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STUDY OF POWER REQUIREMENTS FOR X-BAND JAMMING FROM SURFACE VESSELS

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ABSTRACT

An investigation has been made to determine the power requirements for X-band jamming from surface vessels, taking into consideration the near-zone propagation effects. Experimental data obtained from actual jamming exercises designed to give quantitative results show remarkable agreement with theory. The beam powers required to jam a surface search radar and a fire-control radar are given. It is also shown that if the multiple factors involved in a jamming situation are not clearly identified, errors in power determination amounting to several db can result. The data is also valid in the surface-to-air problem when surface reflection is a factor.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

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STUDY OF POWER REQUIREMENTS FOR X-BAND JAMMING FROM SURFACE VESSELS

INTRODUCTION

The need for definite information on the jamming power required for a given situation is probably felt most severely by those who must formulate performance specifications for use in systems procurement. Although considerable work has been done by various activities on the theoretical determination of power requirements by relating radar and jammer parameters in propagation equations, very little has been done on experimental field-evaluation to obtain a correlation between theoretical and practical results. This is particularly true in the microwave frequency ranges, where jamming equipment is only now starting to become available, and under conditions encountered in surface fleet operations when, because of attenuation and reflection conditions, low angles of signal transmission over water create large variations in received signal levels with range and elevation. The familiar jamming equation contains certain factors which appear definite at first sight, yet upon closer examination lead to a rather indefinite conclusion, i. e., to an error of the order of 10 db or more in the final determination.

A search of the literature reveals that considerable effort has been given to the experimental determination of radar area and the theoretical determination of jamming effectiveness and minimum jamming range. In the case of radar area it is clear that there are two distinct values for a given target when that target is in the interference region. These are called the near-zone and the far-zone radar areas. A third radar area is normally assigned to a target that is in free space. Thus, when selecting a value of radar area to use in a mathematical formula, the user needs to exercise care, if the particular radar area selected for consideration is not clearly defined. It is observed that more recent determinations of values of radar area tend toward an average effective value rather than the peak value previously used. This report deals only with the near-zone radar area, for which both peak and average values will be given. Of particular significance is the small amount of surface-ship radar area data available in X-band despite the fact that modern fire-control radars are almost exclusively in X-band. This is one reason for exploring the jamming problem in this band.

Another point of uncertainty appears in the use of jamming effectiveness, or jamming-to signal ratio. It appears that some correlation needs to be made between actual jamming results and simulated jamming results obtained in a laboratory. Once such information is available, a much broader application of jamming data can be made and it will not be necessary to test a specific jamming system on each and every class of ship.

The surface-to-air problem is not unlike the strictly surface problem. Here again it is necessary to identify the radar area which is to be used in the jamming equation.

In order to obtain information on X-band jamming, the AN/ALT-2 jammer was installed aboard a picket boat at the Chesapeake Bay Annex and operated against both a search and a fire-control radar. A jamming operation was planned which would give a maximum of quantitative information. By completely calibrating the jammer and the radar installations, it was possible to determine the radar area of the picket boat and the relation of the jamming energy to the radar energy for jamming two radars. Such information is particularly needed when surface-ship jamming problems are under consideration.

RADAR SYSTEM

The system used for taking the measurements (Fig. 1) is very similar to that used at the Naval Research Laboratory[1] for several years for quantitative radar measurements. The apparatus is actually a composite in that it serves to calibrate the system, to measure the radar area, and to record the jamming energy. The radar antenna gain, G_t, was determined by transmitting over a range R from the radar to the power meter using a standard horn H, and then using the following relation:

$$G_t = \frac{G_c P_1}{P_0}\left(\frac{4\pi R}{\lambda}\right)^2 \frac{1}{G_H},$$

where

G_c = Insertion loss of directional coupler

P_1 = Power received from radar at range R

P_0 = Average power of radar into power meter through directional coupler

R = Range in yards

λ = Wavelength

G_H = Gain of standard horn

Radar area measurements were made using the radar as the generator and substituting the target for H. The near-zone radar area, σ_n, is then determined by pip-matching with the signal gnerator and use of the relation

$$\sigma_n = \frac{P_r'}{P_0}\left(\frac{G_c}{G_t}\right)^2 D\left(\frac{4\pi R^2}{\lambda}\right)^2 4\pi,$$

where

P_r' = Peak power from signal generator when matching pips

D = Duty cycle of transmitter

Jamming-energy recording was made by substituting the jamming transmitter for H and sampling the 30 Mc of the radar immediately following the first detector for wide-range amplification in the logarithmic i-f amplifier. Calibration of this particular system was done by feeding jamming energy directly into the radar system through the directional coupler. The auxiliary scope was used for visual monitoring during the jamming runs. The SG-6 radar was used to keep the SU-2 antenna trained on the target and to provide accurate range marks. The manner in which the jamming signal varies with time and range, as will be seen in a later section, is important to the understanding of the X-band jamming problem. The auxiliary recording channel was necessary owing to the narrow dynamic range of the SU-2 receiver. A preliminary study of the SU-2 receiver showed a dynamic range of about 20 db.

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[1] Katzin, M., "Quantitative Radar Measurements," Proc. I.R.E., 35:1333-1334, November 1947

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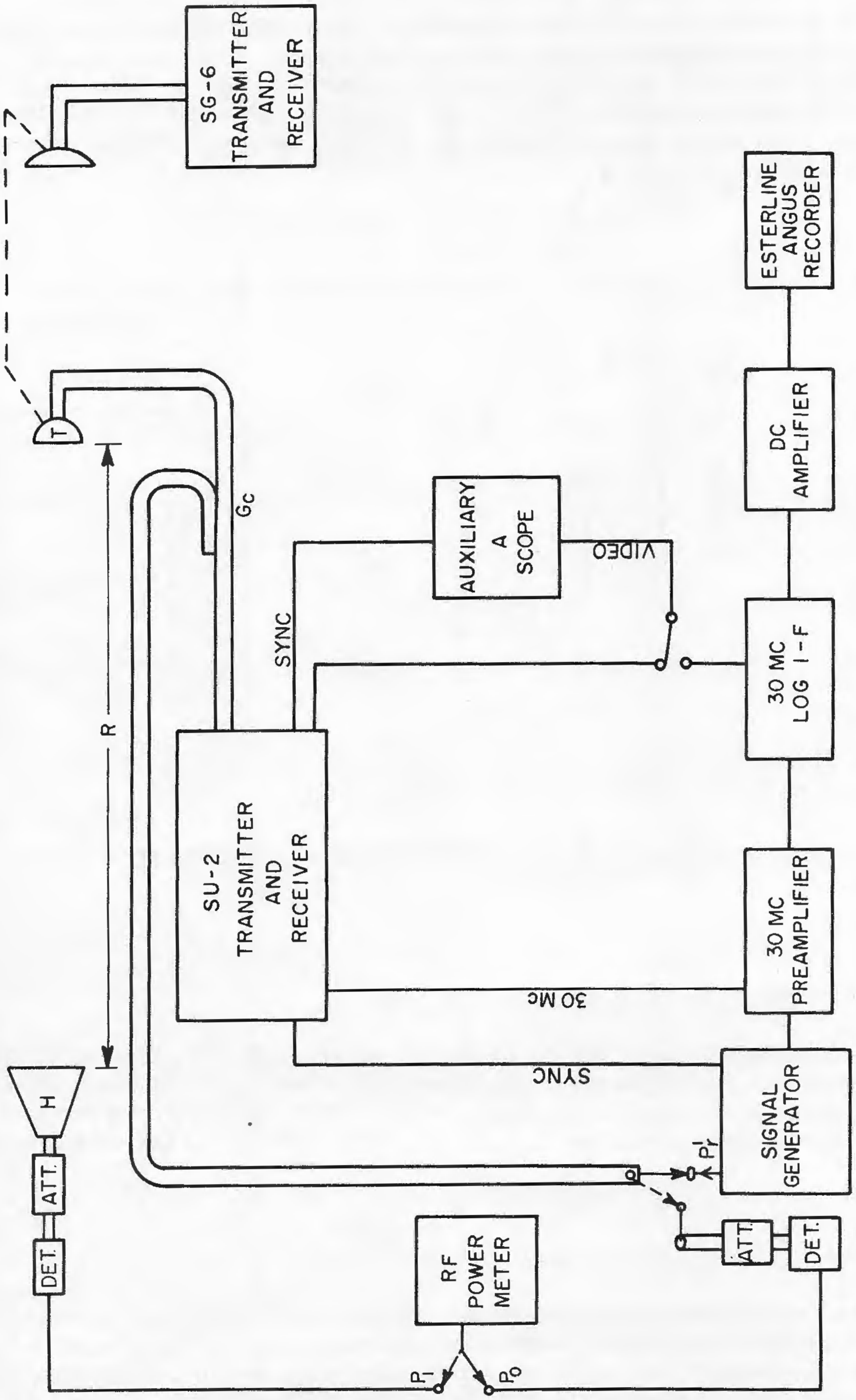

Fig. 1 - Block diagram of radar system

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A propagation curve (Fig. 2) was calculated for a radar antenna height (h_1) of 140 feet and a jammer antenna height (h_2) of 10 feet. This curve shows that a dynamic range of at least 55 db would be required if the jammer energy followed the full depth of nulls indicated. A logarithmic 30-Mc amplifier having this dynamic range was therefore used as an auxiliary unit for recording. The output of the amplifier was rectified by a crystal diode and the dc applied to an Esterline-Angus recorder. In order to avoid the effects of saturation, the input signal was obtained from the first stage of the SU-2 receiver directly following the mixer.

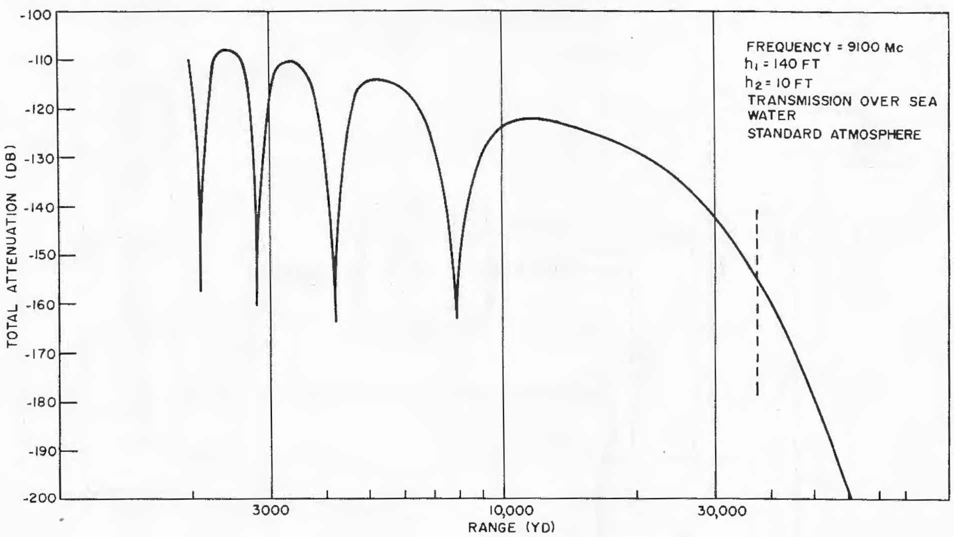

Fig. 2 - Attenuation of electric field strength, horizontal polarization

JAMMING SYSTEM

With the installation of the AN/ALT-2 on the picket boat (Fig. 3) it was possible to monitor continuously the frequency, modulation, and power output of the jamming signal. The jamming antenna was trained manually on the radar location during the tests. This antenna was circularly polarized with a gain for both vertical and horizontal polarization of 12.9 db.

CALIBRATION

In order to make quantitative measurements the complete system was calibrated. Standard procedures were used to determine antenna gains, transmission-line loss, etc., and the same noise-modulated jamming transmitter was used for this calibration as was used in the tests. The characteristics of the radars used are given in Table 1. Preliminary runs indicated a jammer power of 50 watts was optimum for obtaining quantitative results with the other parameters derived for the complete system. This level was obtained from the AN/ALT-2 by using a power divider. The optimum value was determined by

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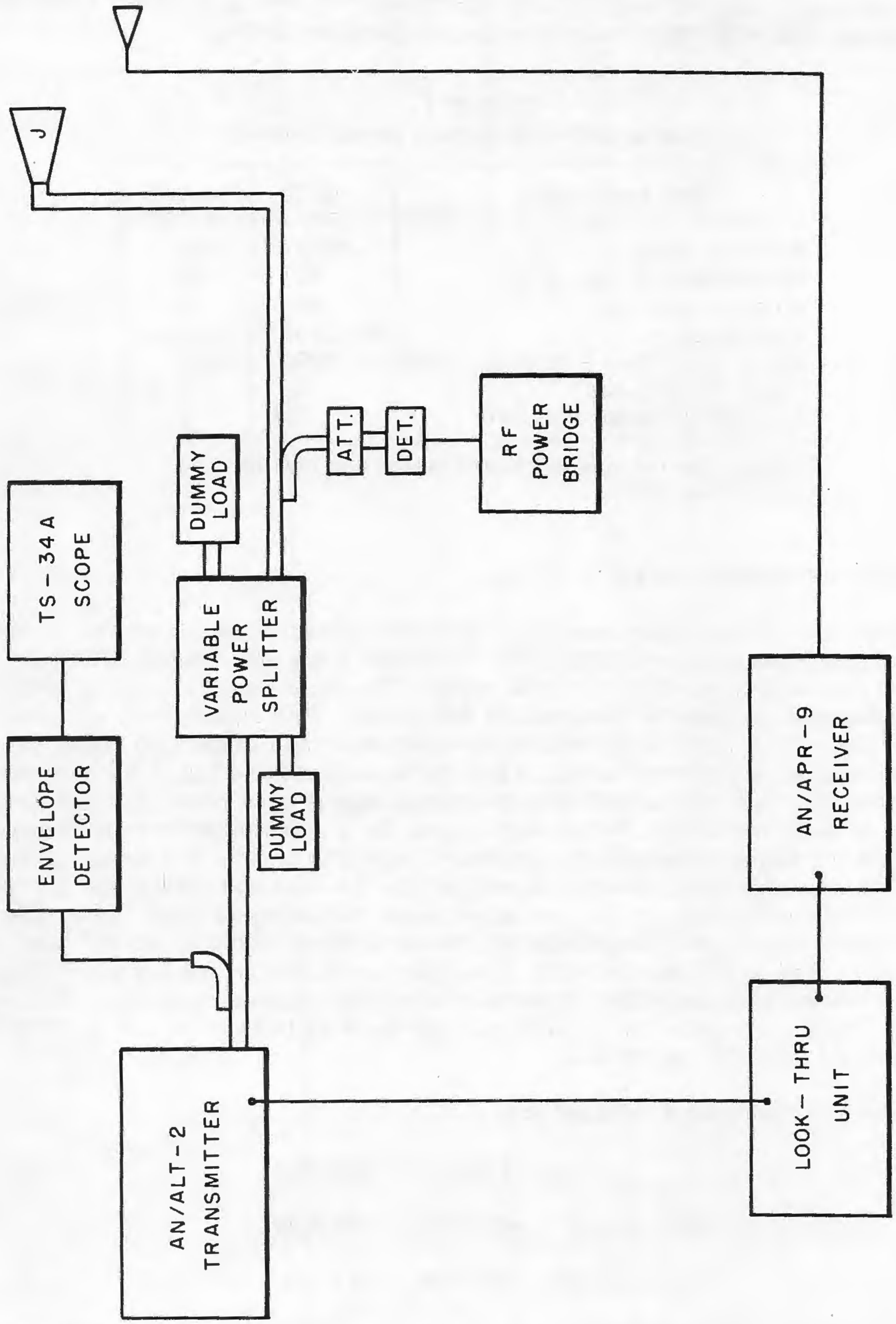

Fig. 3 - Block diagram of picket boat installation

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calculating the jamming energy which would be expected in the radar receiver for ranges between 3000 and 10,000 yards, comparing the result with the radar signal expected from the target and finally determining that the logarithmic recording amplifier could be adjusted to the particular dynamic range calculated for the jamming energy.

TABLE 1
Characteristics of Radars Being Jammed

Characteristic*	SU-2	Mark 25
Frequency(Mc)	9100	9150
Transmitter Power (kw)	17	70
Antenna Gain (db)	35	42
Polarization	Horizontal	Vertical
Pulse Repetition Frequency (pps)	600	1320
Pulse Width (μsec)	1	0.25
Acceptance Bandwidth (Mc)	3.8	9

*These figures are not necessarily nominal for the particular set.

RADAR AREA OF PICKET BOAT

The radar area of the picket boat was measured by having the picket run to and from the radar station; therefore, only stern and bow areas were determined. The radial run of the picket extended from 4000 to 12,000 yards. The signal level return as viewed on the SU-2 radar was recorded at intervals of 500 yards. This signal level was determined by pip-matching with a signal injected into the system from a calibrated signal generator. Values thus obtained are plotted in Fig. 4 for the bow aspect and Fig. 5 for the stern aspect. For each range both a peak and an average signal were recorded. The peak signal was usually of short duration. The average signal for a given measurement represents the level at which the signal remained for the longest interval of time and appeared most often. To determine the radar area, straight lines (one for the peak and one for the average readings) were fitted on log paper to the measured points according to an R^{-4} law. The near-zone radar areas of idealized targets giving echoes corresponding to the R^{-4} lines were then computed. Had an R^{-4} line failed to fit all the points, the indication would have been that the near-to-far zone transition range was within the measuring range. This was not expected since previous data[2] on an LCM gave an R_t of 14,000 yards, and an LCM does not differ greatly from the picket boat.

The values of radar area obtained are:

	Peak	Average
Bow aspect	+29.9 db	+22.3 db
Stern aspect	+36.9 db	+27.3 db

(The decibel readings are relative to one square meter.) These calculated values show a spread between peak and average values of 7.6 db for the bow aspect and 9.6 db for the

[2]Amant, W. S., MacDonald, F. C., and Ringwalt, D. C., "Radar Areas of Small Landing Craft," NRL Memorandum Report No. 117 (Confidential), January 15, 1953

[redacted]

stern aspect. From Figs. 4 and 5 it can be seen that a much wider spread of values actually was recorded, 14 db for the bow aspect and 18 db for the stern aspect. In fitting the R^{-4} lines to the measured points, the values giving the largest radar area for the particular case were chosen.

JAMMING EXERCISE

The jamming exercise was carried out in a manner similar to that for determining the cross section by making range runs to and from the radar station with the picket boat. Figures 6 through 9 show the recorded average of jamming-signal level compared with the theoretical value taken from Fig. 2. The nulls correspond in level and location very well. The points shown on these figures are average points taken from a continuous recording. Cross-section curves (average curves from Figs. 4 and 5) are also plotted in Figs. 6 through 9 to show the theoretical level of the radar return in relation to the jamming energy in the radar. The data for Fig. 7 are taken from the recording shown in Fig. 10.

During the run recorded in Fig. 7 the picket boat became visible through the jamming for three to four hundred yards at approximately the 8000-yard range and for a short interval at approximately the 3000-yard range. Since jamming was monitored by an auxiliary range scope throughout each run, it was possible to identify the signal as the reflection of the picket at these two positions. The picket was not viewed continuously, but off-and-on as the radar return exceeded the jamming. An indication that this should happen can be obtained from Figs. 4 and 5, which show a fairly large variation in the radar return from the picket, and from Fig. 10 which shows some rapid variations in the jamming signal entering the receiver.

It will be observed from Fig. 2 that the first null in the propagation curve occurs at about 7800 yards and also that the jamming signal increases rapidly, for increasing range, to a maximum at 11,500 yards. In the first null the target was visible; at a range 3000 yards greater, the average target return had dropped to 22.5 db below the theoretical jamming. Therefore, in estimating the jamming power required for a particular set of conditions, the first null in the propagation curve is of major importance. A range where the direct and sea-reflected rays are 150 degrees out of phase has been defined[3] as a limiting range. This point is where the power begins to decrease rapidly in the first null for decreasing range. The limiting range, R_{lim}, is given by the relation

$$R_{lim} = 2.4\, h_1\, h_2.$$

For the conditions under which this test was run, R_{lim} = 10,330 yards as indicated in Fig. 7. At this range the average echo power, as determined from cross-section measurements, was 20 db below the jammer power at the receiver. For a jamming-to-signal factor, K, of one the picket would be considered screened with 0.5 watt of jammer power.

At the time the echo was visible in the neighborhood of 8000 yards, an estimate of the jamming energy required to screen the echo was made. It appeared to two observers that the echo was screened for a jamming level of -46 dbm. This would make the over-all jamming-to-signal factor, K, about +3 db. This K might be considered a dynamic case including the variations in the jamming signal.

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[3] Carter, W. W., "Nomograms for Calculating Minimum Jamming Range for Ships." NRL Report R-2495 (Confidential), May 1, 1945

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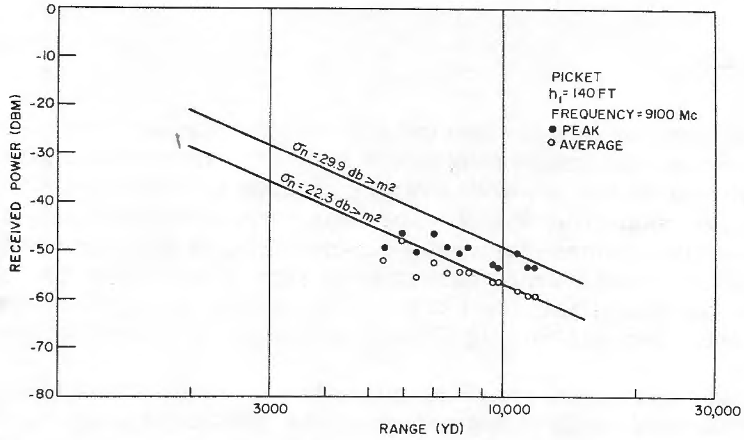

Fig. 4 - Received power vs. range of the SU-2 radar, bow aspect

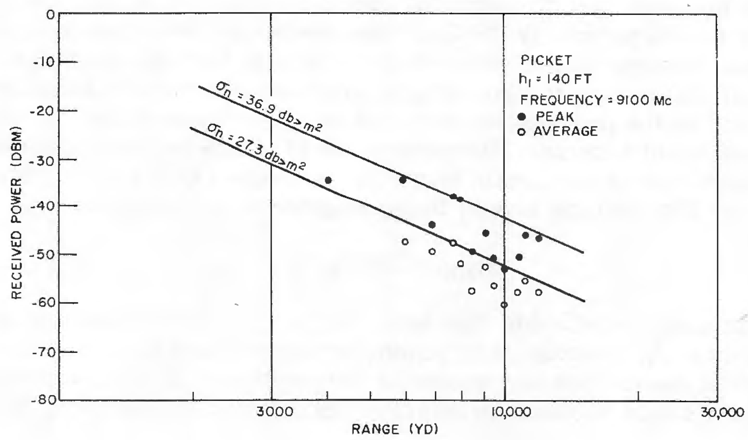

Fig. 5 - Received power vs. range of the SU-2 radar, stern aspect

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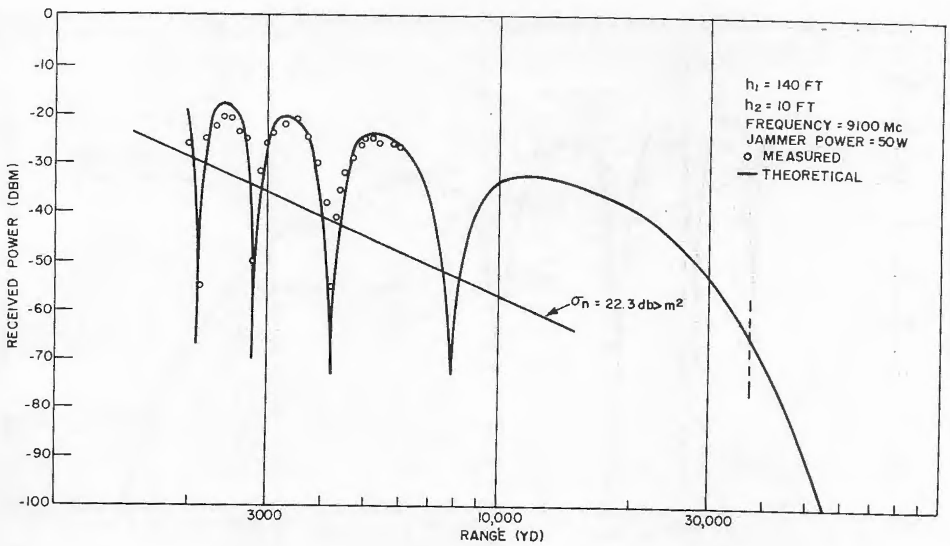

Fig. 6 - Received power vs. range of the AN/ALT-2 jammer, horizontal polarization, bow aspect

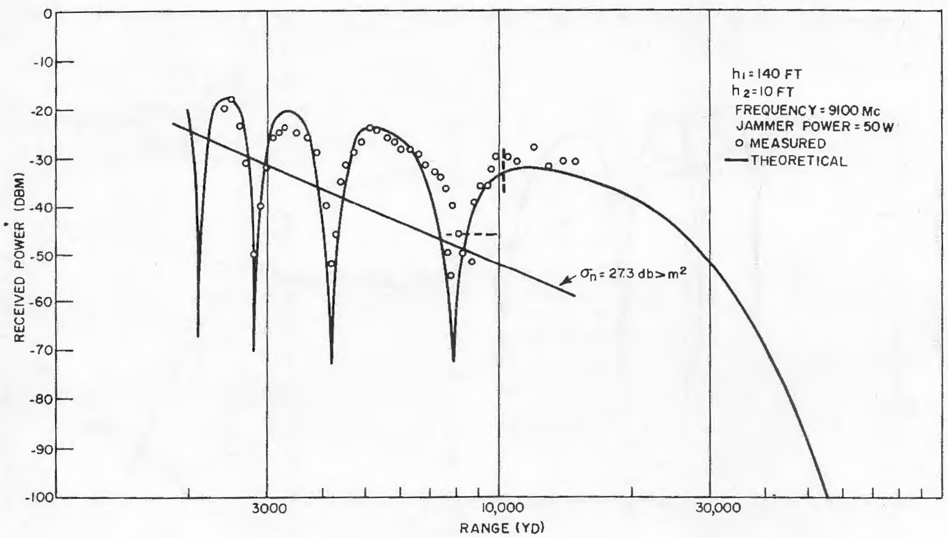

Fig. 7 - Received power vs. range of the AN/ALT-2 jammer, horizontal polarization, stern aspect

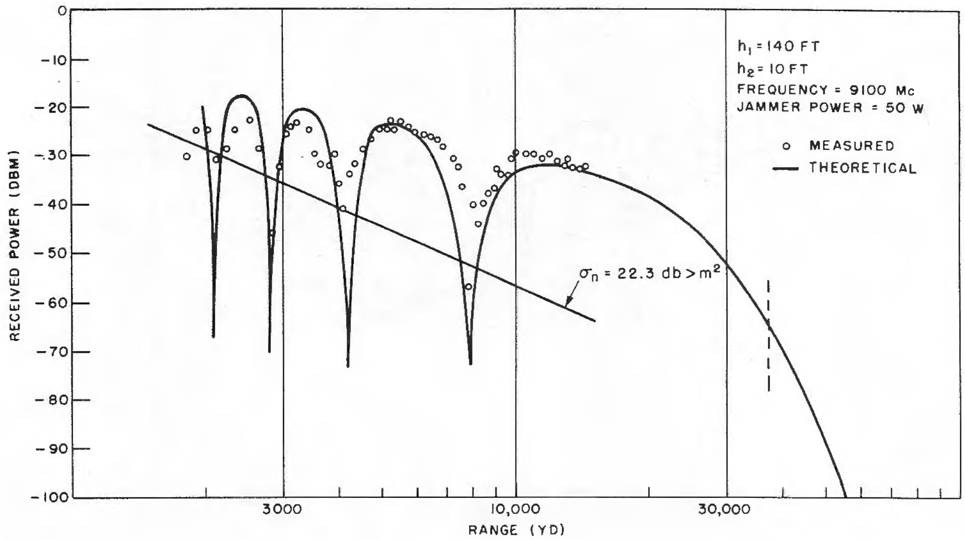

Fig. 8 - Received power vs. range of the AN/ALT-2 jammer, horizontal polarization, bow aspect

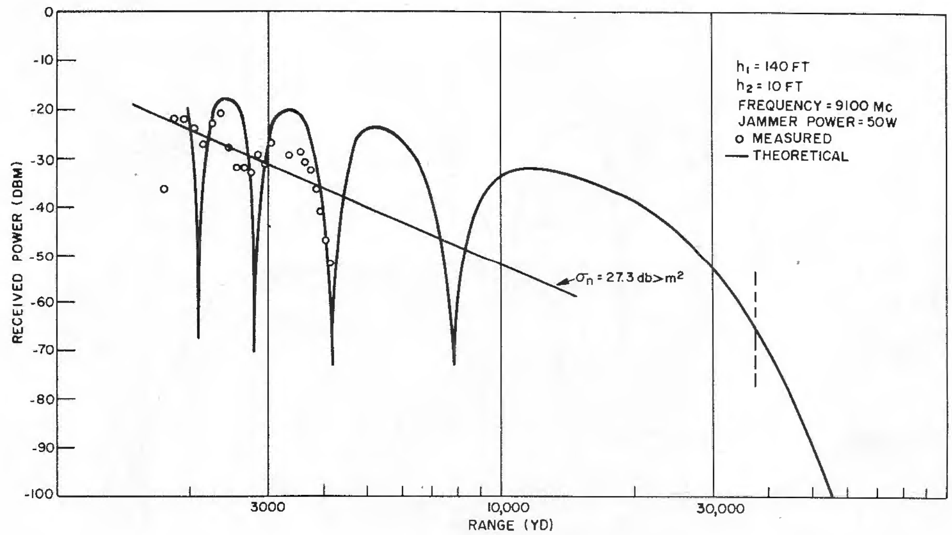

Fig. 9 - Received power vs. range of the AN/ALT-2 jammer, horizontal polarization, stern aspect

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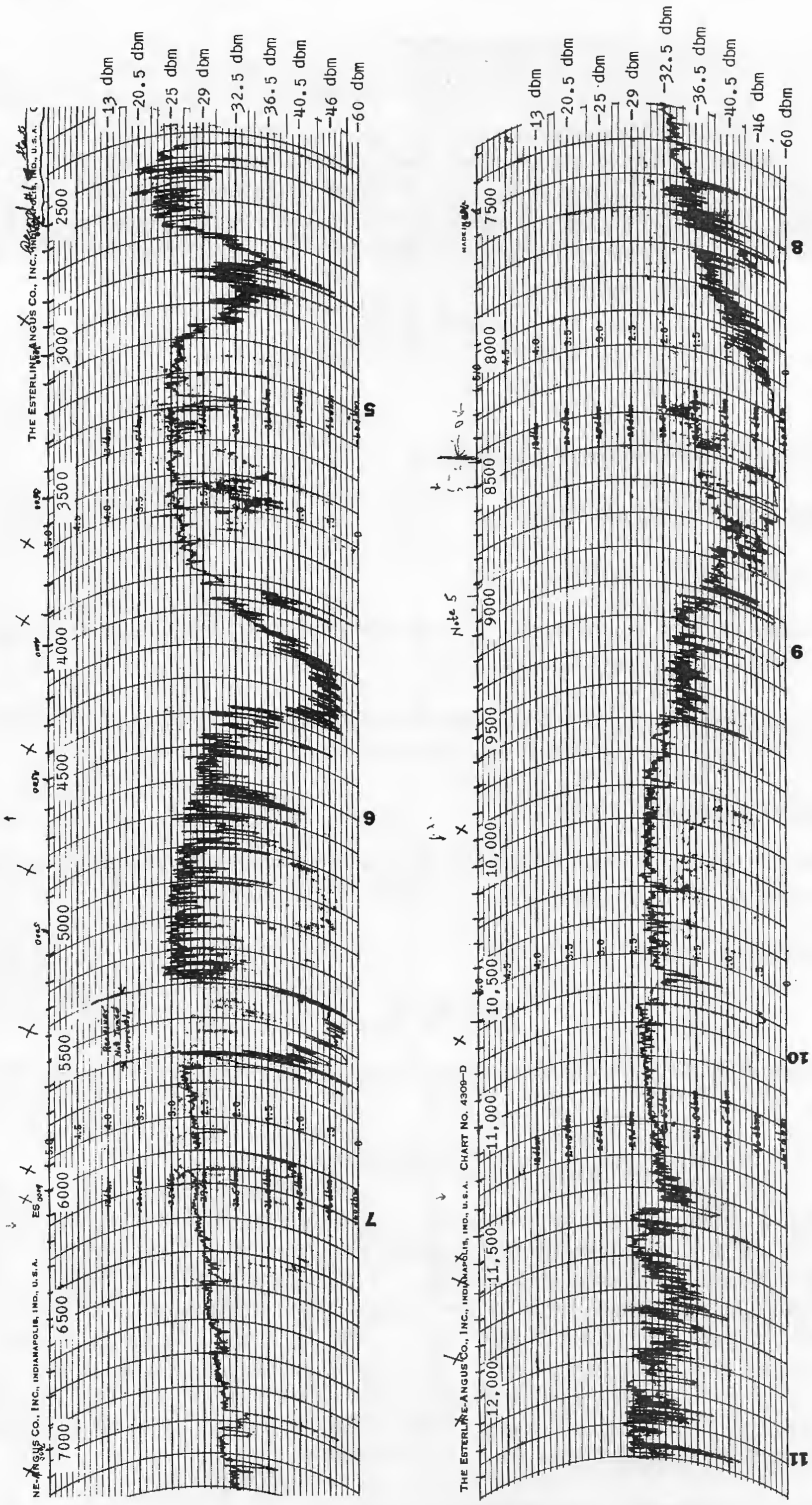

Fig. 10 - Sample recording of jamming energy received

It might be well, before proceeding, to discuss K more thoroughly. In the case of the search radar the point of jamming is not necessarily the point at which the average jamming power equals the peak radar power in the receiver. There is a proportionality factor, K, which relates the two power levels. In the case of automatic tracking radars the detection is made by an electronic control mechanism instead of the eye. However, this mechanism may not determine a condition of jamming at the same jamming-power level as does the eye. Therefore, a different value for K will result. Nevertheless, for either the visual or the electronic detection of the jamming condition we can use the same expression:

$$P_j = K \frac{P_t G_t \sigma_n}{G_j 4 \pi R^2},$$

where

P_j = Required jammer power in watts

P_t = Radar peak power in watts

G_j = Gain of jamming antenna

In order that P_j take on different values, K must be broken down into subfactors. Three such subfactors are as follows:

K_a = Propagation factor, which includes the variations in path attenuation and the loss due to being off the beam maximum

K_b = Peak to average radar area

K_r = Receiver factor, which includes the receiver bandwidth acceptance of the jamming power radiated and the receiver integration factor

By these definitions it is seen that

$$K = K_a K_b K_r.$$

However, if it is assumed that normal propagation exists and the target is on beam center, then

$$K = K_b K_r.$$

The value K_b is useful in attempting to correlate actual jamming in the field with bench measurements using a stable pulse generator as the target source. The stable generator would correspond to a peak radar area. It is observed that the peak radar area occurs only a small percentage of the time in the field. If one wishes to determine the jamming power required to jam a given average radar area, K_b becomes one. If a peak radar area is given, K_b takes on values greater than one and a much larger amount of jamming power is required. For an accurate interpretation of the data, the particular radar area used must be identified. In this report the average radar area, as given in Figs. 4 and 5, will be used in determining jamming power requirements.

It was shown earlier that the picket boat would be considered jammed at the limiting range by 20 db. It has been determined that K is +3 db for the SU-2 and AN/ALT-2 combination. The picket with a σ_n of 27.3 db > m^2 will therefore be jammed at 10,300 yards with 1 watt.

The value of 27.3 db, it will be noted, is the average value measured. Figure 5 shows this value to be 9.6 db lower than the absolute maximum observed. The lower value, however, is considered to be the true value of radar area for use in the jamming equation. A similar result has been observed previously.[4] Although the earlier measurements were made in a manner different from those reported here, it was observed then that the ship was not visible in the presence of marginal jamming until the maximum echo exceeded the jamming by 8 to 11.5 db. This was attributed to the bobbing of the pip in the earlier tests and is similarly explained for the present tests.

Some recent measurements of the radar areas of naval vessels (Table 2) were made at the Chesapeake Bay Annex by comparison with a standard spherical reflector.

TABLE 2
Radar Areas of Various Naval Vessels

Type of Vessel	Near-Zone Radar Area	
	m^2	db > m^2
Battleship	3.8×10^6	+65.8
Aircraft Carrier	1.2×10^6	+60.8
Heavy Cruiser	4×10^5	+56.0
Destroyer	6×10^4	+47.7
Destroyer Escort	4×10^4	+46.0

Since the σ_n for a destroyer is 47.7 db > m^2 it will require 47.7 - 27.3 = 20.4 db above 1 watt, or 110 watts, to jam the destroyer at 10,300 yards. This value is based on the measured average radar area of the picket as obtained from Fig. 5.

A more general method of determining the power requirements makes use of the beam power of the jammer rather than the generated power, thus accounting for the antenna gain. A plot of the radar signal in the SU-2 receiver is given in Fig. 11 for various types of vessels. With a K of +3 db, the destroyer will miss being jammed at 5500 yards by +6 db. At this range it would take 18.9 db (6 + 12.9) above 50 watts, or 3880 watts of beam power, to jam the destroyer. Beam power values for jamming the other vessels are shown in Fig. 12 along with the values for the AN/SLT-1 and AN/ALT-2 jammers.

It should be noted that the maximum of the jamming curve occurring at 5500 yards corresponds to an optimum antenna height. Thus, a maximum can be placed at any range by choosing the optimum jammer antenna height to correspond to a given radar height. The envelope of the maximum energy points will be a straight line whose slope is proportional to the inverse square of the range.

JAMMING OF FIRE-CONTROL RADAR

The discussion so far has been concerned with the jamming of a search radar but, in practice, the jamming of a fire-control radar should be of equal or greater value. A series

[4] White, W. D., "Study of Power Requirements for S-Band Jamming From Surface Vessels," Harvard Univ., RRL Report No. 411-113, December 1944

[redacted]

of measurements, which would provide information similar to that obtained on the SU-2 radar, was therefore planned for the Mark 25 Mod 3 radar. Figure 13 shows the theoretical attenuation curve for the installed antenna heights. The received jamming level can be determined from Fig. 13 and the known system constants:

$$P_j = 40 \text{ w} = +46 \text{ dbm}$$

$$G_j = +12.9 \text{ db}$$

$$G_t = +42 \text{ db}$$

The received jamming energy is then +46 + 12.9 + 42 - 120 = 19.1 dbm at 5200 yards. The full curve of received jamming energy is shown on Fig. 14.

Using the average radar area of 27.3 db $>$ m^2 (Fig. 5), the radar power received in the radar receiver will be

$$P_r = \frac{P_t G_t^2 \sigma_n \lambda^2}{(4\pi)^3 R^4} ,$$

where

P_t = 70 kw = +78.5 dbm

G_t = +42 db

σ_n = +27.3 db $>$ m^2

λ = 0.033 m = -14.8 db $>$ m

R = 5000 yards = 4592 m = +36.6 db $>$ m

4π = 12.566 = +11 db

Thus

$$P_r = (78.5 + 84 + 27.3 - 29.6) - (33 + 146.4)$$
$$= 189.8 - 209.0 = -19.2 \text{ dbm}.$$

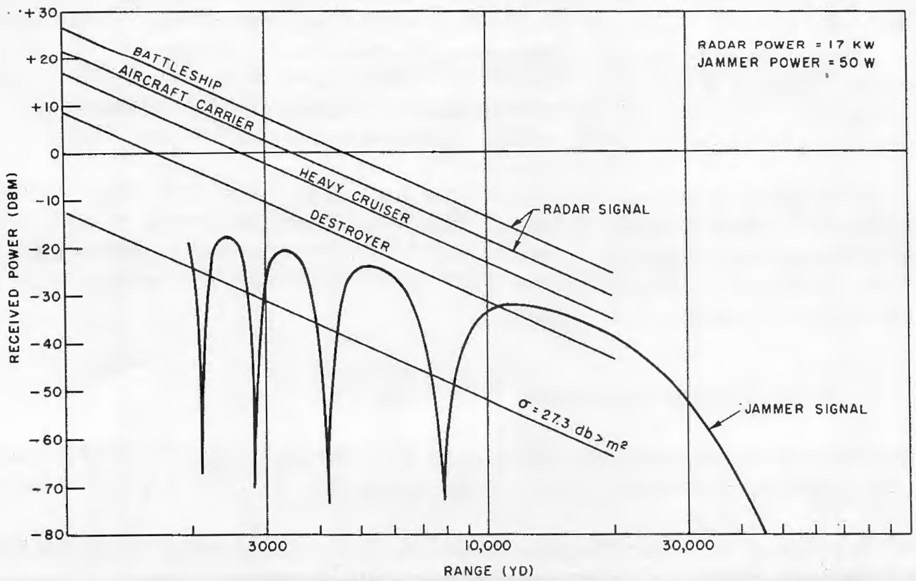

Fig. 11 - Comparison of received power vs. range for the SU-2 radar and the AN/ALT-2 jammer

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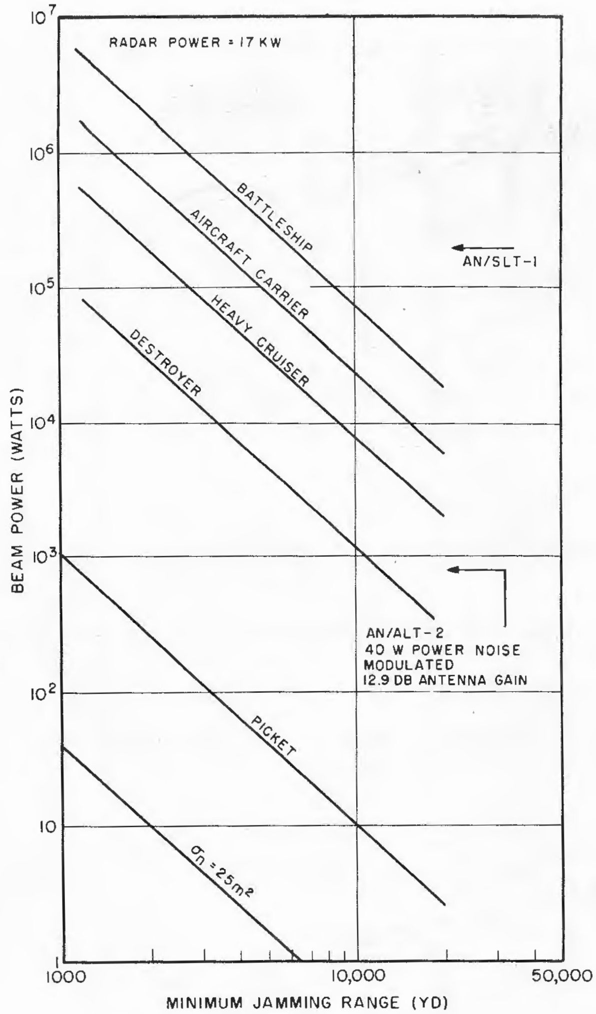

Fig. 12 - Beam power required for jamming the SU-2 radar

Thus the radar signal level in the receiver at 5000 yards will be -19.2 dbm. This is also shown on Fig. 14.

If it is assumed that K is one for the Mark 25 Mod 3 and the AN/ALT-2 jammer, the radar will not be jammed for ranges less than 5000 yards under the conditions of this test. Jamming in the case of the Mark 25 will be considered as the operating point at which the radar has lost track.

The value of K is not necessarily one but, as indicated earlier, depends upon many factors. The value which is sought is that which will allow future jammer planning to arrive at the correct power level for a particular jammer.

A value for K was determined by an actual jamming exercise in which the picket boat of known radar area made runs to and from the Mark 25 Mod 3 radar installation under the various radar and jammer operating conditions shown in Table 3. Both a bow and a stern run were made for each set of conditions and the last six runs were made with reduced

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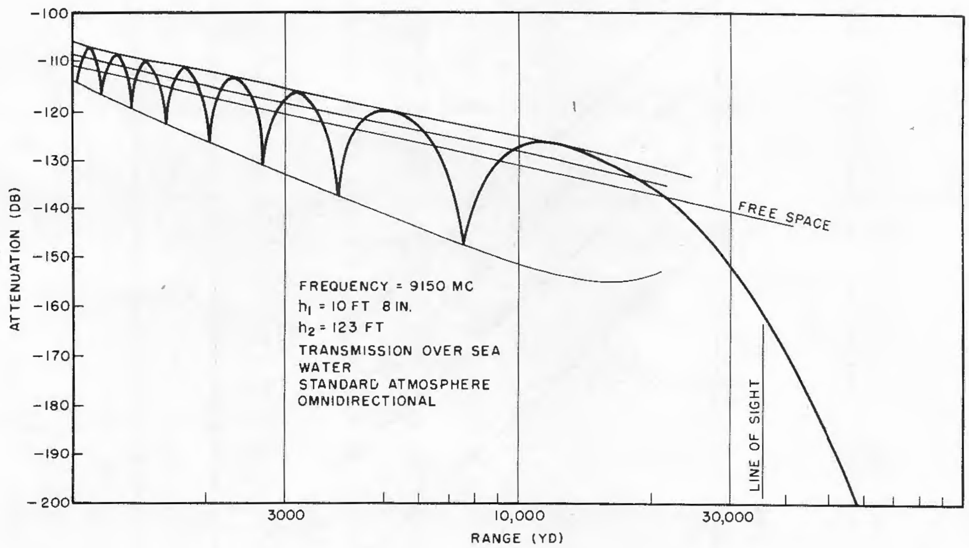

Fig. 13 - Attenuation of electric field strength, vertical polarization

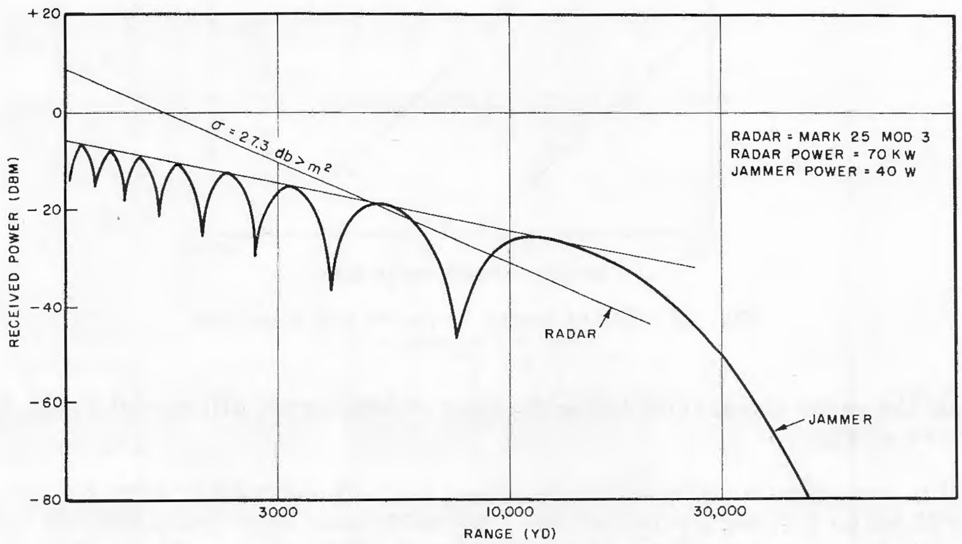

Fig. 14 - Received power vs. range of the AN/ALT-2 jammer, vertical polarization

antenna gain. Figures 15 through 20 show the condition of the radar for each run plotted along the line of theoretical radar return from the picket with aspect taken into account.

The qualitative analysis shows first that the radar is sensitive to the nulls of the jamming signal. All the runs show that the distinctive pattern of jamming occurs for the

[redacted]

maximum jamming signal as predicted by Fig. 13. The data in Fig. 17 are particularly accurate in this respect with clean breaks occurring between jamming and tracking into a very short range. Also shown in Figs. 15 through 20 is the sensitivity to radar area. Figures 4 and 5 show the average bow and stern radar areas to be 22.3 and 27.3 db, respectively. Jamming occurred in at least one closer jamming maximum for the smaller radar area than for the larger in all the graphs except Fig. 16, and might have occurred in this if the run had been continued. Thus, a difference in radar area of 5 db is readily observable by the radar in the presence of jamming.

TABLE 3
Radar and Jammer Operating Conditions

Run No.	Figure Reference	Radar			Picket		Jammer		
		Manual	AGC	FTC	Bow	Stern	Noise	cw	G_j (db)
1	15		x			x	x		12.9
2	16		x		x		x		12.9
3	17	x				x	x		12.9
4	18	x			x		x		12.9
5	19	x				x		x	12.9
6	20	x			x			x	12.9
7	21	x		x		x		x	5.0
8	22	x		x	x			x	5.0
9	23	x				x		x	5.0
10	24	x			x			x	5.0
11	25		x			x		x	5.0
12	26		x		x			x	5.0

A study of the detector circuit of the Mark 25 indicated a possibility of jamming with straight cw. A change from noise modulation to cw with some incidental FM was made after the fourth run. Therefore, from the data in Fig. 17 it appears that cw might be superior to noise modulation, and when the first four runs, taken as a group, are compared with the last eight runs (Table 4), cw is found to be superior. The ratio of the jamming energy to pulse energy for the make- and break-track conditions at three different ranges is determined by superimposing Fig. 14 upon each of Figs. 15 through 20 with due regard for the antenna gain and reading the decibel difference between the curves at the make and break points closest to the selected ranges. The result of such an analysis is shown in Table 4. Some spaces are missing owing to the absence of a make or break sufficiently close to the selected ranges. A negative decibel value indicates that the jamming energy is below the pulse energy.

The average for both the make- and break-track conditions is seen from Table 4 to be less for the cw jamming than for the noise jamming. The break-track grand average for noise modulation is -4.0 db and for cw operation is -8.1 db. The AN/ALT-2 is then 4.1 db less effective when noise modulated against the Mark 25 radar than it is when operating cw.

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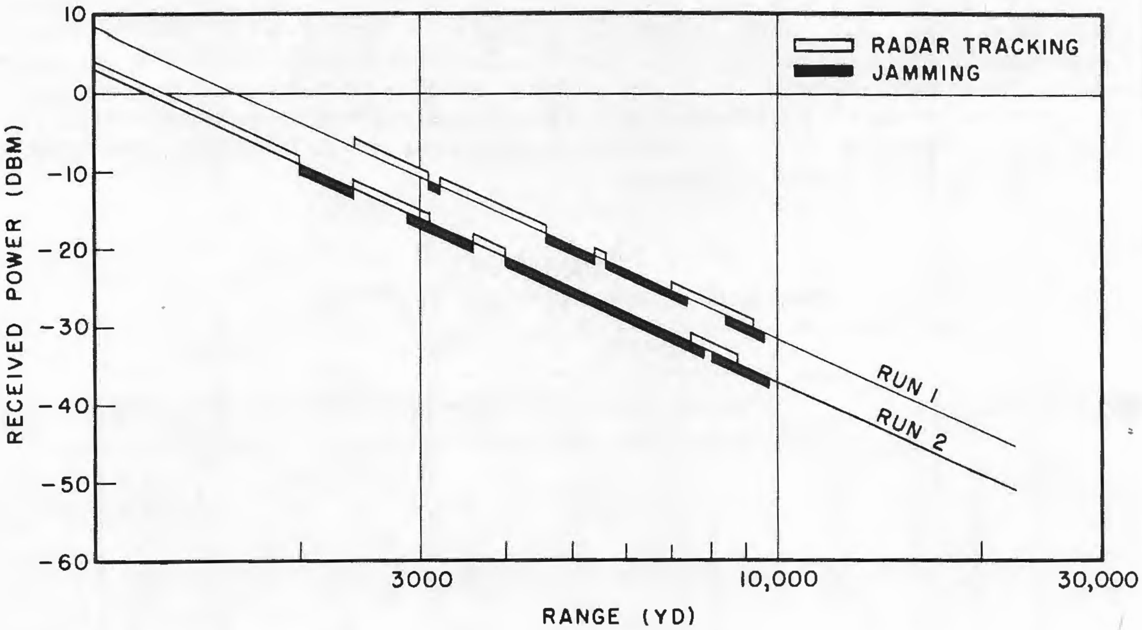

Fig. 15 - Jamming conditions of Mark 25 Mod 3 radar, runs 1 and 2

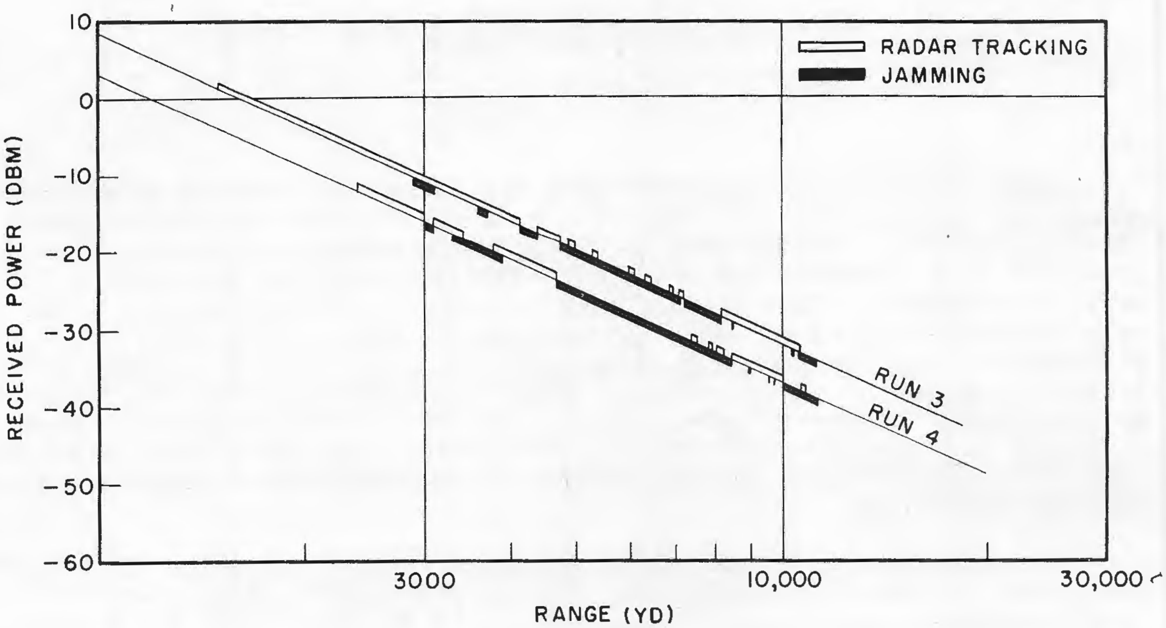

Fig. 16 - Jamming conditions of Mark 25 Mod 3 radar, runs 3 and 4

[redacted]

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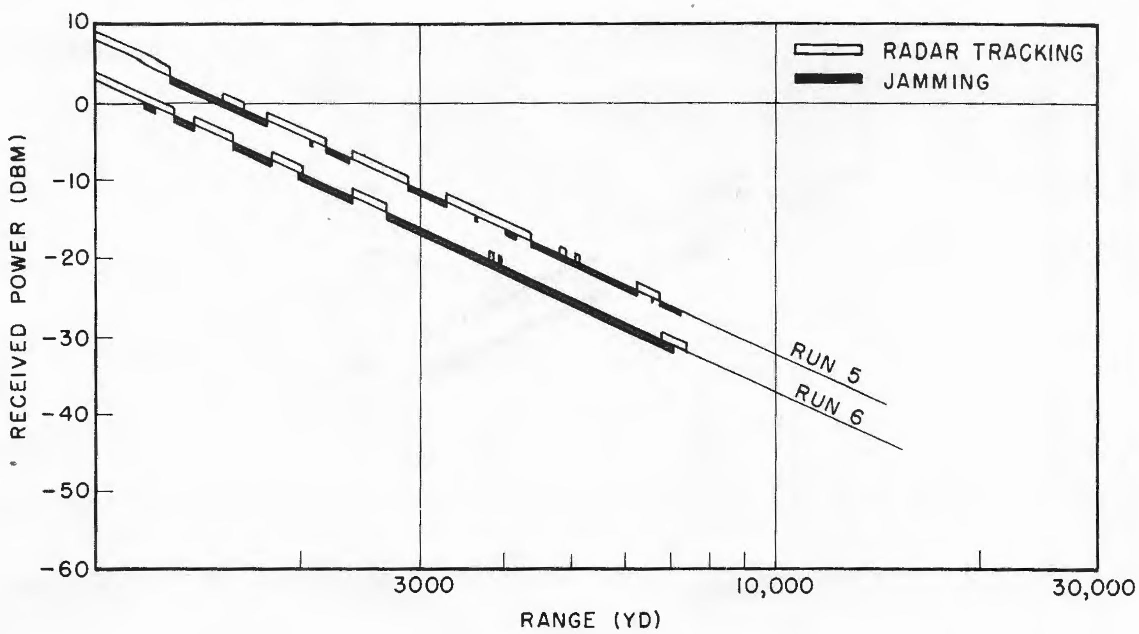

Fig. 17 - Jamming conditions of Mark 25 Mod 3 radar, runs 5 and 6

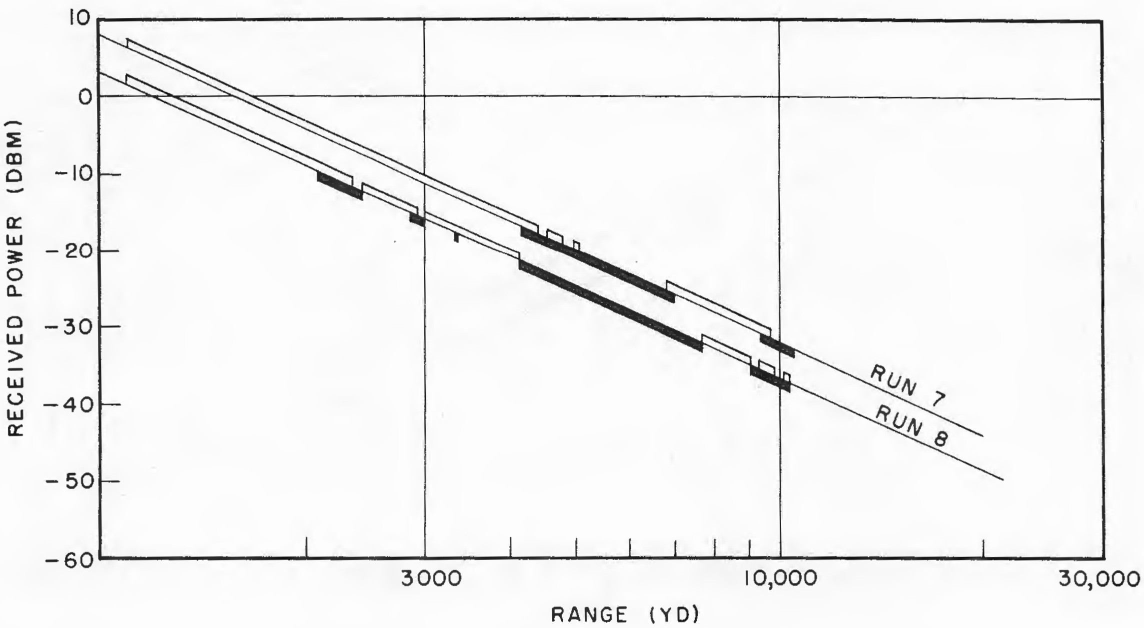

Fig. 18 - Jamming conditions of Mark 25 Mod 3 radar, runs 7 and 8

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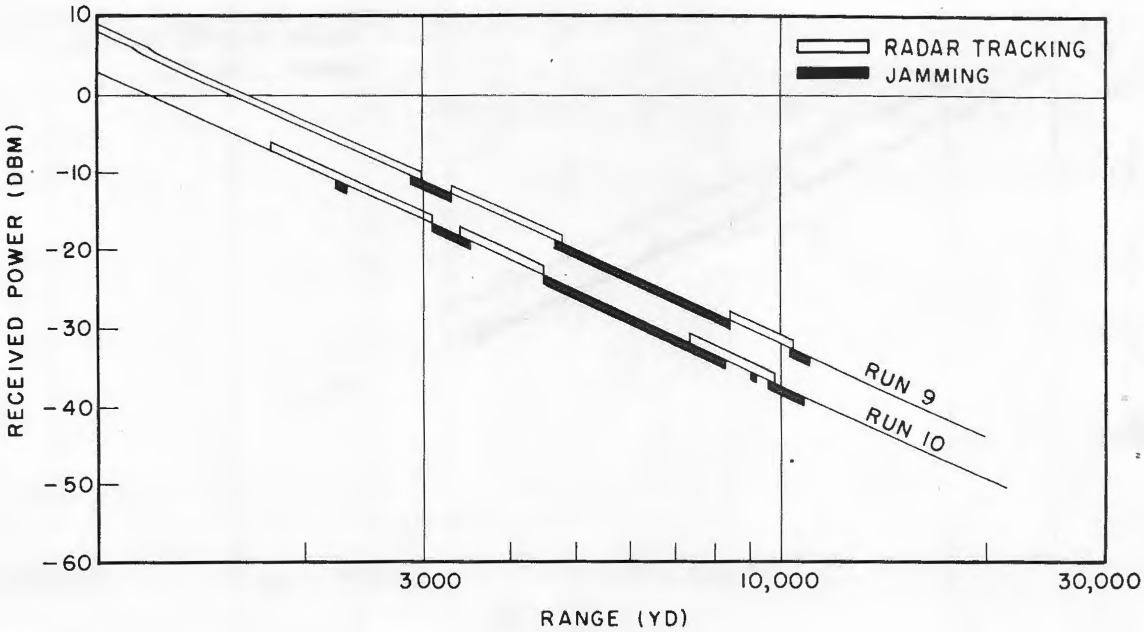

Fig. 19 - Jamming conditions of Mark 25 Mod 3 radar, runs 9 and 10

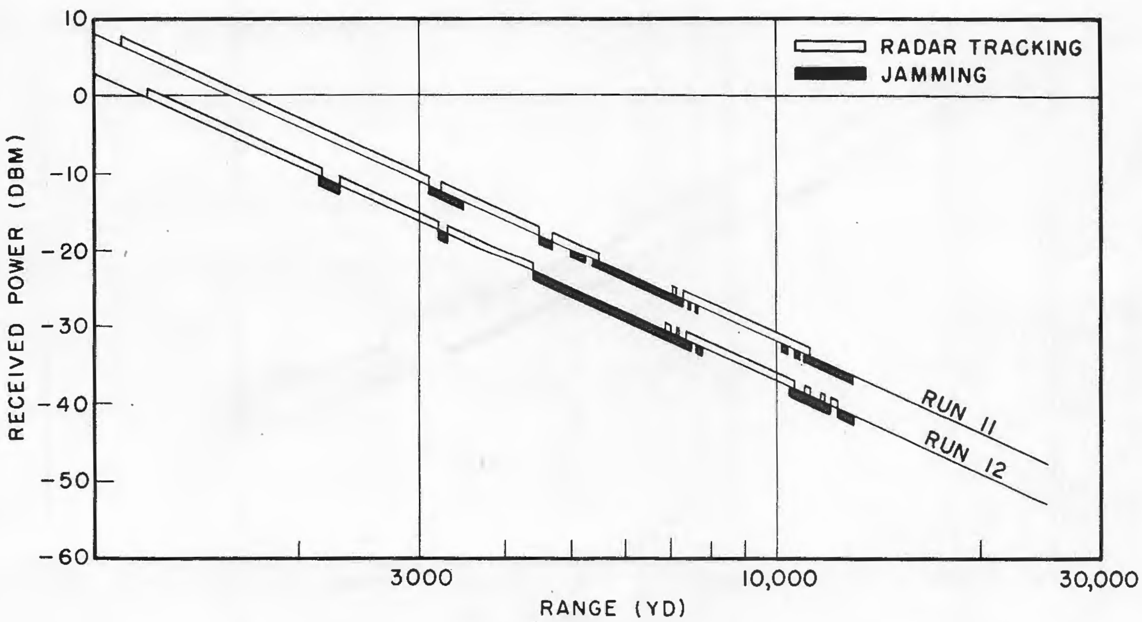

Fig. 20 - Jamming conditions of Mark 25 Mod 3 radar, runs 11 and 12

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TABLE 4
Analysis of Fire-Control Jamming Runs

Test Condition	Run No.	3000-Yd Range Make (db)	3000-Yd Range Break (db)	5000-Yd Range Make (db)	5000-Yd Range Break (db)	7500-Yd Range Make (db)	7500-Yd Range Break (db)
Noise	1	-3.5	-5	-1	-3	-8	-5.5
	2	+1	-2	-9	-2	+3	-6
	3	-4	-8	-5	-1.5	-9	-11
	4	0	-1	-3.5		+1	+1
	Avg. 1-4	-1.63	-4	-4.62	-2.17	-3.25	-5.37
CW	5	-3.5	-7	-1.5	-4.5		
	6	-11	-2				-3.5
	7			-15	-11.5		-5
	8	-11	-9	-12		-3	-16
	9	-11	-15.5		-8.5	-11.5	
	10	-7	-7.5	-6		+2.5	-9.5
	11	-12	-12	-9	-12	-19	0
	12	-5.5	-6	-7		-18	
	Avg. 5-12	-8.71	-8.43	-8.42	-9.13	-9.8	-6.8

The beam-power method will again be used to determine jammer power requirements. To begin with it can be seen from Fig. 14 that the radar signal level returned at 5300 yards is -20.2 dbm. The jamming signal level at the same range is -19.0 dbm. Using a K value of -8.1 the jamming signal level is found to be 9.3 db greater than necessary to break track. At this range it would take 3.6 db (12.9 - 9.3) above 40 watts, or 91.6 watts of beam power, to break track on the picket. Values for radar areas of interest are summarized as follows:

	σ_n (db > m^2)	Beam Power (watts)
B-29 Bomber	14.0	4.28
Picket	27.3	91.6
Destroyer	47.7	10,000
Heavy Cruiser	56.0	68,000
Aircraft Carrier	60.8	205,000
Battleship	65.8	648,000

These values are plotted and extended for various ranges in Fig. 21. The Mark 25 was operating at 70 kw for these tests. Figure 21 will have to be corrected for other values of operation according to the jamming equation. If, for example, noise modulation on the AN/ALT-2 was being considered, the beam power required would increase by 4.1 db because of the change in the modulation. It is possible to extend the range only by assuming

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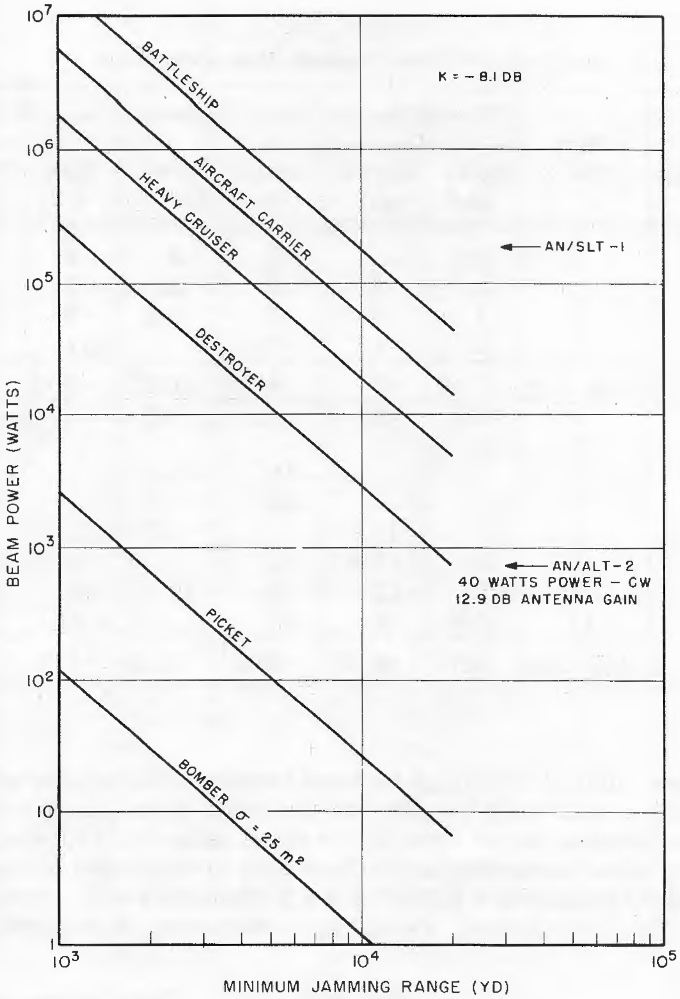

Fig. 21 - Beam power required for jamming the Mark 25 Mod 3 radar operating at 70 kw

that optimum antenna heights are available, thus presenting at all times maximum jamming energy to the radar. If other than optimum antenna heights are used, an increase in jamming power will be required.

Optimum antenna height signifies that maximum jamming energy is being received by the radar for the range chosen. It is generally considered that this range is the range of the first maximum, and that for shorter ranges the jamming signal will pass through minima and additional maxima. A curve of optimum jammer-antenna height versus range for several radar heights is given in Fig. 22. In Fig. 23 a curve of additional power required for a jammer antenna height other than optimum at a range of 13,000 yards is shown. For Figs. 15 through 20 the antenna height was optimum at 13,000 yards, and as the range decreased a number of nulls were encountered in which the jamming energy decreased to a point of ineffectiveness. The upper line of Fig. 13 is the locus of jamming energy maxima occurring at optimum antenna heights. This line can therefore be used, as is done

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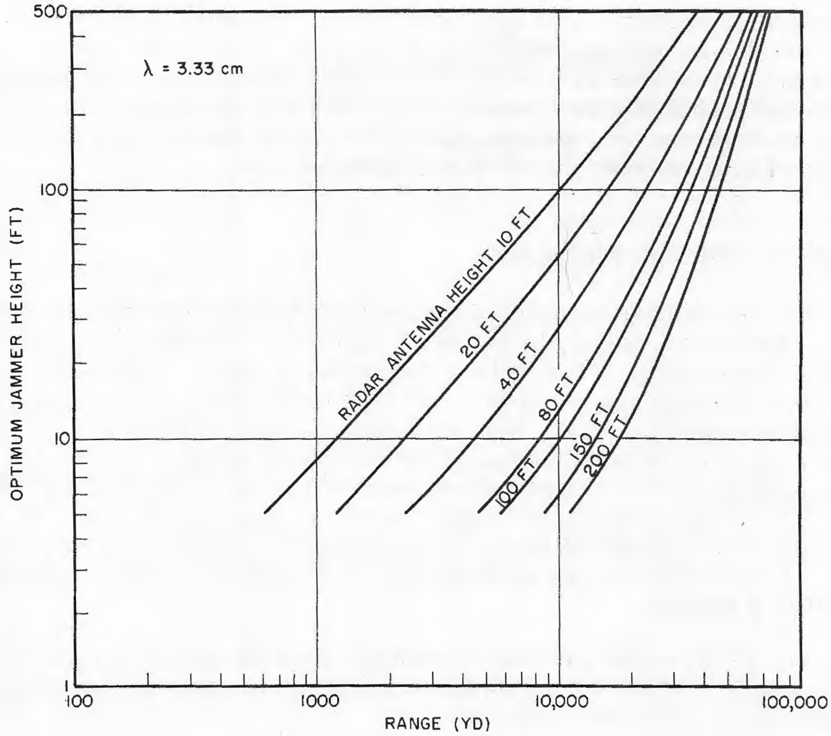

Fig. 22 - Optimum antenna height vs. range

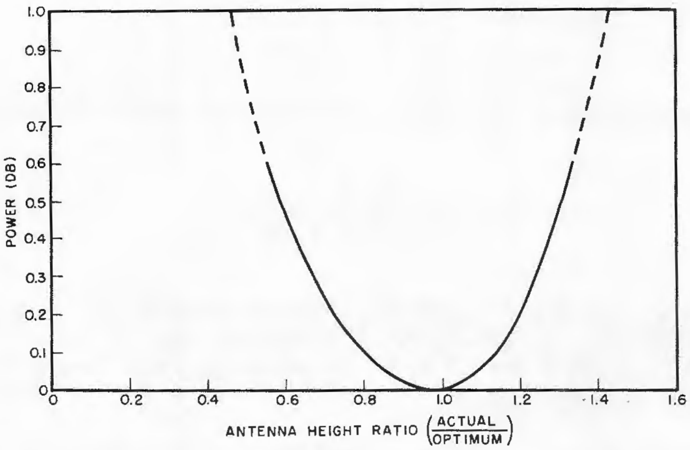

Fig. 23 - Increase in power required for antenna heights other than optimum at a range of 13,000 yards

in Fig. 14, to determine a crossover point providing the antenna height is optimum. It was only incidental that the crossover occurred near the second maximum of Fig. 14. Had the radar area been 4 db greater, the crossover would have occurred at about 7500 yards and therefore in the middle of the first null.

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For a given percent deviation from optimum, Fig. 23 shows a more rapid increase in required power for an antenna height that is too high than for one that is too low. From Fig. 22 it does not appear that on a ship of reasonable size the optimum antenna height for short ranges could practically be reached. Thus, results such as are shown in Figs. 15 through 20 can be expected for marginal jamming powers unless some provision is made, such as the use of dual antennas, to fill in the jamming nulls.

APPLICATION TO THE AIR PROBLEM

Although the measurements included in this report were made with a picket boat as the target, the results are applicable to the air problem particularly in the case of a low flying aircraft. The location of the nulls in the jamming curve (Fig. 2) is a function of the height of the radar antenna and the target. As the height of either is raised the range of the farthest null is extended. It has been observed that an aircraft flying at an altitude of 140 feet exhibits deep nulls in the jamming curve. These nulls, however, are much closer together at a given range; for example, at a range of 10,000 yards they were separated about 1000, yards and were correspondingly closer for shorter ranges. The effect on the jamming is to cause a form of "blinking" in the appearance of the jamming on an A-scope presentation. The jamming is thus sufficiently reduced in the nulls to allow the target signal to be clearly visible.

Although this problem has not been thoroughly investigated, it is expected that similar results would be observed for target elevation angles up to several degrees, depending on the beamwidth in elevation of the radar antenna.

The choice of a B-29 bomber as the aircraft cited in this report does not relate in any way to its mission. It merely supplies a name to a flying target with a smaller radar area.

CONCLUSIONS

The near-zone jamming power required in a given situation depends upon the factors in the relation

$$P_j = K \frac{P_t \, G_t \, \sigma_n}{G_j \, 4\pi \, R^2} .$$

In this relation the factors K and σ_n are of particular importance. It was found that σ_n will vary as much as 18 db for a given target. The correct value to use is believed to be the average value, which varies from 7.6 to 9.6 db below the peak; thus a clear identification of the value selected is necessary.

Using the average value of σ_n as measured for a picket boat, the value of K for the AN/ALT-2 jammer working against the SU-2 radar was found to be +3 db for noise modulation of the jammer. For the AN/ALT-2 jammer working against the Mark 25 Mod 3, a K of -4.0 db was found for noise modulation of the jammer and -8.1 db for cw operation. These figures correspond to 1200 watts of beam power to jam the SU-2 radar with the AN/ALT-2 jammer on a destroyer at 10,000 yards, and 2900 watts of beam power to break track on the Mark 25 Mod 3 at 10,000 yards with cw operation. All these figures assume optimum antenna heights.

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The spread of 7.0 db between jamming the SU-2 and the Mark 25 is only an indication of the possible variance in power requirements for jamming of different radars. It is possible that the spread will be found even greater for other radars. Such variation in power-level requirements makes the specific application of a jammer of major importance. This is particularly true when power requirements approach or exceed present system capabilities.

The Mark 25 Mod 3 radar is capable of distinguishing between radar areas which differ by as little as 5 db.

The fact that only limited information is available on the X-band radar areas of surface ships at present, and the existence of wide variations in power requirements, as exhibited in Table 4, indicates that a tolerance of several db should be allowed in any determination of system requirements.

ACKNOWLEDGMENTS

The author wishes to acknowledge the work of J. R. Williams, F. T. Griffin, and V. J. Volkel of the Countermeasures Branch in assembling and calibrating the systems, as well as their continuous aid in collecting the data. The assistance provided by personnel of the Chesapeake Bay Annex in providing test facilities and test coordination also is gratefully acknowledged.

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LIST OF SYMBOLS

D = Duty cycle of transmitter

G_c = Insertion loss of directional coupler

G_H = Gain of standard horn

G_j = Jammer antenna gain

G_t = Radar antenna gain

H = Standard horn

h_1 = Radar antenna height in feet

h_2 = Jammer antenna height in feet

$K = \dfrac{\text{Actual required jammer power}}{\text{Theoretical required jammer power}}$

K_a = Propagation factor

K_b = Peak to average radar area

K_r = Receiver factor

λ = Wavelength

P_0 = Average power of radar into power meter

P_1 = Power received from radar

P_j = Required jammer power in watts

P_r = Returned peak radar signal in the receiver

P'_r = Peak power from signal generator when matching pips

P_t = Radar peak power in watts

R = Range in yards

R_{lim} = Limiting range

R_t = Transition range in yards

σ_n = Near-zone radar area of target

* * *

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