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THE MEASUREMENT OF VULNERABILITY TO JAMMING

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NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

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THE MEASUREMENT OF VULNERABILITY TO JAMMING

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ABSTRACT

A method of measurement is described which involves the use of a low-powered jammer operating at close range instead of a high-powered jammer operating at greater range. Measurements were made against a shipboard surface search radar at X-band. Results are compared with those obtained by use of a medium-power jammer. Measurements made by this method are reasonably accurate. The power necessary to jam an X-band radar set is presented. Excessively high jammer power is required to screen a surface target from detection.

PROBLEM STATUS

This is an interim report on one phase of NRL Problem R06-30. Work on the general problem is continuing.

AUTHORIZATION

NRL Problem No. R06-30 (BuShips Problem S1454).

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THE MEASUREMENT OF VULNERABILITY TO JAMMING

INTRODUCTION

Measurements of the vulnerability of radar equipments to jamming are made for a twofold purpose. They determine the degree of excellence achieved in the design of the radar and they also determine the feasibility of building jammers to operate against a particular type of radar. Since no high-power X-band jammers were avaliable when this work was begun it was necessary to devise a substitute method. This was accomplished in the following manner: A low-power jammer was placed at a close range and the signal compared to the echo signal from a target of known reflection characteristics. Propagation equations were then used to convert the power and range to a high-power jammer at useful ranges.

All jammer power values in this report represent the power required to produce a noise signal in the radar receiver equal to the target echo signal and do not include a screening ratio. The effect of the screening ratio on the jammer power required for screening a target is defined as:

$$\text{screening ratio} = \frac{P'_{jt}}{P_{jt}}$$

where P'_{jt} = jammer power required to prevent detection of the target echo on the radar indicator by the operator, and

P_{jt} = jammer power required to produce a signal at the radar receiver equal to the target echo signal.*

EQUIPMENT

A 2K39 Klystron energy source was used to feed a horn antenna which had a gain of 15 db, and radiated 90 milliwatts. The power was measured with an X-band thermistor bridge and an attenuator. The 2K39 was modulated at the repeller, giving a combination frequency modulation and amplitude modulation. The bandwidth of the jammer, measured with the TSX-4SE spectrum analyzer, was 8.5 megacycles.

A TS-13 signal generator was used to compare the signal strength of the echo to the signal strength of the jammer.

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* R. L. Henkel, T. S. Kuhn, L. B. Lusted, and R. E. Reid, "Measurements of Jamming Effectiveness," Harvard University, RRL Report No. 411-250, (August 21, 1945).

The standard target used in the measurements was 5584 yards from the antenna of the radar under test and had an equivalent echoing area of 817 square meters. This standard target is an angle iron, 6 ft 8 in. long and 4 in. on a side, rigidly mounted almost vertically and used as a dihedral corner reflector. The length of the corner and its mounting are such that the re-radiation pattern has a null in the direction taken by water reflection back to the radar antenna. The echo return is then due to the direct reflection from the corner reflector.

METHOD OF SIMULATION

The propagation equations below are used as a basis for simulation of high power jammers using data obtained with a low power jammer. These equations, which appear in various places in the literature, were taken from J. L. Lawson.†

$$P_{jr} = \frac{P_{jt} G_j \lambda^2 G_r}{(4\pi)^2 R_j^2} \tag{1}$$

$$P_{rr} = \frac{P_r G_r^2 \lambda^2 \sigma_n}{(4\pi)^3 R_r^4} \tag{2}$$

where P_{jr} = jamming power at radar receiver input,

P_{jt} = power of jammer within receiver bandwidth,

G_j = gain of jammer antenna,

λ = radar and jammer wavelength,

R_j = range of jammer,

G_r = gain of radar antenna,

R_r = range of radar,

P_{rr} = radar echo power at receiver input,

P_r = power of radar, and

σ_n = near zone echoing area. ‡

For separate jamming transmitters, one low-power and one high-power, placed at different ranges to give an equal signal input to a radar receiver, the following conditions must be satisfied:

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† James L. Lawson, "The Power Necessary to Jam a Microwave Radar Set." MIT Rad. Lab. Special Report No. 72, (March 24, 1943).

‡ The operating range of a radar for surface targets is divided into a near zone and a far zone. In the near zone the echo signal strength falls off as an inverse fourth power of the range and in the far zone the echo signal strength falls off as an inverse eighth power of the range.

$$P_{jr1} = P_{jr2} = \frac{P_{jt1}\, G_{j1}\, \lambda^2\, G_r}{(4\pi)^2\, R_{j1}^2} = \frac{P_{jt2}\, G_{j2}\, \lambda^2\, G_r}{(4\pi)^2\, R_{j2}^2} \qquad (3)$$

where subscript 1 indicates the low-power jammer and subscript 2 indicates the high-power jammer. Using antennas with equal gain for both jammers, the above relationship reduces to:

$$P_{jt_2} = P_{jt1}\left(\frac{R_{j2}}{R_{j1}}\right)^2 \qquad (4)$$

The following relationships are used for calculating the jammer power required to give a signal equal to the echo signal, from targets of different sizes, and at various ranges, when the jammers power has been determined for one target, (all ranges and echoing areas being known).

$$P_{jr1} = P_{rr1} = \frac{P_{j1}\, G_j\, \lambda^2\, G_r}{(4\pi)^2\, R_{j1}^2} = \frac{P_r\, G_r^2\, \lambda^2\, \sigma_{n1}}{(4\pi)^3\, R_{r1}^4} \qquad (5)$$

Writing the same equation for the high-power jammer with subscript 2, solving each for the jammer power, and taking the ratio of the jammer powers, the following relationship results.

$$\frac{P_{j2}}{P_{j1}} = \frac{\sigma_{r2}}{\sigma_{n1}}\left(\frac{R_{j2}}{R_{j1}}\right)^2\left(\frac{R_{r1}}{R_{r2}}\right)^4 \qquad (6)$$

PROCEDURE

A model SU radar was used to make the measurements.

The SU radar, an X-band surface search radar with a nominal peak power of 45 kw and an antenna gain of 28 db, was located at the Chesapeake Bay Annex of NRL.

The low-powered jammer was placed at a range of 65 yards from the radar antenna. This is ample range to obtain, for practical purposes, a plane wave front at the radar antenna, since at 65 yards, the curvature of the wave front from the edge to the center of the parabolic antenna is less than 0.02 wavelength at the SU frequency. This curvature will give a negligible phase difference in the received signal. At a range of 65 yards, the 90-milliwatt jammer produces a signal input to the radar receiver equal to that of a 2000-watt jammer at 10,000 yards.

The jammer signal input was compared to the echo signal from the standard target by the TS-13 signal generator, using the attenuator readings.

RESULTS

With the jammer located 65 yards from the SU antenna and with 90 milliwatts output, the noise input to the radar receiver was 9 db above the echo signal from the standard target. From this data, using equation (4), a jammer power output of 84 watts would be required at the target to give an input noise signal equal to the standard target echo signal.

For a jammer bandwidth of 2-3/4 megacycles which is very near the SU bandwidth, the power necessary would be 28 watts.

A series of NRL Reports entitled, "Radar Cross Section of Ship Targets"§ gives the near zone radar cross-section of a destroyer as 2×10^5 square meters for a 200 megacycle radar, 1×10^6 square meters for a 970 megacycle radar, and 4×10^6 square meters for a 3060 megacycle radar. From the above figures an estimate of 1×10^7 square meters should be reasonably accurate for a 9000 megacycle (X-band) radar. For a radar antenna height of 60 feet, the near zone extends to about 20,000 yards to 25,000 yards for a destroyer target. Since the guns of the largest ship normally carrying the SU have a maximum range of 17,000 yards, jamming would be necessary in the near zone for destroyers. Using the data obtained in this test and equation 6, a jammer power of 35,000 watts would be required.

Figure 1 shows the power required for the destroyer at various ranges. The dotted section is an estimate of the far zone power. The change-over range will vary depending on the jammer antenna height and the change in the slope of the power curve will probably be gradual rather than abrupt as shown.

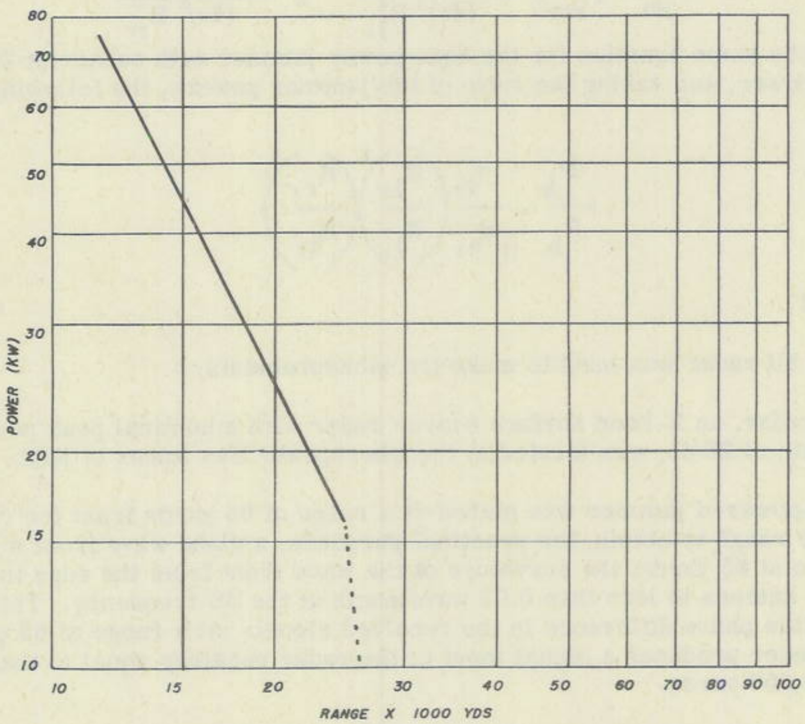

Fig. 1 - Jamming Power vs Range (for a Destroyer)

Jamming the SU from a smaller craft, such as a fast torpedo boat, would be more practical technically if not tactically. For this type of target, the near zone would extend from 7,000 yards to 8,000 yards. The maximum range of a torpedo carried by these boats is about 4,500 yards. Assuming that the boat can drop the torpedo and turn in 500 yards, the jammer must

§ Naval Research Laboratory Reports Nos. RA 3A 213A (January 24, 1944), R-2232 (February 18, 1944), R-2295 (June 27, 1944), R-2332 (July 21, 1944), R-2466 (March 12, 1945), and R-2467 (April 10, 1945), written by various authors.

screen the boat at a range of 4,000 yards, which is in the near zone. Using the echoing areas of reference** as a basis, an estimate of 1×10^4 should be reasonably accurate for a torpedo boat in the near zone. The jamming power required to produce a signal equal to the target signal is 600 watts.

The above statements have been made without considering the effect of nulls in the jamming signal as the range of the jammer changes. This effect is more pronounced at the higher frequencies and, at X-band frequencies, multiple jammer antennas may be necessary to produce a jamming signal at the radar antenna at all ranges. This will increase the power requirement of the jamming transmitter.

"Jamming Power Curves vs Frequency,"†† at X-band frequencies, it is shown that the power required to screen a B-29 at an altitude of 25,000 ft varies from 5 watts to 100 watts. The 5-watt figure is for a very low power radar (2 to 5 kw) and 100 watts for a very high power radar (1 megawatt or more). If the SU antenna were elevated to an air search position, 30 watts jamming power would be required to screen a B-29 at 25,000 ft.

Tests were recently made with a 50-watt X-band jammer with a 10-megacycle bandwidth against the SU radar and the signal input to the radar was between 5 and 6 db below the standard target signal.‡‡ The horn antenna used had a gain of 19 db. Conversion results for a 2.75 megacycle bandwidth and an antenna with a 15-db gain, indicated that the power required to give a signal equal to the standard target would be 20 watts with the jammer at the target. The figure obtained by the simulated method of measurement for these conditions was 28 watts as indicated above. The tests also showed that, at X-band frequencies, very sharp nulls appear in a range run with the jammer.

CONCLUSIONS

(1) The method of measurement used is reasonably accurate by comparison with data obtained from measurements using a medium-power jammer. Measurements with medium-power jammers do not give precise, repeatable results and the simulation method is obviously no better. Results of the proper order of magnitude are considered obtainable.

(2) The jammer power values in this report represent the power required to produce a noise signal equal to the target echo signal. This does not screen the target from detection by the radar operator. The ratio of the power required to prevent detection, to the power required to produce a noise signal equal to the echo signal "screening ratio" reduces the effectiveness of jamming; to overcome this, more power is necessary for effective jamming. The screening ratio is usually 3 or more, depending on the jammer modulation, the jammer operator, and the radar operator.

(3) A very high power jammer is necessary to screen surface targets from detection by the SU radar.

(4) To produce a signal equal to a surface target signal on a modern radar with a high-gain antenna, higher power, and an improved receiver with anti-jam circuits would require, for practical operation, unreasonably high jammer power.

* * *

** Op cit (Cf. p. 4)

†† Letter No. TSELR-10/LS/gs from Air Material Command, Wright Field, Dayton, Ohio, to NRL Code 1240, dated 9 August 1946.

‡‡ Information obtained from tests made by the Jammer Group of the RCM Section using a 50-watt jammer. (Unpublished).

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