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SHIP-SHORE RADIO DIVISION  
RADIO COUNTERMEASURES SECTION

FR-2689

9 April 1946

DECLASSIFIED by NRL Contract  
Declassification Team

Date: 27 SEP 2014

Reviewer's name(s): H. Do, P. HANNA

Declassification authority: NAVY DECLASS  
MANUAL, 11 DEC 2012, OS SERIES

DIRECTION FINDER REQUIREMENTS FOR  
SUBMARINES WITH SPECIAL REFERENCE  
TO THE USE OF THE SV RADAR  
REFLECTOR

By

J.O. Spriggs and H.D. Arnett

- Report R-2689 -



UNCLASSIFIED Lab. Memo 117-46

Approved by

E.A. Speakman - Head, Radio Countermeasures Section

Mr. L. A. Gebhard  
Superintendent, Ship-  
Shore Radio Division

Commodore H. A. Schade, USN  
Director, Naval Research  
Laboratory

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## ABSTRACT

The discussion of the use of the back of the SV radar reflector on submarines, which is the fundamental purpose of this report, necessitates an extensive discussion of the problems associated with submarine direction finding in general. The mechanical and electrical difficulties of providing for direction finders, the time requirements for taking bearings with rotating direction finders on fluctuating signals are investigated and the relative merits of possible types of direction finders are evaluated. In particular, a design for a direction finder of the maximum type for SV mounting is described and the lack of utility of this type, as well as the null type, for signals of varying amplitude is shown. The most desirable alternative is seen to be a series of instantaneous direction finders mounted on a non-rotating extensible mast. As an interim measure only, and for existing submarines where a separate mast cannot be added, a solution is presented in the form of an increase in the range of an existing equipment, the Model DBW, to 1000 Mc, and the addition of a high speed spinning type antenna for "S" and "X" bands, neither type being on an extensible mount. The incorporation of a lobe switching type direction finder in the SV to cover 500 to 4500 Mc. is demonstrated to be less desirable although it gives periscope depth operation. Specific recommendations are made as to the course direction finding for submarines should take in the future.

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## INTRODUCTION

1. Reference (1) requested that the Laboratory develop a submarine direction finder to cover the frequency range 300 to 6000 Mc, using antennas located on the back of the SV radar reflector. The equipment was to incorporate ability to serve as a general search device, be able to take bearings on rotating radars with pulse rates from 60 to 4000 pulses per second, and should be capable of continuous use. The components would necessarily consist of one or more pressure-tight antennas, an r-f switch for selecting antennas, a coaxial rotating joint in the SV radar wave guide, another r-f switch for selecting receivers, and an indicator. Development of the rotating joint and the receivers was specifically excluded from the problem. Some of the considerations involved are discussed in the memorandum, Reference (2).

2. The method of attach used was to develop an antenna suitable for pressure-proofing which would cover as wide a frequency range as possible while maintaining a sharp lobe and low standing wave ratio. Then using a rotating radar mount with a maximum speed about the same as that of the SV (about 6 to 8 rpm), it could be determined by observation whether bearings could be taken on fixed and rotating radars adequately. A pattern with a null in the center was to be tried as a refinement if a beam proved successful. In addition to this, work was done on a separate search antenna which would be a necessary addition if the beam pattern antenna were used. A type of antenna, expected to give a cardioid response pattern, which would eliminate having a separate search antenna, was tried with no success. No work was done on a switch at the time of this writing as this was available (RRL type M2415). It was tentatively decided also that the SV radar indicator could be modified to give the desired type of indication, avoiding the necessity of designing and including a separate indicator.

### MINIMUM REQUIREMENT FOR SUBMARINE DIRECTION FINDERS FOR FREQUENCY RANGE 300 TO 6000 MC.

3. The problems associated with the design of a direction finder for submarines, in addition to those of any shipboard direction finder, are incident to the necessity of the collectors to withstand submersion and depth charging and in some cases, like the present one, to operate while the submarine is at radar depth. Since the periscope themselves are not usable for direction finding antenna mounts, at least in the frequency range of this problem, it is logical to consider the use of the SV radar reflector as a rotating mount since this is the only radar which may be raised, other than the ST in the periscope, and the SD, which the SV replaces. The alternative would be to use a separate extensible direction finding mast.

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4. The direction finder antenna for the SV would have to be so designed as to possess the following characteristics:

- (a) The antenna must be specially designed mechanically for submarine operation. The antenna must be pressure and shock proof, that is, the antenna should be able to operate as usual after being submerged to a depth represented by 450 lbs. per square inch pressure, and after being subjected to the shock of a depth charge of at least 300 lbs. of TNT at a distance under water of 75 feet. This connotes that compromises with the directional performance and pick-up desired from the antenna will undoubtedly have to be made for the sake of satisfying this necessary condition.
- (b) The frequency range specified in the problem is 300 to 6000 Mc with emphasis on the bands 300 to 1000 Mc and 2000 to 4000 Mc. The lower frequency limit is apparently set by the availability of the DBW which covers at present 90 to 320 Mc. It is implicit in the solution of the problem to provide searching ability over this range, that is, it may be necessary to supply additional antennas to give all-round coverage. It is assumed that pickup of both vertical and horizontal polarization is required as either may be encountered in this range. It is to be expected that a frequency range of 20:1 as specified will require more than one directional antenna, although some hope might be held for covering this range (except 4000 to 6000 Mc) with a search antenna. Sensitivity is not of prime consideration since this affects only the quality of operation and not the utility of the equipment. Relegating sensitivity to a secondary position of importance is justified since it may be anticipated that a fairly strong signal or none at all will be encountered due to the rapid change of attenuation as the radio horizon is passed.
- (c) The type of signals of which the direction is to be located may be varying in amplitude, either periodically or at random, and may consist of a series of pulses of various shapes and repetition rates from 60 to 4000 per second. An arbitrary limit of one minute may be set as maximum length of time in which a bearing may be taken and still retain the utility of the equipment. This might have been taken as being somewhat longer except that using present receivers it will be necessary to allot most of the time for getting a bearing on an unknown signal to finding the signal while searching. These requirements are closely related to the maximum speed of rotation of the SV antenna which is 6-8 rpm at present. Cathode ray tube indication is desirable from the point of view of achieving the maximum speed of taking bearings and simplicity of operation, if not construction.

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- (d) Physical considerations, involve simplicity of construction, reliability, accessibility for servicing, long life (must equal the life of the radar), small size and weight, and low power requirements. Simplicity of construction, reliability, accessibility for servicing are best obtained if there are no moving parts outside the submarine's pressure hull as it may be expected that under war conditions no work would be possible above deck while on patrol. The size and weight of the antennas are limited by drag and the capabilities of the supporting members, and silhouette considerations, the maximum permissible aperture dimensions probably being those of the radar reflector. Minimum size and weight for the accessory equipment, such as the indicator, suggest aircraft type construction, particularly since receivers now used on submarines are of the aircraft rack type, or combination with other existing equipment e.g. the SV indicator.

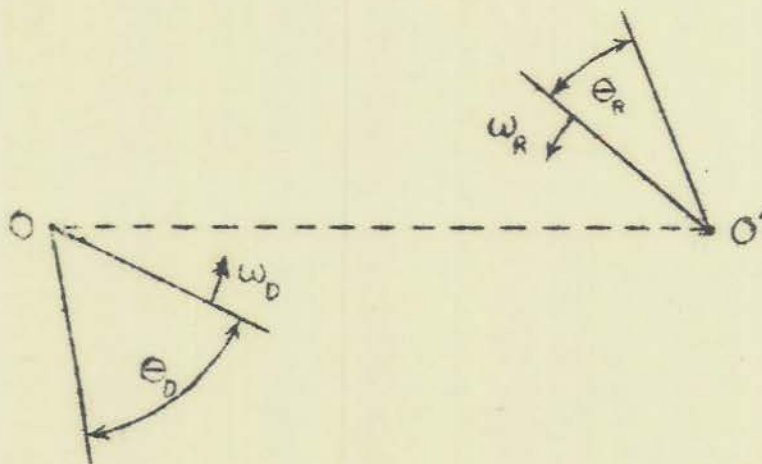
#### THEORETICAL INVESTIGATION OF ROTATING DIRECTION FINDERS

5. Direction finders using a rotating antenna pattern and the information obtained from the variation in receiver output obtained thereby are subject to certain limitations in their capabilities not attendant on an instantaneous or "ideal" direction finder. On a steady signal the time required to assure taking a bearing with a rotating pattern is limited to a minimum of one rotation of the antenna pattern, whatever it may be. Types such as the Model DBM, ideally having no  $180^\circ$  ambiguity, will give a bearing on a steady signal in one revolution, assuming the frequency of transmission and gain required have already been determined. In other types a good many revolutions may be required and more than one pattern may be used e.g., the figure-eight and the cardioid of the Model DAQ equipment.

6. However, if the signal, of which the direction is sought, is varying in amplitude there is no longer the direct correlation between the antenna pattern and the receiver output that there was formerly. It may readily be seen that the transmitted signal may vary in amplitude in such a manner that no bearing can be obtained. This condition will frequently occur where the pattern of the transmitting antenna has a sharp maximum in one direction, and the antenna is rotated, as in the case of a radar equipment. The rate of rotation of the direction finder beam for certainty of interception in a certain time is determined by the width of the beam of the direction finder, the width of the radar beam, and speed of rotation of the radar.

7. In this problem the speed of rotation of the direction finder is inherently limited to six revolutions per minute. Furthermore, the maximum length of time for taking a bearing that would be permissible in any case is one minute, as explained in Paragraph 4 (c). The practical beam width of the direction finder is limited to a maximum of  $45^\circ$  which gives  $\pm 22.5^\circ$  accuracy on one interception in the ideal case assumed for the purposes of this discussion. The radar beam widths to be encountered are probably less than  $10^\circ$  wide. The result of these limitations is that with only a limited range of speed ratios may the radar be intercepted in the requisite length of time. The question then is, what is the range radar d.f. speed ratios that permit interception and is this range useful? The following mathematical analysis will show that the ranges are so small and scanty even for the theoretical case, that a direction finder is useless against a radar rotating at approximately the same speed or even within a ratio of 2:1 or 1:2. Where practical d.f. and radar patterns are considered, the results become even less favorable due to substantial back and side lobes adding spurious interceptions.

8. The problem is illustrated by the following figure:



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9. At  $O'$  is located the source of a rotating radar beam of beam width  $\theta_R$  and assumed to be rotating with a uniform angular speed  $\omega_R$ . A direction finder beam of angular width  $\theta_D$  rotates with a uniform angular speed  $\omega_D$  about the point  $O$ . Each of the points  $O$  and  $O'$  is considered to be stationary. It is assumed that the radar signal is of constant maximum strength over the angle  $\theta_R$  and zero over the remaining  $360^\circ - \theta_R$ . Likewise it is assumed that the sensitivity of the direction finder is constant and maximum over the angle  $\theta_D$  and zero over the remaining  $360^\circ - \theta_D$ . Furthermore it is assumed that any reception of energy from the radar beam by the direction finder is sufficient for obtaining an interception.

10. The initial orientation of the two beams is arbitrary. Certainty of interception results when the number of rotations of the radar and direction finder beams is sufficient to cause an interception from any initial orientation. Of course there is the very likely possibility that an interception will occur in less time than required for certainty. In a report shortly to be published by this Laboratory (Reference 8), conditions for assuring an interception are established. Here only the final results will be given and conclusions drawn from them.

11. Let  $N_R$  be the number of rotations of the radar beam and  $N_D$  the number of rotations of the direction finder beam required to assure interception. It is shown that  $N_R$  and  $N_D$  are integers which are relatively prime. For a given value of  $N_R$  permissible values of  $N_D$  are all those integers relatively prime to  $N_R$  and larger than

$$N_D = \frac{360^\circ - N_R \theta_D}{\theta_R} \quad (1)$$

Likewise for a given value of  $N_D$ , the permissible values of  $N_R$  are all those integers which are relatively prime to  $N_D$  and larger than

$$N_R = \frac{360^\circ - N_D \theta_R}{\theta_D} \quad (2)$$

12. In the case encountered here  $N_D$  is inherently limited to values of six and less since an interception is required in one minute and the rotational speed of the direction finder beam can be no greater than six rotations per minute. Let  $\theta_R = 10^\circ$  and  $\theta_D = 45^\circ$ . As pointed out previously these are about as large as can be expected. Then for  $N_D = 6$ , equation (2) gives

$$N_R = \frac{360^\circ - 6 \times 10^\circ}{45^\circ} = 6\frac{2}{3} \text{ rotations.}$$

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Hence, for  $N_D = 6$ ,  $\theta_R = 10^\circ$ , and  $\theta_D = 45^\circ$  the permissible values of  $N_R$  are 7 and all numbers greater than 7 which are relatively prime to 6; i.e., the permissible values of  $N_R$  are 7, 11, 13, 17, etc. Tabulated below are the permissible values of  $N_R$  for  $\theta_R = 10^\circ$ ,  $\theta_D = 45^\circ$ , and  $N_D = 1, 2, 3, 4, 5$ , or 6.

| $N_D$ | $N_R$                   |
|-------|-------------------------|
| 1     | 8, 9, 10, 11 . . . . .  |
| 2     | 9, 11, 13, 15 . . . . . |
| 3     | 8, 10, 11, 13 . . . . . |
| 4     | 9, 11, 13, 15 . . . . . |
| 5     | 7, 8, 9, 11 . . . . .   |
| 6     | 7, 11, 13, 17 . . . . . |

13. It is thus seen that for these beam widths a minimum of 7 rotations of the radar beam is required to assure an interception within six rotations of the direction finder.

14. Let the ratio of the rotational speed of the direction finder beam to that of the radar be called the speed ratio; it is designated by the symbol  $A$ . Thus the speed ratio is defined by the relation

$$A = \frac{\omega_D}{\omega_R} \quad (3)$$

15. It is shown in Reference 8 that for given values of  $\theta_D$  and  $\theta_R$  a permissible set of values of  $N_D$  and  $N_R$  determines a region of value of  $A$  for which interception is certain. This region is called an intercept region. A set of values of  $N_R$  and  $N_D$  determines a single intercept region. The lower limit to this region is given by the equation

$$A_{\min} = \frac{360M - \theta_D}{360 \left( \frac{MN_R - 1}{N_D} \right) \neq \theta_R} \quad (4)$$

The upper limit to this region is given by the equation

$$A_{\max} = \frac{360(N_D - M) \neq \theta_D}{360 \left( \frac{N_R - MN_R - 1}{N_D} \right) - \theta_R} \quad (5)$$

Before  $A_{\min}$  and  $A_{\max}$  can be evaluated, the number  $M$  must be determined. This number is evaluated by the requirement that

$$\frac{MN_R - 1}{N_D} = \text{an integer} \quad (6)$$

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The number M is the smallest integer which will satisfy the relationship (6). For small values of  $N_R$  and  $N_D$  the value of M is quickly obtained by a method of trial and error since M is always smaller than  $N_D$ . For large values of  $N_R$  and  $N_D$  this method becomes laborious. For the general method of solving (6) the reader is referred to Reference 8 or to a text on the theory of numbers.

16. Equations (4), (5), and (6) will be illustrated by  $N_R = 7$ ;  $N_D = 5$ ;  $\theta_R = 10^\circ$ ;  $\theta_D = 45^\circ$ . First, equation (6) is used to determine M. It is found after trying  $M = 1$  and 2 that  $M = 3$  and  $\frac{MN_R - 1}{N_D} = 4$ .

$$\text{Thus } A_{\min} = \frac{360^\circ \times 3 - 45^\circ}{360^\circ \times \frac{4}{7} - 10^\circ} = .7138;$$

$$A_{\max} = \frac{360^\circ(5-3) + 45^\circ}{360^\circ(7-4) - 10^\circ} = .7150.$$

Thus interception is certain to occur within 7 rotations of the radar beam and 5 rotations of the direction finder beam if the speed ratio lies between 0.7138 and 0.7150.

17. In order to make the interception of radar signals by direction finders more difficult, it is likely that radar equipment will not in the future be operated continuously. After executing a certain number of rotations of the radar beam the radar equipment will be switched off and then turned on again at an arbitrary time later. In the present case in which an interception is required within 6 rotations of the direction finder the intercept regions are few and narrow if the radar rotates 10 times. It is likely that no more than 10 rotations of the radar beam will be made.

18. Reference to the table of permissible values of  $N_R$  for  $N_D = 1, 2, 3, 4, 5, 6$  shows that are 11 possible intercept regions for  $N_R = 10$  and less. Actually there are only 9 distinct intercept regions since the three regions given by  $N_D = 1$ ;  $N_R = 8, 9, 10$  overlap giving a single intercept region. These 9 intercept regions as calculated from equations (4), (5), and (6) for  $\theta_R = 10^\circ$  and  $\theta_D = 45^\circ$  are:

#### INTERCEPT REGIONS

| <u>(Values of A)</u> | <u>(<math>N_D</math>; <math>N_R</math>)</u> |
|----------------------|---|
| 0.0969 to 0.1286     | (1; 8, 9, 10)                               |
| 0.2172 to 0.2262     | (2; 9)                                      |
| 0.2890 to 0.3048     | (3; 10)                                     |
| 0.3729 to 0.3785     | (3; 8)                                      |
| 0.4315 to 0.4482     | (4; 9)                                      |
| 0.5514 to 0.5704     | (5; 9)                                      |
| 0.6193 to 0.6285     | (5; 8)                                      |
| 0.7138 to 0.7150     | (5; 7)                                      |
| 0.8514 to 0.8581     | (6; 7)                                      |

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19. Since the rotational speed of the direction finder beam is limited to a certain maximum value ( 6 r.p.m. here) it may be impossible to reach some of the intercept regions. For example, if the rotational speed of the radar beam is 10 r.p.m. and the maximum rotational speed of the direction finder beam is 6 r.p.m., the maximum speed ratio which can be reached is 0.6. Hence, only the first 6 of the 9 intercept regions calculated above can be utilized. If only the first 6 regions can be used then 8 rotations of the radar beam will be required for certainty of interception instead of the 7 rotations which would be required if all 9 intercept regions were usable.

20. For some speed ratios certainty of interception will never result even with an infinite number of rotations of the radar beam. For example, if the speed ratio equals unity, interception will occur either on the first rotation of the direction finder beam or never. There are many other speed ratios for which certainty of reception will never result. These speed ratios are easily calculated after the lowest permissible values of  $N_D$  and  $N_R$  have been found from equations (1) and (2). For speed ratios less than unity those for which an interception can never be assured are obtained by dividing  $N_D$  by those integers which are less than the lowest permissible value for  $N_R$ , greater than  $N_D$ , and relatively prime to  $N_D$ . Thus for  $\Theta_R = 10^\circ$  and  $\Theta_D = 45^\circ$ , certainty of interception cannot be assured for the following speed ratios less than unity:  $1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 2/7, 2/5, 2/3, 3/7, 3/5, 3/4, 4/7, 4/5,$  and  $5/6$ . There are also speed ratios greater than unity for which certainty of interception will never result. To obtain these, one divides by  $N_R$  those integers which are less than the lowest permissible value of  $N_D$ , greater than  $N_R$ , and relatively prime to  $N_R$ . In the case of  $\Theta_R = 10^\circ$  and  $\Theta_D = 45^\circ$  there are 71 such speed ratios larger than unity and they will not be written down here, since if the direction finder beam is limited to 6 r.p.m. it is not likely that the radar speed will be sufficiently slow to permit speed ratios greater than unity. Plate 13 shows, on a logarithmic plot, the intercept regions calculated above together with the speed ratios, unity and less, for which interception can never be assured if the beam widths are  $45^\circ$  for the direction finder and  $10^\circ$  for the radar.

21. The analysis of Paragraphs 5 through 20 may be summarized as follows:

- (a) For a direction finder limited to a maximum of 6 r.p.m., at least 7 revolutions of the radar beam are needed to assure an interception within one minute if the radar beam width is  $10^\circ$ , and the direction finder beam width is  $45^\circ$ .
- (b) More than 7 revolutions of the radar beam may be required as a minimum if the angular speed of the radar is great enough that the speed ratios corresponding to some intercept regions cannot be attained by the direction finder.

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- (c) There exist numerous speed ratios for which interception cannot be assured given even an infinite time.
- (d) If it is assumed that no more than 10 revolutions will be made by the radar before switching off, the intercept regions are so few and narrow that an interception is very unlikely for beam widths of  $45^\circ$  and  $10^\circ$  for direction finder beam and radar beam respectively and for a direction finder limited to a maximum of 6 r.p.m.

#### CONSIDERATIONS IN DESIGNING A DIRECTION FINDER FOR THE SV RADAR

22. A discussion of the factors associated with designing a direction finder of the type suggested by this problem to fit into the present structure of the SV radar as nearly as possible may be divided into three parts, those associated with the antenna, the leads from antenna to the receiver, and the receiver and indicator. The assumption is made, contrary to the indications of the previous section, that a maximum, beam type antenna and indicator is to be employed.

23. The antenna, as has been said previously, would undoubtedly have to be divided into at least two bands to cover the frequency range desired. The division point would be about 1000 to 1400 Mc, since this gives about a 3:1 band to be covered by the lowest frequency collector, which is the maximum range that could be hoped for in a highly directive antenna. These antennas must be mounted on the back of the SV antenna without extending substantially beyond the edges of its reflector since this reflector faces ahead when in the secured position and an increase in the fore and aft silhouette would increase the drag, when submerged, to the danger point for the mount. However, the drag would not be increased too much by filling in part or all of the grill work of the reflector.

24. A number of types of antennas for the lower range would give the desired pattern for both polarizations but may be discarded because of limitations of size and pressure-proofness already stated. A parabolic reflector is immediately seen to be impractical because it needs to be several wave lengths in width at the lowest frequency encountered, 300 Mc. This length amounts to several meters, although the SV reflector is only 48 inches wide by 24 inches high. Parabolas also introduce complicated phasing problems over such a wide range. A long wire antenna such as a rhombic is not very suitable since it requires a large area (several wave lengths on a side) in the horizontal plane, although one might be used if nothing else were found practical. A Yagi array has nothing to offer since this is essentially a narrow-band device. An array with a flat reflecting plane behind offers some possibilities since above a certain minimum frequency the reflector is not frequency sensitive, and a number of antennas spaced one quarter wavelength or less from the reflector may be driven in phase over any frequency range. By

making the spacing between the respective antennas one half wavelength or less at the high end of the band high directivity in the horizontal plane may be obtained at the high frequency end with substantial advantage in directivity over a single antenna at the low end. The way this type of antenna may be made pressure-proof will be covered below under "Types of Antennas Tested".

25. The choice of antennas for the upper frequency ranges would be limited to horn antennas by reason of the necessity for pressurizing. A  $50^\circ$  horn with a circular aperture and the correct type of wave-guide-to-coax matching section could be made to receive all polarizations with a usable degree of directivity. Pressure-proofing could be done by use of a flat sheet of Dilecto over the aperture. Dilecto has been found to be most suitable for underwater shock resistance by experiments under cognizance of the Taylor Model Basin, Carderock, Maryland. However, it might be found more practical to make the wave guide free-flooding and pressure-proof only the coaxial feed. The connection of the antennas and receiver-indicator presents a number of problems which are not too difficult of solution. The use of RG-8/U cable, rather than a larger cable with less attenuation, as a transmission line is practically forced by the necessity of running the line down in the limited space between the torque tube which supports the SV antenna, and the wave guide contained in it. A limitation imposed by the design of the SV is that only one coaxial line may be run out of the torque tube for the direction finder, because of the necessity of a rotating joint near the point where the line runs through the "doorknob" of the SV wave guide. The limitation is also imposed that power for any switching that may need to be done should go through the center conductor of this coaxial joint to avoid slip rings elsewhere. The most feasible arrangement, however, for selecting the antenna would be to mount the r-f switch on the base of the extensible torque tube and operate it by hand, avoiding the considerable complication attendant on getting power in and out of the inner conductor of a coaxial line over a frequency range of 20:1. The transmission lines from each of the antennas would run down through the space mentioned, use of a number of small cables being perfectly practical. Another switch would, of course, be necessary on the receiver-indicator side to route the signal chosen by the first switch into the correct receiver. If a communication system is to be used in conjunction with this rotating joint section in addition to the direction finder, provision must be made for this in the form of extra positions on the radio frequency switches. It is expected a length of RG-8/U cable could be hung in a loop in the retraction well to permit raising and lowering the SV antenna.

26. A separate search antenna (or antennas) is required to cover the complete azimuth for search, if beam antennas such as these are used. It is obvious that if the SV is the only projection above the water except for the periscopes at the time

an interception is desired, a non-directional antenna mounted anywhere other than on the SV (the periscopes are out of the question of course) is useless. Therefore, the search antenna must either be mounted above the SV reflector to get a clear view in all directions or else consist of a number of antennas mounted around the SV antenna so that the total has a clear view all around.

27. The choice or design of a receiver is specifically excluded from the problem so that it is assumed standard receivers would be used with the direction finding components, such as the SPR-1 and the APR-5AX, both of which have a nominal 52 ohm input and a "video" output as well as 600 ohm line for phones. These receivers lend themselves quite readily to any arrangement for indication by reason of this low impedance video output which permits a line of reasonable length to be run to the indicating device without too much attenuation of the higher frequency components of the wave received. As a matter of fact, this is not of much consequence where the wave shape of the pulses received (if they are pulses) is not important as is the case here. The type of receiver used, however, does influence the time available for direction finding as pointed out previously. A discussion of the very difficult problems of designing a search receiver capable of locating signals in a reasonable length of time is contained in References 3 and 4. Standard receivers such as the SPR-1 and SPR-2 are grossly inadequate as these reports show. On the assumption that the APR-5AX receiver would be used at present to cover the frequency range 1000-6000 Mcs., consideration of the design will be limited to a top frequency of 4500 Mc since the APR-5AX performs very poorly between 4500 and 5500 Mc. (Reference 5).

28. The indicator would be a device consisting of a video amplifier, a cathode ray tube, and means of deflecting the beam from a central position in synchronism with the rotation of the SV reflector (shifted in angular space phase by  $180^\circ$  since the d-f antenna is on the back of the SV reflector). Intensity modulation of the beam would be essential to brighten the trace from signals with low pulse repetition frequencies and short pulse lengths. The amplitude of the intensity modulation would preferably be an inverse function of pulse repetition rate of the received signal to maintain equal brilliance on all pulse repetition rates. A 36x and a 1x selsyn output are available from the SV for giving a reference voltage to fix the position of the yoke, but only the 1x would be needed since sufficient accuracy for direction finding can be obtained (a fraction of a degree) with the 1x servo drive system which would be used if it is found the SV indicator cannot be used.

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29. The SV indicator itself embodies most of these requirements so that by making a few changes in the circuit and putting a radar/d-f switch on the panel, an additional indicator unit might be eliminated, also insuring that the radar and d-f would not be on at the same time. In this connection it should be said that any intercept receiver with a crystal input should be switched off from its antenna, when the radar is used, to avoid burning out the crystal. The changes necessary in the SV indicator circuit would consist primarily of provision for injecting the d-f video signal into the intensity amplifier now in the SV, using the output of this to modulate the beam in deflection as well as intensity, and reversing the yoke 180° with respect to the antenna (easily done by interchanging the rotor leads on the selsyn control transformer driven by the yoke).

30. If the SV reflector were to be used for supporting a direction finding antenna it would be almost imperative to use an On-Ships-Course drive for the SV antenna rather than the simple d-c motor now used. This O.S.C. drive consists of a servo system which relates the antenna position differentially to the ship's position and the compass information so that if the antenna is trained or sector swept as it would need to be at times for d-f and IFF operation, (the Mark V IFF antenna is to be incorporated into the SV reflector too), it will maintain its true position as the submarine changes course under it.

#### THE EQUIPMENT FOR SIMULATING THE PROPOSED SV DIRECTION FINDER

31. A test set-up was made using a Model BI IFF pedestal, APR-1 and APR-5AX receivers, and a CXGA amplifier and indicator to permit the conditions of operation to be encountered in a final SV set-up to be simulated, to check the conclusions of the "Theoretical Investigation of Rotating Direction Finders" above as they apply to the limited rotational speeds and beam widths available in the practical system and to eliminate any imponderables. The BI pedestal consists of a permanent magnet motor and reduction gear driving an antenna mount at a maximum speed of ten rpm with a 36x synchro output. It was modified to give a synchro output of 10x to tie in with the 10x drive of the CXGA indicator, and a maximum speed of six rpm to agree with the SV rotational speed. A Ward-Leonard drive was built up permitting rotation of the antenna mount at any speed up to six rpm and reversing direction by means of flipping a switch. A rotating coaxial joint was made in the pedestal for the RG-8/U cable connecting antenna to receiver by the simple expedient of mounting Type "N" plug and jack connectors without the threaded sleeve holding them together in position at the point of rotation. This was quite satisfactory, developing only a small amount of noise after considerable use. If coin silver were used for the female outer conductor and male inner conductor and stainless steel for the male outer conductor and female inner conductor, the Type "N" connector design might be suitable for continuous operation over a very considerable period of time in a slowly rotating joint.

32. The antenna pedestal was installed about 30 feet from the ground on the top of a wooden structure (Plate 9) at the Laboratories direction finder field at Blue Plains, D.C. Cables led down the center of this structure to the small hut below, where the receivers and CXGA amplifier and indicator were located (Plate 10). For the purpose of running patterns with a local signal of controllable frequency and polarization, a 30 foot pole was installed at a distance of 30 feet from the hut and antennas and transmitters were mounted on the platform, located at the top, when patterns were taken. A large hardware cloth screen was mounted approximately halfway between the pole and the hut to reduce the effect on the amplitude and direction of arrival of the signal at the pedestal of the signal normally reflected from the ground. The wire screen (Plate 9), being large compared with a wave length at the lowest frequency to use three wave lengths at 300 Mc), reflected most of the energy back towards the transmitter. Sound powered phones were used between the hut and the operator of the transmitters, the connecting cable running down the pole and around the screen on the ground, paralleling the power leads to the transmitters. Arrangement was made for photographing patterns appearing on the indicator of the CXGA equipment.

#### DISCUSSION OF THE TYPES OF ANTENNA INVESTIGATED

33. In line with the necessity of checking by experiment the unencouraging principles already mentioned, several directional antennas were built up and patterns taken over a wide range of frequencies covering the lower end of the band to be covered (300 to 1000 Mc). Work was commenced on this range first because it presented the more difficult problems, considering the limitations of size and shape. Two types of patterns were desired for test purposes: one, where the response of the antenna is limited largely to a small range of azimuth, and another, where the response is approximately the same in all directions except for a small range of azimuth. Each one would be equivalent of the other as far as the principles governing the bearing-taking-ability are concerned, but the second type would have the advantage of reducing the need for a search antenna possibly to the point where it could be dispensed with.

34. Investigation of a suitable design for the first type was commenced by developing a broad band array to fit the size of the SV reflector. It was immediately seen that individual antennas of the array could not be fed in the manner that is used for radar antennas, since these antennas are essentially narrow-band devices and the currents in the several dipoles rapidly become out of phase as the frequency is changed. This is due to the practice of feeding a number of dipoles at one end of the row. For correct phasing at any frequency the electrical distance from the common feed point to the individual collectors must be the same. Having chosen the top end of the band to be

covered at 1000 Mc, the maximum spacing of the collectors is determined (six inches) since a spacing much larger than one half wavelength results in breaking up of the major lobe whereas a smaller spacing only results in some broadening of the major lobe. This made the largest practical number of elements four, since the SV reflector is 48 inches wide, and a substantial margin should be left at the edges. The length of each radiating element is also fixed in the same manner, as lengths over one half wavelength (end fed) result in a broken-up pattern. The angle to the horizontal at which the elements are set is fixed at  $45^\circ$  by the presumption that the antenna should receive both polarizations of signal. It was tentatively decided to use a terminated antenna which had the same characteristic impedance as the line it feeds to keep reflections in the antenna and on the line to a minimum. This led to a difficulty since it is impractical to build a concentric line of the impedance required to feed one 52 ohm line with four antennas (200 ohm each) in parallel. However, a compromise could be made by using an available line (95 ohm) to connect each pair of two 95 ohm antennas to separate junctions which could themselves be connected to the 52 ohm line. Pressure proofing could be facilitated by mounting the four antennas flush with the surface of a trough one-quarter wavelength deep at the highest frequency (to avoid breaking up of the major lobe). The pressure proofing could then consist of thick sheets of dielectric material sealed over the openings.

35. An antenna was constructed embodying these principles. The first model had a trough five inches wide by three inches deep extending three-quarters of the way across the copper sheet which represented the SV reflector. Patterns taken on it showed the main lobe to vary considerably in its direction with frequency. Coupling between the antenna elements was suspected to be the trouble and another antenna was constructed utilizing a separate depression for each antenna. This was called the "Cupcake" because of its appearance (Plate 12). The radiating elements are made nearly round, (Plate 11), to present an impedance of approximately 100 ohms to the feed lines which are seen running down the face of the reflector. Two one-quarter watt, 200 ohm resistors in parallel terminate the far end of each of the elements within a broad approximation.

36. This redesign using individual depressions proved to be successful and the patterns obtained are shown in Plates 2-8. The arrow in each represents the physical direction of the transmitter. The change in direction of this arrow at 1000 Mc is due to the fact that when these lower frequency patterns were run, the pole was not yet in place and a more distant location in the opposite direction (without the screen) had to be used. These patterns show satisfactory operation between 400 and 1500 Mc. indicating the antenna might be redesigned with a larger

spacing of elements, possibly using only three to reduce the increased sharpness at the high end over the low end, and probably correcting the shift of the horizontal response at 300 Mc. In examining these patterns it should be remembered that an end-fed dipole is inherently asymmetrical. Standing wave measurements were run on the antenna (Plate 1), the average voltage ratio being well under a maximum of 4:1 which occurs at 550 Mc. This curve could be considerably improved by improving the match of the antenna elements and terminating resistors to the line, the latter of which were only nominally correct.

37. A cursory trial at designing an antenna to give the all-around coverage except for a small section, listed as the second type of antenna suggested, was made. A V-shaped reflector of suitable size was constructed to be rotated in the horizontal plane. The collector was a small loop mounted at  $45^\circ$  halfway up the outside of the apex of the V, the thought being that signals arriving in the angle covered by the base of the V would be reflected away from the collecting element. Pattern tests showed, however, that there was no obvious correlation between the numerous and unpredictable nulls and the shape of the reflector. No further investigation of this type of antenna was made although this result was not taken as conclusive since there exist other possibilities for producing this type of pattern although it is expected that development would be difficult and the outcome doubtful.

38. Since a search antenna was quite likely to be needed, a vertical double cone antenna 12 inches in diameter by 10 inches high was constructed, which for vertical polarization was found to be feasible for covering the range 500 to 4000 Mc. The voltage standing wave ratio was found to be less than 2:1 over this range except between 500 and 600 Mc, where it goes up to 2.75:1. A free-flooding antenna of this type could be readily built into the SV reflector if one cubic foot of space could be occupied above the SV reflector. Attempts at conversion of horizontally polarized waves to vertically polarized by numerous wires placed at  $45^\circ$  distributed around the periphery of the cones were not successful due to nulls which appeared in the patterns except over a small portion of the spectrum at the lower end. Tilting the whole antenna is not feasible at the higher frequencies because of the high vertical directivity of the double cone at these frequencies. There remains considerable possibility that a useful search antenna might be designed to cover from 300 or at least 500 Mc to 4000 Mc using variations of the double cone described above.

EXPERIMENTAL CONFIRMATION OF THEORETICAL INVESTIGATION OF  
ROTATING DIRECTION FINDERS

39. The principles discussed previously under "Theoretical Investigation of Rotating Direction Finders", beginning at Paragraph 5 above, were found to hold for the practical application. The "Cupcake" antenna was used to give an approximation to unidirectional response and was taken as representative of what a final model of an SV direction finder might be. Fixed and rotating radars located nearby were observed on the indicator with the direction finder antenna rotating at various speeds up to the maximum of six rpm. Bearings on fixed amplitude signals could be taken to a degree of accuracy limited only by the error in the pattern of the d-f antenna and the width of the beam. However, it was not found possible to take any bearings at all on a rotating or continually sweeping radar, all of the ones observed having rates of rotation equal to or somewhat greater than those of the direction finder, as well as sharper beams. The appearance a rotating signal makes on the screen is a sharp lobe which may flash on the screen in any position regardless of the heading of the maximum lobe of the direction finder antenna. The signal is picked up on minor side and back lobes of the d-f pattern. If the gain of the receiver is reduced to where only coincidence of the two beams will give an indication, doubt immediately arises as to whether the gain may not have been reduced too much, or as to whether the signal is still there at all.

40. The effect of using a broad pattern instead of a narrow one was checked experimentally with a very slight amount of success. An XCY (DBV, DXB) collector was mounted in place of the "Cupcake" and used in the band for which it was designed. It was found that under restricted conditions a bearing could be taken with it. The conditions are that the intercepted signal is strong enough so that its minor lobes may be observed on the screen, that the signal is on for about one minute, that the frequency (in the case of a redesign for the SV) is such that the reflector is very large compared to a wavelength (five wavelengths or more) to greatly reduce backside pickup, and that the operator is experienced in interpretation of the meaning of the numerous pips and grass. The bearing appears in the form of a greater preponderance of pips on one side of an 180° sector of the scope than the other. Such a bearing could probably be taken to within  $\pm 45^\circ$ . Because of the size of the SV reflector the lowest useful frequency would probably be about 1000 Mc. If more than one radar of the same frequency were intercepted at the same time from different directions neither bearing could be obtained.

## ALTERNATIVES TO THE USE OF A SIMPLE UNI-DIRECTIONAL ANTENNA

41. Since the systems that have been described so far in this report are of very doubtful utility in view of the large percentage of signals of varying amplitude upon which the direction finder must work, other systems have been considered as alternatives. Four types, in increasing order of probable utility are: first, an arrangement using a fast acting r-f switch for comparing a search antenna pattern with a highly directional pattern; second, a lobe-switching arrangement, preferably with the two lobes each giving more than 180° coverage on its respective side; third, a high-speed rotating directional antenna, similar to the DBM to supplement the DBW; fourth, a separate non-rotating extensible mast supporting four antennas equally displaced around the azimuth, connected to a four channel receiver to give instantaneous indication of direction.

42. The first of these, the search-directional antenna comparison system, while theoretically possible does not seem to lend itself readily to practical construction. It is readily seen that this product of the amplitudes of a circular pattern and a directional pattern would not be a function of the absolute amplitude of any signal they might be picking up but only a function of the orientation of the directional antenna with respect to the direction of arrival of the signal. However, the practical construction of a system like this using only one coaxial lead to connect antennas to receiver, involves use of a fast acting lobe switch mounted, in the case of the SV installation, outside the pressure hull or on the lower end of the extensible torque tube. It also requires that the outputs of the receiver due to the individual inputs be sorted correctly and applied to a circuit which will give a multiplication of the two outputs after integrating them, possibly requiring a very fast a.v.c. in the receiver. This latter is in itself very difficult when the signal received may consist of very short pulses widely spaced. In addition to this, the difficulty of producing a search antenna with a pattern somewhat resembling a circle is great.

43. Lobe switching of two broad patterns seems to be somewhat more feasible than the system just described but has the limitation in common with the other that information as to which antenna is connected to the receiver must be conveyed to the indicating device. This requires in both cases, either using the center conductor of the coax for the power and information, or using slip rings on the torque tube. Using the center conductor presents very difficult problems in the form of getting the power and information together and apart and in and out of the center conductor while maintaining a 20:1 ratio of frequency in the signals passed through the rotating joint.

44. Assuming for the moment that this could be done or that slip rings could be used, two antennas would be required in each frequency range with overlapping response patterns, preferably as wide as could be made, up to something over  $180^\circ$ . This  $360^\circ$  coverage is not available, of course, from the backside of the SV reflector only. Slightly over  $180^\circ$  in two  $100^\circ$  (maximum angle, not half power points) lobes is probably the best that could be done, requiring the use of a search antenna for the remainder of the  $360^\circ$ . The indication would in either event be in the form of two traces, spaced a few degrees apart, radiating from the center of a cathode ray tube. The amplitude of each trace would be proportional to the amplitude of the signal received by its respective antenna. The azimuth of the line bisecting the angle thus formed would correspond to the azimuth of the signal received when the lines are equal length. Sense would be obtained by the direction of relative shift of line length with rotation of the collector if two  $180^\circ$  lobes are used. A medium speed a.v.c. would also be very helpful here, since it would reduce the total fluctuation in and out as compared to the differential fluctuation which carries the useful information.

45. A suitable lobe switch might be designed using one of two methods, either a mechanically operated switch or an electronically operated switch. The mechanical switch would consist of a rotating member which would alternately make capacitive connection between the individual input ~~axes~~ and the output coax. Indication from experiment with this type of switch shows that a single switch could be designed to cover the frequency band 300 to 4000 Mc with acceptable reflection. The electronic switch would probably utilize a pair of lighthouse tubes as "valves" to cut off reception alternately from each antenna. The tubes would be used as grounded (for r-f) grid amplifiers and a rectangular voltage would be applied to these grids reciprocally to cut them off in sequence. Such a switch could be designed for from 300 to somewhat above 1000 Mc. The maximum speed of switching need be no faster than the slowest pulse repetition frequency encountered, i.e., 60 cycles per second or 3600 rpm.

46. The third choice is that of using a DBM type equipment adapted for submarine use. This could either be mounted on a bracket on top of the shears such as is planned for the DBW, or on a separate mast if available. Such a device for "S" band or higher could probably be made pressure tight by a plastic dome about 12" to 18" diameter. For frequencies below "S" band this system would not be feasible because of the difficulty of producing a high speed, pressure tight rotating joint. This joint would be necessary because below this band the antennas would be too large to permit the use of a plastic dome of reasonable size and weight. This third choice may well fit in with the plans now being made to extend the operation of the DBW to the range 40 Mc to 1000 Mc, this device filling in above 1000 Mc.

47. The fourth alternative, a four-collector, non-rotating antenna system could be used if a separate extensible mast were made available. This system could be used to supplement the DBW above its present frequency range. The DBW would be built into the mast in this case although design of an instantaneous direction finder to replace the DBW should be planned. The direction finder system would consist of the four collectors covering each its respective quadrant with a tangent-circle pattern, four cables leading below with matched attenuation, and either a switch for alternately passing the four inputs through a single channel and distributing them on an indicator, or preferably, instead of the switch and single channel, four separate channels matched in gain, feeding the four plates of an indicator directly could be used. Either system would give automatically and quickly the bearing of a signal, although only the second type would give instantaneous indication. The first type corresponds to the Model CXFF equipment and the second to a German equipment known as the "Verstarker Westerland".

48. The collectors would consist of four square screens placed in a square around the mast. The antennas, to get the desired half-figure-eight pattern for both polarizations, would probably take the form of bent dipoles mounted in the center of the screens at  $45^\circ$ . It might be found desirable to mount two antennas on each screen, one above the other, to get vertical directivity and increased gain. The maximum size of the screen is a function of the lowest frequency to be used and must be at least  $11/16$  wavelength square at this lowest frequency. If the lowest limit in frequency is 300 Mc, 27 inch square reflectors would be required. These could be made of wire screen with holes of increasing diameter towards the edges. However, a cube 27 inches square even in the form of a grating would be rather large mounted on a mast on a submarine. It would seem preferable to raise the lower frequency limit for this equipment to 400 or 450 Mc and decrease the size of the screen to 20 or 18 inches. This should be accompanied by an increase in the upper limit of the DBW, which now covers the range 90 to 310 Mc, to 400 or 450 Mc. It would then possibly be desirable to divide the DBW into two bands, say 150 to 450 Mc and 50 to 150 Mc, and its antennas incorporated in the mast. Each set of four antennas and reflectors could be expected to cover a 3:1 range placing the upper limit of the lower band at about 1300 Mc. The next band would cover 1300 to 4000 Mc and could be mounted on the same reflectors with the lower band. It would not be very difficult to provide three antennas to cover the frequency range if found desirable for improved patterns and consequently greater accuracy.

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49. A two or three position tandem r-f switch of the coaxial type would be required to permit connecting electronic or rotary switches to collectors for the different ranges, and another r-f switch to connect the output of the switch to the respective receivers. In the case of the instantaneous type, no switching need be done and the receiver would have to be built to match the frequency range.

50. All cables could be run down through the mast and looped at the bottom if the mast is extensible, or permitted to flex at the joint if a lever type mast is used.

51. If, as will be suggested later direction finding coverage is provided for the complete spectrum, the various receivers and indicators should be coordinated in design and incorporated in one cabinet especially made to fit a particular location in the most common types of submarines, probably the navigator's corner of the control room. This cabinet should contain wide-band panoramic receivers for watching the spectrum, with provision for setting the direction finder on the frequency of any signal of interest and switching from panoramic receiver to direction finder as quickly as required.

52. If separate panoramic receivers are available, present receivers will be satisfactory for direction finding in the case where a fast-acting switch is used. If an instantaneous indicator is used on the other hand, design of four channel receivers matched in gain in each channel will be required. This latter may be possible since the same oscillator would be used for each channel and the channels will be wide band. It may further be found practical to inject a superaudible signal as modulation which will travel through the four channels and the discrepancy at the output used to match gains. This system also lends itself to automatic gain control which is very desirable to prevent overloading of channels and aid in observation of fluctuating signals.

#### EVALUATION OF THE RELATIVE MERIT OF THE SEVERAL TYPES OF DIRECTION FINDERS PRESENTED

53. An evaluation of the relative merit of these direction finders requires first some prognostication of the types of signals such direction finders will be required to work against. Since the signals to be encountered will largely be radar signals, this again requires a discussion of what types of radar a prospective enemy may have or develop before a change in design of the direction finder may be made. Indeed, the types of radar of our own armed forces are of consequence since submarines are subject to attack from friendly as well as enemy sources.

54. At the recent termination of hostilities, radar in this country had reached a high state of development which can also be expected to be obtained in the near future by other countries. Nearly all U.S. search radars are of the continuously rotating or sector sweep type, some few obsolescent types still being omnidirectional. Fire control radars may be of the sector sweep type, lobe switching or conical sweep, usually combined with the ability to be trained for precision ranging and azimuth determination. The latest techniques and developments include provision for keying these radars on for only a short time (as for instance, two or three revolutions of a rotating radar) and off for a much longer time, and provision for frequency-modulating the transmitter as a countermeasure against "window". In addition, random variation of the pulse repetition rate may be included, which would not make the direction finding problem easier. A very excellent discussion of this is found in Reference 7. It is expected future developments will include increasing the rotational speed, random variation of this speed, and possibly random variation in the transmitted power. An increase in rotational speed in and of itself may increase the ease of direction finding, at least in the case of a slowly rotating direction finder.

55. Since the utility of a submarine direction finder is largely in knowing the direction from which a signal is arriving before the source of the signal gets within radar range, it may be safely said that the direction of signals of varying amplitude (usually rotating radars) will be more often of use in the tactics of submarine operation than the direction of steady signals. This is true for the reason that if a radar signal is steady the radar is probably trained on the submarine, and is consequently within the submarine's radar range. It might be pointed out here that merely finding one signal and learning its location is of secondary importance tactically since there may be a number of signals on in the area of operations, some friendly and some enemy. Even the signals of saturation strength are not of consuming interest since submarines cannot afford to dive every time a saturation signal is received. A submarine commander will need to keep track of a number of signals at the same time, so that a constant flow of information on variation in amplitude and variation in direction or a number of signals is required of the direction finder. This puts an even greater burden on the direction finder because of the speed demanded of it for such operation.

56. Since it has been shown that maximum type direction finders rotating at the speeds available in the SV are nearly useless for taking bearings on rotating radars, this type may be discarded immediately from consideration. This leaves the relative merits of (a) rotating antenna direction finders with lobe switching, and (b) fixed antenna direction finders (both rotating pattern and instantaneous) to be discussed.

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57. A lobe-switching direction finder (including both the maximum-search and switched broad lobe types) is theoretically feasible for use on rotating signals assuming that the speed of switching is fast compared to the variation of the amplitude of the signal, but presents considerable practical difficulties. A lobe-switch must necessarily be a capacitive-type-switch, continuously rotating and motor driven to attain the switching speeds required. Since the lobe-switch will be in constant use it would have to be available for repair or replacement on patrol, requiring it to be mounted on the base of the extensible mast. It requires power and must provide a means of identifying the position it is in at any moment. This requires two or more slip-rings on the extensible shaft. Some special provision would have to be made for switching the traces on the indicator back and forth five degrees or more in synchronism with the switching. A separate search antenna would probably be required. The result would be a useful but not completely satisfactory instrument.

58. A fixed antenna direction finder has a number of advantages and disadvantages which are difficult to weigh. One great disadvantage is the requirement of the installation of a separate mast, which could either be mounted on an extensible torque tube as in the SV, or raised as a lever as in the German Schnorkel. Redesign of the SV mast so that only the SV antenna, and not the tube, rotates, permitting the addition of numerous other antennas, has not been considered here, although it should be investigated. If it is possible to more easily make a separate mast available, it would have a considerable advantage over the rotating SV mount in that a number of other direction finder antennas could be mounted thereon such as those of the DBW as well as communications, IFF and others. In this regard it might be said that direction finding on all signals between 15 kc and 30,000 Mc should eventually be provided for submarines and such a mast could be used to hold the antennas to cover the whole range. The cables from the several antennas could be run down through the extensible tube or through the flexible joint to the various receivers without any rotating joints or moving parts in the electrical circuit except at the receiver-indicator location, with the exception of frequencies above 5000 Mc where wave guides or remote tuning might be required.

59. The advantages of providing instantaneous automatic bearings should not be underestimated. Ease and simplicity of operation is an outstanding consideration in the design of any piece of equipment and is particularly important in a direction finder for submarine use. Since the personnel of a submarine is limited, watches on intercept equipment are frequently stood in their "spare" time by enlisted men with other regular duties. Instantaneous direction finders are considerably easier to operate than other types, requiring only

the manipulating of tuning and gain controls (and sense, if required) to obtain a bearing. Reliability of the bearings is of greatest importance. There always remains some doubt as to the correctness of bearings hastily obtained on other devices. The instantaneous type assures the correctness and in addition assures that all bearings will be obtained for the signals observed, no matter of how short duration. It is also possible to take two bearings at once under the usually encountered conditions. Furthermore, in the case at hand, a separate search antenna is not required, since there is no sense ambiguity. The latter statement is true for frequencies above 300 Mc where half figure-eight patterns are used, and it could be made true for lower frequencies, where a separate sense antenna is required. In this case the two usual direction channels could be supplemented by a third sense channel matched in phase, or each of the two channels could be used intermittently for sense by electronic switching.

60. It may be seen from the foregoing discussion that whereas the lobe switching arrangement for SV mounting has an advantage in that it utilizes a mounting already available, it has no place in a long range program of supplying direction finding coverage of the whole frequency spectrum for submarines, unless it is impossible to provide an additional mast for countermeasures, communications, IFF and future developments along other lines such as infra red ray equipment which are in prospect for the future.

#### CONCLUSIONS

61. It is concluded that:

(a) A maximum or null type direction finder is unsuitable for incorporation in the Model SV radar reflector for use against signals of varying amplitude such as rotating radars. This is predominantly because of the extreme lengths of time that may be required for taking bearings on such signals, necessitated by the slow speed of the SV mount.

(b) The SV reflector may be utilized as a mount for a direction finding antenna, if necessary, by the design of a lobe switching antenna system and indicator, with the modifications mentioned under Recommendations.

(c) In view of the planned extension of the Model DBW direction finder to 1000 Mc, the most feasible interim solution may be the addition of an "S" band and possibly "X" band high speed rotating pattern direction finder to be installed on the submarine shears to supplement the DBW.

(d) The design of a system for permanent installation on new submarines should consist of a series of direction finders covering all the frequencies of interest to submarines (ultimately 15 kc to 30,000 Mc) mounted on a separate extensible mast either of the periscope tube type or the lever type. If Schnorkels are to be put on the new vessels, the direction finders might be incorporated in them.

(e) Direction finders for this permanent installation should be instantaneous in operation and combined with panoramic frequency coverage for speed of location of new signals.

#### RECOMMENDATIONS

62. It is recommended:

(a) That if it is possible on submarines already constructed to employ a separate mast for direction finding and other purposes, the Laboratory be requested to design a direction finder utilizing this mast to cover the frequencies of greatest use in the operation of submarines. In this case the laboratory should be requested to cancel the present problem.

(b) That, if interim gear is required while such a direction finding mast is being designed, the DBW be extended as planned to 1,000 Mc and that the Laboratory be requested to design a spinning direction finder to cover "S" and "X" bands for shear mounting. In this case the present problem should be cancelled.

(c) That if the installation of a direction finder mast is not possible on existing submarines, and recommendation (b) is not satisfactory, the Laboratory be requested to consider that the present problem includes the design of a lobe-switching type direction finder antenna for use on the SV radar reflector if submerged operation down to 400 Mc is required. It is anticipated that this third recommendation will not be practical unless slip rings are available on the SV torque tube, and that coverage from 4500 to 6000 Mc cannot be given unless some other receiver than the APR-5AX is available. On-Ships-Course rotational control of the SV radar will be necessary if the SV is used for direction finding and would be desirable in any event. Other limitations will be found in the text.

(d) That if recommendation (b) or (c) is adopted, provision be made in future submarine design for a separate mast for direction finders and other antennas, and that complete coverage of the frequency spectrum be provided by direction finders of the instantaneous type coordinated with wide band panoramic display.

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3. JEIA No. 7829, "An Appreciation of the problems involved in Centimeter Radar Interception".
4. NRL Interim Report S-S67/69(342C), Ser. 4847 of 2 July 1945, to BuShips.
5. RRL Report "Test Specifications for S and X Band Shipboard Radar Intercept Systems", 411-TS-27 also RRL 411-152 of 19 June 1945.
6. Captured German Document RF/13787/NID "Verstarker Westerland".
7. NDRC Report "Factors Involved in the Randomization of the Radar PRF" OSRD No. 5124, 15 June 1945.
8. NRL Report, R-2779, "The Conditions for Certainty of Interception of an Intermittent Signal by a Rotating Directional Antenna".

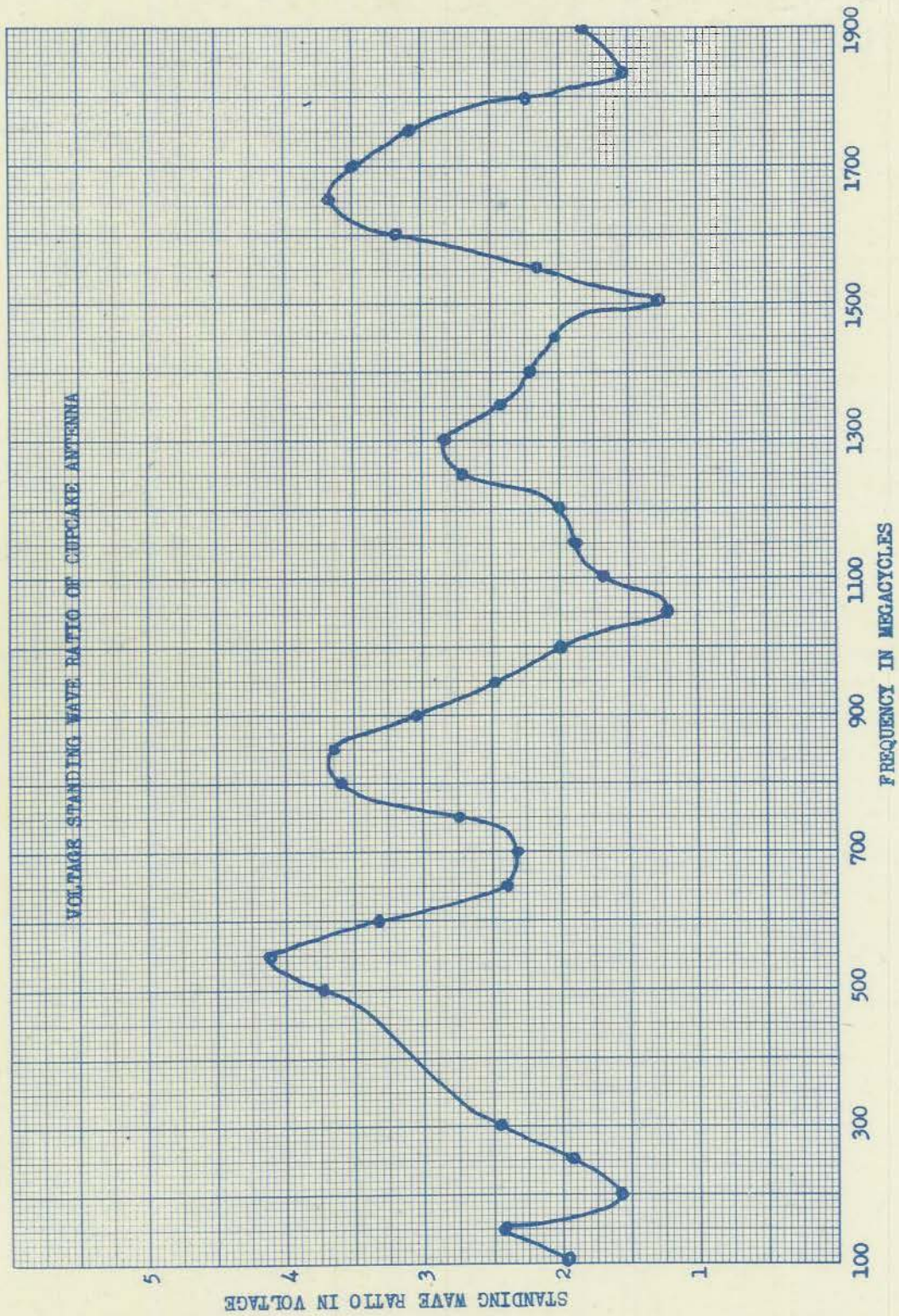
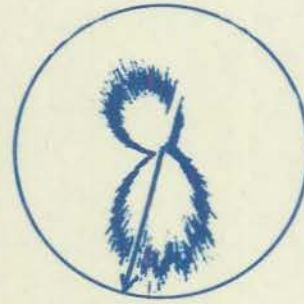
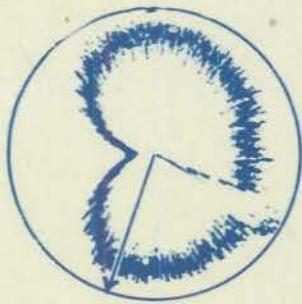
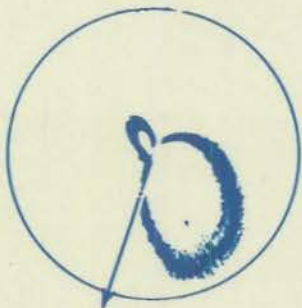


PLATE I

DECLASSIFIED



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175 MEGACYCLES

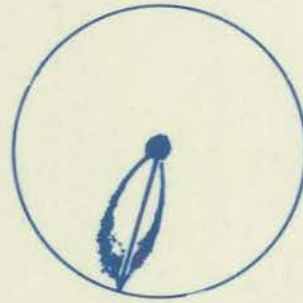


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HORIZONTAL -- POLARIZATION -- VERTICAL  
PATTERNS OF CUPCAKE ANTENNA

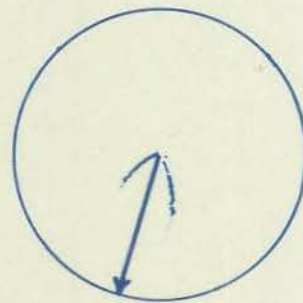
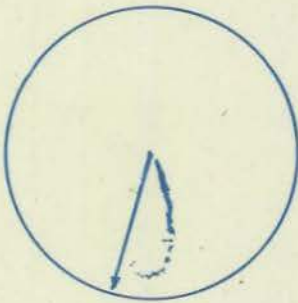
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DECLASSIFIED

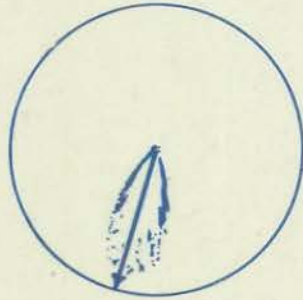
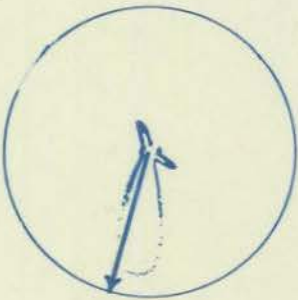
PLATE 2



300 MEGACYCLES



400 MEGACYCLES

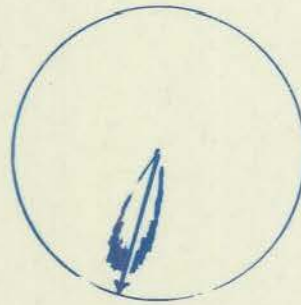
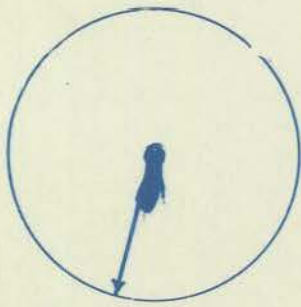


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PATTERNS OF CUPCAKE ANTENNA

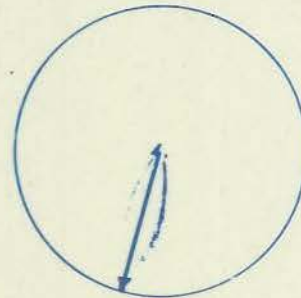
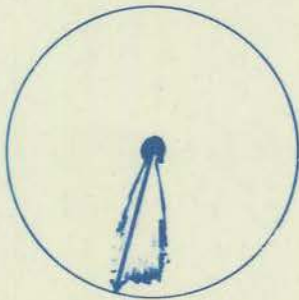
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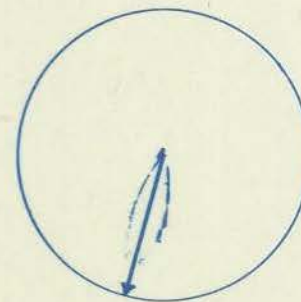
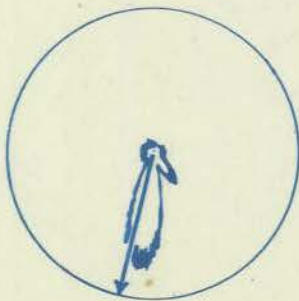
PLATE 3



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700 MEGACYCLES

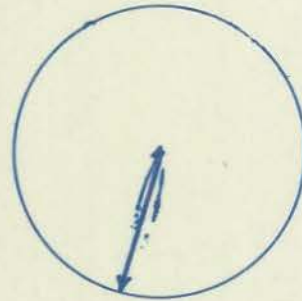
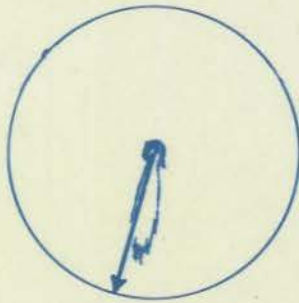


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HORIZONTAL --POLARIZATION -- VERTICAL  
PATTERNS OF CUPCAKE ANTENNA

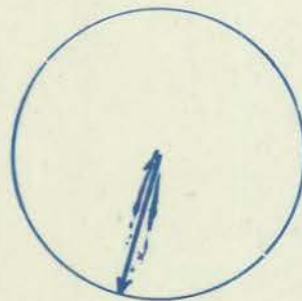
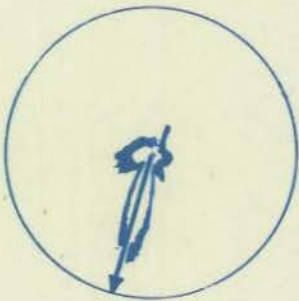
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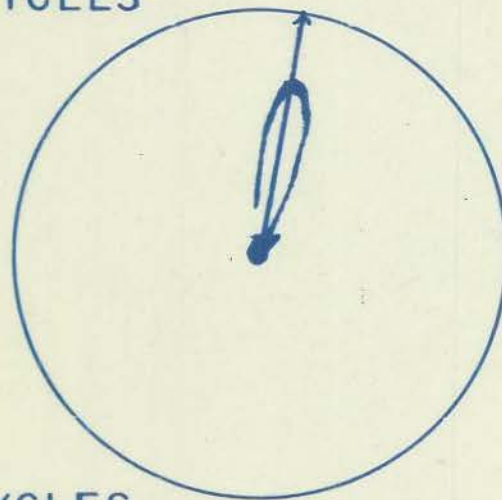
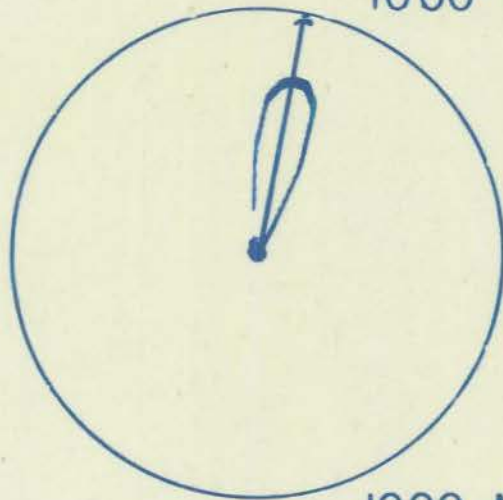
PLATE 4



900 MEGACYCLES



1000 MEGACYCLES

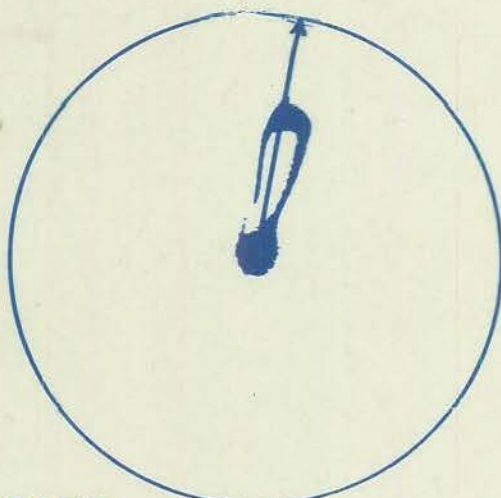
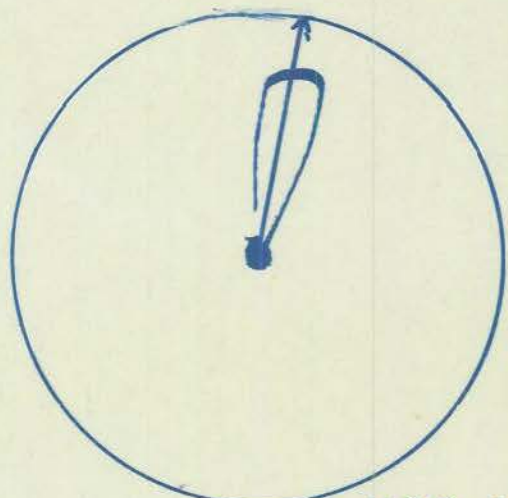


1000 MEGACYCLES  
HORIZONTAL --POLARIZATION-- VERTICAL  
PATTERNS OF CUPCAKE ANTENNA

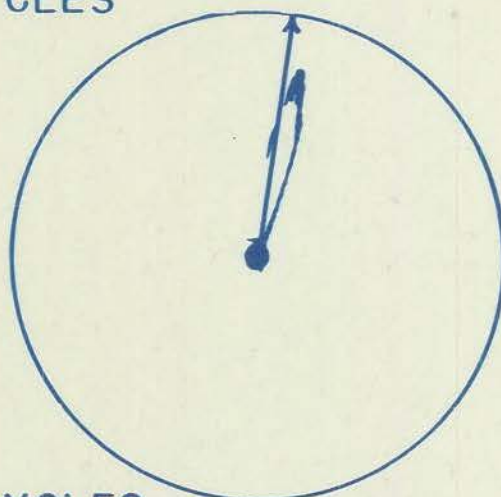
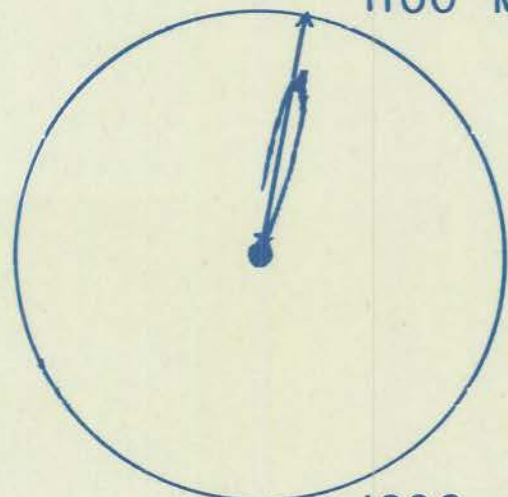
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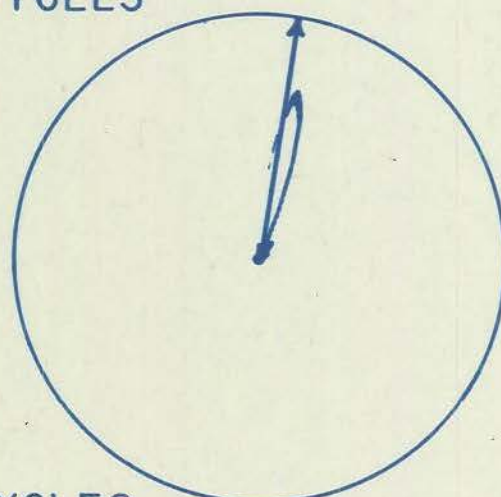
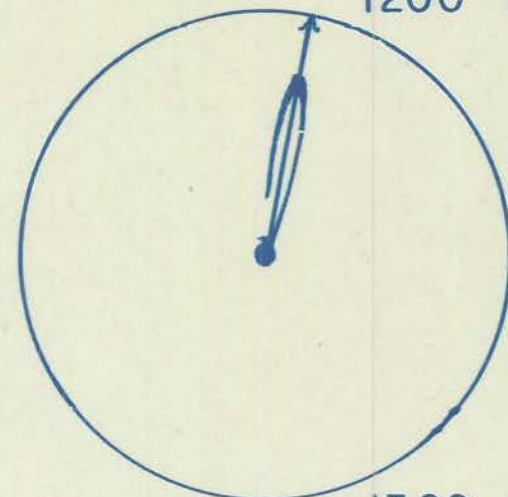
PLATE 5



1100 MEGACYCLES



1200 MEGACYCLES

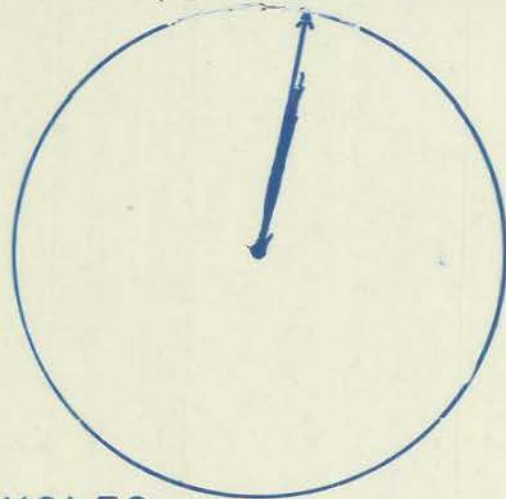
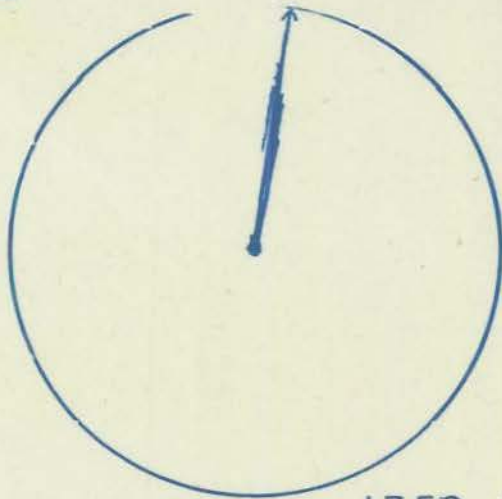


1300 MEGACYCLES

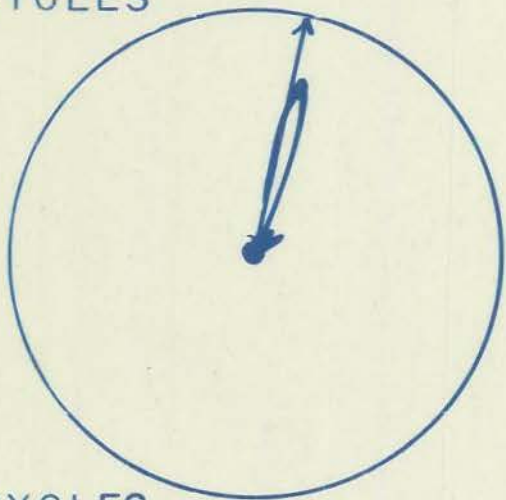
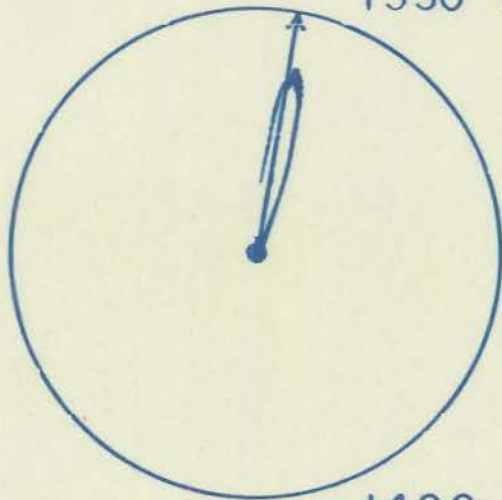
HORIZONTAL -- POLARIZATION -- VERTICAL  
PATTERNS OF CUPCAKE ANTENNA

PLATE 6

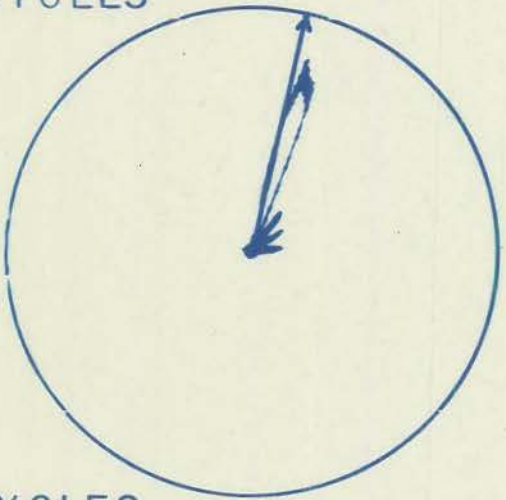
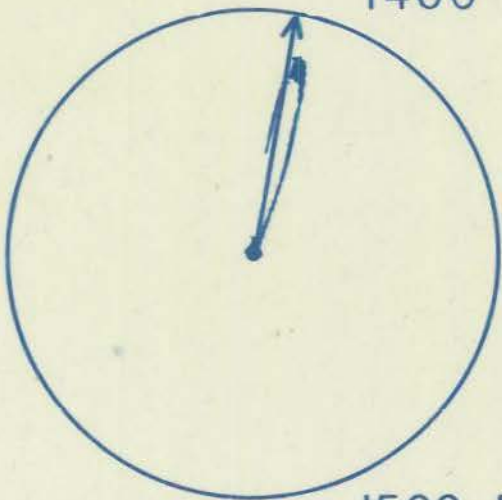
DECLASSIFIED



1350 MEGACYCLES



1400 MEGACYCLES



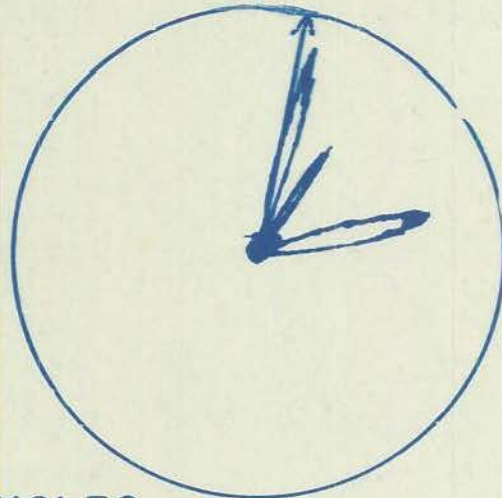
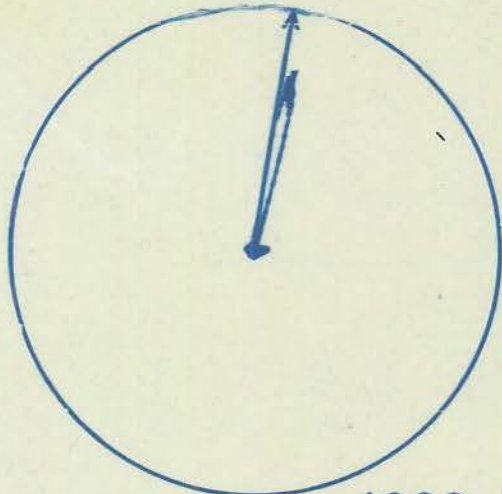
1500 MEGACYCLES

HORIZONTAL - POLARIZATION - VERTICAL  
PATTERNS OF CUPCAKE ANTENNA

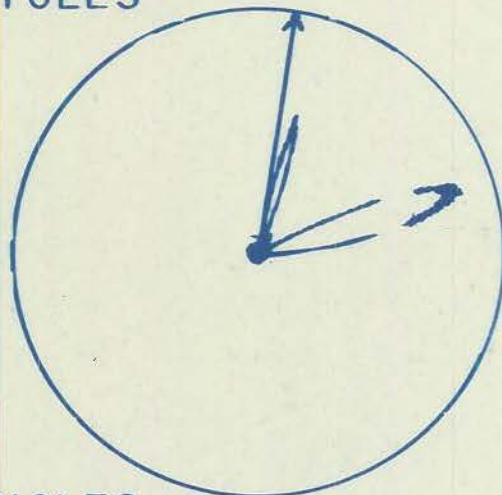
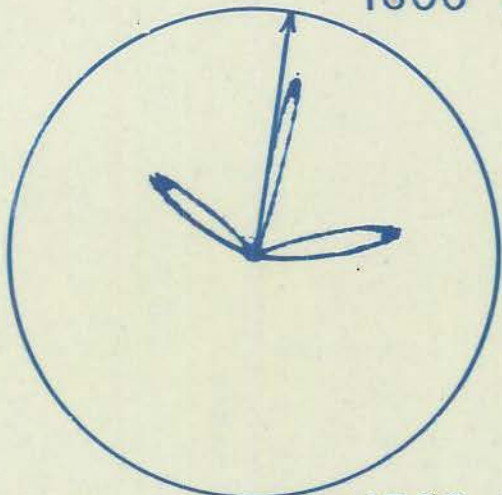
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PLATE 7

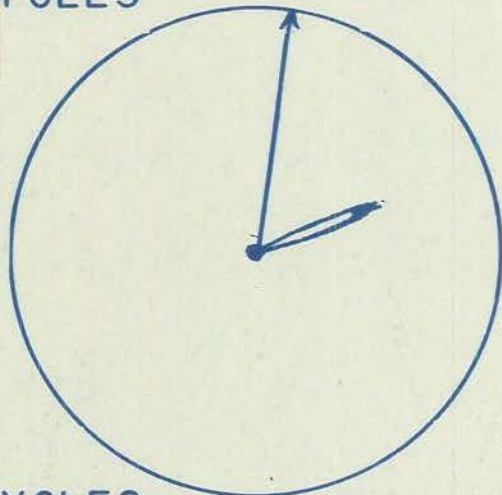
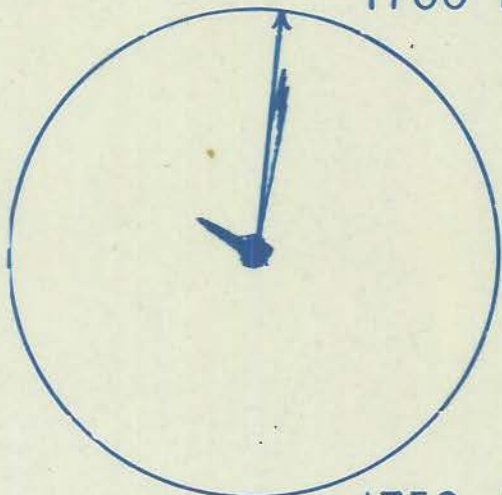
DECLASSIFIED



1600 MEGACYCLES



1700 MEGACYCLES



1750 MEGACYCLES  
HORIZONTAL - POLARIZATION - VERTICAL  
PATTERNS OF CUPCAKE ANTENNA

~~CONFIDENTIAL~~

PLATE 8

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FIELD TEST INSTALLATION  
EXTERIOR VIEW SHOWING ROTATING MOUNT,  
SCREEN AND TRANSMITTING ANTENNAS

DECLASSIFIED

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PLATE 9

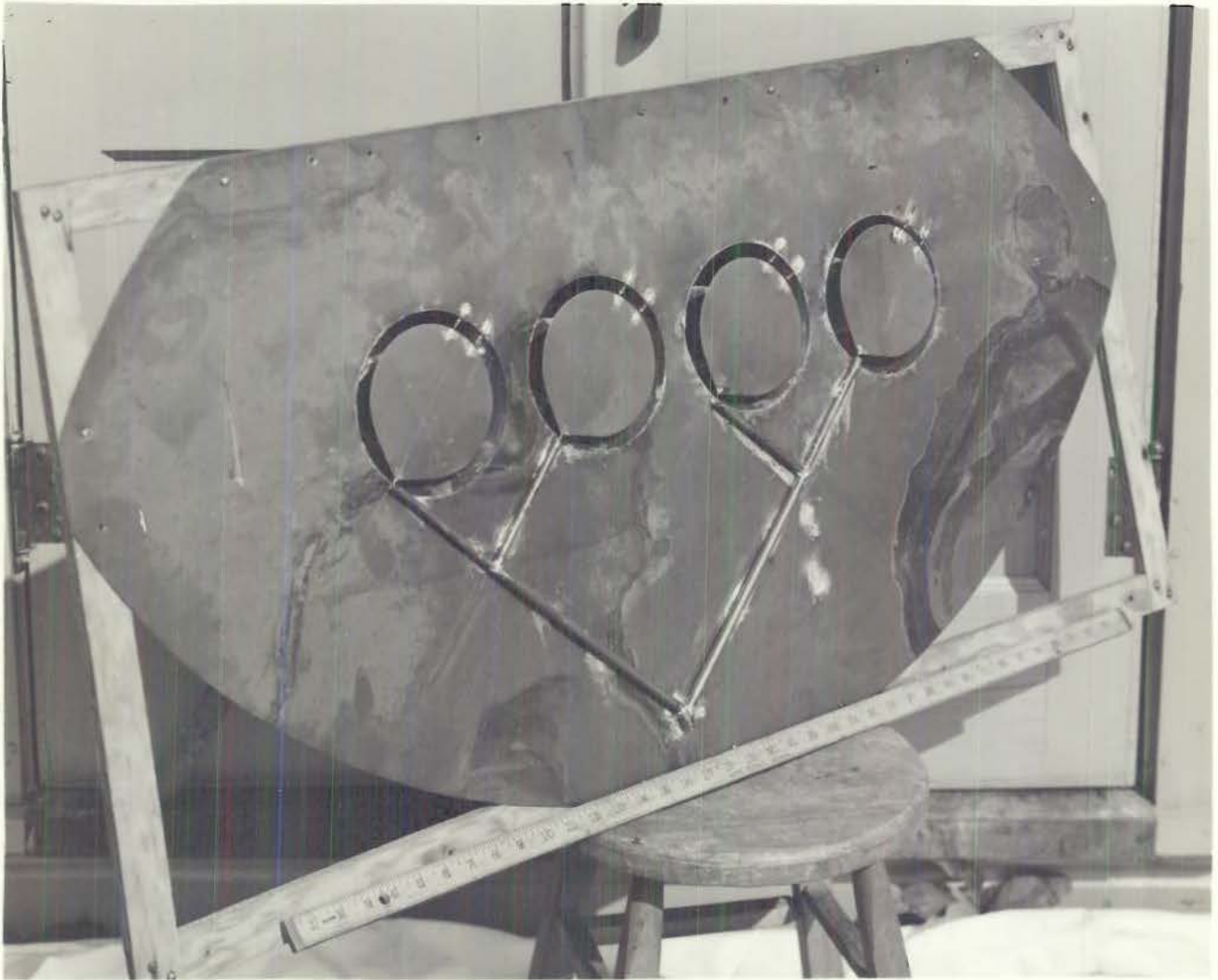


FIELD TEST INSTALLATION  
INTERIOR VIEW SHOWING RECEIVERS,  
INDICATOR MOTOR CONTROL DEVICE AND CAMERA.

DECLASSIFIED

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PLATE 10

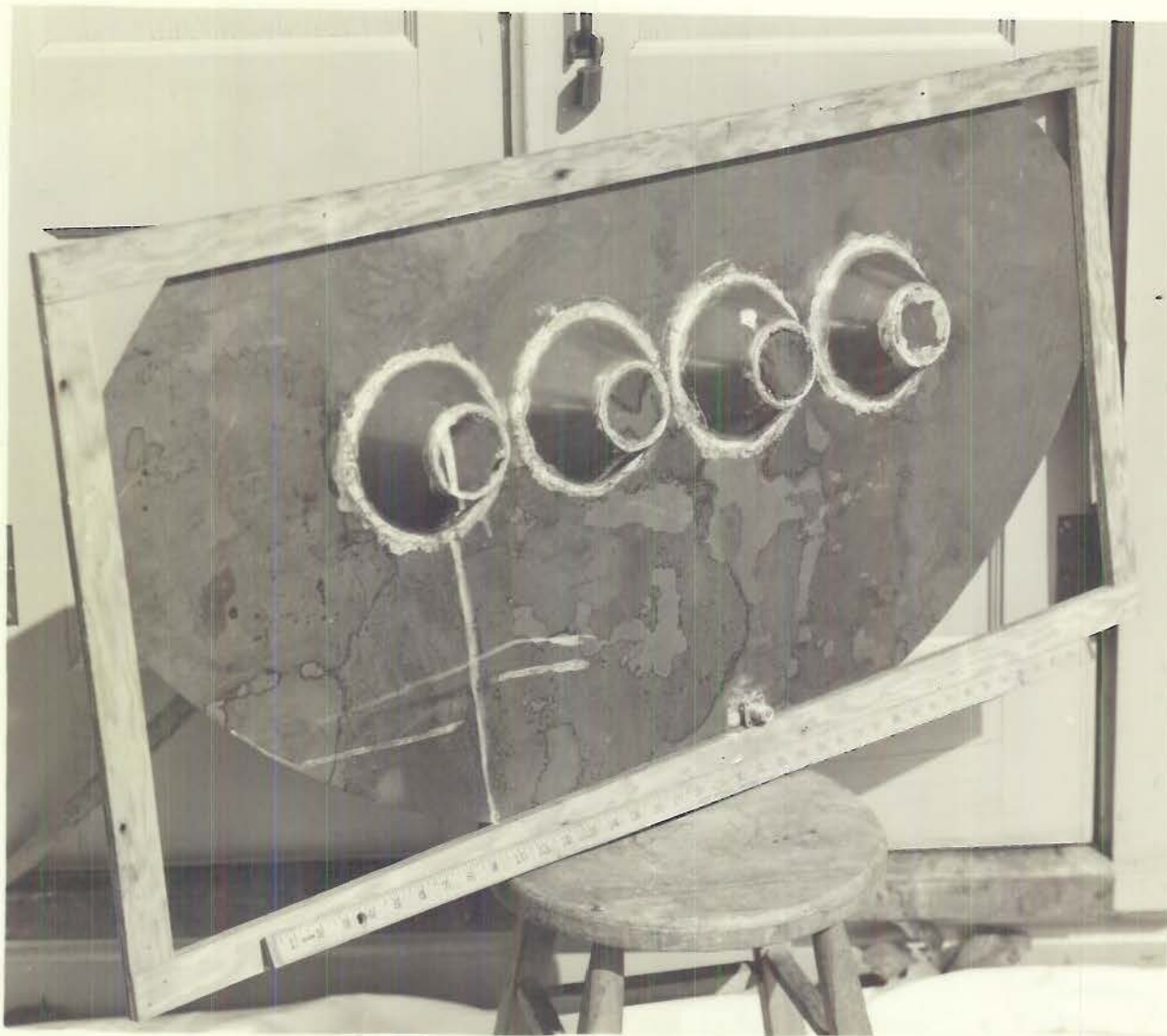


"CUPCAKE" ANTENNA - 3/4 FRONT VIEW

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PLATE II



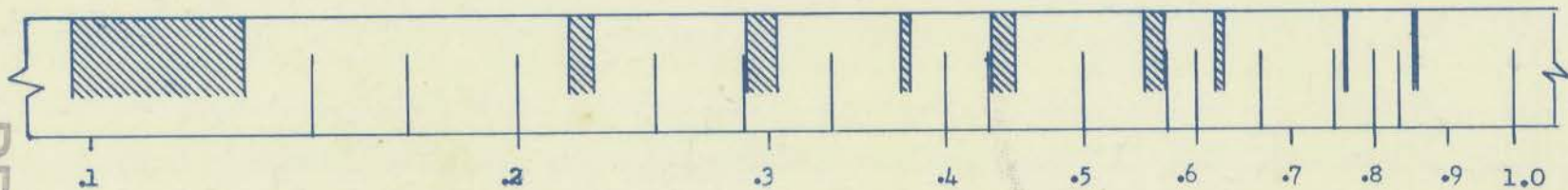
"CUPCAKE" ANTENNA - 3/4 REAR VIEW

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~~CONFIDENTIAL~~

PLATE 12

DIRECTION FINDER-RADAR INTERCEPT LIMITATIONS



Ratio of Direction Finder to Radar Speed

- (a) Upper, shaded areas represent conditions for interception in one minute if  $\theta_D = 45^\circ$ ,  $\theta_R = 10^\circ$  and the direction finder is limited to a maximum speed of 6 r.p.m.
- (b) Lower, single lines represent ratios for which there is no certainty of ever obtaining an interception.

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PLATE 13