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PROPOSAL FOR A NEW TYPE OF RAPID-SCANNING SEARCH RADAR

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PROPOSAL FOR A NEW TYPE OF RAPID-SCANNING SEARCH RADAR

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July 20, 1951

Approved by:

L. A. Gebhard, Superintendent, Radio Division II

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ABSTRACT

A hemispherical-coverage radar with a new scanning antenna system and high transmitter power is proposed. This radar would give good angular resolution and accuracy and permit a scan rate comparable to that of the AN/SPS-3 radar while providing a coverage twice as great in maximum range. The new system would have several advantages over the AN/SPS-3: (a) its coverage could be properly shaped to use the transmitted power more efficiently; (b) the antenna structure would be compact and of light weight; (c) the antenna system would be simple to design, construct, and maintain.

The proposed antenna would have six spaced, vertically stacked beams, covering up to 80 degrees elevation. The antenna would rotate relatively fast in azimuth — 60 rpm or faster — and would "nod" at a slower rate through the angle of beam spacing, to give complete coverage in four azimuth revolutions — four seconds or less.

The high transmitter power — three megawatts — would be obtained by using a 5600-Mc pulsed klystron transmitter, which should be available in the near future. Alternatively, magnetron transmitters of medium power could be used, with resultant detection ranges somewhat better than those of the AN/SPS-3. The problem of presenting the output of several receivers on a single display might be solved by using storage-tube methods, or by a peak-selection system. The elevation angle accuracy might be improved greatly, at the cost of considerable complexity, by using the TAB system of simultaneous lobing.

Two simpler systems using three and four beams and giving coverage up to 60 degrees elevation are also proposed. The three-beam system with moderate transmitter power at 3-cm or 5.3-cm operating wavelength would give performance comparable to that of the AN/SPS-3 with extremely low topside weight, and would be especially well suited for destroyer installation.

PROBLEM STATUS

The work described in this report is an independent part of a larger, more general problem. Further investigation of some phases of it will be made before a decision is made on the extent to which this work should be carried. The parent problem is a continuing one on which additional work will be done as new ideas or specific requirements arise.

AUTHORIZATION

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PROPOSAL FOR A NEW TYPE OF RAPID-SCANNING SEARCH RADAR

INTRODUCTION

Radar equipment on naval vessels may be divided into two main categories: fire-control radar (including missile-guidance radar) and search radar. These two types are not entirely independent. The information from search radars is used for target evaluation, designation, and as an aid to target acquisition by the fire-control radars.

The operation of taking raw information from a search radar and processing it for purposes of evaluation, designation, and acquisition will, in the near future, be performed by specialized systems designed for the purpose. One such target-designation system—the Mark 2—is being developed for the Bureau of Ordnance by the Radio Corporation of America. Another longer-term, larger-scale development of the same kind is being carried out by the Bell Telephone Laboratories. The resulting system will be called the Mark 3.

It is accordingly very important to provide search radar equipment which will permit optimum utilization of these systems, and contribute to a better solution of the over-all antiaircraft fire-control problem, by furnishing information of the desired quality, at the desired ranges, and at the desired rate.

A comprehensive discussion of this problem is contained in an NRL report written in 1947.[1] A report by the Bureau of Ordnance in 1949[2] discussed the problem in more detail, and listed some conclusions concerning the requirements that the problem imposed on search radar. No existing search radar, nor any system being developed either then or now, could meet these requirements. The report concluded that no single radar system could meet them, and therefore proposed two radars, one having short range and very high information rate, the other having somewhat greater range and a moderately high information rate. However, no specific ideas for achieving these proposed radar characteristics were advanced, for the very good reason that system components of the required capabilities simply did not exist, and there were no indications that they would be obtainable soon. These remarks apply principally to the proposed intermediate-range system. The short-range system could possibly be designed and built, but it would be somewhat pointless to do so if the companion system could not also be provided.

The present report is primarily concerned with a proposal which may be the answer to some of the requirements set forth in the Bureau of Ordnance report for an

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[1] Page, R. M., and Trevor, J. B., Jr., "Shipborne Radar Fire Control from the System Viewpoint," NRL Report R-3091, May 1947

[2] Marvin, J. R., and Sunde, D. H., "Search Radar Requirements for Naval Antiaircraft Gunnery," Navy Bureau of Ordnance, NavOrd Report 476, Feb. 7, 1949

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intermediate-range system. Before this proposal is set forth, however, some of the technical background and general history of the problem will be discussed.

SYSTEM REQUIREMENTS

Fire-control radar is, in general, single-target radar. That is, during the interval when the radar is performing its function, only one designated target is observed, and the information the radar gives about this target is used, through suitable computing systems, to bring the guns associated with this radar on the target until its destruction or release to engage a more threatening target. There is therefore a sequential operation in which the radar acquires the target, tracks it to the time of abandonment, then shifts to the next designated target to repeat the sequence. During the tracking phase, the other elements of the fire-control system perform various functions in the following sequence: verification of target identification, by the gun-director IFF equipment; transformation of tracking data into predicted target position at the time a projectile from the guns could reach the same position, and determination of the gun direction and fuze setting, by the computer; transmission of gun orders (electrical signals controlling the aiming and firing of the guns); and finally the continuous firing of the guns as long as gun orders are received.

The time required for the fire-control radar to shift from the abandoned target to a new one and find and get on it (acquisition) is obviously wasted time for the guns since they can be used only when accurate tracking information is passing through the computers and solutions are available in the form of gun orders. This waste time is not particularly serious when the attack density is low, for the range of the fire control radar is ordinarily well beyond that of the guns and the operations occurring during the idle time of the guns can be performed before they can be used anyway. But when attack density is high, the time consumed for these operations results in a direct loss in the effectiveness of the ship's gunnery system.

The time required for a fire-control radar to acquire a new target depends on its own design and on the quality of information about the target which has been gained by the search radar prior to this operation. Improvements in fire-control radar have in general been directed toward greater tracking precision and this has usually meant sharper antenna beams, the consequent restriction in field of view acting to make the acquisition process more critical. Indeed, this has become so critical a feature that consideration has been given to increasing this field of view in a number of ways: (1) provision for changing between a narrow-beam and wide-beam condition; (2) provision of scanning by the fire-control beam over an area of several beamwidths; (3) use of a dual system in which a second wide-view (acquisition) radar operates with the fire-control radar through a common antenna system.

On the other hand, the trend in new search radar development has been toward greater sensitivity and range, which is often partly obtained by sacrifice of precision and amount of information. In fact, the lower frequency, air-search radars with their broad antenna beams, long pulses, relatively slow scanning, lack of accurate height information, and lobed vertical coverage patterns, are by no means obsolete, as they have advantages in clutter, storms, and possibly in dependability with respect to performance under various atmospheric propagation conditions. There has also been specialization of function, so that, for example, there are surface-search radars which give no height information, and fighter-direction radars with high-sensitivity and height-finding but without close-in coverage. These radars are not suitable for target designation or as aids to fire-control-radar target acquisition.

There is, therefore, an intermediate-range deficiency in search-radar coverage which is of urgent concern for both the search and fire-control functions. This would ideally be satisfied by a fast-scanning radar of intermediate range having the following performance:

1. Coverage of all targets from the earth's surface to the altitude of the highest flying target — say 70,000 feet — and from the ship to a range of 25 or perhaps 50 miles.

2. High resolution to maintain effectiveness even during high-density attacks.

3. Precise 3-dimensional information good enough for pointing the fire-control radar to a sure-fire acquisition position. Ideally this information should be good enough for computer use for a preliminary predicted-target-position solution.

4. Fast all-around coverage to give information never sufficiently stale to affect its reliability even for 600-knot planes.

DEFICIENCIES OF EXISTING SYSTEMS

The most significant attempt to meet the performance requirements has been the development of Hemispheric Radar AN/SPS-3. This project, taken over from the MIT Radiation Laboratory in approximately its present form at the close of the war, is still short by about a year of a completed laboratory model which can be tested. A great deal has been learned in the work at the Naval Research Laboratory on this project, not the least of which is how tough the problem really is — even in this radar for which the claims have been rather modest, at least since the present firm design[3] emerged from some of the earlier more speculative proposals. Among the conclusions that have come from the AN/SPS-3 work are the following:

(a) To meet requirements, the radar must be large, heavy, and complicated — much more radar than a modern surface-search equipment, for instance.

(b) Its antenna should have a high position on the ship with unobstructed view — a difficult requirement considering its size and the competition that exists for such positions.

(c) The severity of the requirements may even make the use of two complete radars, rather than one, desirable to achieve the best over-all economy of weight, size, and flexibility. (Actually the AN/SPS-3 is a dual radar system in which only the antenna system and a few other components are common to the two.)

(d) The technical requirements on a radar to achieve the desired performance could not be completely satisfied with components existing at the end of the war, or for that matter even now. In particular, new transmitter tubes are needed which are still not developed, although their successful development can now be foreseen.

(e) The Foster-scanner antenna system[4] used in the AN/SPS-3, although its design details present the largest still-unsolved problem in the way of successful completion of

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[3] Blake, L. V., "Interim Report on Development of Model SPS-3 (XDK) Shipborne Hemispheric- Search Radar," NRL Report R-3165 (Confidential), August 1947

[4] Lantz, P. A., Shoemaker, J. R., and Adams, R. J., "Design of the Antenna for AN/SPS-3 (XDK) Hemispheric Radar," NRL Report 3652 (Confidential), April 1950

the AN/SPS-3 radar, is almost without competition as a wide-angle scanner. It is true that other designs of wide-angle scanners have recently been proposed. These are usually based on some principle which has been demonstrated in the laboratory, but all of them have practical deficiencies which are likely to become more evident, as was the case with the Foster scanner, as work progresses. None of these other proposed scanners is as near the completion of an experimental model as the Foster scanner. This assumes that one or the other of the two Foster scanner types[5] now being worked on can be successfully completed. There is no indication that they cannot, but the mechanical problems have been difficult and the design has not yet been tested in actual operation.

The deficiencies of the AN/SPS-3 have been recognized for several years and have been the subject of many examinations and re-examinations, the outcome of which has always been that it was the best approach yet proposed and should be continued to the end. There is little doubt that the AN/SPS-3 Hemispheric Radar was at the time of its inception an ingenious system whose development to a working model was, and still is, highly desirable. Perhaps the admitted deficiencies of the AN/SPS-3 have served mainly to emphasize the difficulty of solving this search-designation problem and to give a common basis on which interested people might estimate the size of the system really needed for this function. While these re-examinations have not revealed any new solution,[6] they have certainly served to stress the need for one.

Probably the most serious deficiency of the AN/SPS-3 is its 15-mile nominal maximum range. But to improve this without sacrificing information rate or precision would require more transmitter power (with possibly a more elaborate antenna system to utilize the power efficiently), or more receiver sensitivity, or a larger antenna at a lower frequency, and of these only the first is really a practical possibility. Scanning systems pose a real problem to the transmitter system, because in general a varying load is presented by the scanning antenna which magnetrons, the usual power source, do not accept very well, especially if separated from the antenna by any considerable length of transmission line. Because of this, the two high-power magnetrons used in the AN/SPS-3 are mounted in the antenna structure. Any appreciable increase of transmitter power would, with this arrangement, be disastrous in this system whose antenna structure is already too large and too heavy.

PROPOSED SYSTEM

Transmitter

The prospect of high-power pulse klystrons (already a laboratory reality) offers the possibility of higher power without increased topside weight. These tubes make possible a power-amplifier type of transmitter which is relatively insensitive to load variations, thereby permitting transmitter locations remote from the scanning antenna; the distance would be limited only by transmission-line or waveguide losses. The klystrons could thus be located off the antenna structure and accordingly the transmitter's weight would be a far less important consideration. It is therefore possible for power levels as high

[5] In addition to the work on the scanner described in NRL Report 3652, some preliminary work has been done on design of a model with stationary line-source feeds and a rotating shell, carrying toothed mirrors. This permits a smaller, lighter rotor design.

[6] With the possible exception of the Bureau of Ordnance report cited in footnote 2

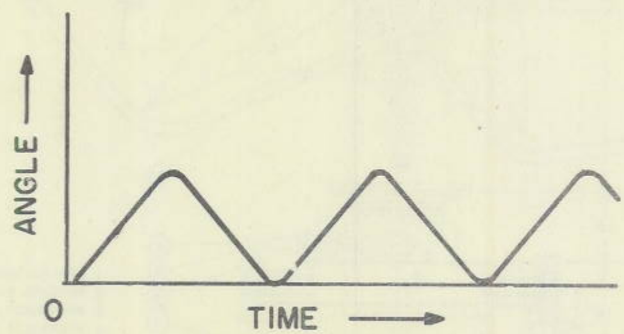
as 2 to 3 megawatts to be considered practical, in contrast with the two 150-kilowatt magnetron transmitters of the AN/SPS-3.

Antenna

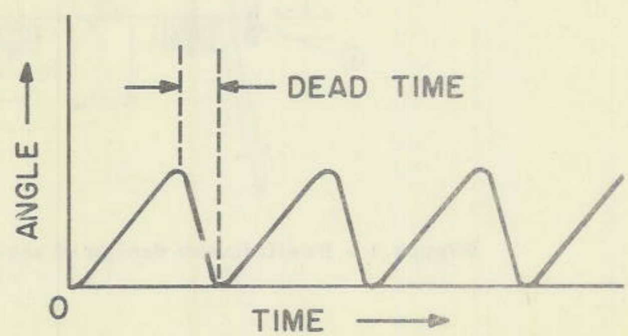
At the megawatt power level, ranges at least double those of the AN/SPS-3 are within reach, but "hemispheric" coverage would be wasteful because only moderate range is needed at the higher elevation angles. Therefore, some other type of scanning system is dictated, in which the available power can be distributed over the scanned angle to give the desired vertical coverage. (This was not a requirement for the shorter-range AN/SPS-3.)

A new type of antenna has therefore been proposed by one of the authors (RCG) which will permit distributing the total transmitted power nonuniformly over the total elevation angle scanned by the radar. The feature which permits this is the use of several beams stacked vertically at equal intervals through the vertical coverage angle. The beams are fed from a common transmitter (klystron), with the feed system arranged to put a greater proportion of the power into the lower beams. This type of stacked-beam, tailored-coverage arrangement is used in the AN/SPS-2 long-range radar, with adjacent beams of such width and spacing that there is considerable overlap, giving solid vertical coverage without vertical scanning. The novel feature of the present proposal is that the beams would be narrow and spaced several beamwidths apart. Complete vertical coverage would then be obtained by nodding the entire antenna through a vertical angle equal to the spacing of adjacent beams. The entire antenna would also be rotated rapidly about a vertical axis, for azimuth scanning, at the rate of one full turn during the time required for the vertical nodding to go one vertical beamwidth. Thus if the vertical spacing of adjacent beams were four beamwidths, the antenna would have to make four complete azimuth scans during one vertical scan.

The nodding, in its simplest form, would be of a symmetrically triangular nature, and a plot of elevation angle against time would have the following general appearance:



Unless otherwise specified, a nodding motion of this nature is assumed for the various antenna and system proposals. However, an investigation is being made into the feasibility of a nod motion of a sawtooth nature, as shown:



There appears to be a good possibility of achieving this type of motion with a "dead time" of only about 20 percent. This type of scan would have definite advantages over the type first proposed, the chief one being that the time between "looks" at a target would be the same for targets at all elevation angles.

Assuming a vertical coverage requirement of 80 degrees, a six-beam system is proposed, with four-beamwidth spacing of the beams. Since it would be impossible to obtain six narrow beams of good shape with a spread of 80 degress from a single dish, it is proposed to use two dishes back-to-back, with three beams from each dish. This permits a relatively compact, lightweight structure, and it is believed that it could be nodded and rotated to give an average scan period of four seconds (60 rpm azimuth scan). Figure 1 shows the probable general appearance of such an antenna. It is believed that its mechanical and electrical design would be relatively straightforward, and it would have important advantages in weight and size compared to other antennas with equivalent scanning rate and coverage. A minor yet not insignificant advantage is the fact that ordinary synchros could be used for both azimuth and elevation data transmission. (The speed of the Foster scanner cone is too great for synchros.)

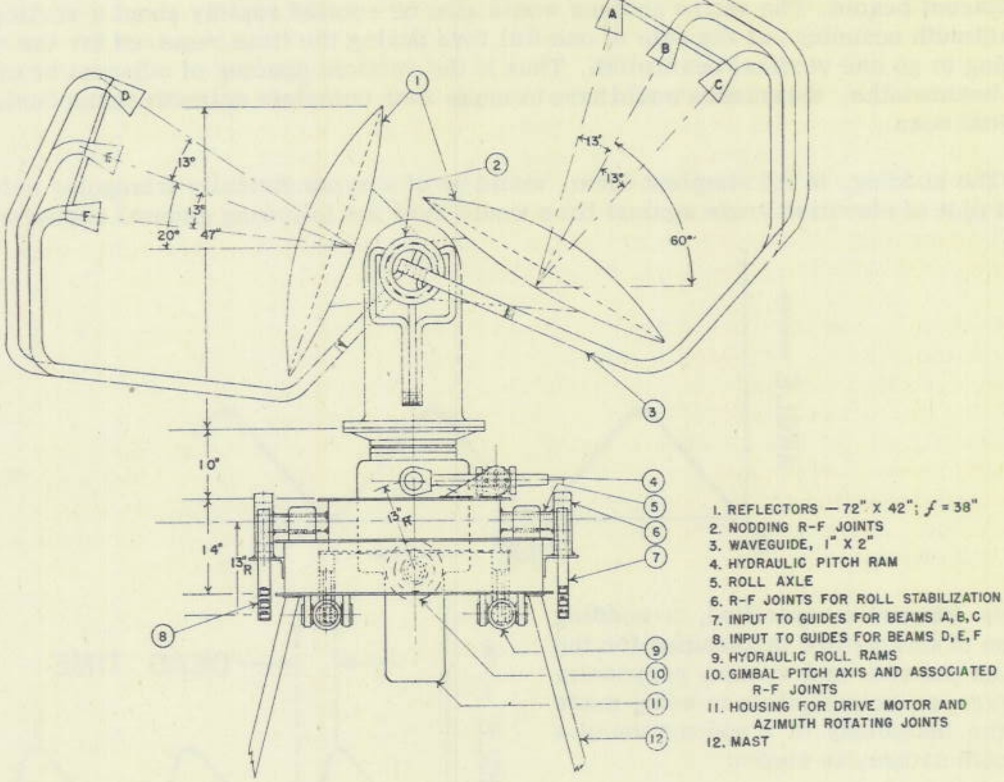


Figure 1 - Preliminary design of six-beam 5600-Mc nodding antenna

System for 80-Degree Coverage

The tentative characteristics of the complete system, based on use of this antenna with a 3-megawatt 5600-Mc klystron transmitter, are as follows:

Pulse power — 3 megawatts divided among the six beams as follows, starting with the lowest (Figure 1): beams 1 through 3, each 3/4 megawatt; beam 4, 3/8 megawatt; beams 5 and 6, each 3/16 megawatt.

Repetition rate — 2100 pps
Pulse length — 1.5 μsec
Beamwidths — Vertical, 3.5°; Horizontal, 2°
Antenna gain — 36 db
Antenna reflector size (paraboloid)—6-foot width, 3-1/2 foot height

Azimuth scan time — 1 second (60 rpm)
Elevation scan time — 4 seconds (8-second nod period)
Average scan period — 4 seconds
Receiver noise factor — 10 db
Pulses on target per scan at horizon — 12 (more at higher elevation)
Range on 10-square-meter target at low elevation — 32 miles[7]
Elevation angle accuracy — ± 1.8 degrees (see subsequent paragraph on possible improvement of elevation accuracy)
Azimuth angle accuracy — ± 0.25 degree or better (depending on indicator)
Range accuracy — ± 100 yards (depending on indicator)
Moving Target Indication (MTI) — reasonably good MTI performance may be expected with the approximately 12 pulses per target per scan.

Figure 2 shows the vertical nod pattern of the six beams for the minimum nod position. The beams are all shown at the same azimuth in this figure, whereas actually the upper beams 4, 5, and 6 are rotated 180 degrees in azimuth with respect to the lower beams 1, 2, and 3. Figure 3 shows the expected coverage pattern for a 10-square-meter target, extrapolated from an assumed range of 15 miles for the AN/SPS-3. Figure 4 is a comparison of coverages expected from the AN/SPS-3, the AN/SPS-13, the AN/SPS-2, and the six-beam nodding radar.

Even in this rather elaborate system some shortcomings are immediately evident. For instance, the information period will be as great as 8 seconds on targets at some elevation angles (for instance, at the horizon and at the highest elevation angle) although elsewhere it will be less — as low as 4 seconds on targets at favorable elevation angles. Possibly this rate could be improved. Resolution is less than that of the AN/SPS-3, but

[7] This is based on an assumed range of 15 miles on the same target for the AN/SPS-3, which was calculated (see footnote 3) without considering refinements of radar range theory such as target scintillations, probability of detection, etc. However, range calculations of this simpler kind are not without meaning, and they are of definite value for purposes of comparing rival radar systems. A study of the range capabilities of the AN/SPS-3 radar has been made by the Operations Evaluation Group. The computations presented in their study indicate that the 15-mile maximum range estimate for the AN/SPS-3 (on a 10-square-meter target), and similarly the 32-mile range for the nodding radar, are conservative.

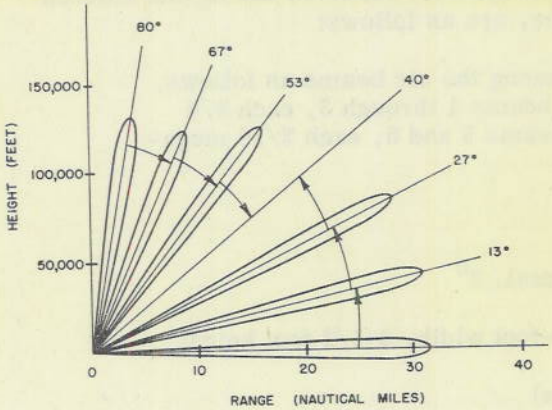


Figure 2 - Instantaneous vertical pattern of six-beam antenna — nod position minimum (upper beams rotated 180° in azimuth)

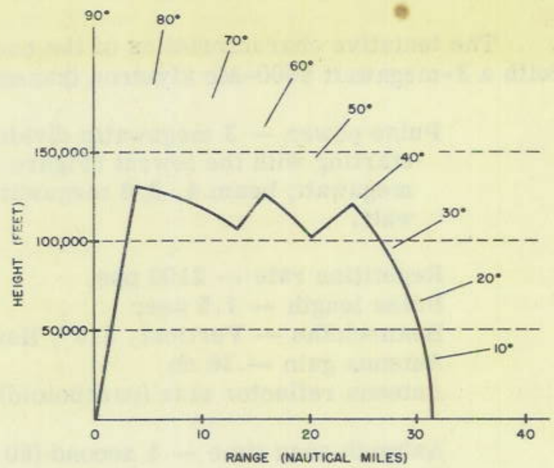


Figure 3 - Vertical coverage pattern of six-beam system

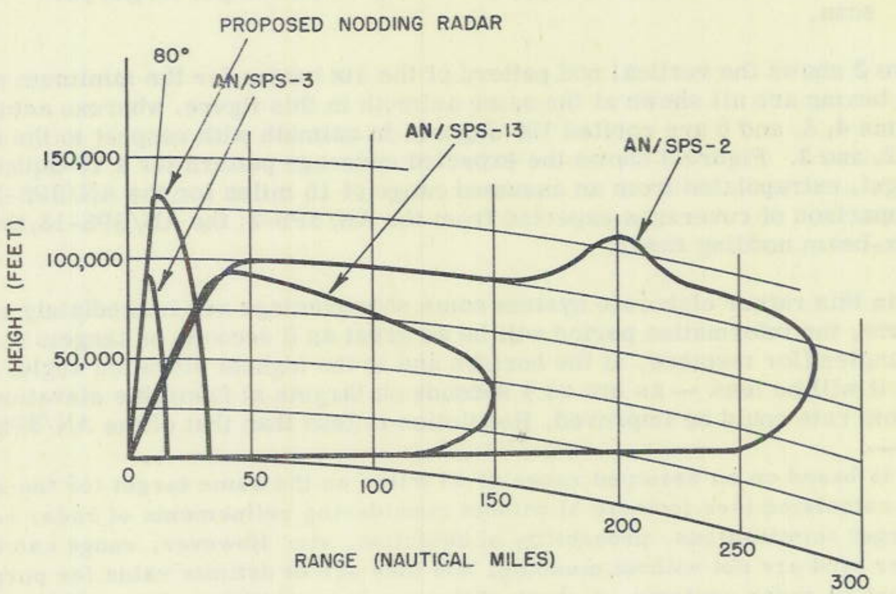


Figure 4 - Comparison of coverage with AN/SPS-2, AN/SPS-3, and AN/SPS-13 radars, for 10-square meter target

not very much less. Elevation angle accuracy is only fair, but subject to improvement, as discussed later. However, it should be noted that although elevation angle accuracy is less than that of the AN/SPS-3, azimuth accuracy is greater — this may be a fortuitous exchange to the advantage of the new system.

A 60-Degree System

It would be possible to make a single-dish antenna of the nodding type with either three or four beams to give a total elevation coverage of 60 degrees. There are some grounds for believing that this is an acceptable coverage angle if the range of the system is sufficient, and the idea is very attractive for the following reasons:

(a) A single-dish antenna of this type would permit the fullest exploitation of the light weight and simplicity which are the chief virtues of this scanner.

(b) The total number of beams would be reduced to three or possibly four, with consequent reduction in the number of receivers and complexity of the indicator system.

The 3-beam system would present less of an antenna-design problem than the 4-beam system. The beamwidth would be greater, however, with a resulting loss of elevation accuracy and resolution, and also reduced antenna gain. (The resulting reduction of system sensitivity amounts to about 2.5 db, corresponding to a range factor of about 0.87.) For a 3-beam system the total transmitter power would probably be divided among the beams in the following portions, starting with the lowest beam: 50%, 25%, 25%. For the 4-beam system the figures would probably be: 50%, 25%, 12.5%, 12.5%. (These figures reflect the fact that power division is ordinarily done in 2-branch dividers which divide power into equal portions.) Thus the lowest beams in both cases would have a 3-db transmitter-power advantage over the 6-beam system, together with reduced antenna gain.

The coverage that would be obtained with these two types of 60-degree scanners (10-square-meter target) is shown in Figures 5 and 6, assuming a total of 3 megawatts of power at 5600 Mc, with other system parameters the same as for the 6-beam system, except for antenna beamwidth and gain. It is seen that for the 3-beam system, coverage is solid up to almost 60,000 feet out to the maximum range. For the 4-beam system the maximum range is somewhat greater in the lowest beam, but the maximum height for solid coverage to this range is about 45,000 feet, or conversely the maximum range for solid coverage to 60,000 feet is reduced to about 30 miles, or about the same as the 3-beam system. Coverages for a one-square-meter target are shown dashed. It is seen that these ranges are comparable to those of the AN/SPS-3 on a 10-square-meter target.

The 60-degree maximum elevation angle makes the minimum "ground range" about 6 miles for a plane at 60,000 feet, 4.5 miles for 45,000 feet, 3 miles for 30,000 feet, and 1.5 miles for 15,000 feet — in short, 0.1 mile for every 1000 feet of altitude. Possibly these are acceptable minimum range figures in terms of the probable tactics of attacking aircraft and the possible defensive actions that may be taken. If this radar is regarded as an intermediate-range radar, and is backed up by a very short-range, high-angle radar, as suggested in the previously referenced Bureau of Ordnance report, then the 60-degree coverage is certainly adequate.

Because of the very light weight and small size of these 60-degree scanners compared to more "conventional" types (Foster, organ pipe, etc.), their use in applications where weight is a primary consideration (i.e., more important than the extra 20 degrees

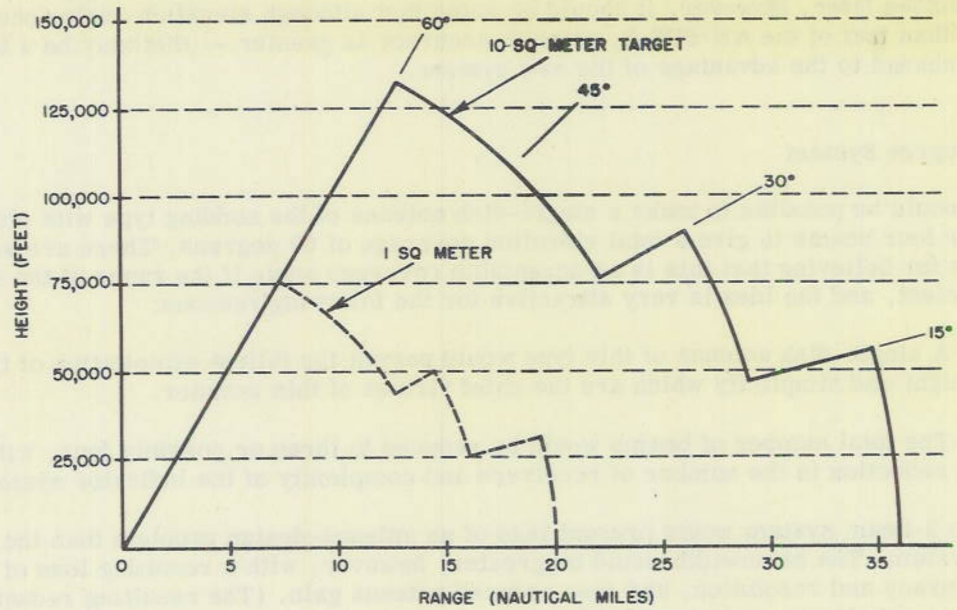


Figure 5 - Vertical coverage pattern of four-beam 5600-Mc system

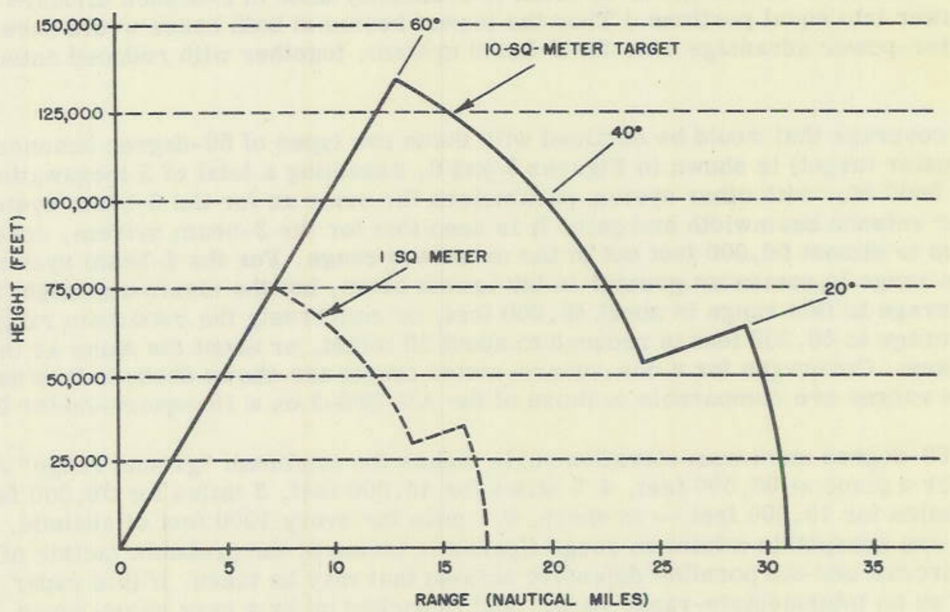


Figure 6 - Vertical coverage pattern of three-beam 5600-Mc system

of coverage) may prove advantageous. For example, it was originally intended to install the AN/SPS-3 radar on destroyers, and the topside weight limit set for this reason was around 1000 lb. At the present time, however, the estimated topside weight for the AN/SPS-3 is 2400 lb, and the radar will not be installed on present types of destroyers.

The need of these ships for some kind of a radar having the AN/SPS-3 type of coverage is an urgent one, and it might not be possible to meet the weight requirement with a 5600-Mc system. It has been pointed out that on the present destroyers it has been necessary to replace the original steel mast with an aluminum one to get on even the present radars, and any additional radar would have to replace one of the existing radars without appreciably exceeding the present topside weight. Practically, this means that the system being considered here would have to take over the duties of the present surface-search radar in addition to the other functions, and its topside weight should, if possible, be around 500 lb maximum.

It seems possible that this difficult requirement might be met by a 60-degree 3-beam scanner of the nodding type at X-band. This would mean relinquishing the high transmitter power which was one of the primary purposes of choosing 5600 Mc for the other proposals of this report. (There is of course also a gain in system sensitivity at the lower frequency due to the larger antenna if the same beamwidths are used.) However, it is obvious that some sacrifices in performance are necessary when a severe weight limitation is imposed. The aim is to provide a radar which will give somewhere near acceptable performance within the weight limit, and the proposal should be considered in view of the alternative, which in this case seems to be no radar at all. An X-band antenna of the nodding type, with three beams giving 60-degree coverage, would surely be very nearly the ultimate in light weight and simplicity for a scanner of this coverage.

The relatively small size of the dish at X-band suggests the feasibility of spinning in azimuth at an even faster speed, up to perhaps 120 rpm. In the proposal set forth below, a speed of 75 rpm is adopted, to permit using a narrower vertical beamwidth than would be possible at 60 rpm. The dish size is 44 inches wide by 22 inches high. Further vertical-beam narrowing would not be permissible because of the off-axis feed system, but a further increase of azimuth rotation speed might be desirable to give better elevation accuracy even with the same vertical beamwidth.

It might be feasible to operate the present AN/SPS-3 system — transmitters, receivers, modulator, etc. — with this X-band nodding antenna and a lighter stable base. It is believed that the total topside weight would be minimized by mounting the enclosure containing the present AN/SPS-3 r-f system (with one additional receiver front-end) in a fixed position on the mast, with waveguides going through the stable base and rotating mount by means of ring-type joints. (These are quite small at X-band.) The high-power-pulse and i-f rotating joints would be eliminated; one magnetron would be used entirely for the lowest beam; and the output of the other magnetron would be divided equally between the two upper beams.

The weight requirement for destroyers might possibly be met at the lower frequency, 5600 Mc, with less than the 3-megawatt transmitter power heretofore assumed. (Actually, the chief reason for this reduction of power would be to meet the below-decks weight and space requirement, which would probably be exceeded by a 3-megawatt klystron transmitter.) There are some developmental magnetrons in the 5600-Mc region with power ratings of 175 to 250 kw. One of these feeding all three beams (with a 50% - 25% - 25% power division) would give reasonable performance. The transmitter could be located off the stable base, and the power fed to the antenna via TM_{01} type rotating joints. This would avoid the line-stretcher action of the ring-type joints, and permit a reasonable length of waveguide between the magnetron and the antenna — perhaps 60 feet if a voltage standing-wave ratio as low as 1.1 can be realized.

The characteristics and performance of these two alternative ultralight-weight proposed systems relative to that of the AN/SPS-3 are tabulated below:

	9375 Mc System	5600 Mc System
Pulse power, Beam No. 1	150 kw	125 kw
Beam No. 2	75 kw	62 kw
Beam No. 3	75 kw	62 kw
Reflector size	22 x 44 in.	29 x 72 in.
Horizontal beamwidth	2.2 deg	2.2 deg
Vertical beamwidth	4.0 deg	5.0 deg
Azimuth scanning	75 rpm	60 rpm
Vertical nod period	8 sec	8 sec
Pulse repetition frequency	3000 pps	3000 pps
Pulse length	0.67 μsec	0.67 μsec
Pulses on target per scan	22	27
Scan loss improvement over AN/SPS-3	3.5 db	4.0 db
Wavelength gain	0 db	4.5 db
Two-way antenna gain reduction	1.0 db	3.0 db
Transmitter power reduction, low beam	0 db	0.8 db
Net improvement (lowest beam)	2.5 db	4.7 db
Range ratio relative to AN/SPS-3 (approx.)	1.16	1.30

This tabulation assumes use of the present AN/SPS-3 r-f system for the X-band radar, and a 250-kw magnetron at 5600 Mc. It might be possible to reduce the system weight materially by using 400-cycle power, if this could be made available on some ships. The lower-frequency system might have some advantage in reduction of cloud clutter and attenuation due to rain.

Improvement of Elevation Accuracy

At the cost of considerable complexity, the elevation angle accuracy could be improved greatly. This radar system, with its well-spaced antenna feeds, could be readily adapted to use the TAB[8] (simultaneous lobing) feature in elevation angle. It seems probable that an accuracy between 1/10 and 1/20 of a beamwidth, or approximately 1/4 of a degree, might be obtained. This accuracy, together with azimuth accuracy of the same order and range accuracy of better than 100 yards, might allow a preliminary computer solution to be obtained prior to and in anticipation of the acquisition of a target by the fire control radar. The complication introduced into the antenna system is discussed under Antenna Design.

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[8] Originally described by Trevor, J. B., Jr., and Hastings, A. E., "Analysis and Specifications of Simultaneous Lobing System TAB," NRL Report R-2554 (Confidential), July 1, 1945. (Original proposal contained in letter to BuOrd dated Jan. 16, 1945.) For a bibliography of simultaneous lobing reports and an analysis of the antenna problem, see Kales, M. L., "Optimum Design Criterion for Simultaneous-Lobing Antennas," NRL Report R-3451 (Confidential), April 20, 1949

Indicators

Because the information from the antenna of this system would be divided among three or more receivers (depending on which of the alternative systems is considered), there is a problem of how to display the information without resorting to a separate indicator for each receiver. (This is a less serious problem, obviously, for the 3-beam 60-degree coverage system than for the 6-beam system.) There are, however, some promising approaches to this problem.

The most obvious one is the use of storage tubes. The general method would be to connect the video output of each receiver to a storage tube, and then read off the information from all of them, on a time-sharing basis, onto a single display tube of any desired type (e.g., PPI, RHI, G-scope, etc.), using something like a television type of raster and television frame rates. This method would have the incidental merit of solving the problem of getting sufficient light intensity in the display of the relatively low-duty-cycle information characteristic of narrow-beam wide-coverage radars.

This method is subject to the criticisms (a) that storage tubes and storage-tube techniques have not advanced sufficiently to make this approach immediately practical, and (b) the use of storage tubes would add a large amount of complex equipment to the system. Neither of these criticisms necessarily constitutes a fatal or even a permanent objection, however. Storage tube developments are advancing rapidly.

Another method of avoiding multiple indicators is the use of a peak selection system in which all six (or three, as the case may be) receiver outputs would be connected to a single indicator, but at any instant the only receiver that would be delivering output to the indicator would be the one in which the output voltage was momentarily the greatest. This receiver having the greatest output voltage would operate circuits which would "blank" all the other receivers, and also cause the cathode-ray-tube spot to assume the proper position on the screen. At any instant there would be as many possible positions of the spot as there were receivers; the proper one would be determined by switching tubes actuated by the output of the highest-output receiver. Thus, during a complete scan, the possible positions of the spot would include all elevation angles within the scanned sector. There would be as many separate elevation-data generators as there were receivers, and as many azimuth-data generators as there were reflectors ("dishes") in the antenna system. The type of display would be determined by the waveform of the data generators. Possible types would be RHI and G displays. For a conventional PPI display, of course, height information is lost anyway, and the only advantage of using peak selection would be to reduce total noise incident to the mixing of several receiver outputs. In the case of the two-dish 6-beam system, two PPI's would be required unless storage tubes were used.

Figures 7 and 8 are block diagrams indicating in a general way the two proposed methods of displaying outputs from several receivers on a single cathode-ray tube. These diagrams are intended to be only indicative of the general methods. It is possible that the separate data generators and switching tubes could be replaced by a single unit of relatively simple design.

It seems pertinent to remark that a stacked-beam system such as the one proposed here fits in very well with the target-designation system being developed by the Radio Corporation of America for the Bureau of Ordnance. This system, known as the Mark 2, divides the elevation data of the designation radar into six equal segments, each of which is identified on the display by a different color. This is not meant to imply that other

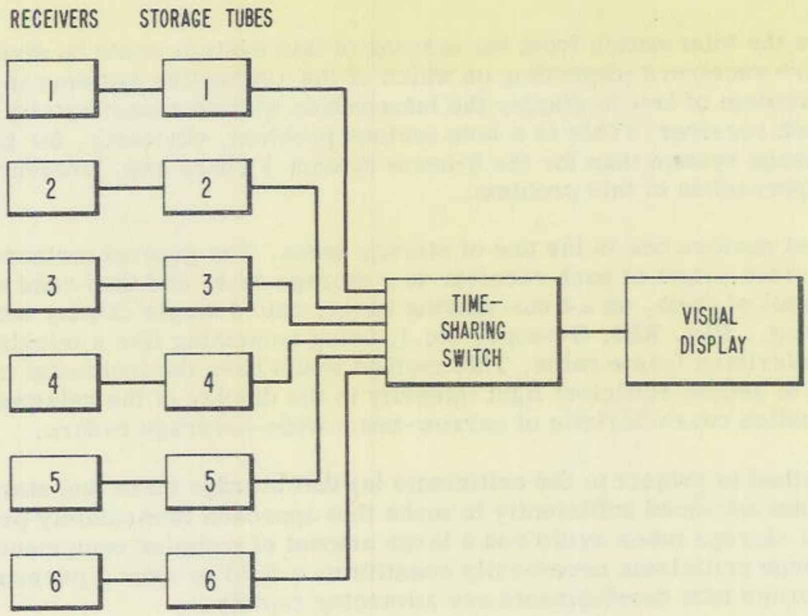

Figure 7 - Block diagram of storage-tube display system for multiple-beam radar (shown for six beams)

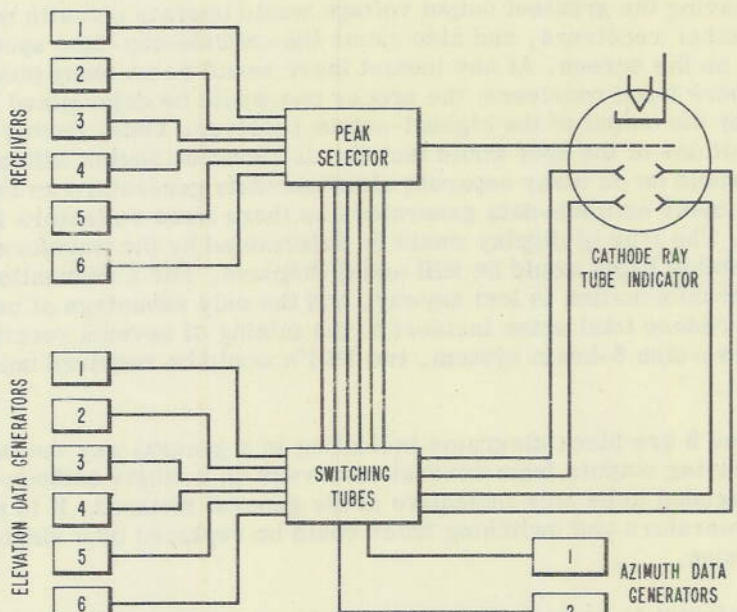

Figure 8 - Block diagram of peak-selection display system for multiple-beam radar (shown for six beams)

target-designation systems would have any particular difficulty with the information from this proposed radar, but merely that it would be peculiarly well suited to the Mark 2.

ANTENNA DESIGN

Choice of Parameters

The design of a multiple-beam nodding antenna requires careful compromise among several parameters: number of beams, nodding angle, vertical and horizontal beamwidths, and azimuth rotation speed. In the two designs under consideration the coverage angle, Φ, assigned to a given reflector is either 40 or 60 degrees, and the nod angle (or angle between beams) is

$$\varphi = \frac{\Phi}{N}, \tag{1}$$

where N is the number of beams per dish. N should be kept small to avoid complexity in the waveguide system. It is apparent from the fact that a target occupies at least a vertical beamwidth (θ_v) on an RHI or G-scope that very little height information will be gained unless the nod sector contains four or more beamwidths:

$$\frac{\varphi}{\theta_v} \geq 4. \tag{2}$$

This same condition must be met to obtain a satisfactory transmitting pattern, for the adjacent coherent beams interfere to produce objectionable side lobes when the beam centers are spaced closer than about four beamwidths. The minimum azimuth rotation speed compatible with solid coverage:

$$\text{rpm} = \frac{60}{T/2} \cdot \frac{\varphi}{\theta_v}, \tag{3}$$

is at the rate of one revolution in the time required for nodding through one vertical beamwidth. The nod period, T, is taken as 8 seconds, and 60 rpm seems a practical upper limit for an antenna of 5-ft turning radius. With these values, condition (3), together with (2), determines the only permissible value of φ/θ_v as 4. The quality of the individual receiving patterns depends on their offset, in beamwidths, from the reflector axis. The greatest offset,

$$M = \frac{N-1}{2} \cdot \frac{\varphi}{\theta_v}, \tag{4}$$

should not exceed 5 if the ratio, f/H, of reflector focal length to vertical aperture is to be kept to a reasonable figure. Thus it appears that a maximum of three beams per dish should be used, although the choice $N = 4$, $M = 6$ deserves study.

Some possible designs for 40 and 60 degree coverage are listed in the tabulation below:

Design	Φ	RPM	φ/θ_v	N	M	φ	θ_v	Elev. Acc.	θ_h	Az. Acc.	n
1	40°	60	4	3	4	13.3°	3.3°	±1.7°	2°	±0.2°	11.7
2	60°	60	4	3	4	20°	5°	±2.5°	2°	±0.2°	11.7
3	60°	60	4	4	6	15°	3-3/4°	±1.9°	2°	±0.2°	11.7

The elevation accuracy has been taken as $1/2\ \theta_v$ because of "spoking" in the vertical plane, while the azimuth accuracy should be about $\theta_h/10$. (θ_h is the horizontal beamwidth.) The number of pulses on target per scan, n, is given by

$$n = \frac{\theta_h}{360} \cdot \frac{60}{\text{rpm}}\ f_r, \tag{5}$$

where the repetition rate, f_r, is limited to 2100 per second by the maximum range of the set. With a 2-degree horizontal beamwidth, n is great enough to permit MTI operation.

The first two designs in the above tabulation could be reduced to practice with very little developmental effort. The reflector would be a paraboloid of revolution, symmetrically cut to an elliptical contour, with an f/H ratio of between 0.8 and 0.9. The feed horns would be large enough to provide a 20 db taper to the reflector edges, in order to preserve the gain and pattern quality of the off-axis beams. Figure 1 shows the dimensions appropriate to a frequency of 5600 Mc. The third design would require an f/H ratio of at least 1.0; the minimum acceptable value should be determined by experiment.

R-F Components

The rat races or 3-db Riblet couplers[9] used to divide the transmitted power would be located at the high-power klystron, as indicated in Figure 9A, rather than on the antenna as in Figure 9B, for the following reasons:

(a) the duplexers would be below deck and easy to service

(b) the full transmitter power would be carried in a single guide for only a short run

(c) one less waveguide channel would be required, and

(d) the antenna would carry less weight.

Each waveguide channel passes through a nodding joint, stabilization joints for roll and pitch, and an azimuth joint. The first two types involve a limited angular motion of 50 degrees or less; their design may be taken from any of a number of recently developed ring-type waveguide rotating joints or switches.[10] Three such joints can be built into a single waveguide ring of reasonable diameter. In Figure 1 there are three nod joints at either trunnion and three stabilization joints at each end of the roll and pitch axes. Alternatively, more conventional joints of the TM_{01} type could be used, inasmuch as 360° rotation is not required. A stack of Sperry Transvar Coupler ring joints,[11] located within the stabilized cylindrical housing, provides for azimuth rotation.

[9] A compact narrow-face coupler developed by H. J. Riblet, Microwave Development Laboratory, Newton, Massachusetts

[10] For example, Breetz, L. D., "A Waveguide Rotating Joint with Waveguide Feed," NRL Report 3795 (Unclassified), January 18, 1951. W. F. Gabriel, Antenna Research Branch, Radio Division I, has developed an H-Plane ring joint.

[11] "Final Engineering Report on Study of High-Power Rotary Joints," Sperry Gyroscope Company Report No. 5224-1195, Contract NObsr-42419 (Confidential), June 30, 1950

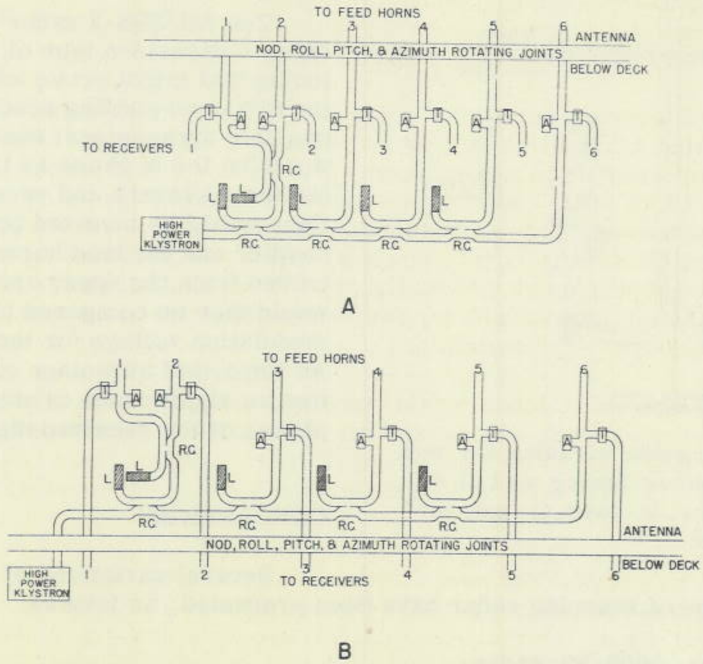

Figure 9 - Possible arrangements of r-f components
R. C. - Riblet coupler, L - load, T - TR, A - ATR

Simultaneous Lobing

As discussed earlier, the elevation accuracy can be improved by application of the simultaneous lobing principle. Figure 10 shows a possible arrangement of the waveguide circuits. Associated with each beam are two vertically disposed feed horns of proper dimensions, connected through a Riblet coupler to sum and difference waveguide channels, each containing a rat race duplexer. In the absence of the difference channel duplexer, the transmitted signal appearing at the difference receiver might be as great as 750 watts, since coupling between the two horns will be about 30 db. It is evident that the incorporation of simultaneous lobing doubles the required number of receivers, as well as the number of nod, pitch, roll, and azimuth waveguide joints. In addition, the following problems will require investigation:

(a) The accuracy obtainable from an r-f comparison type simultaneous lobing system depends on the preservation of phase in both r-f and i-f circuits. The first is accomplished by using equal lengths of guide between the horns and the first coupler, but i-f phasing includes a requirement for maintaining a constant difference in the electrical length of associated sum and difference channels, from the coupler to the receivers. A reasonable i-f phase variation of 20 degrees corresponds at 5600 Mc to a length variation of approximately 5/32-inch. Thus the waveguide joints must be identical, in pairs, to very close tolerances.

(b) In a simultaneous lobing modification of this system, the vertical deflection voltage in the G-scope or RHI is corrected by a modulation voltage proportional to the ratio of the difference signal to the sum signal, whenever an off-axis signal is received. Since any target lying within the 3 db points of the sum pattern will be visible, the difference-to-sum ratio should be linear within this range. No such requirement exists in tracking systems.

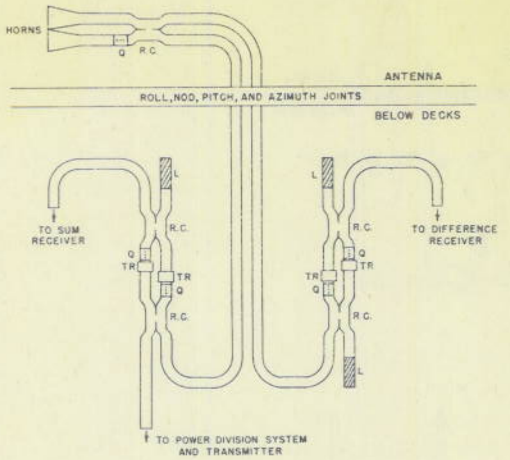

Figure 10 - Waveguide circuits for one beam of simultaneous-lobing antenna. R.C. - Riblet coupler, L - load, Q - quarter-wave phase-shifter

Video Comparison

The AN/SPS-2 radar[12] utilizes a video-comparison type of simultaneous lobing that might prove advantageous for the proposed nodding scanner. In one possible arrangement each pair of horns would be fed in phase as in Figure 10, but the duplexers and receiver connections would be inserted between the Riblet coupler and the feed horns. Signals received from the upper and lower beam would then be compared to derive a modulation voltage for the height indicator. An important advantage of this scheme is that no significance is attached to the phases of the received signals.

CONCLUSIONS

Several variations of the basic proposal for a new type of scanning radar have been presented, as follows:

(1) High-power, 5600-Mc radar

- (a) Two dishes, 6 beams, 80-degree coverage
- (b) One dish, 3 or 4 beams, 60-degree coverage

(2) Ultralight-weight, single-dish, 60-degree coverage, medium-power radar

- (a) 9375 Mc
- (b) 5600 Mc

The coverage expected with the 5600 Mc, high-power versions of this proposed radar backs up that of such radars as the AN/SPS-2 and AN/SPS-13 nicely, as is seen in Figure 4. It is evident that it handles an important search and height-finding function. In addition, the surface-search capability in normal operation would be comparable to that of existing surface-search Fleet radars. There appears to be no reason why the nodding radar should not take the place of one such equipment on board ship, thereby offsetting to some degree the weight and space requirements for this new radar. The 60-degree systems are particularly attractive if backed up by a short-range, high-angle radar.

The "ultralight-weight" proposals, on either 5600 or 9375 Mc, may offer the solution to an urgent problem of providing radar of this type on existing destroyers. At any rate, they certainly appear to represent nearly the ultimate in light weight for these scanning requirements, at practical radar frequencies, and without sacrifice of maximum range compared to the AN/SPS-3 — in fact, they would have increased range at low angles, as part of the repayment for loss of coverage above 60 degrees.

[12] Varela, A. A., "Interim Report on the AN/SPS-2(XDQ) Radar System," NRL Report R-3313 (Confidential), July 14, 1948

The radar systems proposed are tentative. It is recognized that they have some objectionable features, and it is hoped that most of these have been pointed out. At the same time, they have some important advantages of simplicity, light weight, serviceability, relatively low cost, and high performance. They offer a way of meeting accepted requirements, and are believed to be the only way so far proposed for meeting some of the requirements.

In addition to the specific system proposals, the new type of scanning antenna offers many advantages, especially light weight and mechanical simplicity. This type of antenna might conceivably find applications other than the ones proposed here.

ACKNOWLEDGMENTS

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