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).

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* 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 psuedo 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 ± *10° of antenna boresight:* more than 23 dB down on mainlobe;
- all other sidelobes more than ± *10° 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

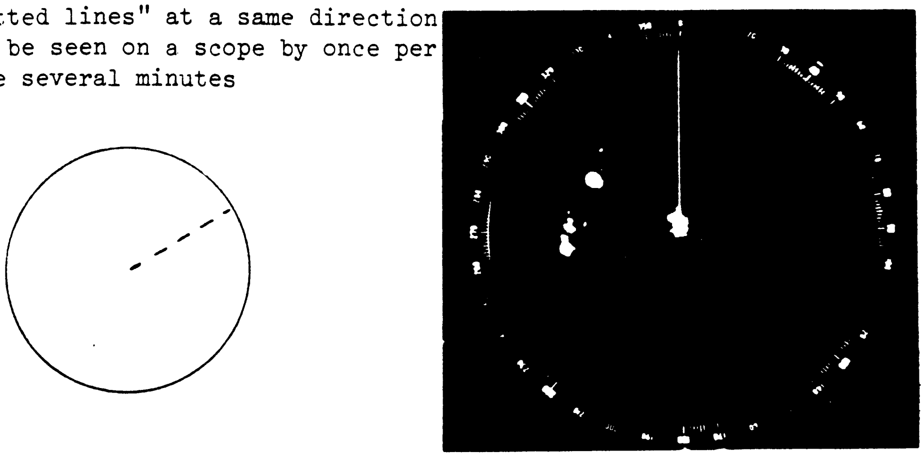
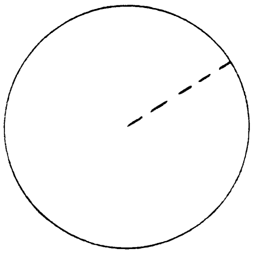


FIGURE 2 - Similar as Fig. 1, but a rate increases by once per several scans (some 10-30 seconds)



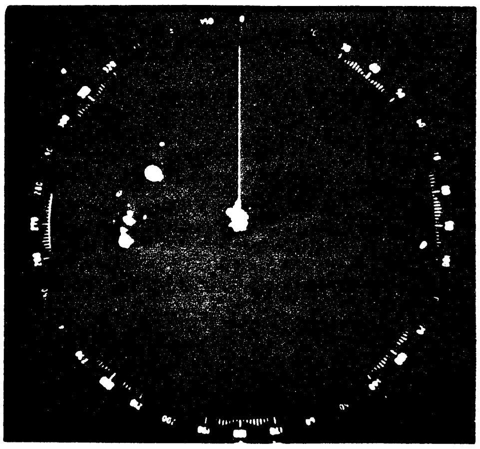


FIGURE 3 - One interference as like as "dotted lines" can bee seen at a same direction and another interference at an undefined direction by every scan

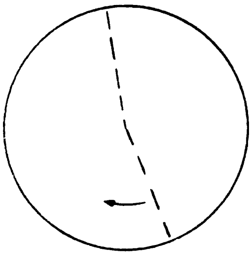


FIGURE 4 - "Dotted lines" can be seen at a same direction and another undefined direction by every scan and an interference centred at other direction spread out some 30-40 degrees sector can be seen by some several scans

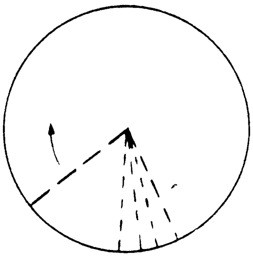
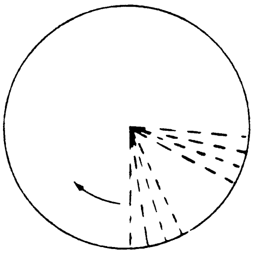


FIGURE 5 - Interferences centred at a same and an undefined direction are spread out some 30-40 degrees by every scan



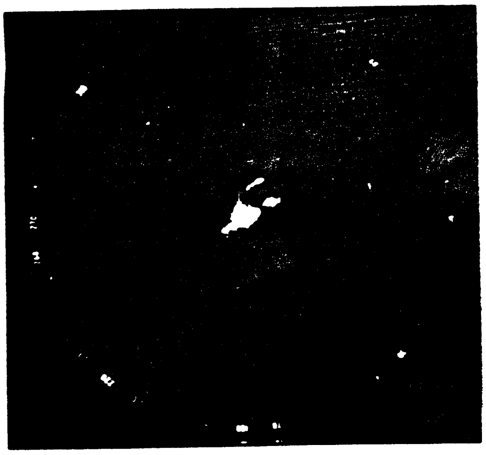
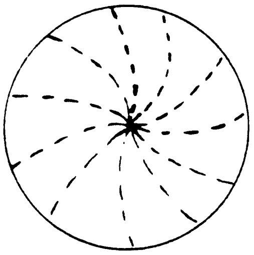
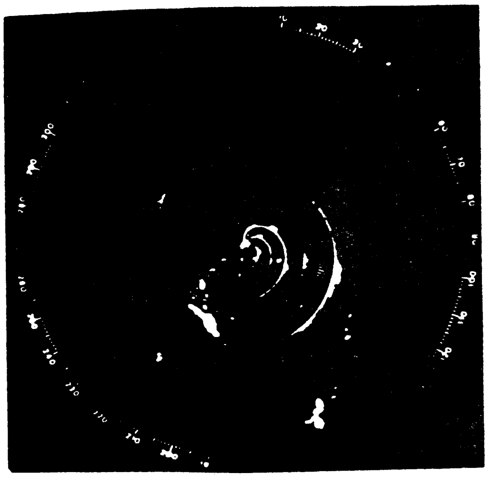


FIGURE 6 - Interferences can be seen almost everywhere on a radar scope





In Japan, examples of Figs. 1 to 6 have been shown to more than 200 ATC Controllers. According to their answers, it was concluded that Figs. 1 and 2 present the limit of permissible interference to a radar scope displaying raw video.

In some countries, most of the ATC radars employ processed video. Raw video is not displayed on the scope. For these types of radars, controller opinions are not appropriate nor reliable indicators of interference determination.

4.3 Frequency domain reduction techniques of radar interference

It is important to know that the frequency domain interference rejection techniques are primarily important, because, the interference signal itself can be suppressed, on the contrary, the time domain techniques so called AIRT can only reject the received interference pulses.

In this connection, before applying time domain techniques such as AIRT, the frequency domain techniques and the combination of both should be considered.

4.3.1 Spurious emission levels of transmitter tubes

The inherent spurious emission levels of a radar transmitter are generally dependent upon the essential characteristics of the radar output tube type.

It is important to know the inherent spurious emission levels and variances for the different types of transmitter output tubes in order to assess the potential for interference between radars. This information is important in identifying microwave radar tube types ~~which~~ promote efficient use of the spectrum and as a parameter in interference prediction.

The microwave radar tube inherent spurious emission noise generally dominates at frequency separations greater than 100 MHz from the radar operating frequency. Thus, at frequency separations of greater than 100 MHz the radar emission spectrum is independent of radar system characteristics such as the pulse modulation parameters (e.g., rise/falltime, CW pulsed, chirped pulsed or phase coded pulse). Based on measurements [1] in several radiodetermination bands between 1.25 and 10.5 GHz and a review of tube characteristics with major microwave radar tube manufacturers, the inherent spurious emission level for the various types of microwave tubes used by radars is as follows:

TUBE TYPE	SPURIOUS EMISSION LEVEL RELATIVE TO THE CARRIER MEASURED IN A 1 MHz REFERENCE BANDWIDTH (dBc)
CROSS FIELD	
Cross Field Amplifiers (CFAs)	-40 to -70
Magnetrons (unlocked)	-65 to -80
Magnetrons (locked)	-75 to -90
Coaxial Magnetrons	-60 to -75
LINEAR BEAM	
Coupled Cavity TWTs	-105 to -115
Klystrons	-110 to -120

Additional attenuation of spurious emission levels can be achieved through the use of radio frequency (RF) bandpass filters. With the use of RF bandpass filters, the spurious emission levels of CFAs, magnetrons and coaxial magnetrons can be reduced below -100 dBc.

[1] Hinkle, Robert L., Background Study on Efficient Use of the 2700-2900 MHz Band, NTIA Report 83-117, August 1983, NTIS # PB 83-214288.

4.3.2 Applicable filtering devices

There are many applicable filters for transmitting and receiving. The transmission filters are primarily effective, of course, the insertion loss of the filtering devices should be taken into account as a degradation of the detection probability.

It should be noticed that in some cases the out-of-band emission level of a radar is higher than expected at another radar frequency. In this case, the preselector of another radar that is interfered with is no longer a key device except image rejection effect, because, out-of-band emission component of a radar at another radar frequency is received without any attenuation by the preselector.

4.4 *Asynchronous interference reduction techniques for fixed radar systems*

4.4.1 *Introduction*

The transmitter emission spectrum of a pulsed radar station in the radiodetermination service is usually much wider than the spectrum of general communications systems. It is sometimes very difficult to achieve interference-free operation between stations by frequency assignment procedures alone when such stations are within a certain range of each other. Consequently, in addition to frequency assignment procedures, interference reduction techniques are required to achieve interference-free operation. A type of interference reduction technique used in air traffic control (ATC) radars operating in the aeronautical radionavigation service is described herein.

4.4.2 Interference reduction techniques in the time domain are considered to be the most practical for ATC radars when considering the present ATC technology in the world and when comparing techniques in the frequency domain, time domain and mixtures of methods of both time and frequency domains. The Asynchronous Interference Reduction Techniques (AIRT) as described herein are in the time domain. They are utilized in Japan where their effectiveness is recognized. Peripheral techniques used to increase the effectiveness of the AIRT are also described.

4.4.3 *AIRT description*

Desired return data signals of a radar are received in the same range (or time) within a certain azimuthal angle while interfering signals from other radars are generally asynchronous to the desired return signals. Consequently, desired return signals can be extracted, for example, by storing the return data signals of two to four desired radar pulse periods. Such return data signals are stored in a memory and used to perform range (or time) correlation of the stored data and the latest return data signals. A description of the AIRT system used in the simulation study described herein is presented in Annex I.

4.4.4 *Factors impairing AIRT performance and improvement measures*

4.4.4.1 *AIRT performance deterioration*

The prerequisite for effective performance of the AIRT circuitry is to limit the width of a pulse signal entering the circuitry to a specific value or less. When this condition is not met and the pulse width is greater than the limited value, the required time correlation of the asynchronous signals will be increased and the effectiveness of the AIRT will decline. This is due to the wide pulse width and the excessive intensity of the interfering signal.

Figure 7 shows the relationship between the interfering signal intensity (relative to mean noise level) and the output pulse width. Figure 8 shows the block diagram of the measurement circuit. The simulation of the deterioration of the AIRT performance caused by the wide pulse width was conducted by using the signals shown in Fig. 9 In this case, the pulse width in space for both the desired signal and asynchronous interfering signal is assumed to be one microsecond. As a result of this simulation, the boundaries causing interference are indicated by the solid line shown in Fig. 10a and 10b.

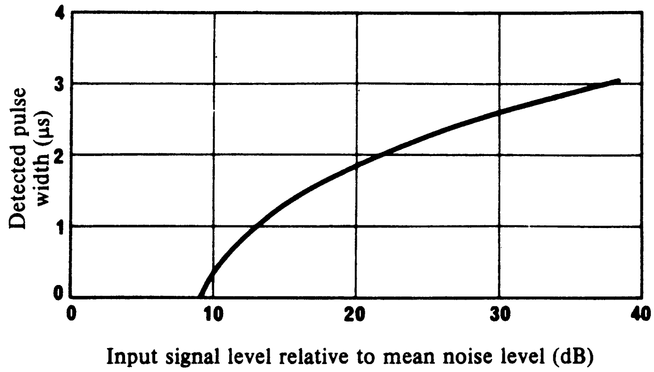


FIGURE 7 – *Detected pulse width versus input signal level*

FIGURE 8 – *Measurement circuit*

A: pulse modulated signal input, 1 µs
B: matched filter
C: threshold circuit, 10.8 dB relative to average noise level
D: detected pulse output

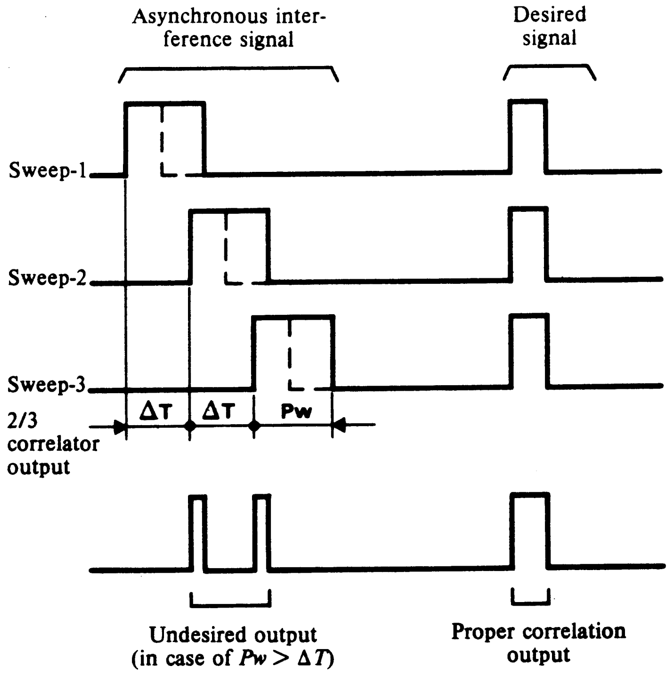


FIGURE 9 *–The restriction of interference suppression*

T: difference between desired signal pulse period and interference pulse period.

Pw: detected pulse width that is the function of interference signal strength as shown in Fig. 1. (The limited width waveform by the pulse width discriminator is illustrated in dashed line.)

4.4.4.2 *Alleviating AIRT performance deterioration*

In order to alleviate the AIRT performance deterioration produced by overly wide pulses, it is necessary to perform a pulse width discrimination before AIRT signal processing. Such pulse width discrimination is provided by the Moving Target Indicator (MTI) circuitry. The interfering signal is shaped into a specific width regardless of the input signal pulse width or level. Examples of the shaping circuitry are the Fast Time Constant (FTC) circuit and the Logarithmic/Constant False Alarm Rate (Long/CFAR) circuit. This pre-processing effect, as shown by the dotted line in Fig. 10a and 10b ensures the effective operation of the AIRT when the interfering signal exceeds a certain pulse width or level.

4.4.5 *Techniques for improving AIRT performance*

4.4.5.1 *Reducing the degree of correlation*

The AIRT provides interference reduction by using the time (or range) correlation between the desired received signals and the interfering signals that are asynchronous to them. The AIRT performance can be improved by reducing the degree of correlation between the desired and interfering signals without deteriorating the minimum detectable signal level of the desired signals.

4.4.5.2 *Staggered PRF*

In order to improve the velocity response of the MTI, the ATC radar varies (at a certain ratio) the time interval between transmitted pulses. This is called staggering the pulse repetition frequency (PRF). If either of two radar stations provided with this staggered PRF reverses the sequence of the staggered pulse interval between them, the degree of correlation between them will decline, thereby increasing the AIRT performance.

4.4.5.3 *Increasing the number of samples of correlation*

Increasing the number of samples of correlation will increase the effect of the range correlation filter. For example, simulation was performed for the case where desired signals are those that are correlated two or more in three samples, and for the case where desired signals are those that are correlated three or more in five samples. The effect of the filter technology proved to be better in the latter case. The results are shown in Fig. 10a and 10b.

4.4.5.4 Degradation of target detection probability when applying AIRT

It is evident that there is no AIRT, which has no degradation of the target detection probability, because of second thresholding by majority voting and coincident pulses.

A simple (worst case) estimation of degradation factor is made, if we use a conventional majority voting of 2/3, then this factor would be up to 4.8 dB. Because, the required one pulse S/N will be 14.8 dB for AIRT, on the other hand, 10 dB is required for a normal video integrator.

4.4.5.5 An improvement of target detection probability on an AIRT

Some improvement can be expected was applying the following technique on an AIRT, which generally has double thresholding of the amplitude and the voting.

If majority voting is modified as below, some improvement in weak target detection can be achieved.

Case 1: "2/3 voting" ---------- Output condition <u>0/3</u>, 2/3, 3/3
Case 2: "3/5 voting" ---------- Output Condition <u>0/5</u>, 3/5, 4/5, 5/5

These modifications may improve the target detection probability, however, weak interference may not be suppressed.

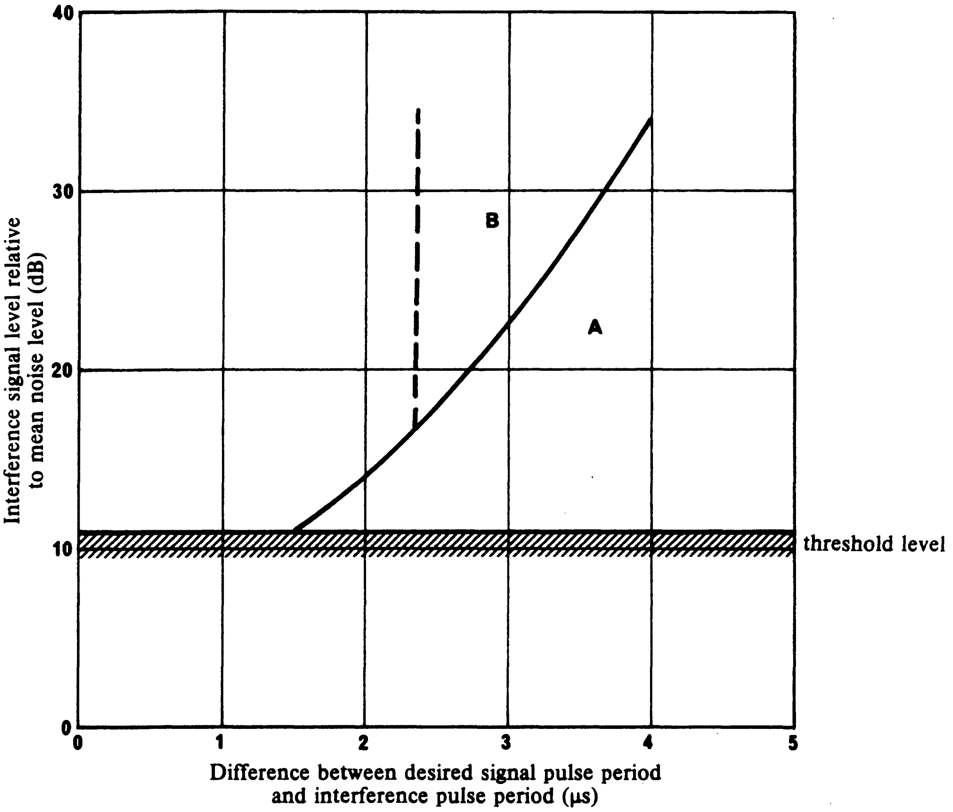


FIGURE 10a – *The suppressed regions for interference signals by 2/3 correlator*

A: suppressed region without pulse width discriminator
A + **B**: suppressed region with pulse width discriminator

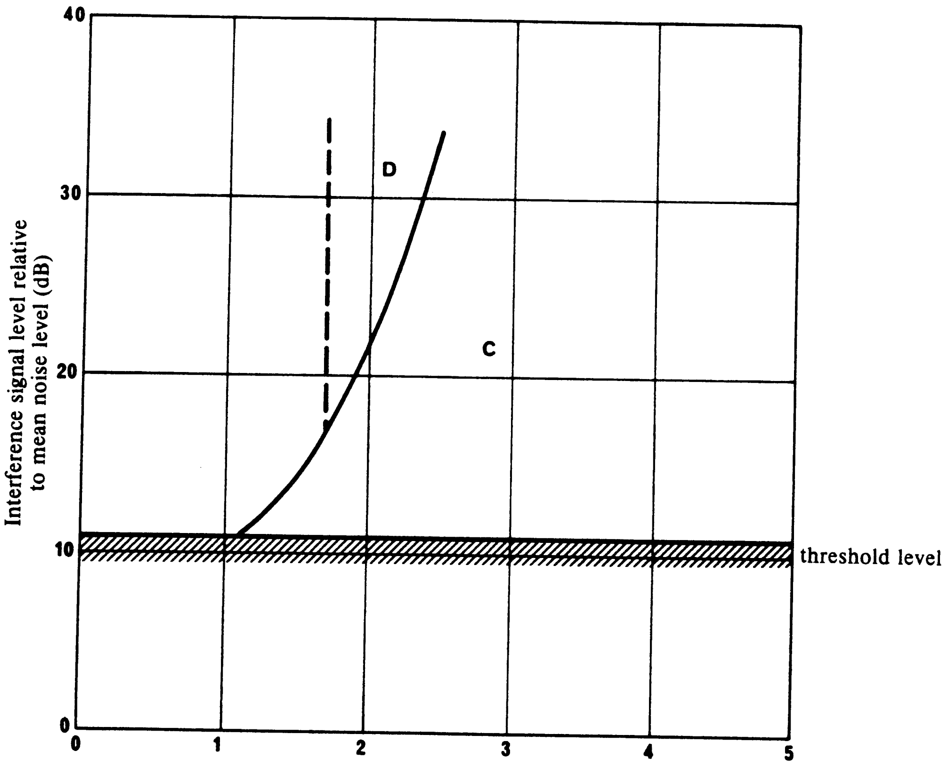


FIGURE 10b – *The suppressed regions for interference signals by 3/5 correlator*

C: suppressed region without pulse width discriminator
C + D: suppressed region with pulse width discriminator

4.5 *Summary of fixed radar interference reduction*

4.5.1 *Pulse repetition frequency discrimination*

The technique of PRFD could be used in other frequency bands to improve the spectrum utilization and could, in principle, also be applied to pulse radar applications other than those described in this document. The application of the PRFD technique must be considered with other desired signal performance factors such as receiver sensitivity. In the case of mobile radars the benefits are limited by the impossibility of predicting the relative position of radars using the same pulse repetition frequency.

4.5.2 *Asynchronous interference reduction techniques*

4.5.2.1 The AIRT utilizing the asynchronous nature of interfering signals are extremely effective in ordinary ATC radar systems.

4.5.2.2 The following are required for improving the effect of the AIRT:

- provision of a pulse width discriminator before performing the processing by the AIRT,
- providing a function of reversing the staggered PRF sequence in the MTI radar having a staggered PRF,
- increasing appropriately the number of samples of the correlator of the AIRT.

5. Interference reduction methods: radar beacons

5.1 Maritime radar beacons (racons) operate in the 9300-9320 MHz band. Ground-based aeronautical radar beacons (ARBs) share this band on a non-interference basis to maritime radar beacons. An aeronautical radar beacon is a receiving and transmitting device operating at a fixed location for the purpose of aeronautical radionavigation. When triggered (interrogated) by an airborne radar, the ARB acts as a transponder and automatically identifies itself by returning a distinctively coded signal.

5.2 As stated in the Radio Regulations No. 825, ground based radar beacons are permitted in the band 9300-9320 MHz on condition that they do not cause harmful interference to the maritime radionavigation service. If interference suppression techniques are used, harmful interference to maritime radars from ARBs can be avoided.

5.3 Signals from an ARB could be intercepted by shipborne radars which are expecting to receive maritime racon signals on the same frequency. This may result in unwanted displays or degraded performance of the shipborne radar unless special measures are taken. Several techniques for spectrum sharing were considered in an analysis of compatibility between the ARB and the maritime racon. Among these techniques are: separation of frequencies, pulse coded interrogations, pulse repetition frequency (PRF) discrimination, geographical separations, antenna polarization discrimination, antenna vertical pattern control, and pulse width discrimination. The method that was determined to be the most economical and technically feasible was that of pulse width discrimination. There are two ways by which a maritime radar could receive signals from an ARB. The maritime radar could trigger the beacon and receive a synchronous reply, or another radar could trigger the beacon and the maritime radar could receive an asynchronous reply. The synchronous reply is a more serious interference problem but it can be avoided by pulse width discrimination.

5.4 The ARB will distinguish between aeronautical and marine radars by using this pulse width discrimination method. Maritime radars in the 9300-9500 MHz band operate with pulse widths of less than 2.0 µs. Aeronautical radars will interrogate ARBs with pulse widths of 2.35 µs. This difference will allow the ARB to use pulse width detection circuits to discriminate between the two types of radars.

5.5 As a result of the radar discrimination process, interference will be diminished because marine radars will not trigger aeronautical beacons and, therefore, will not receive unwanted replies. However, a marine radar may receive an asynchronous ARB signal if the beacon is first triggered by an aeronautical radar. This situation requires both radars to be within certain distances of the ARB at the same time. This rarely-occurring situation should considerably reduce the chance of interference. Also, ARBs and maritime racons are coded differently for identification purposes. This coding will allow processing in the marine radar to prevent falsely identifying an ARB as a maritime racon.

5.6 Apart from the techniques used by the ARB for interference reduction, several methods for promoting compatibility are discussed in Report 774, "Technical parameters of fixed frequency radar beacons (racons)".

5.7 *Summary of interference reduction ARB to racon*

5.7.1 As stated in the Radio Regulations, the aeronautical radar beacon operates in the band 9300 to 9320 MHz. It is greatly needed for helicopter navigation in poor weather and in many critical landing areas.

The ARB is in agreement with the frequency allocations of the Radio Regulations. The technical parameters for ARBs were developed considering operational performance in varying weather conditions, as well as compatibility with maritime racons. Frequency sharing between the aeronautical and maritime beacon systems will require careful planning to ensure compatible operations. Pulse width discrimination and discrete beacon coding for identification provide methods of achieving compatibility with maritime racons.

6. Characteristics of future radar equipments

6.1 Question 35/8 (see § 2) seeks information on the technical characteristics of radar. This section examines the millimetric waveband between 30 GHz and 150 GHz and provides a general review of the likely use of this part of the spectrum for radar purposes.

6.2 *Advantages and disadvantages of millimetric wavelengths for radar*

6.2.1 The main advantages of working in the millimetre wavelength region are:

6.2.1.1 The fact that relatively small antenna apertures can give high values of gain and very narrow beamwidths, the latter allowing good angular resolution and minimizing the unwanted effects of ground reflections and ground clutter even at quite low angles of elevation.

6.2.1.2 The large spectrum widths available, compared with those permitted at lower frequencies, allow excellent range resolution to be obtained. In addition, for the longer term, it will often be possible to have many radars in a band, all in close proximity geographically and even perhaps having frequency agile transmitters, without incurring serious mutual interference.

6.2.1.3 A lower probability of interference to other services because of the atmospheric attenuation effects and the narrow beamwidths likely to be used.

6.2.2 The principal disadvantages of these wavelengths for radar, many of which would also affect other possible applications in this region are:

6.2.2.1 The residual attenuation in clear air, especially for propagation at sea level, which is present even in the "windows" where most radar applications are likely to be located. (See Reports 719 and 721.)

6.2.2.2 The high additional attenuation, and the large amount of radar back-scatter, in rain, even of low intensity (though the narrow antenna beamwidths and good range resolution usually employed will help reduce the effects of the back-scatter). This characteristic would be likely to make these bands unsuitable for long range airborne weather radars.

6.2.2.3 With very narrow beams (which are more likely to occur in these bands, see § 6.2.1.1), it becomes more difficult to make the compromise between the number of pulses per illumination and the data renewal rate for continuously scanning radars, even with the higher PRF's which can be used in short range equipments.

6.2.2.4 The limited performance of many active and passive components. As a rough general rule the peak powers obtainable from a given type of transmitter tube are reduced in proportion to at least (wavelength)^2, and the problems of removing unwanted heat can mean an even more rapid fall in mean power; the receiver noise factors tend to increase with frequency, and attenuation losses in waveguide etc. become more and more significant.

6.2.2.5 The relative cost of components is currently higher than those for longer wavelengths, principally because of the high mechanical precision needed in their manufacture (though limited production volume is a factor).

The factors in § 6.2.2.1 to 6.2.2.4 above, mean that nearly all potential applications at millimetre wavelengths will be in relatively short range systems.

6.2.3 *Some possible applications of radar in the millimetre wavelength bands*

For the present purpose the potential future applications for radar in the millimetre wavelength region may be classified under four headings:

6.2.3.1 Ground radars such as airfield surface movement indicators taking advantage of the high angular ($\approx 0.1°$) and range resolutions obtainable at these wavelengths. They would be used continuously and with antenna rotation times typically in the order of a few seconds.

6.2.3.2 Certain airborne radar systems such as those for terrain following, and for obstacle and power-line avoidance in helicopters; they would utilize the good angular resolution (≈ 0.5° to 1°) obtainable with antennas of moderate size, and sector scan times would be in the order of 1 s or less. Another possibility is the high resolution (≈ 0.1°) sideways-looking (i.e. non-scanned) airborne radar for ground mapping, etc. Except perhaps in a few areas, for example near heliports, these would probably cause only relatively infrequent interference with other equipments on the same frequency.

6.2.3.3 A small number of ground radar applications such as short-range surveillance, tracking and guidance systems, the latter taking advantage in particular of the reduction of ground reflection effects etc. down to low angles of elevation which is made possible by the narrow antenna beamwidths (≈ 0.2°). The probability of these interfering with other equipments would seem to be small.

6.2.3.4 A very few extremely powerful systems for space tracking, planetary radars and similar purposes, with large antennas having high gain (≈ 80 dB) and very narrow beams (≈ 0.02°), and high power transmitters. These would not be scanned continuously but would be pointed in directions well above the horizontal so that atmospheric attenuation effects are kept to a minimum.

6.2.3.5 A few other possible very low power radar-like devices such as millimetre wave "security fence" type systems, motorway headway detectors etc. might also use these frequencies. However, with their low e.i.r.p.s and very restricted coverage it is unlikely that they would ever cause a significant interference problem, except in the vicinity of extremely sensitive receivers such as those used in radioastronomical observatories.

6.2.4 It is seen that there will probably be a wide diversity of millimetre wavelength radar systems, and radar parameters will depend very much upon the application. Thus very short range radars usually will have relatively modest antenna gains (≈ 30 or 35 dB) and low transmitter powers provided by solid state sources; "medium" range systems may have antenna gains in the order of 40 to 50 dB (i.e. about 1° beamwidth) and magnetron transmitters delivering several kilowatts of peak and a few watts of mean power, while the space radars will often require $G_T \approx$ 80 dB and high power gyrotron transmitters.

6.2.5 The only common features will be that all radars will have quite short pulse lengths (in the order of 0.1 μs or less), or will obtain the equivalent good range resolution by using pulse compression techniques, so that the maximum spectral power density will tend to be comparatively low, and also that pulse recurrence frequencies will always be quite high. Depending mainly on the maximum range of the radars, the PRF's will be 3000 pps or more; the exceptions will be the space radars, but even here a high order of range ambiguity will be accepted.

6.2.6 *Summary of probable transmitter power capability at millimetre wavelengths*

6.2.6.1 The most promising form of pulsed sold state transmitter device appears to be the IMPATT diode. Because of heating effects during the pulse, it is thought that at around 100 GHz the highest power likely to be obtained from a single device in the foreseeable future will be in the order of 10 W peak, the maximum pulse length being limited to about 0.1 μs. It will, of course, be possible to obtain higher powers at longer wavelengths, and by combining the power from several diodes it is probable that at any frequency something like 5 times the power output of a single device will be obtained.

6.2.6.2 Performance of vacuum tube type transmitters is best summarized by giving the power levels already achieved in different frequency bands. Except where noted, the pulse length for pulsed transmitter tubes will be less than 1 μs; the frequencies and power levels quoted are only approximate.

Backward wave oscillators (BWOs): More than 50 W CW at 35 GHz; 40 W CW at 75 GHz.

Klystrons: 800 W CW at 55 GHz; 500 W CW in the 80 GHz region. It is also estimated that at about 80 GHz it should be possible to obtain 10 kW peak in 10 µs pulses with up to 0.005 duty ratio.

Travelling wave tubes (TWTs): 1 kW CW at 35 GHz; 150 to 200 W CW, or 5 kW peak, at 55 GHz; 100 W CW or 1 kW peak in the 80 GHz region.

Magnetrons: Up to 100 kW peak at 35 GHz; 5 to 10 kW peak in 50 ns pulses in the 80 GHz region; 2.5 kW peak at 120 GHz.

Gyrotrons: 100 kW CW, or at least 250 kW peak in long pulses with 0.05 duty ratio, at 35 GHz; 50 kW CW at 55 GHz; 15 kW CW near 80 GHz. These devices currently tend to be "noisy".

6.2.6.3 It is seen that in all frequency bands the gyrotron gives the highest powers so far achieved; but it should be remembered that this is a rather large device using megavolt (or near-megavolt) electronics, which could only be accommodated in large fixed radar installations.

6.2.6.4 While it would be rash to assert that no other forms of solid state or vacuum tube type transmitter will be developed for the frequencies of interest here within the next 20 years, it must be remembered that there will always be fundamental limitations to the peak and mean power outputs imposed by device size and heat removal problems. There are also limitations to the peak power levels which can be handled by conventional waveguide at atmospheric pressure (5 kW peak in WR 12 for use between 70 and 90 GHz, for example): these can be overcome to some extent, however, by pressurizing, or by filling the guide with, for example, sulphur hexafluoride gas, or – with care – by using overmoded (that is, oversize) waveguide.

REFERENCES

BLYTHE, J. H. [1970] Separation of radars on common frequencies by pulse-repetition frequency discrimination. GEC J. *Sci. and Tech.*, Vol. 37, **4**, 157.

ANNEX I

1. AIRT system description

A functional block diagram of the AIRT is shown in Fig.8 . Here the input signal is sent to the video switch gate circuit and to the threshold detector. Only a signal having a level above a certain value (for example, mean noise level + 10 dB) is detected by the threshold detector, and sent to the two-staged sweep memory.

Now the latest data A and the two sweep (transmitting period) data are sent to the sweep correlation circuit, which detects the absence or presence of an interfering signal in the same range of the three signals (a specified period after the transmitted pulse), and a gate signal which inhibits the video signal is made only when there is an interfering signal.

This circuitry functions in the same concept for either of the analogue and digital signals.

2. Conditions of AIRT simulation

- The amplitude response of the receiver filter in Fig.11 is assumed to be a Gaussian characteristic;
- the criteria of the AIRT sweep correlation circuit permit correlation for data within the range of 0.5 µs (half the pulse width) before and after (along the time axis) of an input signal in view of the target detectability;
- the threshold level of the threshold detector is to be set at a value that meets the false alarm probability and probability of detection to be specified at the video output.

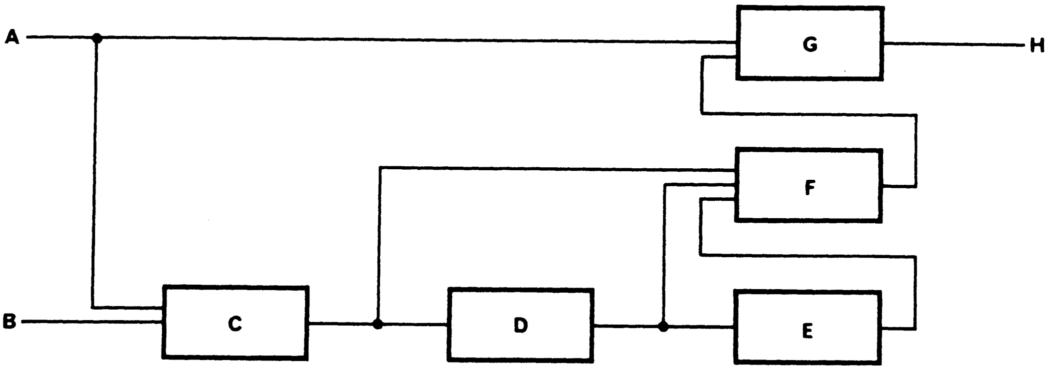


FIGURE 11–*Asynchronous interference reduction circuit block diagram*

A: radar video signal input
B: threshold control data
C: threshold detector
D: sweep memory
E: sweep memory
F: sweep correlation
G: video switch
H: radar video signal output

REPORT 1039*

PRESENT AND EXPECTED USE OF THE BAND 9320-9500 MHz BY MOBILE RADARS OF THE RADIONAVIGATION SERVICE

(Question 63/8)

(1986)

1. Introduction

1.1 CONSIDERING (*g*) of Question 63/8 draws attention to the increase in harmful interference occurring in the frequency band 9300-9500 MHz due to the increasing number of shipborne radars, the increasing need for navigational aids working with primary radars and the increasing number of stations of the aeronautical radionavigation service.

1.2 This Report is the result of studies and measurement by the United Kingdom and the United States of America on present and expected use of the band 9320-9500 MHz by mobile radars of the radionavigation service.

2. Present use of the band 9320-9500 MHz

2.1 The band 9320-9500 MHz is allocated world-wide on a primary basis to the radionavigation service and is used particularly heavily by shipborne primary radar. It is also used extensively by aeronautical ground and airborne radar. The use of primary radar by shipping is a valuable aid to navigation in open and confined waters and is recognized as such by the International Maritime Organization which is amending the International Convention on the Safety of Life at Sea, 1974, to include additional requirements concerning the carriage of radar.

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