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Broadbeam ECM Antennas for Destroyer Installations

[Unclassified Title]

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Radio Division
Countermeasures Branch

March 18, 1966

U.S. NAVAL RESEARCH LABORATORY
Washington, D.C.

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CONTENTS

BROADBEAM ECM ANTENNAS FOR DESTROYER INSTALLATIONS
(Unclassified Title)

ABSTRACT

Site reflections reduce the isolation of omniazimuth antennas below the value required for stable operation of the high-gain amplifiers used in electronic decoy systems, unless the top of the highest mast is used as an antenna site. An analysis and development program to build a dual semi-circular azimuth coverage antenna has been conducted. The objectives were to choose a universally available site, measure the ships structure reflection from this site, develop an antenna with a pattern shaped to fit the measured contour and test the antenna aboard ship to prove the satisfactory operation of the beacon with properly designed antennas.

Horizontally polarized slot antennas were designed to fit the required pattern in the S and X bands. They were installed aboard the USS KRAUS, one of the ships whose contour was measured, and tested at sea where experimental verification of satisfactory performance was obtained.

PROBLEM STATUS

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

AUTHORIZATION

NRL Problem 54R06-10

BUSHIPS Project SF 010-02-01-9299

INTRODUCTION

The work being reported here was performed in 1961 and resulted in an internal memo at that time. Recently problems have emerged concerning the electronic instability of decoy repeater systems aboard destroyers where ships structure reflections appear to be causing a regenerative condition. The production antennas now installed are a direct outgrowth of NRL work; however, the "fall-off" specifications have been relaxed from those originally specified in the text of this report. Thus, it is believed necessary that the earlier work be reported at this time to provide the BuShips with additional information and perhaps illustrate a potential cause of the instability.

Electronic decoys are capable of giving all ships apparent radar echoes of equal size and thus hinder recognition of capital ships through radar echo size, by an enemy equipped with stand-off-weapons. Previous evaluations of S- and X-band electronic decoy systems, reference 1 and 2, have illustrated the ability of decoys to provide this deception. In the early phases, these systems have utilized antennas with doughnut shaped patterns providing 360° azimuth coverage. This type of antenna, due to the characteristics of the equipment, has very stringent siting requirements. It is imperative that it be situated where it has an electrically clear site over the full 360 degree coverage of the antenna, if system regeneration is to be avoided. Aboard ship few sites meeting this requirement are available (e.g. the top of the mast) and this is usually reserved for other equipments.

An alternative to this is to provide two antennas with 180° coverage diametrically opposite each other. This approach increases the choice of sites but practical problems of both installation and antenna design dictate that a practical approach requires the beamwidth to be less than 180°. This report presents the steps taken to solve the shipboard decoy antenna problem. The topics covered in this report shall:

1. Illustrate how the choice of decoy antenna installation was effected.

2. Describe the preliminary work undertaken to determine the reflection characteristics of the superstructure of DD class destroyers with respect to the selected antenna site.

3. Describe the antenna development oriented toward producing the best possible antenna meeting both system and site requirements.

4. Report the test results obtained using this antenna in a fleet evaluation C/S 10 FY61 coordinated by OPTEVFOR.

5. Outline the specifications to which the Bureau of Ships antenna program for ULQ-5 and ULQ-6 deception equipments should conform.

ANTENNA SITING CONSIDERATIONS

The systems for which the subject antennas are intended are deception repeaters operating in the 2 Gc to 4 Gc frequency band (ULQ-5) and the 7 Gc to 11 Gc frequency band (ULQ-6). They amplify any signal received in the stated frequency bands to a power density equivalent to that of the skin return of a carrier. This allows any repeater equipped ship to appear, to a radar, to have a return echo equivalent in amplitude to an aircraft carrier. Tolerable line losses dictate that a primary consideration in antenna location take into account the location of the equipment with respect to the chosen antenna site. The maximum desirable length of waveguide between equipment and antenna has been set at 25 feet to minimize losses.

From a purely electrical standpoint the ideal location for two 180° beamwidth antennas would be a bow and stern configuration. At these points all reflecting surfaces would be well beyond the ± 90° points. There are several considerations however which made this site undesirable:

1. There is no assurance that bow and stern location would be available especially on the stern of FRAM ships where interference with the drone helicopter would be possible.

2. The structural mounting of the bow antenna to withstand heavy seas would be a severe requirement and difficult to meet.

3. Equipment location within 25 feet of these sites would be difficult to effect.

This fore-aft configuration would provide 360° coverage with the usual interference pattern and attendent nulls at the cross-over point on each beam.

The second approach would be to locate the antennas along the sides of the ship. These antennas would have to be located within the beam extremities of the ship for both heavy seas and docking considerations. This configuration makes possible a central equipment location within 25 feet of the antennas but imposes a serious limitation upon the azimuthal coverage. In this location the reflections from the superstructure necessitate a narrowing of the beam to some value less than the desired 180°.

The first step in determining a beam shape required a choice of site that would be available on all destroyers. Many locations were considered but the site meeting the maximum number of requirements available on all destroyers was below the ends of the crossbar attached to the forward edge of the after stack. This site provided for an installation with the required 25 ft. waveguide length, a common equipment location, and a universally available, practical site. The major requirement not fulfilled by this site is the electrically clear 180° sector, ± 90° from the beam. It appears that a deviation from this requirement is justifiable when all the practical aspects of the installation and design of antennas of this type are taken into consideration even though the coverage will not provide the desired 360°.

In order to determine the maximum usable beam widths, the reflection characteristics of two ships, relative to the chosen site, were measured.

REFLECTION CHARACTERISTIC MEASUREMENTS.

The "X" band reflection characteristics of the superstructure of two destroyers, the USS KRAUS and USS JOHN R. PIERCE, were measured relative to the previously chosen antenna site. A special test apparatus was designed and constructed at NRL to permit mounting at the exact location chosen for the antennas. This fixture secured at the test site a pair of identical high gain, linear polarized horns (23 db) whose beams are axially aligned. Three degrees of freedom of horn movement were allowed by the fixture.

(1) The polarization could be fixed at either vertical or horizontal.

(2) The horn axis could be adjusted and fixed at any vertical angle between $\pm$ 40 degrees.

(3) The horn assembly could be rotated in the horizontal plane through all angles covering up to 360 degrees. Mechanical rotation was transformed to an electrical reference for continuous recording of the angular position on an X-Y recorder.

Figures 1 and 2 are pictures of the test antennas taken during the measurement of the USS JOHN R. PIERCE and a close-up of the instruments required for the measurement. The block diagram of the test set up is given in Figure 3.

One horn was operated as a transmitting element while the second collected the r.f. energy reflected from the ship's structure. The horn beamwidths (about 10 degrees) were considered adequate for the resolution required since only an averaging condition and not point sources of reflection were to be utilized to describe the contour as pertaining to the broad beam antenna design under question. The ratio of incident to reflected power from all angles of interest is recorded on the vertical axis of an X-Y recorder as a function of azimuth angle position on the horizontal axis.

The maximum measurable isolation with the setup as shown in Figure 3 was limited to 116 db. To calibrate the system a calibrated 3 db directional coupler was inserted between the signal generator and the ratio meter thus calibrating the latter with two signals of equal magnitude. The circuit was then changed to the one shown in Figure 3. A calibrated 30 db attenuator was inserted between A and B in Figure 3 and the ratio meter was again zeroed by adjusting the variable attenuator. This calibrating procedure took into account the waveguide and cable losses of the system. The system was then restored to that of Figure 3. Measurements were taken over a full 360° and at elevation angles from +30° to -30° at 500 Mc intervals between 7 and 11 Gc. A typical sample of data is shown in Figure 4. Some of the reflections are identified. The reflective isolation contour was thus recorded in absolute values as a function of fixed conditions of vertical angle, frequency and polarization.

Analysis and summarization of the data resulted in a maximum reflective isolation contour as observed from the stated site. This contour, in terms of required antenna isolation, is illustrated in Figure 5(a) and 5(b).

Maximum reflection, over a 7 to 11 Gc band was predominant for horizontal polarization and a depressed elevation angle of 20 degrees (the specified half power angle below the horizon). These maximum values are shown in Figure 5(a) for a comparison of the two destroyers measured. Note that in general the contours are similar but shifted in azimuth. A single antenna contour design should, however, suffice for both ships assuming that at installation the azimuth angular position is adjusted to conform to the particular ships reflection contour.

In order that the azimuth half power beamwidths and rate of pattern fall-off may be analyzed, Figure 5(b) provides a plot of the reflection characteristics for three elevation angles measured on the USS KRAUS (the destroyer having the narrower reflection beamwidth). It is observed that, as stated previously, -20 degrees emerges as the limiting factor for an allowable azimuth beamwidth. Since this is the vertical half-power angle, the system isolation for this condition is reduced to 102 db and thus a 167 degree beamwidth is available. The pattern fall-off would then have to be at a rate greater than 2 db per degree, creating a difficult antenna design problem. However, relieving the half-power beamwidth to 160 degrees reduces the required fall-off to approximately 1.0 db per degree requiring an isolation of about 95 db at the 170 degree beamwidth point. As noted, the fall-off is less stringent at angles beyond this beamwidth. It follows that a broader beamwidth would therefore be possible at the 0 degree plane; however, by using the above criterion as the basis for the azimuth (0 degree plane) pattern contour a system safety factor of about 3 to 6 db is present which can allow for site degradation due to variations in reflective contour of other destroyers.

From this data, for a practical antenna design characteristic, the antenna azimuth fall-off characteristic may be stipulated.

Gain *(db)	-3	-9	-12	-15
Beamwidth (degrees)	160	170	180	190

It is seen that approximately 10 degree "shadow zones" fore and aft are present; however, with the normal destroyer movement it is anticipated that this may appear as a fading effect to the search radar. Since this is based on half power beamwidths, decoying response will still be available within a portion of this zone.

From Figure 5(b) one may also determine the approximate vertical fall-off characteristic by observing the maximum deviation of isolation for an elevation change of 10 degrees (-20 to -30 degrees). As an average value the same 1.0 db per degree would appear to be satisfactory here also and thus the vertical characteristics may be stipulated.

Gain **	-3	-9	-12	-15
Max. vertical beamwidth (degrees)	40	50	60	70

It should be noted that at this site the antennas are not at the outer perimeter of the hull but are inboard by 6 to 10 feet. Placement of an antenna near the outer hull could certainly relieve the fore and aft shadowing to some extent but would also increase installation costs which were to be kept to a minimum.

Antenna Development.

The design objectives were primarily determined by system requirements coupled with data obtained as a result of the structure reflection measurements. Assuming the "S" band reflection characterics of the ships were the same as those measured at "X" band, an antenna was developed with the following design objectives:

Frequency -

Band 1	2 Gc to 4 Gc
Band 2	7 Gc to 11 Gc

Isolation -

Band 1	96 db
Band 2	106 db

Gain - 6 db nominal over beamwidth and bandwidth

* The gain is referenced to the nominal or average value over the forward half-power beamwidth sector of the antenna.

** The gain is referenced as for the azimuth characteristics.

Beamwidth

Horizontal - compatible with above site reflection characteristics.

Vertical - 20 degrees to horizon and compatible with above site reflection characteristics

Polarization - Horizontal (Ultimate design will cover both horizontal and vertical polarizations with 45^{o} slant linear)

SWR 2:1

Size 10' high and 3' wide

With these preliminary objectives and pattern shapes as guidelines, and assuming the reflection characteristics are similar at S-band, an antenna development was initiated. Initial work at X-band indicated that a waveguide fed, horizontally polarized slot, 2.6 inches long by 0.4 inches wide, centered on a 36 inch wide by 15 inch high ground plane gave reasonably sharp fall-off characteristics, approximately 1.0 db per degree with a VSWR of less than 2:1 over the band. This is the order of magnitude of fall-off desired; however, the patterns are somewhat broader than allowable having a half-power beamwidth of over 165 degrees. The integrated S- and X-band decoy antenna is shown in Figure 6. An NRL developed track break antenna is seen centrally located on the same mounting and was utilized for the Guided Missile Mode of the AN/ULQ-6 system but is not discussed in this report. Reduction in the size of the decoy antenna ground plane narrowed the beamwidth but at the same time decreased the rate of fall off. By placement of a flap 4 inches wide, extending the full height and at each side of the ground plane, a shadowing effect is obtained whereby the beamwidth is narrowed and the fall-off virtually unchanged. Large undulations in gain over the beamwidth are evidenced, however, as a result of the reflective surfaces of the flap. Facing flaps with r-f absorber material * relieves the situation and results in gain variations of the forward beam that are no more than observed without the flaps. The half-power beamwidth can be varied by over 10 degrees depending on the angular position of the flaps (Figures 7,8,9, and 10).

* This material is of special quality and developed by the Electromagnetic Materials Branch at NRL, it is designated type MX-2097/u.

Figure 11 graphically represents the maximum and minimum beamwidth-frequency function vs flap angle setting. The shaded areas describe the variance of beamwidth with frequency. A flap angle of 20 degrees best fits the gain-beamwidth specifications previously set forth. At this setting only the -15 db gain point does not fall within specification. A check of the antenna pattern shows that only at 8.0 Gc are the specs not met; however, because of the rapid fall off characteristic, the 190 degree beamwidth at this frequency corresponds to -13 db gain. Considering the decision discussed in the previous section that a 3 to 6 db safety factor should exist, the antenna should be satisfactory even at the 8.0 Gc frequency.

The S-band slot is a scaled version of that at X-band (7.8 inches by 1.34 inches); however, the same width ground plane, 36 inches, was desired for mounting. To scale the ground plane would have been prohibitive since it would have required a width of 108 inches. As a result, the patterns are of poorer quality with only about 0.25 db per degree overall fall-off. The half-power beamwidth is about 140 degrees in order that a gain of -12 db be achieved for 180 degrees. A 4 inch wide flap faced with S-band resonant absorber material was used to realize the above characteristics. The patterns are shown in Figures 12, 13, 14, 15, 16 and the gain beamwidth in Figure 17. The beamwidth at a normalized gain of -15 db is broader than desired; but, at -13 db gain the beamwidth is less than 190 degrees. The same argument of a 3 to 6 db safety factor for this condition should hold here. Thus, a flap angle of 20 to 30 degrees should be sufficient and provides a half-power beamwidth of 140 to 145 degrees. Although this is not considered adequate at half-power beamwidth, the fall-off characteristics at the other specified points are sufficiently close to those required so as to show at ship installation whether the assumed values are acceptable.

ANTENNA ISOLATION

A second consideration of the antenna is the isolation (decoupling) between antennas at both S- and X-bands. The receiving and transmitting slots are separated by approximately 7 feet on the NRL fabricated antenna system. The major contributor to the antenna coupling, except under extreme nearfield conditions, is the side lobe energy radiated in a direct line between the antennas. The vertical patterns at S-band are shown in Figure 18. The side lobe radiation (90 degrees from major axis) at 3.0 Gc is less than -35 db relative to the major lobe gain. The gain was measured to be approximately 6 db. Thus, the absolute side lobe gain is less than -29 db. A simple calculation reveals the anticipated isolation for this level of side lobe power.

$$\text{Isolation } (I) = \frac{P_t}{P_r} = \left(\frac{4\pi R}{G\lambda} \right)^2$$

where: R = Separation between antenna = 2 meters

G = Side lobe gain = -29 db

λ = Wavelength = 0.1 meters

I = $>$ 106 db

This method of isolation measurement allows the utilization of a high gain standard antenna and thus minimizes the effects of reflections from nearby test site objects that normally confuse the data under standard isolation measurements. Interconnecting surface currents and near field phenomena cannot be taken into account in this method if and when they would exist in an antenna configuration; however, they are considered to be second order effects and less pronounced than the reflection existing at a poor test antenna site.

In addition to the above, the standard isolation measurement method (a comparison of input and output coupled pulses, P_t/P_r of the actual antenna system) was utilized (Figure 19). Data was recorded at all minimum isolation frequencies. All precautions were taken to eliminate site reflection but in some cases they still existed and, therefore, the isolation should be generally somewhat better than the measured data. Note that the measured isolation at 3.0 Gc is greater than 103 db while that calculated from the side lobe power is greater than 106 db. These are believed to be in fair agreement. The isolation at 2.4 Gc falls below that of the objectives; however, the 3 db involved should not compromise the equipment.

The isolation of the X-band antenna system is measured by recording the coupled r-f energy and comparison with a standard calibrated level. Site reflections are more easily handled at X-band and the results are relatively free from reflection errors. Figure 20 shows the fine grain characteristics of isolation and indicates no points less than 103 db. This is 3 db less than the objective but should be adequate for system operation. The gain was measured to be approximately 6 db.

ANTENNA INSTALLATION AND EVALUATION

The USS KRAUS was designated for the installation and evaluation of the NRL antenna combined with a ULQ-5/6 hut system fabricated at NRL. Installation was accomplished dockside at the Naval Weapons Plant (Figure 21 and 22). Since fleet planning provided for only one equipment per ship, power dividers were utilized to simultaneously feed both port and starboard antennas and give near 360 degree coverage.

It should be noted that the power dividers were observed to have as high as 3 db ripple in their divided power ratios. During the ensuing fleet tests, the S-band system enhancement capability was found to be marginal. Because of the poor power division quality of the power dividers utilized, they were removed and the enhancement characteristics were improved. Although the X-band enhancement capability appeared normal with the power divider installed, they too were removed as a precautionary measure. Thus only the starboard antennas were coupled to the equipments for evaluation.

The antenna system, both S- and X-band, was adjusted to provide acceptable system performance. To allow proper operation, i.e. operation with required ULQ-5/6 system electronic gain but no r-f oscillations, the flaps on the antennas had to be set at approximately 20 degrees at X-band and 30 degrees at S-band. A review of the data for these flap settings shows that they correspond very well with the antenna pattern contour found to be necessary from the measurements of ship structural reflections.

Evaluation on Project D/S 89

Prior to the planned OPTEVFOR fleet evaluation, c/s10 FY61 (Ref 3) the USS KRAUS installation was operated on preliminary sea tests Project D/S89, to demonstrate the operational characteristics and azimuth coverage capability of both S- and X-band antennas. An aircraft carrier was not available; therefore, qualitative echo enhancement measurements by comparison with a large radar echoing surface could not be made. However, early fleet tests had already proven the system techniques to be adequate and antenna checkout was of prime importance at this time.

For checkout of the ECM system the airborne radars utilized were the AN/SPS-20E aboard the WV-2 and the AN/APS-38 aboard the S2F. Technical observers were present on both aircraft, and radar scope photographs recorded the radar presentation on film. The destroyer was rotated in a tight turn with the aircraft at essentially constant ranges in an effort to describe the effects of the countermeasures antenna response.

The destroyer echo was utilized to determine enhancement properties where applicable. Previous operational experience of the technical observer personnel aided in determination of adequate enhancement conditions compared to the destroyer echo. An estimated figure of 10:1 or greater was used.

At X-band, normal enhancement capabilities were evidenced over an average beamwidth of 170 degrees on the destroyer beam (± 5 degrees as a function of range). Saturation of the countermeasures at near range and video limiting in the radar probably cause this range deviation. Radial range runs with respect to the destroyer beam indicated that the enhancement echo was observed to near radar horizon range (60 to 70 nm) whereas the destroyer skin return in general was not detected prior to half this range.

S-band observations indicate similar average 170 degree beamwidths as at X-band but are not as well defined. At times full azimuth enhancement coverage appeared to emerge with no shadowing. On radial runs the countermeasure echoes were evidenced at ranges in excess of 120n miles but the destroyer skin return was not detected until much less than this range.

Thus it is apparent that both antennas provide coverage as anticipated and that with the prescribed electronic gains, no r.f. oscillation was noted. The usable enhancement characteristics are somewhat broader than the pattern response would dictate.

The OPTEVFOR fleet evaluation c/s10 FY61 report of ref 3 provides additional information on the effectiveness of the system.

Of considerable interest is the possible mutual interference existing between the ULQ-5/6 and the SLR-1 intercept receiver. Although anticipated, there was no evidence of interference in this evaluation on the USS KRAUS. The intercept system was checked and found to be operating adequately.

CONCLUSIONS

A practical decoy antenna site, providing a minimum installation cost, is available on the beam at each end of the after stack crossarm. Ship structural reflections from this site result in an antenna system shadowing of about 10 degrees both fore and aft. These "shadow zones" are undesirable but believed to be tolerable under anticipated tactical situations.

The ship structure reflections, at the destroyer site investigated, demand that the antenna "fall-off" characteristics average 1.0 db per degree from a half-power beamwidth of 160 degrees. A horizontally polarized antenna having these characteristics was developed and fabricated. Performance of this antenna installed on the USS KRAUS was satisfactory, indicating that the reflectometer method of determining antenna requirements pertaining to reflection problems is indeed useful.

Although a horizontally polarized antenna was utilized, measurements of ship superstructure reflections were maximum for this polarization and therefore the desired antenna having both vertical and horizontal polarization should require the same pattern contour as given for both polarizations.

To prevent marginal enhancement conditions, a dual ULQ-5/6 system should be employed, one for each beam aspect of the ship.

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