

REPORT ITU-R M.2076

Factors that mitigate interference from radiolocation and Earth exploration-satellite service/space research service (active) radars to maritime and aeronautical radionavigation radars in the 9.0-9.2 and 9.3-9.5 GHz bands and between Earth exploration-satellite service/ space research service (active) radars and radiolocation radars in the 9.3-9.5 and 9.8-10.0 GHz bands

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1 Introduction

Question ITU-R 234/8 calls for study of technical characteristics, performance criteria, and other factors of radiolocation and radionavigation systems in the bands 9 000-9 200 MHz and 9 300-9 500 MHz and of the interference criteria for those systems. In addition, Resolution 747 (WRC-03) has established Agenda item 1.3 for WRC-07 to consider upgrading the allocations to the radiolocation service in the 9 000-9 200 and 9 300-9 500 MHz bands to co-primary and to consider extending the primary allocation to the Earth exploration-satellite (EES) (active) service and space research (SR) (active) service in the band 9 500-9 800 MHz band contiguously by 200 MHz. Characteristics of representative terrestrial radars in the 8 500 MHz-10.5 GHz band are contained in Recommendation ITU-R M.1796. This Report is a further contribution to the studies required by Question ITU-R 234/8 and Resolution 747 (WRC-03).

Recommendation ITU-R M.1372-1 – Efficient use of the radio spectrum by radar stations in the radiodetermination service, describes some of the most important interference suppression techniques that are used in radars generally. The emphasis in that Recommendation is on post-detection processing, although one of the techniques described there can be implemented prior to detection. The factors discussed herein include some of those covered in Recommendation ITU-R M.1372 as well as some that complement those.

1.1 Summary of findings

The main form of interference degradation that pulsed interference is likely to cause is an increase of the rate of false alarms. This is naturally mitigated by some common characteristics of radars, including low antenna sidelobes and asynchronous pulsing. Responses to individual pulses, including fast time constant, matched filtering effects, and other pulse-shortening effects, are beneficial. The form of coupling of most concern is sidelobe-to-main-beam coupling.

Prudent radar design can mitigate pulsed interference in numerous ways. These include:

- multiple-pulse techniques, including *M*-out-of-*N* processing;
- deliberate removal of individual asynchronous pulses;
- sensing of asynchronous-pulse effects in post-processing review of Doppler-filter outputs;
- nonlinear and time-varying processes such as limiting and sensitivity time control;
- scan-to-scan correlation.

2 Types of radars in the bands

Several types of radionavigation radars operate in the 9 000-9 200 and 9 300-9 500 MHz bands. Ground-based aeronautical radionavigation radars operate in the 9 000-9 200 MHz band; they include precision-approach radars (PARs) and airport surface detection equipment (ASDE) radars. These are discrete-target surveillance radars. The 9 300-9 500 MHz band is used by a large number of maritime radionavigation radars, the great majority of them being aboard ships, and by airborne weather-avoidance radars. The maritime systems are discrete-target radars while the airborne systems are distributed-target radars.

The radiolocation service operates on a secondary allocation basis in the 9 000-9 200 and 9 300-9 500 MHz bands. Land-based weather radiolocation radars operating in the 9 300-9 500 MHz band are privileged with respect to other radiolocation radars (Radio Regulations (RR) No. 5.475). Radiolocation radars also operate in the 9 500-9 800 MHz and 9 800 MHz-10.0 GHz bands on a primary-allocation basis.

Spaceborne synthetic-aperture radars (SARs) in the EES/SR (active) services currently operate in the 9.5-9.8 GHz band on a co-primary allocation basis. The proposal to extend that allocation by 200 MHz is driven by a desire to enhance the range resolution of the SARs.

3 Types of potential interference effects

The two most prominent types of performance degradation that radiolocation or EES/SR (active) radars could inflict on discrete-target surveillance radars such as PARs, ASDEs, or maritime navigation radars fall into the categories of:

- missed target detections;
- generation of false target detections or “false alarms” and false target tracks.

These two effects can be thought of as a decrease in probability of detection and an increase in probability of false alarm, respectively.

Although radiolocation or EES/SR (active) radars could conceivably inflict some degree of desensitization (missed target detections, etc.), that effect is expected to be minor, as has been demonstrated in several measurement programs, so attention will focus on the generation of false targets.

Pulsed signals from other radars create a potential for generation of false target detections even when a well-designed “constant-false-alarm-rate” (CFAR) operation is provided in the terrestrial radar. However, the remainder of this Report shows that these effects can largely be avoided by good design. Discrete-target radars, including target-dedicated tracking radars, are also subject to aggravation of position-estimation errors and target-classification errors due to unwanted signals. However, these effects are more likely to be inflicted by continuous, noise-like interference than by pulsed interference from other radars.

Performance degradation that radiolocation and EESS radars could inflict on distributed-target radars, including weather-avoidance radars or weather surveillance radars, consists of discrete (e.g. single-pixel) false alarms (referred to in the weather-radar community as speckle) and introduction of inaccuracy into derived measures of weather phenomena. The degradation that interference of any kind can inflict on synthetic-aperture imaging radars is being expressed by the space-science community as an increase of the variance of processor output power in any pixel¹.

¹ Recommendation ITU-R RS.1166 – Performance and interference criteria for spaceborne active sensors.

These effects are in contrast to the effect of continuous noise-like interference on discrete-target radar that has effective control over its false-alarm rate. In that case, the probability of false alarm tends to remain unchanged, but the curve of probability of detection as a function of target range or radar cross section (RCS) inexorably suffers a shift to shorter range or higher RCS as the undesired signal becomes stronger. This is generalized desensitization, predominately affecting targets that are small, distant, or poorly illuminated due to adverse propagation conditions such as multipath propagation or adverse ducting. It also degrades other functions such as tracking precision. However, continuous noise-like interference is outside the purposes of this Report.

4 Interference-mitigating characteristics commonly found in radars

Interference can be mitigated by weak or transient power coupling, certain receiver nonlinearities, time-varying gain, signal processing, post-processing, and separation in carrier frequency. In radar-to-radar interactions, separation in frequency is not always necessary for compatible operation because high degrees of isolation in power coupling and in time either occur naturally or can be achieved by good design. Isolation through polarization mismatch occurs in some combinations of radiolocation and spaceborne radars and navigation radars, but cannot be relied upon in the general case because radars of a given allocated service often use horizontal, vertical, and/or circular polarization.

Specific mechanisms that contribute to such mitigating factors are identified in the following sections. Many of them apply to pulses coupled from radiolocation or spaceborne-sensor radars to maritime, airborne, and air-traffic-control radars, while some apply mainly to radars in just one or another of those categories.

4.1 Isolation in power coupling (antenna-mediated effects)

Interactions between two radars of different types almost always involve asynchronism between the scanning of the two antenna beams. This is virtually assured when one of the radars is a radiolocation radar and the other is a radionavigation radar, because differences between their missions lead to differences between their system characteristics. Asynchronous scanning is enhanced further in interactions involving radiolocation radars that are “3-dimensional”; those radars use pencil beams scanned in elevation as well as azimuth, whereas navigation radars for surface use (maritime and air-traffic-control) are usually “2-dimensional”; i.e. they scan only in azimuth. Eight of approximately 14 radiolocation radars described in Recommendation ITU-R M.1796 have pencil beams that scan in elevation as well as azimuth. Thus, the pencil beams of these radiolocation radars normally spend much of the time searching regions either above the horizon, where they cannot couple strongly to the surface-based radionavigation radars or, in the case of airborne radars, at varying depression angles, so they illuminate a particular surface-based or airborne navigation radar only occasionally. The most powerful radiolocation radars are surface-based and have radiation nulls on the horizon, so they couple poorly with surface-based radionavigation radars. Further, radiolocation radars often use electronic steering and scan in patterns that are deliberately pseudo-random or in patterns that are quasi-random because they adapt to the target environment. In such cases, the main beam of the radiolocation radar revisits the direction of the navigation radar only at irregular intervals instead of periodically. This makes it unlikely that discrete-target radionavigation radars will interpret main-beam-to-main-beam interfering radar signals as a valid target. In any event, the fact that main beams of all radars are narrow causes the fraction of time during which main-beam-to-main-beam conjunctions prevail to be extremely small. Consequently, the situations that are normally of concern are limited to:

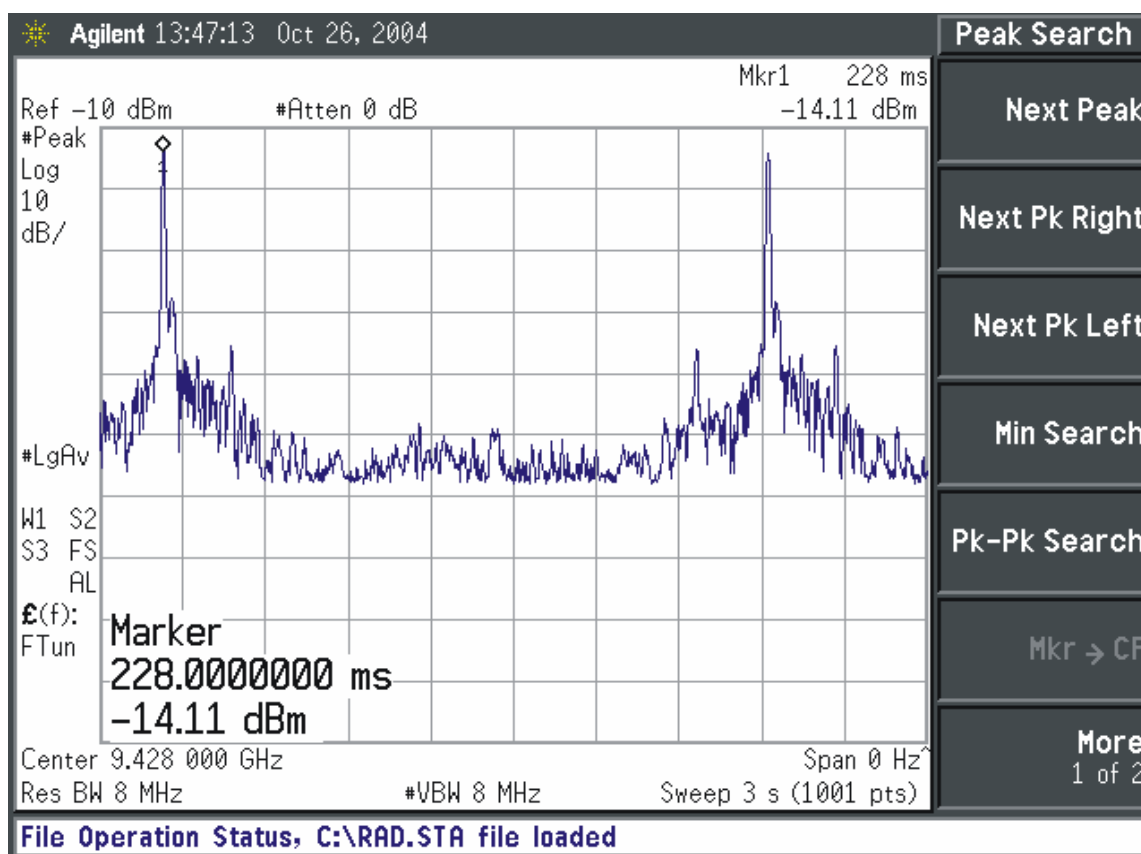
- radiolocation radar sidelobes to radionavigation radar sidelobes;
- radiolocation radar main beam to radionavigation radar sidelobes; and

- radiolocation radar sidelobes to radionavigation radar main beam.

4.1.1 Sidelobe-to-sidelobe coupling

The bulk of the sidelobes of both radiolocation and radionavigation radars have gains that are at least 30 dB below the main-beam gains. In fact, median sidelobe levels of such high-gain antennas tend to be approximately -10 dBi, so that median sidelobe suppression factors are typically about 40 dB. Maritime navigation radars operating around 10 GHz normally use slotted waveguide array antennas. Consequently, they have rather good sidelobe suppression. In addition, they have relatively narrow beams in the azimuth plane. An example of an azimuth-plane antenna pattern measured on a commercial maritime navigation radar operating in the 9.3-9.5 GHz band is presented in Fig. 1. As that figure shows, the strongest sidelobe is suppressed by about 25 dB and the median sidelobe level is at least 47 dB weaker than the main beam gain.

FIGURE 1
Azimuth-plane antenna-gain pattern of 10 GHz band maritime navigation radar



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This kind of performance is not reflected in most published sidelobe gain values, including those presented in Recommendation ITU-R M.1796, because specifications and standards usually state only the levels of the highest, close-in sidelobes. But it is readily understandable. Since an antenna can only concentrate energy and not amplify it, any gain in its main beam can only be achieved by lowering the directive gain in most other directions below the average of directive gain over all directions $4\pi(\text{sr})$, which is necessarily 0 dBi. The stated values of main-beam gains are power gains, which account for ohmic losses; i.e. dissipation of the energy that the antenna fails to radiate. They are therefore usually several dB lower than the associated directive gains. The power gain of the entire antenna pattern over all $4\pi(\text{sr})$ of angle is lower than the corresponding directive gain by the same factor, so the average power gain in the sidelobe region cannot possibly exceed about -3 dBi.

Good design concentrates more of the radiated energy in the main-beam region and suppresses most of the sidelobes further. Consequently, most sidelobe-to-sidelobe coupling is typically 66 to 80 dB weaker than main-beam-to-main-beam coupling.

Except when separation distances are quite short, therefore, sidelobe-to-sidelobe-coupled pulses are usually too weak to evoke false alarms.

It does happen that antennas having rectangular or quasi-rectangular apertures concentrate their sidelobe gain into ridges lying in planes that contain the longitudinal and transverse axes of the aperture, in which sidelobe gains can average higher than -10 dBi, but in those cases the sidelobes in all other planes are suppressed to values averaging less than -10 dBi. In addition, any false alarms that are evoked by sidelobe-to-sidelobe coupling will be spread randomly over a wide range of azimuth values, so they tend not to appear as targets.

4.1.2 Main-beam-to-sidelobe coupling

Apart from low-powered beacon transponders, the radiolocation radars in these bands, described in Recommendation ITU-R M.1796, typically have antenna gains ranging from about 28 to 42 dBi, with weather radars having gains as high as 46 dBi. The primary radars have narrow azimuth beamwidths, ranging from 1.5° to 5.75° at 3 dB down, with weather radars having beams as narrow as 0.9° . If their azimuth coverage is uniform over 360° , as is typically the case, their main beams will illuminate other radars no more often than $1.5/360 * 100 = 0.42\%$ to $5.75/360 * 100 = 1.6\%$ of the time, and as little as $0.9/360 * 100 = 0.25\%$ for weather radars, and the many radars that scan in elevation will illuminate them via the radiolocation radar main beams much less often than that. The low values of these percentages do not assure compatibility by themselves, but they are important by virtue of several facts:

- the occasional illuminations occur at intervals differing from the radionavigation radars' scan period;
- the interference is pulse-like and asynchronous;
- any interference effect tends to take the form of false alarms.

Thus, false alarms, including apparent weather blips, inflicted via the main beam of a rotating-beam radiolocation radar will normally migrate through the apparent azimuths of the radionavigation radar, typically falling along spiral loci on the plan-position indicator (PPI) display. Unless they are extremely dense, those can be discarded visually or in track-while-scan processing algorithms. Radiolocation radars that have electronic beam steering often scan pseudo randomly since they are not constrained to scan at a uniform angular rate; when such nonuniform scanning is done in the same plane as the (usually uniform) scanning of a radionavigation radar, false alarms that might be inflicted via the radiolocation main beam will be spread randomly over a wide azimuthal sector of the radionavigation radar, thus not correlating to form false-target tracks.

4.1.3 Sidelobe blanking

An optional feature that is sometimes incorporated into radars is that of sidelobe blanking [Skolnik, 1990; Maisel, 1968]. That arrangement supplements the high-gain antenna that is typical of radars with an auxiliary low-gain antenna feeding a separate receiver having the same gain as the main receiver. Logarithmic amplifiers are provided in both channels so that the ratio of signal powers in the two channels can be conveniently derived by a subtraction network. The purpose of such blankers is to prevent detection or other processing of strong target return pulses and interference pulses via radar antenna sidelobes. That is accomplished by using an appropriate ratio of auxiliary-antenna gain to main-antenna gain and appropriate values of blanking threshold for the ratio of signals received via the two antennas. This technique cannot protect against continuous interference since if such interference were strong enough to blank the receiver it would do so most of the time, drastically degrading system effectiveness. The value of sidelobe blanking for