

REPORT 914-2*

**EFFICIENT USE OF THE RADIO SPECTRUM BY RADAR
STATIONS IN THE RADIODETERMINATION SERVICE**

(Question 35/8)

(1982-1986-1990)

1. Introduction

1.1 Question 35/8 seeks to study what efficiency can be achieved in the radiodetermination service through the use of interference suppression techniques for radar stations (DECIDES 1), information on the technical characteristics of radar (DECIDES 2) and what radiodetermination services can utilize interference suppression techniques effectively (DECIDES 3).

1.2 This Report examines aspects of the Question relating to interference reduction techniques for maritime radionavigation shipborne radars, fixed radars in the radiodetermination service, and maritime radar beacons (racons) in the case involving unwanted signals from aeronautical radar beacons (ARBs).

1.3 The millimetric waveband between 30 GHz and 150 GHz is examined for the purpose of providing a general review of the likely use of this part of the spectrum for radar purposes.

2. Interference reduction : general

2.1 There are a number of methods to reduce mutual interference and enable stations of the radiodetermination service in close proximity to use the same frequencies.

Some of these techniques applicable to:

- shipborne radars;
- fixed radars; and
- frequency sharing between ground-based aeronautical and maritime radar beacons in the 9300 to 9320 MHz band are outlined below.

The techniques, however, are not necessarily interchangeable between categories; while interference suppression methods described for shipborne radars may be applicable to fixed radars on a case-by-case basis, the reverse is not necessarily true.

2.2 Techniques that might be capable of reducing radar-to-radar interference can be divided into the following groups:

- those techniques applied to a radar transmitter which reduce the quantity of unwanted signals generated that are likely to cause or create interference (primarily shipborne interference suppression);
- those techniques applied to a radar receiver which reduce the effects of any signals that cause or create interference (primarily shipborne interference suppression);
- those techniques applied to a radar receiver which allow it to discriminate between wanted and unwanted signal pulses (primarily fixed radar or aeronautical radar beacon interference suppression).

* The Director, CCIR, is requested to bring this Report to the attention of the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO) and the International Association of Lighthouse Authorities (IALA).

3. Interference reduction methods : shipborne systems

3.1 Techniques which are in principle capable of contributing to the reduction of radar-to-radar interference between shipborne primary radar systems can be used separately or together to reduce either the generation of interfering signals (or their strengths) by the user, or the effects of interference on the user. Methods which may be applied include:

- pulsed magnetron transmitted spectrum,
- transmitter modulator – and transmitted radio frequency – pulse profile,
- radar spurious emissions,
- radar receiver selectivity,
- video processing,
- random pulse repetition frequency,
- antenna gain and sidelobe performance.

3.2 Pulsed magnetron transmitted spectrum

Magnetrons employed in maritime radar systems may be expected to have a spectral bandwidth that is never better than 10 to 13 dB down from peak at

$$\pm \frac{5}{4 \times \text{Pulse Width } (\mu\text{s})} \text{ MHz}$$

from natural centre frequency and will still be no better than about 26 dB down at ± 100 MHz from centre frequency at X-band (about 9 GHz). When this is related to the bandwidths allocated to maritime radionavigation systems at X-band and also to the vast and increasing number of operating systems on that band it is clear firstly, that any contribution to reducing the spectral emission from such magnetrons would tend to reduce levels of radar to radar interference and secondly, that there is considerable scope for dramatically reducing the current bandwidths and levels of spectral emission - even to the costly alternative of changing from magnetron devices to, for example, klystrons. In any case reducing bandwidths and levels of spectral emissions in one type of radar transmitting equipment will always improve the performance of associated receivers and will reduce interference to other radar users.

3.3 Transmitted pulse profile

Techniques are available to control the profile of transmitted pulses. Radar range accuracy is largely dependent on the slope of the transmitted radar pulse leading edge. Thus, if there is a requirement for a given range accuracy this will control the minimum necessary pulse rise time. Shortening the rise time beyond that necessary value will involve transmission of sideband energy that:

- will not be used by the originating radar, and
- will cause interference to other radars.

The pulse leading edge should only be as short as is absolutely necessary to generate the required range accuracy.

A complementary argument applies in relation to range discrimination requirements. This is largely dependent on the slope of the pulse trailing edge (and also on pulse length). A requirement for a given target range discrimination will be a control on the minimum necessary pulse decay time and also on the pulse length. Shortening the pulse decay time beyond that necessary value will involve transmission of sideband energy that:

- will not be used by the originating radar, and
- will cause interference to similar radars.

The pulse trailing edge should only be as short as necessary to provide the required range discrimination.

At present the spectral profile of primary radar transmissions extends a long way in both directions from the centre frequencies of the transmissions. Only a limited proportion of this energy spectrum is used by the associated radar receivers, and the remainder need not be transmitted.

3.4 *Radar spurious emissions*

Pulsed magnetrons generate radio energy on spurious frequencies. These rarely bear any relationship to operational frequencies. These spurious emissions can be controlled by transmitter design. Interference could be reduced if acceptable levels were agreed on an international basis.

3.5 *Radar receiver selectivity*

There is a minimum receiver bandwidth required once range accuracy is specified. Other considerations, such as minimization of the effects of sea clutter, and requirements for automatic frequency control (AFC) have led to the design of receivers with special characteristics which require wider bandwidths than those resulting from only the range accuracy requirement. Such receivers are therefore more susceptible to interference from other radar transmissions. It would be possible, in principle, to specify minimum bandwidths. Beyond this bandwidth, receivers should reject heavily as much radiation as possible since it is not required. This could be achieved by using existing techniques.

3.6 *Video correlation and other video processing techniques*

Radar receiver video correlation techniques may be applied to minimize the effects of some types of interference. Video echo information received from one (i.e. own) radar pulse is recorded. Video echo information received from the next succeeding, (own) radar pulse is then recorded and also compared with previously recorded echo data.

Several such systems are in practical maritime use. The main limitation of this technique is that it is not effective against sea clutter because such radar returns correlate over periods that are long compared with typical radar pulse repetition intervals. There is also some slight risk of reducing the capability to detect weak echo signals.

Another significant limitation of this technique is that it will inhibit the response of stepped sweep racons (see § 2.1.2 of Report 774) commonly used by the United States of America. The response from a stepped swept racon would normally remain on a shipborne radar screen longer than would a response from a slow sweep racon. But since the radar would receive at most only every fourth racon pulse transmitted, a radar using video correlation techniques would inhibit the response from the racon.

Video processing using differentiation circuitry, such as the anti-clutter rain control of constant false alarm rate (CFAR) circuitry, is also useful in limiting unwanted interference. Such techniques, however, display only the leading edge of a racon response. Unless the racon is a fast swept version (a type difficult to encode with a Morse identifier, and limited to only a few installations), the Morse identifier would not be discernible on the display of a shipboard navigation radar using this video processing technique, and in many cases the response would not be visible on the display at all. Note that this limitation when using differentiation circuitry would exist for nearly all racons operating world-wide today.

A means whereby such loss of a racon response can be avoided would be to modulate the first racon pulse with a unique code and to detect the code at the IF of the radar, thus bypassing the video processing circuits. The details of such a system are being investigated in the United Kingdom (see also § 5 of Report 774).

3.7 *Random pulse repetition frequency*

The use of a jittered or pseudo-random variation in the pulse repetition frequency (PRF) could reduce radar-to-radar interference, if used in association with the video correlation techniques already described. By applying pseudo random variation to the radar pulses the time relation between them and any pulses received from any other radar in a potentially interfering configuration will be made random, and therefore the suppression action of the video correlation process will ensure that only a small proportion of the interfering pulses are displayed. If the video correlation is extended to 3 successive pulses the probability of an interfering pulse being displayed is very small indeed.

The principle is theoretically constrained, at least, in this application in two respects:

- the maximum PRF will be limited by the range scale selected;
- the minimum PRF will be limited by the need to avoid unacceptable loss of information. A jitter ratio of about 2 : 1 represents the theoretical scope safely available.

Systems incorporating this pseudo-random technique are not known to be in use at this time, although variable PRF techniques are already applied for other reasons. The only operational constraint is, as mentioned above, a slight but controlled reduction in the rate of information received.

3.8 *Antenna gain and sidelobe performance*

3.8.1 Typical present radar antenna performance is approximately:

- gain: ~ 24-30 dB;
- first major sidelobe level within $\pm 10^\circ$ of antenna boresight: more than 23 dB down on mainlobe;
- all other sidelobes more than $\pm 10^\circ$ from antenna boresight: more than 30 dB down on mainlobe.

3.8.2 The above performance can be improved to:

- gain: 40 dB;
- first sidelobe: 33 dB down on mainlobe, (gain = 7 dB);
- all other sidelobes: more than 40 dB down on mainlobe, (gain = 0 dB).

This design of antennas for shipborne use would involve an increase in size and weight and would necessitate considerable tightening of all mechanical tolerances. This would restrict application to larger vessels. It is also open to question whether the associated narrower main beam widths are advantageous e.g. with regard to sea clutter.

In addition, the improved antenna and associated receiver do not improve the performance of the antenna and receiver combination in the ability to reject interference from other radars.

3.8.3 A similar performance to that in § 3.8.2 has been attained by using sidelobe reduction techniques on the type of antenna in § 3.8.1, which would largely obviate the penalties mentioned in § 3.8.2.

3.8.4 To obtain the advantage of the last two antenna designs (see § 3.8.2 and 3.8.3) it would be necessary to reduce transmitter power to achieve the same e.i.r.p.

3.8.5 *Summary of shipborne interference reduction*

Table I lists the forms of interference reduction techniques described above and offers an indication of possible advantages and disadvantages. None of the techniques identified will cause significant loss of system sensitivity. However, certain techniques cause the loss of the display of radar beacon signals and of small targets. It is desirable in these cases for operational reasons to provide the capability for switching out the interference rejection circuitry. In specific instances, techniques in isolation or in combination could improve either sensitivity and/or range accuracy and/or range discrimination. This brief review of techniques available implies that several methods exist that could contribute to the reduction of interference. Some may appear unattractive for a variety of non-technical reasons. An important technical criterion of any method is that its use should preserve unimpaired the compatibility between all systems. In only one instance (see § 3.8), would an interference reduction technique limit future use of an assigned frequency. The narrower the antenna beam width (i.e. the higher the gain) the narrower becomes its usable bandwidth. This would prevent the use of a directive antenna for concurrent use with a radar beacon and/or shipborne transponder system operating at frequencies only about 3% away from own radar frequency.

TABLE I – *Interference reduction for shipborne mobile radars*

Interference reduction technique	Ease of use and operation	Reliability	Maintenance	Switched off when not in use	Remove beacon responses	Long term potential	Limitation of broadband use
1 Controlled transmitted pulse leading edge	E	NK	NE	NA	no	yes	no
2 Controlled transmitted pulse trailing edge	E	NK	NE	NA	no	yes	no
3 Reduce spurious emissions	E	NK	NE	NA	no	yes	no
4 Improve/substitute magnetron	E	NK	NE	NA	no	yes	no
5 Improve radar receiver selectivity	E	NE	NE	NA	no	L	no
6 Video correlation techniques	E	NE	SI	yes	L	yes	no
7 Random pulse repetition frequency	E	NE	SI	yes	no	yes	no
8 Improve antenna gain/sidelobes	E	NK	NE	NA	L	L	yes

E : easy
 NK : not known
 NE : no significant effect
 SI : slight increase (additional circuits)
 NA : non-applicable
 L : limited

4. Interference reduction methods: fixed radar systems

4.1 Pulse repetition frequency discrimination

4.1.1 In some areas of the world which have a high density of ship or aircraft traffic there is a need to operate several fixed radar installations within interference range of each other. Anomalous propagation conditions can, at certain times, increase the range at which interference occurs, particularly in lower latitudes such as the Mediterranean region.

4.1.2 Some of the techniques described in § 3 above, may be applied to reduce interference between fixed radar stations. Another technique involving pulse repetition frequency discrimination is described below.

4.1.3 Interference between fixed radar stations may be avoided by radio frequency separation or pulse repetition frequency discrimination (PRFD). The frequency band allocated to radio navigation may not be wide enough to assign separate frequency channels to all stations within interference range. This is particularly so when the radar stations are mobile, as on ships or aircraft.

4.1.4 The effect of interference may be reduced if the pulses radiated from a radar can be given some characteristic such that only those received pulses conforming to this characteristic are displayed on the radar screen. By using different PRFs for different stations it can be arranged that a signal is only displayed when two successive pulses with the correct time delay are received back from a target. This method has been used successfully in the network of 600 MHz radar stations used for air traffic control purposes by the Civil Aviation Authority in the United Kingdom.

4.1.5 The methods for selecting suitable PRFs have been published [Blythe, 1970]. The selection is complicated because such radar stations use Moving Target Indicator (MTI) to differentiate between radar reflections from fixed or slowly moving objects, such as buildings and clouds, and those from rapidly moving aircraft which are required to be seen even in the midst of "clutter". Such MTI methods use phase comparison between successive reflected pulses to cancel out signals which are returned with the same phase relationship to the transmitted pulse. Unfortunately, as well as cancelling reflections from stationary objects, reflections from targets moving with certain radial velocities are also cancelled, and aircraft moving at these blind speeds are not displayed by the radar. To avoid loss of these targets the radar pulses are not emitted at a regular rate, but two or more different intervals are used in the train of pulses. This is known as pulse stagger.

4.1.6 The planning of the radar radio frequencies and the pulse repetition rates for both pulse stagger and PRFD will depend upon the relative locations of the radar stations and the propagation conditions in the area. By using PRFD the number of stations working without interference can be considerably increased and thereby the spectrum may be more economically used.

4.1.7 Taking these techniques into consideration, it was possible in the United Kingdom to plan to operate a number of high-power 50 cm radars in a relatively narrow frequency band; for example, seven such radars operate on the frequency of 591 MHz and five on the frequency of 597 MHz. These techniques also enable two high-power radars to operate at the same airport, and in the same frequency band, without unacceptable interference.

4.1.8 In the 600 MHz radar band, PRFD has been used in the United Kingdom to avoid the need to expand the spectrum required, and to enable the required number of radars to work in the restricted allocated band without causing unacceptable interference between themselves or to television reception in other countries.

4.2 Limit of permissible interference to a radar scope displaying raw video

There is no method to completely suppress interference without any degradation of detection probability, so it is important to know what level of interference can be allowed. Of course, an allowable interference level is very much dependent upon subjectivity of ATC controllers, then a consensus of ATC controller's opinions against the following radar scope samples is derived as a common measure:

FIGURE 1 - Some interference as like as "dotted lines" at a same direction can be seen on a scope by once per some several minutes

