any pair of carriers at frequencies ("tones") f1 and f2 may produce 3rd-order products of either f3 = 2*f1 - f2, or f3 = 2*f2 - f1. Where f3 is inside the IF bandwidth, on-tune interference power is generated which is further amplified and processed by the radar receivers IF and baseband sections.

Intermodulation effects increase significantly with single tone power level. A 10 dB increase of single tone power causes 30 dB increase of intermodulation product power. The (theoretical) point where 3rd-order intermodulation product power starts to exceed amplified single tone power is called 3rd-order output intercept point ($IP3_{out}$). For RF low-noise amplifiers as used in radar front-ends, $IP3_{out}$ lies 10 to 15 dB above the 1 dB compression output power $P_{1dB,out}$.

Interference power mapped by 3rd-order intermodulation from outside to inside IF bandwidth is to be treated like on-tune interference, i.e. it must be in combination with interference power entering the IF band directly and fulfil the requirements laid down for the I/N ratio in the appropriate ITU-R Recommendation.]

3.2 Degradation of sensitivity

The desensitizing effect, on radiodetermination radars from other services of a CW or noise-like type modulation is predictably related to its intensity. In any azimuth sectors in which such interference arrives, its power spectral density can, to within a reasonable approximation, simply be added to the power spectral density of the radar receiver thermal noise.

The initial step in assessing compatibility is the determination of the signal level at which the radar receiver performance starts to degrade, I_T.

$$I_T = I/N + N \qquad (15~~2~~)$$

where:

I/N: interference-to-noise ratio at the detector input (IF output) necessary to maintain acceptable performance criteria (dB)

N: receiver inherent noise level (dBm)

$N = -114 \text{ dBm} + 10 \log B_{IF} \text{ (MHz)} + NF$

where:

B_{IF}: receiver IF bandwidth (~~k~~MHz)

NF: receiver noise figure.

~~If there is no specific *I*/*N* ratio provided for the radar being analysed (see relevant ITU-R Recommendations), an *I*/*N* ratio of –6 dB should be used. When multiple interferers are present, the tolerable *I*/*N* ratio depends on the number of interferers and their geometry, and needs to be assessed in the course of analysis of a given scenario. The aggregation factor can be very substantial in the case of certain high density communications systems. If CW interference were received from most azimuth directions, a lower *I*/*N* ratio would need to be maintained. An alternative to adjusting the *I*/*N* ratio for aggregate effects is to use an automated aggregate model guided by Recommendation ITU-R M.1316.~~

Equation (15~~3~~) can be used to determine whether systems in other services can operate within particular distances of radars and are separated in frequency by certain amounts.

$$I = P_T + G_T + G_R - L_T - L_R - L_P - FDR_{IF}$$

(16~~3~~)

where:

I: peak power of the undesired signal at the radar receiver input (dBm)

P_T: peak power of the undesired transmitter under analysis (dBm)

G_T: antenna gain of the undesired system in the direction of the radar under analysis (dBi)

G_R: antenna gain of the radar station in the direction of the system under analysis (see Note 1) (dBi)

L_T: insertion loss in the transmitter (dB)

L_R: insertion loss in the radar receiver (dB)

L_P: propagation path loss between transmitting and receiving antennas (dB)

FDR_{IF}: frequency-dependent rejection produced by the receiver IF selectivity curve on an unwanted transmitter emission spectra (dB).

The FDR value to be used in equation (13) can be determined from Recommendation ITU-R SM.337. Calculation of the FDR, requires the radar receiver IF selectivity response and the emission spectrum characteristics of the radar transmitter. If the radar receiver IF selectivity response is not provided, a selectivity fall-off of 80 dB per decade from the 3 dB bandwidth should be used.

3.3 Protection criteria

If there is no specific *I*/*N* ratio provided for the radar being analysed an *I*/*N* ratio of –6 dB should be used in the case of radar systems used for non-safety of life applications. For guidance, the use of an I/N ratio of –6 dB may result in the following effects on radar system performance:

[Text to be developed but could include references to reduction in Pd at a given range, loss of low RCS targets in clutter close in to the radar etc.].

For [safety of life radionavigation] radar applications where no specific *I*/*N* ratio is provided, an I/N ratio that is more stringent than [–6] dB may be necessary, taking into account the type of radar and the type of interfering signal present. In the case of radar systems operating in bands for which ITU-R Recommendations on radar characteristics and protection criteria exist then the relevant Recommendation should be consulted for frequency band specific I/N guidance.

The effect of pulsed interference is more difficult to quantify and is strongly dependent on receiver/processor design and mode of operation. In particular, the differential processing gains for a valid target return, which is synchronously pulsed, and interference pulses, which are usually asynchronous, often have important effects on the impact of given levels of pulsed interference. Several different forms of performance degradation can be inflicted by such desensitisation.

Assessing it will an objective for analyses of interactions between specific radar types. In general, numerous features of radiodetermination radars can be expected to help suppress low duty-cycle pulsed interference, especially from a few isolated sources. Techniques for suppression of low duty-cycle interference are contained in Recommendation ITU-R M.1372 - Efficient use of the radio spectrum by radar stations in the radionavigation service.

When multiple interferers are present, the tolerable I/N ratio remains unchanged (because it depends on the type of radar receiver and its signal processing characteristics). However, the total interference level actually arriving at the radar receiver (which has to be checked against tolerable I/N) depends on the number of interferers, their spatial distribution and their signal structure, and needs to be assessed in the course of an aggregation analysis of a given scenario. The aggregation factor can be very substantial in the case of certain high-density communications systems. If interference were received from several azimuth directions, an aggregation analysis has to cumulate simultaneous contributions from all these directions, being received via the radar antenna's main beam and/or side lobes, in order to arrive at the actual I/N ratio.

4 Choice of propagation model

In determining the propagation path loss, appropriate propagation models and possible indirect coupling should be used taking into consideration antenna heights and terrain when appropriate. In the general case, no account should be taken of shielding offered by terrain or man-made obstructions. In specific sharing cases where accurate data is available, a detailed path analysis and loss calculation may be carried out, or where the actual path loss between the interferer site and the victim radar are determined experimentally for all frequencies of interest, may be accepted. If the calculated peak power of the ~~undesired station~~ aggregate interference sources at the radar receiver input, I, exceeds the threshold at which receiver performance degrades, I_T, necessary steps to ensure compatibility need to be taken.

In the case of radars used for safety purposes, such as air traffic surveillance, the propagation model must take into account all enhancing phenomena, which, even for short periods, could cause the acceptable limit to be exceeded. Due to their operational requirement, radar systems used for safety of life purposes, for example airport surveillance, require to be protected against interference both for long-term and for short-term periods stated in seconds. Where the interfering signal can originate without location identification over an area and be of short duration, special caution must be observed.

NOTE 1 – Most radiodetermination radar antennas scan 360° in azimuth to substantial elevation angles. However some radar system antenna scan in sectors, but the radar platform can ordinarily be oriented in any azimuth. Interference to radar systems generally occurs when the radar antenna mainbeam points at the undesired signal. Therefore, the radar mainbeam should ordinarily be used in the analysis. In some special situations, the radar mainbeam may not illuminate the interacting station (e.g., sector blanking), in which case the appropriate antenna sidelobe level should be used.