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FR-2143

REPORT NO. R-2143

DATE 14 August 1943

SUBJECT

Survey of Techniques for Very High Frequency and Ultra High Frequency Direction Finding

by

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NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

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NAVY DEPARTMENT

Report on

Survey of Techniques for Very High Frequency and Ultra High Frequency Direction Finding

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages: Text - 12 Plates - 1

Authorization: Bureau of Ships conf. ltr. Ser. No. 95 (928-1) of June 26, 1943 to NRL, Bureau of Ships problem D23-C, Priority B.

Date of Investigation: July 26, 1943 to Aug. 10, 1943.

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Distribution

1 copy (original) to Buships

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Survey of Techniques for Very High and Ultra High Frequency Direction Finding

I. Authorization

1.1 This problem was authorized by the Bureau of Ships conf. ltr. Ser. No. 95 (928-1) of June 26, 1943 to NRL and is designated as Bureau of Ships problem D23-C, Priority B.

II. Introduction

2.1 The Laboratory was requested to investigate and report on the general problem of vhf and uhf direction finder techniques with specific comments as to pertinent developments in radar, counter-measure, receiver design and direction finder fields, and possible modification or adaptation of existing equipment in these fields that might be useful in providing vhf and uhf shipboard direction finding facilities. In addition, recommendations were requested as to the type of research and/or development which should be pursued. A final report on the project was requested not later than August 15, 1943.

2.2 While the unusually broad scope of the problem makes it practically impossible to completely crystallize all of its phases at this time, in view of the many factors that must be based on definite requirements of the Vice Chief of Naval Operations and the Bureau of Ships, this report is submitted as an ad interim report to be supplemented by more specific recommendations after advice is received with respect to particular details of the immediate and future desires of the Vice Chief of Naval Operations and Bureau of Ships.

III. Problem-Scope

3.1 The subject problem specifically covers the realm of very high frequency and ultra high frequency direction finding which if literally interpreted would predicate direction finding in the range of 30-3000 megacycles.

3.2 This direction finding program covers a tremendous frequency range, and involves frequencies of such order as to require consideration of two or possibly three different techniques for its solution.

3.3 A complete solution will probably require information as to the different purposes for which direction finding in the subject frequency bands are required. Thus direction finding as

a counter-measure against frequencies employed for communication purposes might differ in its techniques from that which would be employed as a counter-measure against radar transmissions.

IV. Utilization of Counter-measure and Radar Developments

4.1 It is apparent, that, in a broad sense, radar equipment functions as a direction finder with limited frequency range, since it actually locates reflecting sources of radio transmissions. It should be realized, however, that radar equipments operate more satisfactorily (particularly surface search radar), when preferred topside shipboard locations are employed. When attempting to utilize the direction finder capabilities of radar techniques, similar preferred locations may of necessity be required. The fact that such preferred topside locations are becoming increasingly scarce requires no further comments but is worthy of consideration in the light of practicalities.

4.2 Further pursuance of the directive of the subject problem, consideration of the practicalities of utilizing radar, counter-measure and other similar techniques and equipments indicates the following:

(a) Mechanical gear employed in the control of radar antennas, repeat back of azimuth indications, etc., has been and is developed to the point that it would be entirely applicable, with possible minor modifications, for use with the slower type of rotating directional antenna regardless of the specific use to which such antenna might be put.

(b) In the ultra high frequency range, that is, above 300 megacycles, it would appear that the employment of rotating antennas offers the best possibility and the least complications for providing apparatus with directional receiving qualities. In this connection, the Bureau is advised that in general the directional characteristics that can be obtained (with reflector type antenna) approach optical limitations and bear a definite relationship to the frequency involved, regardless of the specific type of antenna employed, i.e., a directional (beam) pattern generally has a beam width in degrees (measured at the 3 db attenuation points) that is approximately equal to 96.6 divided by the antenna width in 1/2 wave lengths. In order to more clearly indicate

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the limitations existing a result of this relationship, enclosure (1) is a plot of the antenna widths that would be necessary to obtain beams of various widths up to 25° for frequency ranges between 100 and 600 megacycles. From these data it will be noted that an antenna with a maximum width of 17 feet would produce a beam width of approximately 14° at 200 megacycles and for higher frequencies either more narrow beams or more compact antennas could be realized.

V. Most promising Methods

5.1 The directive antenna considerations of 4.1(b) indicate that somewhere in the very high frequency spectrum, that is between 30 and 300 megacycles, a change in direction finder techniques would be required, since at the lower very high frequencies antenna sizes would become prohibitive for beam widths having a usable accuracy.

5.2 For the lower very high frequencies it might be possible to employ loop types of antennas with more conventional direction finder techniques although this proposal has certain controllable limitations as indicated in par. 5.3(b).

5.3 At the higher very high frequencies and the lower ultra high frequencies, where the beam widths of any directional antenna of reasonable size might be so excessive as to preclude the obtainment of the required directional accuracy, either lobe switching techniques or the employment of dual receivers and lobe systems (to preclude switching) might be satisfactory from an accuracy standpoint.

5.4 For the higher ultra high frequencies, it would appear entirely practical to obtain satisfactory narrow beam widths for directional beam reception by employing rotating reflector type antennas of reasonable size.

5.5 The communication or radar type of transmissions that might be involved in the direction finding frequency bands in question, is of importance in the following two respects.

(a) Field strengths that would be involved. These influence the "accuracy versus distance" factor of the equipments and the required receiver sensitivity. It would be logical to assume that communication transmissions would be of relatively low power with respect to the peak powers employed in radar transmissions, so that less accuracy or shorter distances would be involved.

(b) The Wave polarization of the transmissions that might be employed. It is reasonable to assume that most communication transmissions would utilize vertical polarizations while, with a few exceptions, practically all radar transmissions would employ horizontal polarizations. While directional beam antennas can be built to receive either horizontally or vertically polarized waves, no standard design has been developed which permits reception of both types of polarization. This should not be interpreted as indicating that such a type of antenna might not be amenable to development, but such action would require an entire new development which would of necessity involve considerable time and experimentation. Accordingly, the problem would be greatly simplified if the specific type of polarization involved were known. This question of polarization becomes of even greater importance at the lower very high frequencies if the employment of simple loop systems are considered, since such devices are heir to excessive malfunctioning depending upon the polarization and elevation angle of the arriving waves. Furthermore, the utilization of direction finding methods other than those employing simple loops, would not be a complete solution of this problem, since the techniques that might be employed for completely horizontally polarized waves would differ markedly from those that might be employed for vertically polarized waves or waves with a horizontal component.

5.6 The employment of beam types of antennas for direction finder purposes focuses attention upon obtainable frequency band widths over which such antennas could be made usable. Obviously, if spot frequency reception could be employed, the solution of the subject problem is relatively simple, since direct employment could be made of standard radar receiving techniques with antennas and receivers built for and adjusted to the desired frequencies. Radar antennas in current general use can be employed over a range of approximately ±5% of the frequency for which they are built and adjusted. However, this figure may be approximately doubled when such antennas are used for receiving purposes only, since corona and power loss of transmitted power impose the ±5% transmission limitation; also, it is the consensus that the beam width of the antenna (when receiving) is not appreciably affected by operation within a band width of ±10% or possibly even wider limits. However, both of these factors should be experimentally checked.

5.7 Personnel developing radar systems are extremely interested in obtaining wider frequency coverage for these equipments, particularly for their directional antennas; this work is being prosecuted by the Laboratory under Bureau of Ships problem X421S. Hope is expressed of eventually developing directional antennas that will be capable of operating with a 2/1 frequency ratio (based on transmitting limitations). If this is successfully realized, it is likely that the directional antennas when used for reception

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only, may be capable of operating over an even wider frequency range. It should be pointed out, however, that consummation is not as yet within sight, despite the great importance and pressure placed upon this work.

5.8 The two 140-600 Mc shipboard direction finder equipments now undergoing separate development by Federal Telephone and Radio and Radio Corporation of America offer promise of usable systems.

(a) The Federal Telephone and Radio development comprises a 5 monopole and ground plane (automatic) bearing indicating system - using conventional cathode followers, and a motor rotated goniometer. It is understood that the necessary receiver cathode followers and goniometer are in the early stages of development.

(b) The Radio Corporation of America development comprises a Balanced H antenna system with lobe switching, accomplished by controlling the action of an adjacent H antenna reflecting arrangement. Both H's are mounted and manually rotated on the same beam. It is understood that the development has proceeded to the point where the measured antenna patterns show considerable promise for this frequency range.

(c) Since both the Federal Telephone and Radio and the Radio Corporation of America collector systems are being specially developed for vertically polarized transmissions, it is to be expected that even upon successful completion of the systems for the vertically polarized transmissions, the collector system will not function satisfactorily for horizontally polarized transmissions.

5.9 The above discussion is predicated on the assumption that relatively good accuracies of indication are desired for any shipboard direction finder equipments that might be considered usable. Should it appear desirable for certain specific countermeasure purposes to install in vessels "so called" direction finder equipments capable of indicating more or less general directions with a relatively low order of accuracy, the following stop-gap ideas might be considered:

(a) A simple low accuracy direction finder may be obtained as a shipboard adaptation of the Model ARD equipments now installed in certain aircraft. While this equipment is designed fundamentally for the identification of the existance of radar transmissions over a 80-3000 Mc frequency range, as installed in aircraft, its location is such that the body of the plane produces a shadow (minimum) in one

specific direction, so that directional indications may be obtained by orientation of the plane. It is possible that these equipments might be provided with some form of absorption or reflection devices that would permit their shipboard use to indicate general directions of transmissions within their frequency range.

(b) Certain work done by the Laboratory also indicates the possibility of designing antennas with a possible 10/1 frequency coverage, and possessing broad directional characteristics, usable for indicating directions with an accuracy of say, 40°.

VI. Receivers Available

6.1 Receiving equipment developments that might be useful in connection with directional antennas to produce complete direction finding equipments within the uhf and vhf frequency band, are discussed below.

6.2 Standard Shipboard Receivers

The following equipments are rapidly nearing completion as development models of Navy Standard shipboard receiving equipments:

(1) Model CXED	20-100 Mc.
(2) Model CXEE	100-200 Mc.
(3) Model RCN	200-400 Mc.

These equipments, when completed, will complement the RBA, RBB and RBC equipments to give a complete line of standard receiving equipments covering a continuous frequency band from 15 kc. to 400 mc.

6.3 Countermeasure shipboard receivers

The following are simple shipboard type convertor units, possessing only a mixer and oscillator section to generate a suitable intermediate frequency that can be accepted as the input to standard navy shipboard receivers:

(1) Model CUO 46-205)	
(2) Model CUO 46-206)	45-600 Mc.
(3) Model CUO 46-207)	

6.4 Pertinent Aircraft Receivers

(1) 350-1900 Mc. Strictly an experimental development. An early model constructed employs cavity tuning, possesses 2 stages of preselection and requires only single tuning control (for steps greater than 200 Mc, taps need changing). Exhibits

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sliding contact noises (a possibility exists for insulating the plungers to minimize or eliminate these contact noises).

(2) ARC 70-3000 Mc, Intercept Receiver. Has 3 plug in units, condenser (Butterfly System) tuning, employs an intermediate frequency of 30 mcs.

70-300 Mc	(Band I)
300-1000 Mc	(Band II)
1000-3000 Mc	(Band III)

(3) ARD 80-3000 mc. Intercept receiver. Has no preselection - Antenna is adjustable in length for tuning and frequency determination.

It is to be noted that the CUO convertors and the ARC and ARD receivers are of consumated design; they are essentially simple frequency convertors (no preselection) and were designed rather hurriedly for immediate countermeasure use.

6.5 Narrow Band Receivers

Two other standard lines of equipments are, or will be, shortly available, both covering a very restricted frequency range. These are the Army Type BC-639A covering 100-160 megacycles, the Navy RCK, covering 115-156 megacycles, and the Hallicrafter SX27N covering a 2/1 frequency range up to about 220 mc.

VII. Receiver Limitations

7.1 Paragraph VI indicates that receivers of Navy Standard quality and with the required preselection could be obtained for frequencies up to 400 megacycles.

7.2 Design considerations would indicate some possibility of fitting the Model RCN design of receiver with a new preselector portion to cover the range of 400-600 megacycles provided that sufficient manpower and sufficiently high priorities were available. However, it should be pointed out that this would require extensive and new development work (including the probable substitution of new tube types) as well as a careful review of the priority and work load if such a development problem were assigned to the Laboratory.

7.3 The upper frequency limit for standard navy receivers employing one or more stages of preselection and uni-control in operation, is approaching 400 megacycles, the top frequency at which ordinary vacuum tubes and lumped circuits can be used; a possible

extension to 600 megacycles may be viewed as the extreme top. Beyond this, special circuits such as cavities, butterflies, etc., with special tubes must be employed. While a few such receivers covering frequencies in excess of 600 megacycles have been developed for specific Laboratory applications, they are, in general, strictly Laboratory equipments, being noisy in operation when tuning, or having multiple tuning controls or possessing no preselection to preclude manifold spurious responses, cross modulation, etc.

7.4 The above receiver limitations indicate the desirability of restricting the frequency coverage of vhf or uhf direction finder developments to such frequency bands as are of immediate interest or at least adjudicate the coverage in progressive orders of importance, to permit developments in the art to keep pace with operational requirements. It is believed that at present a top frequency of 600 megacycles might be sufficient to cope with all known enemy transmissions.

VIII. Site Factors

8.1 The ultimate performance of direction finding equipment, particularly at the frequencies involved in the subject problem, depend largely on the installation problems and the deleterious effects of the surroundings immediately adjacent to the direction finder collector.

(a) An equipment capable of furnishing accurate directional indications under local conditions cannot be considered as a shipborne direction finder inasmuch as the practicalities of installation are such as to preclude even an approach at idealized conditions. For this reason it is important to bring to the Bureau's attention the fact that it is expected that very and ultra high frequency direction finders when installed in naval vessels will be heir to the same type of disturbing influences as are encountered in the installation of medium and more particularly, high frequency direction finding. Radar experience is indicating that all parts of a vessel's superstructure introduce deleterious influences, since such parts, because of their geometry, are capable of reradiating in various modes at many different frequencies throughout the spectrum involved.

(b) It is expected that antennas for very or ultra high frequency direction finders will, of necessity, have to be mounted in a location clear of all other objects. In view of the extreme restrictions on such locations, this introduces a requirement for a series of compromises. Indications are that it will probably not be possible to obtain suitable locations for more than a relatively few direction finder antennas. This in turn predicates the necessity of employing such few antennas as may be efficiently carried for operation in the most important frequency bands. At the same time it is desirable to restrict the frequency coverage of any one

equipment (including its antenna) as much as possible. In fact, it appears from the present state of the art, that such restrictions are mandatory.

(c) Accordingly it would appear evident that the inauguration of a comprehensive program for the development of direction finding equipments covering the band 30-3000 megacycles in its entirety would not in itself be advantageous in the furtherance of the war effort in view of the limitation on the number of antennas (and consequently equipments) that could be carried in naval vessels would restrict the frequency band coverage to a small portion of the total spectrum connoted by the term "very and ultra high frequency." Therefore a more conservative approach to the entire problem would appear desirable.

IX. Indicating Systems

9.1 No mention has been made in the foregoing of any indicator systems. These are believed to represent no particular engineering difficulty, since the variety of cathode ray indicator developments as well as general knowledge of this particular art are such as to permit the rapid design and production of any particular type of indicator that might be necessary for the specific equipment involved.

X. Conclusions

10.1 Special equipments amenable to rapid development
The following constitutes a summation of present developments in the radar, countermeasure, antenna and receiver field with respect to their usefulness in the rapid development of very and ultra high frequency direction finder equipment.

(a) For frequencies between 20-80 megacycles and vertically polarized transmissions direction finders employing either cross loops and goniometers, or remotely controlled rotating loops, appear to offer the best solution. Such equipment with continuous frequency coverage has not been developed but would appear to lend itself most advantageously to rapid development.

(b) For spot frequencies in the band between 80 and 200 megacycles the employment of rotating directive antennas using radar developed pedestals, rotating gear, repeat backs, etc. and lobe switching or double lobe reception (with differential indicators) would appear to offer the best and most rapid solution. Such devices are not "on the shelf" but could, it is believed, be developed rapidly by utilizing known techniques and equipments.

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(c) For narrow band operation between 200-600 megacycles at definite predetermined frequencies (±5%) standard radar equipment and techniques with relatively simple changes in antenna fabrication and receiver "front ends" to cover the specific frequencies involved, would appear to offer the best and most rapid solution for direction finding.

(d) For operation at frequencies above 600 megacycles, there exists a fundamental bottleneck, in the development of suitable receivers, unless spot frequency or narrow band operation is acceptable.

(e) For wide frequency coverage above about 100 mc. and direction finding accuracies of t e order of 5°, no immediate solution appears feasible although there might be hope of an immediate solution if equipments covering a band width of ±10% are acceptable. The Federal Telephone and Radio Company and RCA work in this frequency band is not considered sufficiently developed at this time to be viewed as immediately applicable.

(f) For very wide frequency coverage and very broad indications of general direction, such as quadrant indications, a rapid solution might be obtained by the adaptation of such equipment as the Model ARD or by employment of semi-directional antennas covering a wide frequency band, provided preselection is not considered essential.

10.2 Specified Performance vs. Development Time

Since the ultimate service operation of vhf and uhf direction finding equipment is essentially a compromise of specified performance versus development time, it is necessary to carefully weigh the following factors, in their order of importance, when establishing an optimum program:

(a) The general purpose for which direction finding is desired, i.e., whether for operation on communication transmissions, radar or other special transmissions.

(b) The exact frequency bands it is desired to cover, with annotations as to their order of importance. While it is realized that complete frequency coverage would be extremely desirable, practicalities indicate that a 30 to 3000 megacycle coverage for shipboard direction finding equipment would not only require developmental and production time that would appear excessive, but would require such a number of separate equipments as to make the obtainment of suitable locations for the antennas difficult if not impossible.

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(c) The order of accuracy that might be acceptable. This is of considerable importance with respect to the speed with which equipment could be developed and put in service and has a definite bearing on the feasibility of certain methods or techniques that might be recommended. Obviously a reduced accuracy increases the possibility of a simpler solution, and its earlier use by the operating forces afloat.

(d) The usefulness of spot frequencies or narrow band operation (e.g. ±10% or ±20% band widths) for specific applications.

(e) The type of interception system that might be employed, e.g. whether the direction finder equipment and operators will be expected to search the frequency band for enemy transmissions in addition to obtaining their bearing, or whether they will be required to guard certain frequencies and/or obtain bearings by directive. It is apparent that if search operations are to be included, consideration will have to be given to methods incorporating some form of panoramic search.

(f) The (minimum) acceptable transmission time of the signal in each portion of the frequency spectrum, since this vital factor governs the final method to be employed, the complexity of its development and the time required for putting it into service.

(g) The types of polarization that might be expected and whether the transmissions will eminate from land-borne, ship-borne, or air-craft-borne (possibly all three) transmitting sources. This information will essentially govern the type of collector system that will be necessary. For example, the type of collector system required for ground wave transmissions will be considerably simpler from those required for aircraft transmissions.

XI. Recommendations

11.1 In view of the tremendous scope covered by the assigned vhf and uhf direction finding problem, and the factual data submitted herein, it is recommended that:

(a) The Bureau's operational requirements and desires be carefully weighed with respect to the time required for consummating the necessary new developments and putting such equipment in service.

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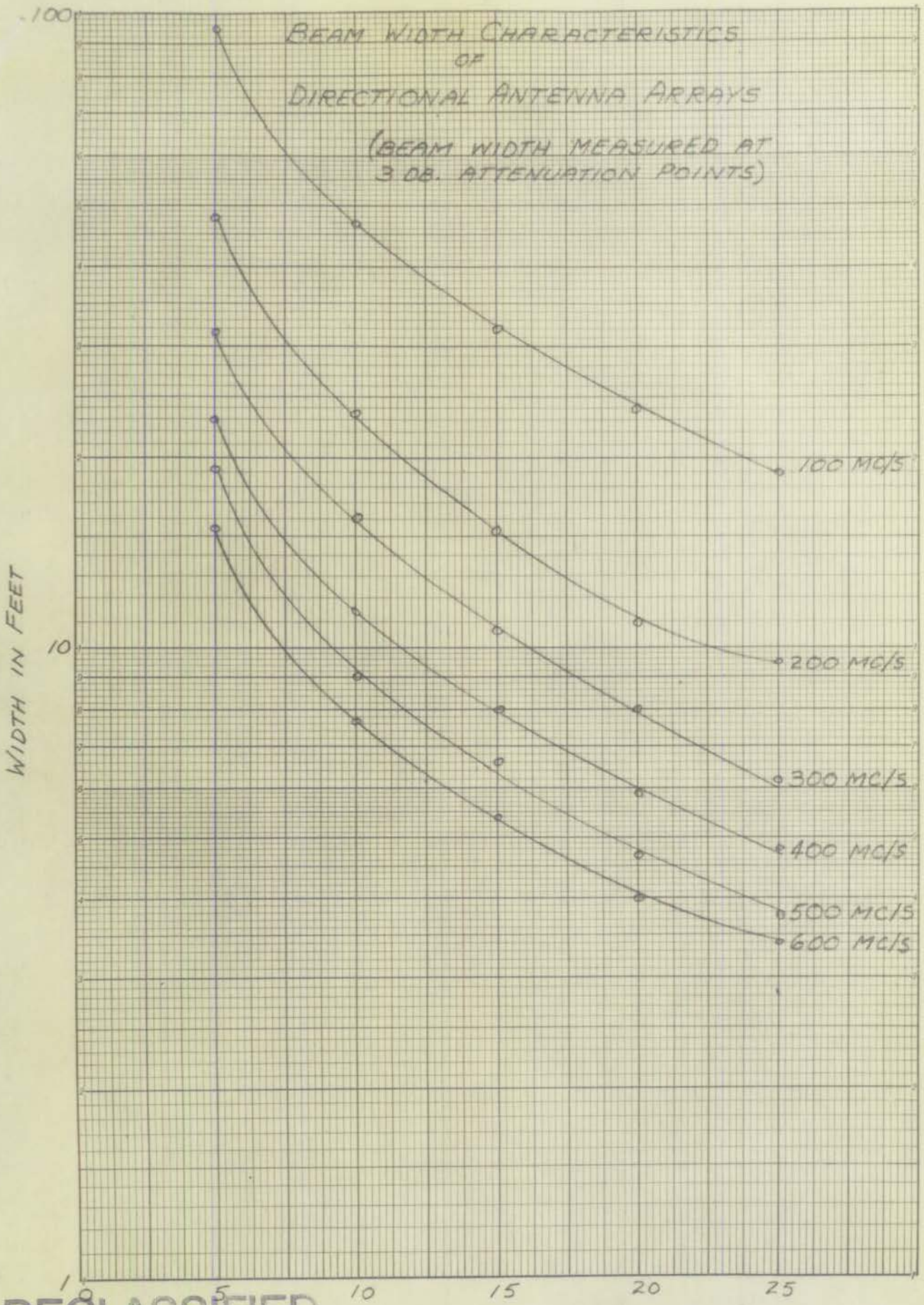
(b) Specific interpretations be made of the more pertinent phases of the problem with due evaluation to the factors listed in paragraph 10.2

(c) Consideration be given to the immediate usefulness of the special equipments listed in paragraph 10.1, in view of their feasibility of rapid development.

(d) Emphasis be placed on the immediate initiation of those direction finder development projects found pertinent in paragraphs 11.1 (b) and (c).

(e) Some consideration be given to the greater fruitfulness generally associated with development programs dealing with frequency bands that are extensions of those bands in which successful designs have been consummated.



ENCLOSURE 1