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).

2.2 Economic and technical considerations have led to much greater use being made of the band 9320-9500 MHz by radar than is made of other bands allocated to the radionavigation service which are suitable for this purpose.

2.3 In many countries magnetrons for radar use in the band 9320-9500 MHz are manufactured to four "spot" frequencies:

Frequency (MHz)	*Service*
9345	Aeronautical
9375	Aeronautical and marine
9410	Marine
9445	Marine

A spot frequency is the nominal frequency of manufacture and is a median value for all magnetrons made to that value. In practice, the centre frequencies of individual magnetrons are of approximately Gaussian distribution about the "spot" frequency, with a 95% probability of variation within ±30 MHz.

3. Operational effect of radar-to-radar interference

3.1 Interference from a single source will be observed typically on a radar display first as one striation. Then as the interference becomes more severe, an increasing series of interrupted striations in arc-shaped form radiating from the centre of the display will be observed.

3.2 If the interference continues to increase due to decreasing range, the number of striations also increases and the arc of the display over which they appear will get larger until finally the display will be totally covered by strong returns around the whole of the display.

3.3 The effect of such interference on the radar observer is related to both the number of striations and to the corresponding area of the display which is rendered useless for normal tasks. This area varies with the pulse widths of the interfering radars.

3.4 Subjective assessment suggests that more than about 15 simultaneous striations or 5% of the display area obliterated would be unacceptable.

4. Measurements of potential interference

4.1 Initial studies of the problem indicated that when two radars are within detection range of each other it is possible to relate the degree of potential interference with the form of the radar antenna azimuth polar pattern (see Fig. 1). The degree of potential interference is largely range related and the three most serious cases are:

4.1.1 at longer ranges when one radar antenna main lobe is looking at the back of another radar antenna, and *vice versa*;

4.1.2 at medium ranges when the first major side lobe of one radar antenna is looking at the back lobe of another radar antenna, and *vice versa*;

4.1.3 at shorter ranges when the radiation from the back lobe of one radar antenna is being picked up through the back lobe of another radar antenna.

4.2 More detailed study of these three cases indicated that the first two represent situations in which the possibility of unacceptable interference is minimal because:

4.2.1 the main lobe is likely to be not greater than about 2° and it would therefore require many other ships equally spaced around one's own ship within the range and frequency criteria before interference became unacceptable; and

4.2.2 similar cases apply to the first major lobe which is unlikely to exceed about 20°.

4.3 The most serious case therefore is the one described in § 4.1.3. This situation was examined in detail by trials carried out in the high traffic density area of the Straits of Dover. Subsequent analysis of the results obtained is given below.

5. Analysis of trials data

5.1 There are many interrelated factors which determine, in practice, whether a radar display has been rendered useless due to interference from other radars. Some of these are:

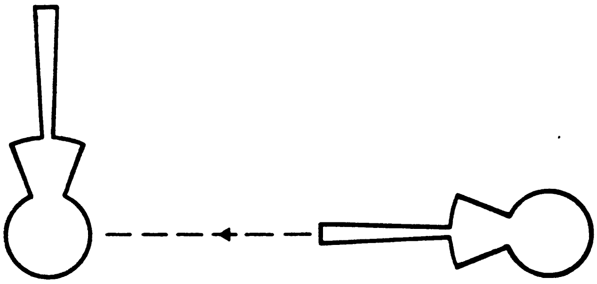
5.1.1 the training of radar observers;

5.1.2 the electronic processing methods used in the radar receiver;

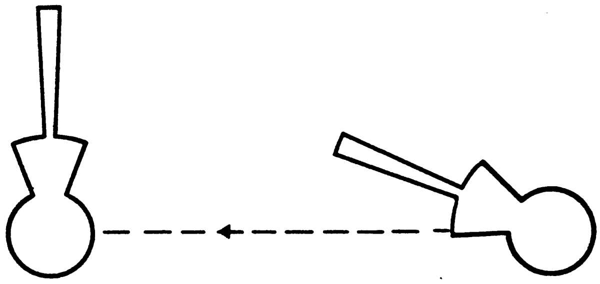
5.1.3 the ranges, frequencies and PRFs of the interfering radars;

5.1.4 the density of possible interfering radars.

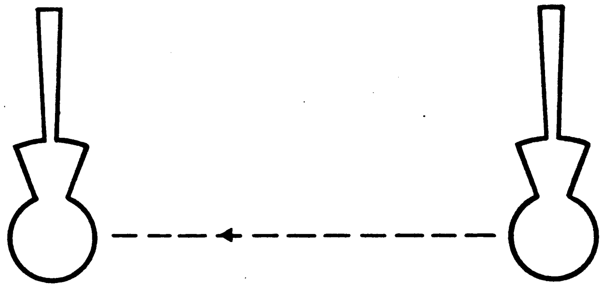
For the purpose of this analysis only § 5.1.3 and § 5.1.4 were considered.



(a) Main lobe to back lobe



(b) Side lobe to back lobe



(c) Back lobe to back lobe

FIGURE 1 – *Antenna pointing for different interference cases*

5.2 An approximation of a fraction of the area, A, of a radar display suffering interference can be expressed as:

$$A = \frac{P_f \cdot k \cdot m \cdot W}{N}$$

where:

P_f: probability of a ship radar using frequency, f;

m: number of ships within an interfering range;

W: pulse width, assumed to be 0.25 μs;

N: average PRI (pulse repetition interval), typically 10^{-3} s;

k: empirical constant ≤ 1, to take account of special receiver processing and bandwidth mismatch. (No information was available from the trials on the extent to which interference reduction circuitry was fitted on ships transiting the Straits of Dover.)

5.3 The major objective of the trials was to collect data that would allow P_f and m to be estimated.

6. Results of trials

6.1 The probability of a ship radar using frequency, f, can be estimated from the histogram chart (see Fig. 2) which shows the number of radars detected during the trials against the radar frequencies being used. The overall form of the histogram shows quite distinct peaks at the three nominal frequencies used by magnetrons fitted to shipborne radars. There were virtually no detections at the magnetron frequency used exclusively by the aeronautical service. However, the fact that the radar used for the trials had a relatively limited vertical aperture of only a few degrees might possibly have influenced this result, although this is considered unlikely.

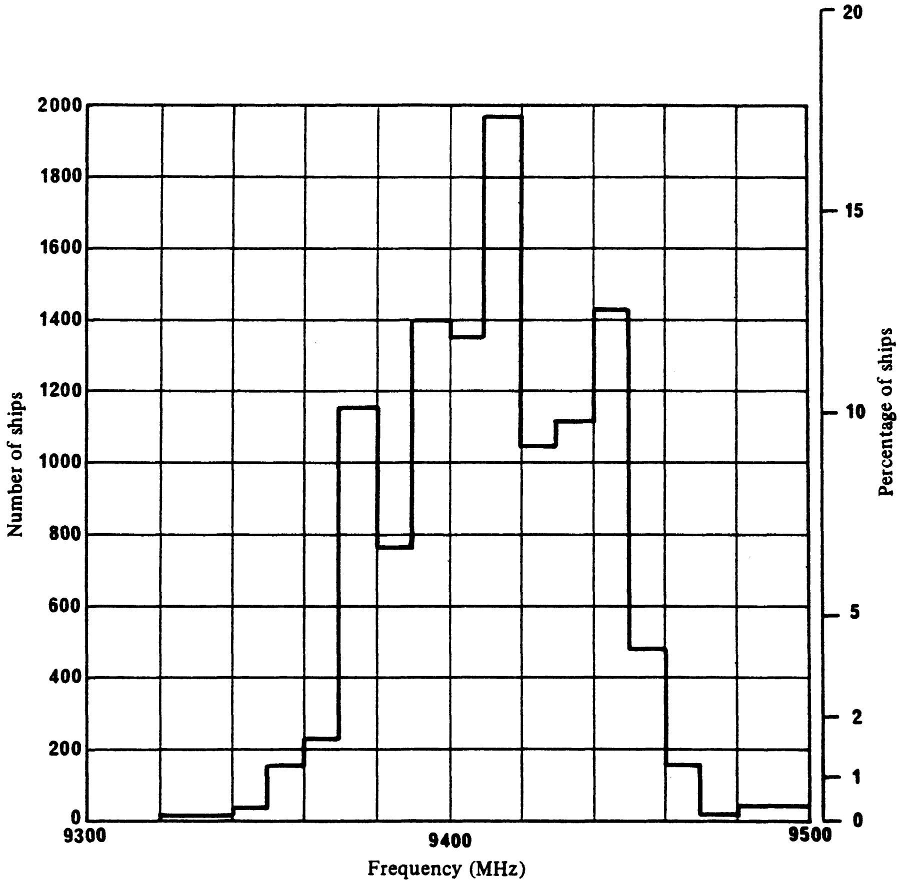


FIGURE 2 – *Ship radar magnetron frequency distribution*

6.2 To enable an estimation of the ships within interfering range, M, the ship population was divided into three classes, large ships of 10 000 gross tonnage and over, medium-sized ships of between 1600 and 10 000 gross tonnage and small ships of less than 1600 gross tonnage. The relevant characteristics of ships of these classes are given in Table I and the approximate class-to-class radar detection ranges are given in Table II.

TABLE I – *Ships' characteristics*

Size of ship	Large	Medium	Small
Radar height (m) (1)	30	15	7.5
Detection range (NM)	25	17	4
Traffic density (%) (2)	20	35	45

(1) The detection ranges given were calculated using standard radar equations.

(2) Derived from UK surveys of marine traffic in the Straits of Dover.

TABLE II – *Radar detection ranges (NM)*

Size of ship	Large	Medium	Small
Large	25	21	18
Medium	21	17	15
Small	18	15	12

Using Tables I and II and numbers/types of ships derived from recent shipping surveys, Table III has been constructed.

TABLE III – *Number of ships (m) within range (NM) for potential interference*

Range (NM) / Size of ship	4	12	15	17	18	21	25
Large	8	50	60	70	75	83	85
Medium	8	50	60	65	67	69	69
Small	8	31	36	38	39	39	39

6.3 Using the worst-case numbers from Table III, the values of P_f from Fig. 2 and the equation for the area, A, of the display suffering interference, Table IV was developed. This represents probably the worst condition of interference that a radar observer is likely to experience while transitting the Straits of Dover.

TABLE IV – *Probable maximum interference*

Size of ship	Number of striations	Display obscured (%)
Large	14	0.35
Medium	12	0.30
Small	7	0.17

6.4 Comparing the results given in Table IV with the subjective assessment of unacceptable interference given in § 3.4, it can be seen that at the present time in an area of high traffic density the probability of unacceptable interference is minimal.

7. Future use of the band 9320-9500 MHz by mobile radars of the radionavigation service

If the number of radars in use in the band increases, as seems very likely, radar-to-radar interference will also increase unless specific counter-measures are implemented. However, most modern radars make use of processing techniques some of which incorporate radar-to-radar suppression capabilities, and which may help to alleviate the problem.

8. Spectrum measurements

In the United States of America, mobile radionavigation radars have assignments to operate in the entire 9320-9500 MHz band rather than on specific frequencies within the band. Therefore, reviews of the frequency assignment records do not provide an understanding on how the band is being used. Sample measurements of the shipborne and airborne emissions in the band in the United States of America and surveys of radar and magnetron tube manufacturers will provide information on the present and expected future use of the band by mobile radionavigation radars.

8.1 *Measurement system and techniques*

The United States government operates a radio spectrum measurement system (RSMS) in support of frequency management processes. The RSMS is deployed in a mobile van and is a computer-controlled receiving system designed to make many different types of measurements between 100 kHz and 12 GHz. The RSMS has been used in measurement programs on communication and radar bands in many high spectrum usage areas in the United States of America. Descriptions of the RSMS have been presented in Matheson, [1977] and in Buss and Cutts, [1980].

One of the techniques used in the RSMS to obtain statistical data of a frequency band is a 24 or more hour observation of the band by the computer-controlled receiving system. During these periods, the system is incrementally tuned across the band, stopping for several seconds after each frequency step. While the receiver is sampling a frequency, a peak detector holds the amplitude of the maximum signal encountered and high speed counters count the number of radar pulses exceeding several preset amplitudes. The band is repeatedly scanned in this fashion, and the measured data is recorded on magnetic tape for later analysis. For the data presented here, the frequency bands were scanned 5 to 124 times. The recorded data was analysed to present:

- the maximum, average and minimum of the peak detected amplitudes at each frequency, and
- the maximum, average and minimum of the number of pulses counted at each frequency for each of several thresholds.

8.2 *Maritime radar measurements*

Measurements of the 9300-9500 MHz band were performed in the harbour areas of Boston, San Francisco, New York City and Seattle (two locations). Measurements were performed to determine the distribution of the frequency usage of the 9320-9500 MHz band.

The measurements in Boston and New York City resulted in identifying usage on or around the 9345, 9375 and 9445 MHz frequencies as shown in Table V. With one or two exceptions, the emitters were identified as shipborne radars. The ships were observed to be registered in the United States of America and many other countries.

TABLE V

Frequency (MHz)	Number of observations	
	Boston	New York City
9345 ± 30	16	21
9375 ± 30	29	24
9445 ± 30	34	13

Table V indicates that the majority of shipborne radars operate on 9375 ± 30 MHz with 9445 ± 30 MHz second. Some overlap exists because 9345 ± 30 MHz is actually 9315-9375 MHz and 9375 ± 30 MHz is 9345-9405 MHz making the 9345-9375 MHz segment common to both entries. Thirty-eight radars were observed in 9345-9375 MHz with twenty of these in the 9357-9360 MHz segment. Radars were observed operating down to 9322 MHz.

Figures 3 and 4 present the cumulative result of an automated measurement program that was performed on the 9200-9600 MHz band at the Mt. Blyn, Washington location in the Seattle harbour area (Puget Sound) over a 24-hour period. The three curves in Fig. 3 represent the maximum, average and minimum power levels received. The curves indicated that the frequency usage is concentrated on 9310, 9340-9460 and 9480 MHz. The 9340-9460 MHz segment is a continuous segment with a relatively high average level that indicates extensive usage over the segment. The peaks in the data at 9310, 9480 and 9510 MHz are attributed to shore-based radars operating in the maritime radionavigation service as part of the vessel traffic system. The remaining signals are attributed to shipborne radars.

Figure 4 represents the pulse count statistics taken at Mt. Blyn, Washington for 53 scans over the same 24-hour period as the data presented in Fig. 3. The dwell time on each frequency was 4 s and Fig. 4 presents the maximum, average and minimum number of pulses received during a 4 s interval for each frequency. Using an average value of 100 pulses as a criterion, Fig. 4 indicates that the 9350-9435 MHz segment is a contiguous segment where 100 pulses is exceeded for the entire segment. The highest value of the average pulse count is at about 9375 MHz and the highest value of the peak number is at about 9450 MHz.

Figures 5 and 6 were obtained by taking 124 scans at Alki Point, Washington, a second location in the Seattle area. Using an average level of −75 dBm as a criterion, Fig. 5 indicates that the −75 dBm value is exceeded for the entire 9350-9500 MHz segment. Figure 6 indicates that the number of pulses equals or exceeds an average of 100 pulses over the 9350-9500 MHz interval with maximum values at about 9380 MHz. Thus, the 9350-9500 MHz segment indicates the most usage in the band with the usage peaking at 9380 MHz.

Figures 7 and 8 were obtained by taking 5 scans at Mt. Diablo, California, a location about 60 km east of San Francisco and having a clear view of the San Francisco harbour area. Using −75 dBm (Fig. 7) and an average value of 100 pulses (Fig. 8) as the criterion, Fig. 7 indicates that the 9320-9460 MHz segment is the most used and Fig. 8 indicates that the 9350-9430 MHz segment is the most used. Both figures indicate that the level and number of pulses peak at about 9370 MHz. The peaks at 9450 and 9490 MHz are vessel traffic system radars on the shoreline.

It can be concluded from the measurements that the entire 9320-9500 MHz band is used by maritime radars with the segment 9370-9380 MHz being the most used.

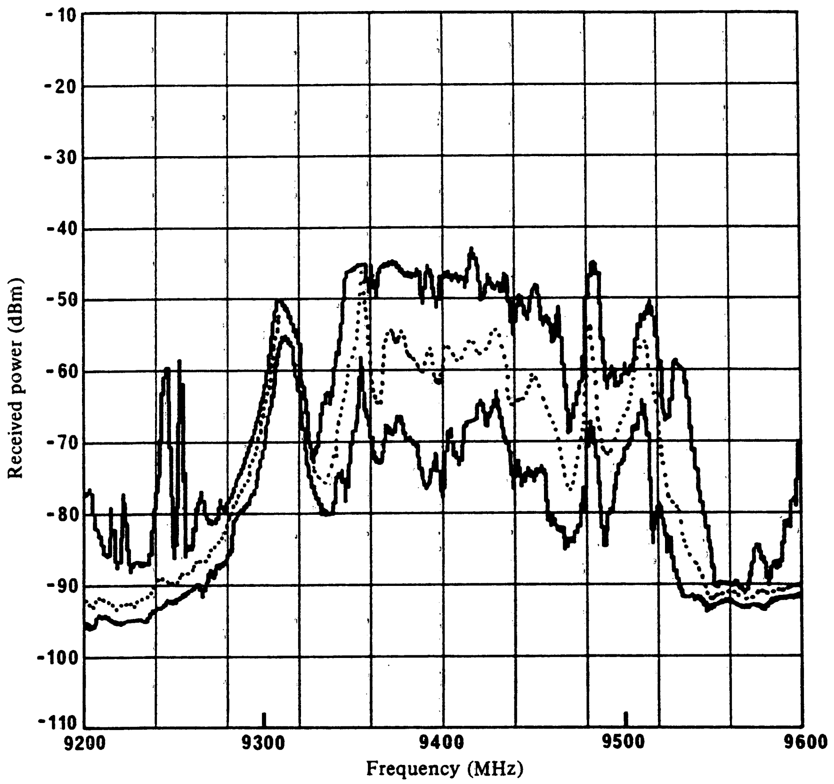


FIGURE 3 – *Received power as a function of frequency*

——— Maximum, minimum

– – – – Average

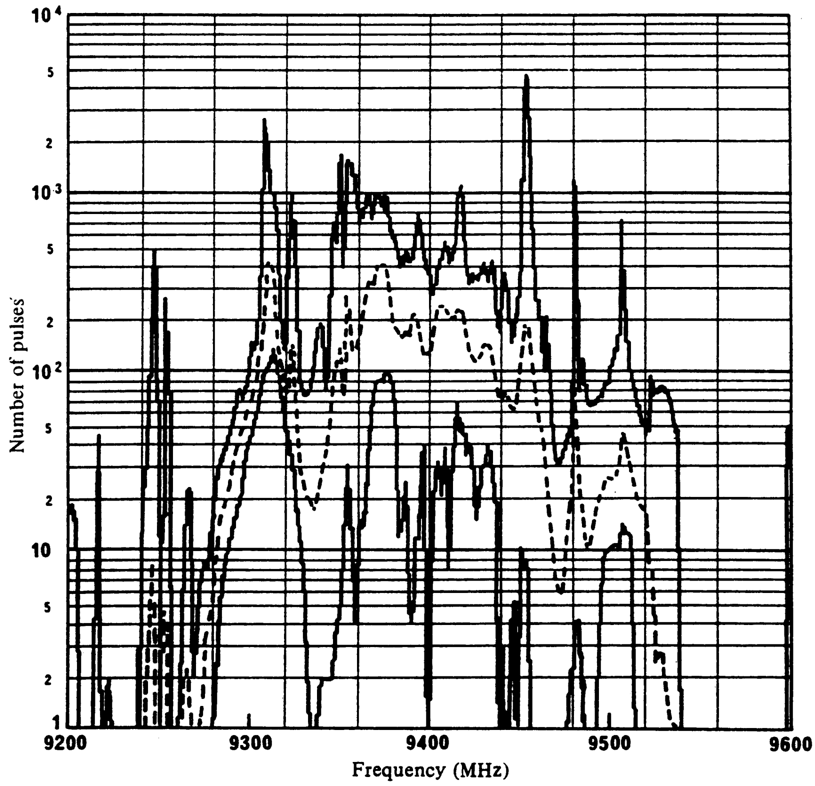


FIGURE 4 – *Pulses received in 4 s as a function of frequency*
Counter, threshold: −80 dB

——— Maximum, minimum
– – – – Average

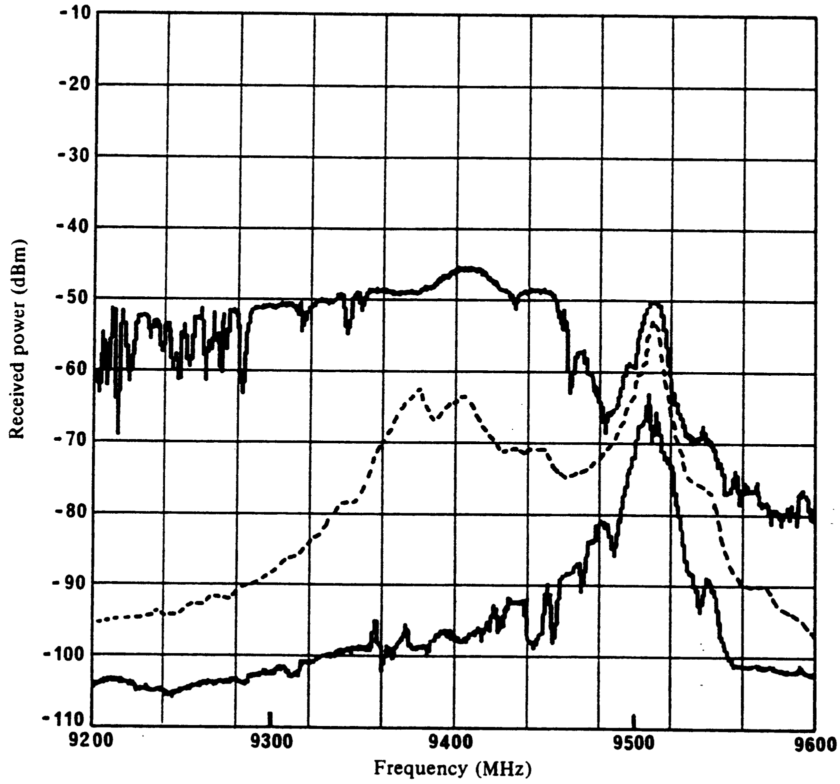


FIGURE 5 – *Received power as a function of frequency*

——— Maximum, minimum

- - - - - Average

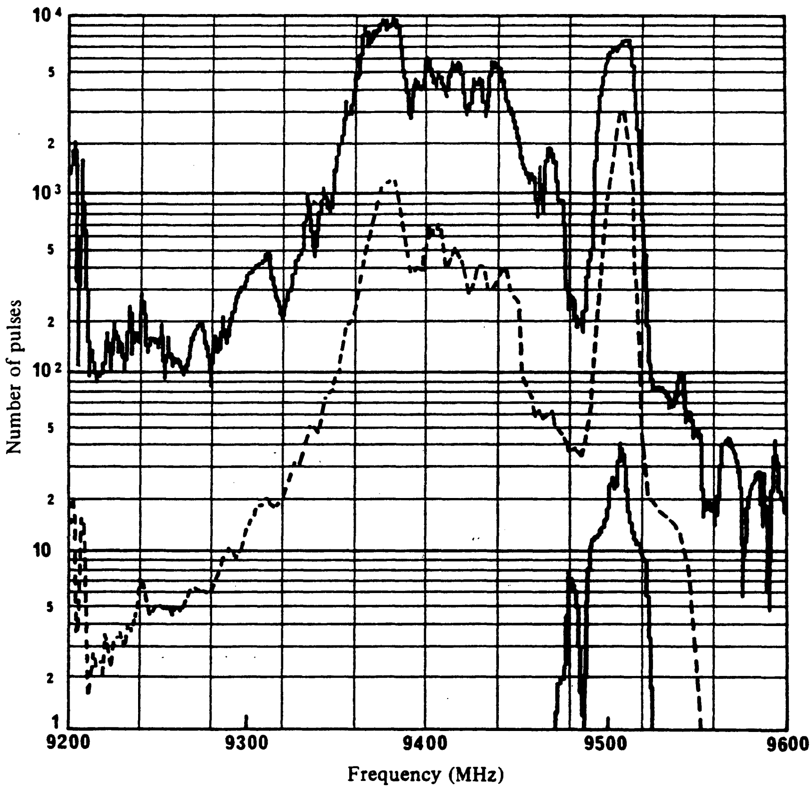


FIGURE 6 – *Pulses received in 4 s as a function of frequency*
Counter, threshold: −82 dB

——— Maximum, minimum
– – – – Average

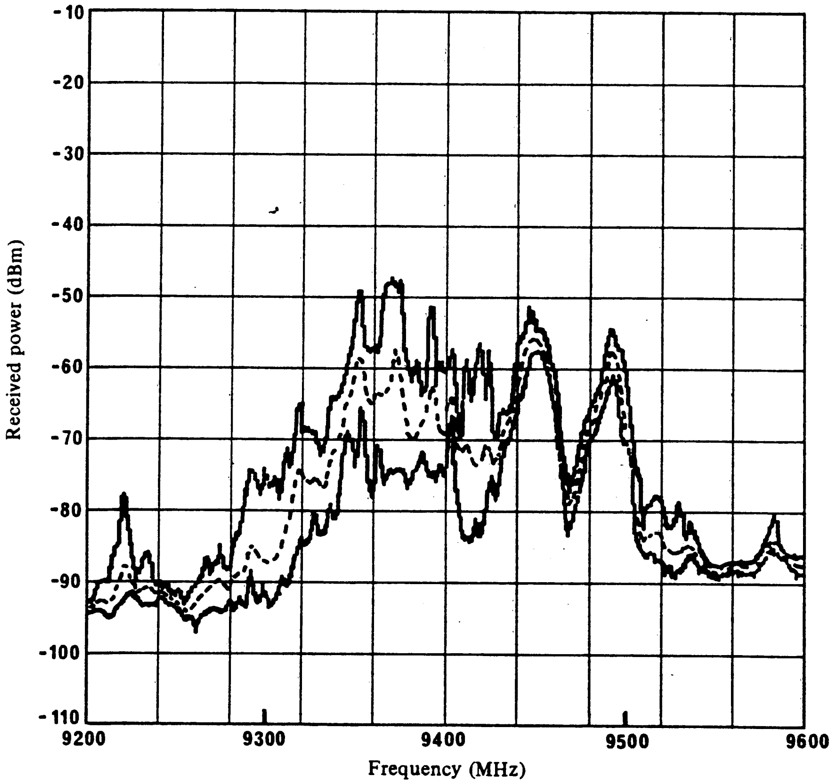


FIGURE 7 – *Received power as a function of frequency*

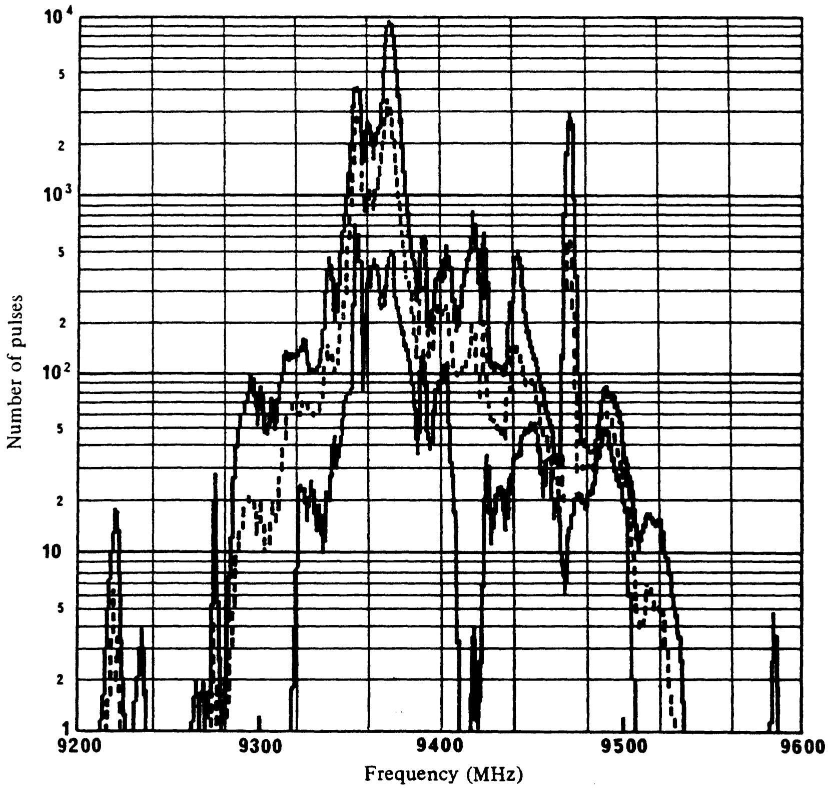


FIGURE 8 – *Pulses received in 5 s as a function of frequency*
Counter, threshold: –83 dB

——— Maximum, minimum
– – – – Average

8.3 *Airborne radar measurements*

Figures 9 and 10 were obtained by taking 119 scans of airborne radar activity at a location near Denver, Colorado. The average received power is essentially flat over the entire band because only airborne radars were measured. The peaks in Figs. 9 and 10 at 9300, 9475 and 9490 MHz are attributed to radiolocation radars on board aircraft. The figures indicate that the airborne radionavigation radar usage is concentrated in the 9330-9400 MHz segment with the average amplitude and pulse count peaking around 9370-9380 MHz.

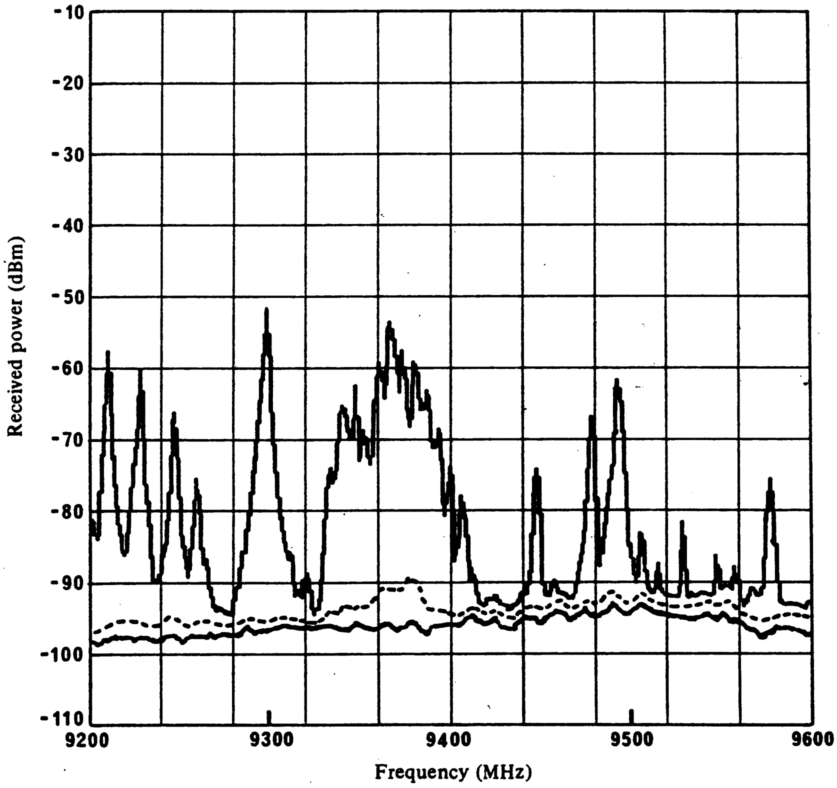


FIGURE 9 – *Received power as a function of frequency*

——— Maximum, minimum

- - - - - Average

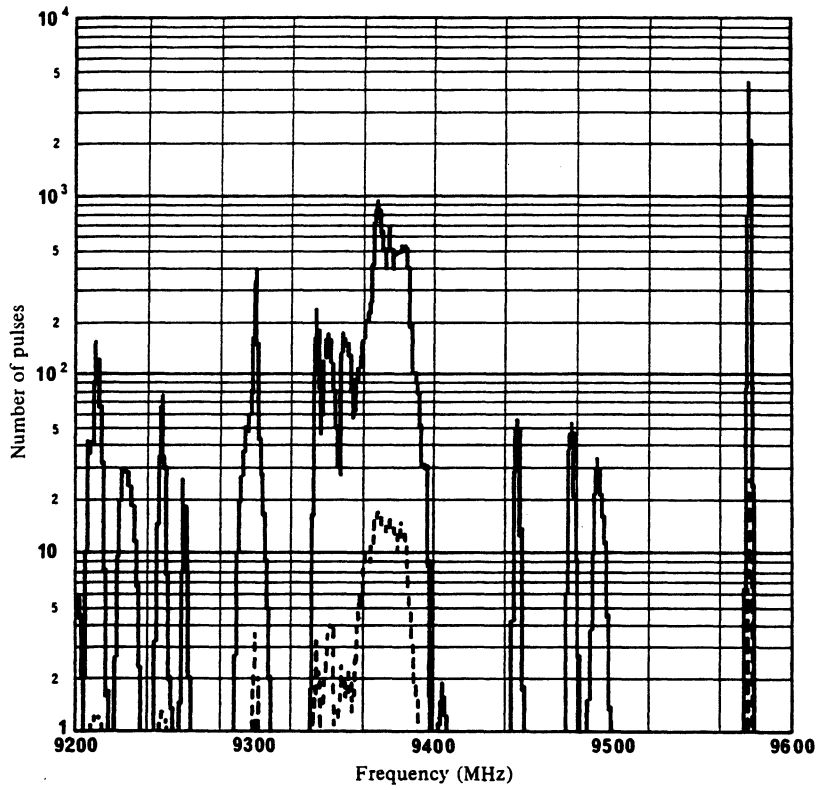


FIGURE 10 – *Pulses received in 4 s as a function of frequency*
Counter, threshold: −80 dB

——— Maximum, minimum
– – – – Average

9. Survey of manufacturers

9.1 *Maritime mobile radionavigation radars*

A survey was conducted of major maritime mobile radionavigation radar manufacturers. The survey included 10 major manufacturers whose radars are used world-wide. The operating frequencies of the surveyed radars were 9375 ± 30, 9410 ± 30, 9410 ± 45, 9445 ± 30 and 9445 ± 35 MHz with 9375 ± 30 MHz appearing most frequently.

9.2 *Airborne radionavigation radars*

Three major manufacturers of airborne radionavigation radars were surveyed. Two manufacturers use 9375 ± 30 MHz (30 MHz is the manufacturing tolerance) in all current models and a third uses 9345 ± 30 MHz in all current models using magnetrons.

Two manufacturers have developed all solid-state airborne radars. Although using a lower power output than conventional magnetron radars, the performance is essentially the same because of the improvement in the receiver due to coherent signal processing. In all solid-stste radars, the operating frequency can be stated with more precision than those radars using magnetrons. One manufacturer is developing all solid-state radars for operation on 9333 MHz and the second on 9345 MHz. Both manufacturers state that the frequency tolerance will be of the order of 0.01% or better. This is equivalent to about 0.9 MHz.

The all solid-state radars use much lower peak power output than the magnetron types, for example 200 W as compared with 50 kW. This reduction lessens the possibility of such radars interfering with other systems. The narrow receiver signal processing bandwidth, for example 50 kHz, reduces the possibility of interference from other radars.

The solid-state radars have been well received by commercial airlines. The future may see a trend towards the all solid-state radars because of their reliability and lighter weight. The solid-state radars would also contribute to more efficient use of the band because of their lower power.

9.3 *Magnetron manufacturers*

A major manufacturer of magnetrons was surveyed. The model 2J42 magnetron is one of the most popular. It operates on 9375 ± 30 MHz and is used extensively in both airborne and shipborne radionavigation radars. The value 9375 ± 30 MHz is a manufacturing tolerance. The 2J42 is fixed tuned within this band.

10. Interference

When interference has occurred to or from shipborne or airborne radars in the 9320-9500 MHz band it has usually been of short duration and has rarely prevented the operator from accomplishing his duty. Manufacturers have realized the possibility of interference because of systems operating on or near the same frequency and in the same geographical area. Interference rejection circuitry is widely used in both airborne and shipborne radars to overcome the problems. However, such circuitry can inhibit the response from certain maritime racons.

The randomness of the operating frequencies obtained from the manufacturer's tolerance on the magnetrons also contributes to minimizing interference.

The 9320-9500 MHz band is used very heavily. The use of interference rejection circuitry and the randomness of operating frequencies both contribute to efficient band utilization. However, future use of tighter frequency tolerances in solid-state radars could reduce the effect of randomness on efficient band utilization. This frequency band should be capable of accommodating more systems without harmful interference.

11. Conclusions

Based on the surveys of manufacturers and measurements of the band 9320-9500 MHz, it can be concluded that:

- shipborne radars can be expected to be operating anywhere in the band from 9322-9480 MHz;
- airborne radar usage is primarily on 9375 ± 30 MHz with 9345 ± 30 MHz also used. The most extensive usage is in the 9335-9390 MHz segment;
- the 9375 ± 30 MHz frequency is used extensively by both airborne and shipborne radars. The segment between 9345 and 9375 MHz is the most used in the entire 9320-9500 MHz band;
- there is very little evidence of band division between the airborne and shipborne users. The shipborne radars can be expected in the entire 9320-9500 MHz band and both airborne and shipborne radars use 9375 ± 30 MHz very extensively. The shipborne users appear to be the majority users of the higher frequencies in the band, but the converse is not true. That is, the lower frequencies in the band, for example 9345 MHz, were not shown to be primarily used by airborne, but were used by both services;

- the band 9320-9500 MHz is also used by maritime swept-frequency radar beacons and by some radiolocation systems;
- the present incidence of harmful interference is low, and such interference is normally of short duration. It is anticipated that, despite the forecast increase in the radar population, the incidence of harmful interference will remain acceptably low;
- the possible introduction of radar transponders for search and rescue purposes and increased use of radar beacons will also tend to aggravate any existing signal congestion and hence interference in the band 9320-9500 MHz;
- if the number of radars in use in the band increases, as seems very likely, radar-to-radar interference may also increase unless specific counter-measures are implemented. However, most modern radars make use of processing techniques some of which incorporate radar-to-radar suppression facilities, and which may help to alleviate the problem;
- in view of the likelihood of tighter frequency tolerances in solid-state radars, random operational use of radar frequencies might assist in the efficient use of the band;
- the 9320-9500 MHz band should be capable of accommodating more systems without harmful interference.

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