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11 April 1946

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REQUIREMENTS OF DIRECTION FINDER INDICATOR AND DETERMINATION OF CORRECT SCANNING RATES FOR DF COLLECTOR SYSTEMS IN THE VHF, UHF AND SHF BANDS

BY
J.R. Gruber and E.H. Flath

- Report R-2648 -

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ABSTRACT

This report contains an analysis of the operation of four (4) basic direction finding systems against signals in the VHF, UHF, and SHF bands. In particular, the parameters which determine the correct d-f scanning rate are discussed for the case where the signal is pulsed and emanates from a rotating, directional antenna. The mathematical probability of obtaining a bearing against radar signals with different d-f systems is presented and examples of such calculations are given. It is shown that the probability of obtaining a bearing during one (1) sweep of a scanning radar transmitter increases as the d-f scanning rate is increased. It is also shown that the maximum usable d-f scanning rate is determined by the pulse repetition frequency of the received signal. The requirements and limitations of d-f indicators for use with the above systems against pulsed signals are discussed. It is found that proper design of the indicator circuits will minimize deficiencies and possible bearing errors.

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INTRODUCTION

1. Since the advent of radar and other pulse transmissions in the VHF, UHF, and SHF bands, it has been found that the types of direction finder systems ordinarily employed at lower frequencies against communication signals are often ineffective against pulse transmissions. In most cases the reason for the ineffectiveness of these well known d-f systems is that they were not designed for operation against scanning, pulsed signals whose characteristics vary through such a wide range. In order to provide more effective direction finding against pulse transmissions several new types of d-f systems have been developed, the most important being the rotating reflector and antenna combination (e.g., the DBM).

2. With some conventional systems, and even with the DBM, conditions of unsatisfactory operation may be encountered. These conditions are a result of rotation at a synchronous or near synchronous rate, or at multiples or sub-multiples of this rate, or reception of too few pulses to obtain a bearing promptly. In order to more fully appreciate these problems of direction finding against pulse transmissions an analysis is made, in this report, of the requirements of d-f scanning rate as determined by the repetition rate, beam width, and scanning rate of the signal under consideration. The term "d-f scanning rate", is used to mean either antenna rotational speed, goniometer rotational speed, or antenna switching rate, depending upon which type of d-f system is being analyzed. In addition to the above mentioned considerations, an analysis is made of the requirements of d-f indicators for use with d-f systems in the VHF, UHF, and SHF bands. This analysis is intended to reveal inherent limitations and inaccuracies in certain types of visual indicators and to show what measures can be taken to minimize any undesired characteristics.

FACTORS AFFECTING D-F BEARING AT VHF, UHF, AND SHF

3. A comprehensive list of the factors which affect d-f bearings can be divided into two (2) general groups:

(a) The characteristics of the transmitter over which there is no control.

(b) The characteristics of the d-f system over which there is control, at least to a certain extent.

4. Under group (a) the important factors are the scanning rate of the transmitting antenna, the type of transmitter modulation, and the antenna radiation pattern of the transmitter. Under group (b) the important factors are the scanning rate, the antenna system, and the indication system of the direction finder. It must be realized that the type of signal most ideally suited for direction finding is a cw or mcw signal emanating from a fixed antenna. The problem of direction finding on a pulse modulated signal emanating from a scanning antenna is much more complicated because of the additional factors which enter into the direction finding "picture". A list of the factors which affect d-f bearings in the VHF, UHF, and SHF bands is given in Table 1. This list serves to illustrate the large

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number of factors which influence direction finding in the higher frequency bands.

5. In order to simplify the analysis, certain logical assumptions will be made at the start. It will be assumed:

(a) That the tuning of the d-f receiver is coincident with the frequency of the signal under consideration. Frequency scanning will not be included in this discussion.

(b) That the polarization of the d-f antenna system is the same as that of the received signal. Most d-f systems which operate above 300 Mc are capable of receiving either vertically or horizontally polarized waves.

6. These two (2) assumptions are made since it is not intended, in this report, to consider the problem of intercepting a signal the frequency and polarization of which are unknown. This intercept problem has been investigated by the British, References (1) and (2), and is treated in a previous report of this Laboratory, Reference (3).

DESCRIPTION OF VARIOUS TYPES OF TRANSMISSIONS LIKELY TO BE ENCOUNTERED

7. This report will be concerned primarily with pulsed radar signals since such signals predominate in the UHF and SHF frequency bands. While non-pulsed signals are used extensively in the VHF band, principally for aircraft communication, direction finding against such signals presents less difficulty than encountered with pulsed signals, and, therefore, need not be considered.

8. A careful survey of the characteristics of known enemy radar systems confirms the opinion that radar development has not advanced as far in Germany and Japan as in this country. In particular, much less use has been made of PPI operation, with attendant intercept difficulties. Also, pulse widths and repetition rates generally have been higher than encountered with U.S. Naval radars. Therefore, Table 2 presents the average characteristics of U.S. Naval radar systems which represent more advanced design practices and which offer considerable difficulty in obtaining direction finding bearings. It is considered that these radars offer the best available yardstick for predicting the performance of direction finding systems against radars which may be used by a future enemy.

TYPES OF D-F SYSTEMS TO BE CONSIDERED

9. Discussion will be restricted to three (3) types of "automatic" direction finders and one (1) "semi-automatic type". The term "automatic" is used here in its broader sense to denote any direction finder which provides a bearing visually, nearly instantaneously, and without requiring manual adjustment. Thus, it is not restricted to systems employing propeller-shaped patterns on cathode-ray indicators; such indicators being termed "automatic bearing indicators" (ABI). The

term "semi-automatic" is used here to denote systems which provide an approximate bearing visually, but which require manual manipulation to obtain an accurate bearing. The semi-automatic type to be considered is that employing antenna switching with visual amplitude matching indicator, as exemplified by the CXFF equipment. The three (3) automatic systems considered are:

(a) The rotating beam antenna type with visual indicator.

(b) The goniometer or spinning loop types with automatic bearing indicator.

(c) The instantaneous cathode-ray tube direction finder.

10. The following generalizations concerning these basic types should clarify subsequent detailed consideration of their probability of obtaining bearings against scanning pulsed signals:

(a) Rotating beam antenna types are exemplified by the CXGA and DBM equipments, but may include systems employing differential dipole antennas. Basically, they incorporate considerable antenna directivity and, at any instant, are only responsive to signals within a limited angle. Unidirectional bearings are obtained from (1) the position of the major lobe in the case of DBM type equipment, (2) the position of the null in the case of differential dipole systems.

(b) Rotating goniometer or loop systems, such as the DAQ, provide bilateral bearings with a propeller-shaped indicator pattern, generally with provision for sense determination by a separate operation with the aid of an auxiliary antenna. Basically, it makes no difference in coverage or probability whether a spinning loop or spinning goniometer is used. At any instant, the antenna pattern is a figure "8" (or a cardioid when using the sense antenna) so signals may be received from any direction except those of the nulls. Obviously, this greater coverage provides better probability of <u>intercepting</u> an intermittent signal, but not necessarily of obtaining a bearing on it.

(c) The instantaneous cathode-ray direction finder, as exemplified by the British FH4 equipment, employs crossed figure "8" collectors feeding the horizontal and vertical plates of a cathode-ray indicator through separate receiving channels, to provide a line or ellipse indication. Separate receivers, or means of "tagging" the separate signals in a single receiver, may be used. Such systems are omni-directional and can be truly instantaneous within bandwidth limitations, but their practical application has been limited by the difficulty of maintaining channel alignment. From the standpoint of this report, the dual receiver instantaneous system provides certainty of obtaining a bearing on even a single pulse, so major emphasis will be placed on analyzing the first two (2) systems.

11. The semi-automatic type, with antenna switching and visual amplitude matching indicator, is of less interest because it provides only an approximate bearing without manual manipulation. The CXFF equipment, for example, displays in succession the outputs from four (4) antennas, each covering a quadrant. One can obtain a rough idea of the direction of a signal within a quadrant from the relative amplitudes of their display pips but these pips must be balanced in amplitude by manual adjustment of a calibrated potentiometer in order to obtain an accurate bearing. Obviously, there is no time for this latter process when dealing with a brief nonrecurrent signal.

GENERALIZATIONS CONCERNING NON-SCANNING SIGNALS

12. No special difficulty is encountered when using any of the above d-f systems against non-scanning transmitters. When the transmitted signal is cw or mcw, the probability of obtaining a bearing in a short interval of time is unity, it being a certainty. When the transmitter is pulse modulated, the probability of obtaining a bearing is still unity provided that a sufficient number of pulses is received by the direction finder in any specified interval of time so that the indicator pattern is reasonably well defined. Each individual pulse produces a complete indicator pattern with the true instantaneous system (c) but a group of pulses must be displayed simultaneously with the other two (2) automatic systems in order to build up the indicator pattern. Since the pulses arrive successively, rather than simultaneously, a number of pulses sufficient to outline the pattern must be received within some prescribed time interval. The question of obvious interest is, "how long an interval can be allowed for adequate delineation of the pattern?" Answering this requires consideration of the persistence characteristics of the indicating system.

LIMITATIONS OF PERSISTENCE

13. If using a short persistence cathode-ray tube, the indicator pattern should be built up within a time comparable to the persistence of vision, say 1/15 second. This would allow not more than five (5) successive pulses from a 60 cycle repetition rate radar. To obtain this number of pulses the DF scanning rate would need to be such that it scanned through the essential portion of its antenna beam width once in this period of time, or its scanning rate would need to be nearly synchronized with the pulse repetition rate so that the pattern could be built up in an equivalent manner without wasting pulses within this period on useless portions of

the indicator pattern. For example, assuming that it is desired to define 20 degrees around the tip of the pattern lobe or around a null within this 1/15 second, the 60 cycle pulses would be spaced every 5 degrees, and a rotational rate of .833 RPS or 50 RPM would be required. A similar result could be obtained by scanning nearly in synchronism with the repetition rate, that is at 60 + .833 RPS, if this were possible. Obviously, this would require highly critical speed control. If the scanning rate were at some intermediate value, say 15 RPS, most of the pulses within any 1/15 second interval would be useless for defining the tip of the pattern lobe on the indicator. If the scanning rate could be increased to complete a scan within the time of a single pulse, each pulse could be made to define the indicator pattern, but the technical requirements of such a system are beyond the present state of the art. Neglecting these two (2) present impracticalities, it is evident that even for continuous pulsed signals there is an optimum scanning rate, fixed, in addition to mechanical considerations, by the repetition rate of the intercepted signal, by the effective persistence of the indicating system, and possibly by the character of the indicator pattern. These considerations apply to both (a) and (b) types of automatic systems.

14. This optimum scanning rate is not too critical but experience shows that lower rates may be used more easily than higher ones, at least as long as only steady signals are considered. Operators can train their eyes to follow a slowly moving trace and select the tip of an indicator lobe with reasonable accuracy, by observation and memory rather than by persistence of vision or of the indicator screen. However, it is far more difficult to coordinate, mentally, information from successive scans of an indicator, especially when scanning at less than 15 revolutions per second.

15. An obvious improvement would appear to lie in the use of long persistence indicators to allow the integration of received information over a longer time interval. This is a definite possibility, but it is not as attractive as it might first seem. P-7 phosphors are characterized by intense initial illumination followed by rapid initial decay to low intensity illumination which fades out very gradually. The operator's eye tends to follow the intense initial spot, or at least to be distracted by it, so that he is unable to derive the maximum information from the long afterglow. This is particularly true with high speed pulse indicators of the DBM-1 type, which consequently employ indicators with medium persistence (P-2) phosphors. This condition may be ameliorated by the use of low-pass optical filters (amber or red) with a corresponding loss in the intensity of illumination. Another possibility, not known to have been tried experimentally, is to blank out the beam after a sufficient number of scans, thus allowing the operator to view only the afterglow. Certainly, against steady signals, long persistence techniques offer an attractive means of dealing with low repetition rates and may make it feasible to use the higher scanning rates which are preferable against other radar signals,

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PERFORMANCE OF ROTATING BEAM SYSTEMS AGAINST SCANNING SIGNALS

Single Beam Antenna Systems

16. The next complication is introduced by attempting to obtain bearings on intermittent signals such as from a rotating transmitting beam as in a PPl radar system. Additional limitations imposed by a pulsed signal will be neglected temporarily. That is, we will assume a cw signal, or pulsed signal of very high repetition rate. For further simplification, assume the antenna beams to be segments, of full amplitude within their beam width and negligible amplitude elsewhere. Actually, practical beams are more nearly of a cosine squared shape, possible with annoying minor lobes. Beam widths customarily are measured at the half power (70.7% of maximum amplitude) points but retain appreciable amplitude at greater widths (see Plate 1). Analysis based on segment beams therefore yields a conservative probability figure. The case where certainty of interception is required within a specified period of time is not considered here but an analysis of this subject will be found in Reference 8, shortly to be issued.

17. First consider the combination of a d-f beam of negligible width rotating with a period of t_d seconds, and a transmitting beam of θ_r degrees width rotating with a period of t_r seconds. The time during which the d-f site will be illuminated from each sweep of the transmitter will be:

$$T = \frac{\theta_r \; t_r}{360^\circ} \qquad (1)$$

From here on, the fact that the signal comes from a rotating transmitting beam will be incidental and results obtained on this basis will be equally applicable to any intermittent transmission, even though keyed on for this time T. During this time the d-f antenna beam will sweep through an angle

$$\phi_d = \frac{T}{t_d} \times 360^\circ = \frac{\theta_r \; t_r}{t_d} \text{ degrees} \qquad (2)$$

It is assumed that the phase of the d-f antenna rotation relative to that of the transmitting antenna is purely arbitrary; that at the beginning of the period of illumination the d-f antenna is just as likely to be at any one position within its 360 degrees of rotation as at any other. However, a bearing will be obtained during the period of illumination only if the d-f beam is within a certain portion of this 360 degrees at the start of illumination. At one extreme it may be pointing at the transmitter at the start of illumination, while at the other extreme it may lag as much as ϕ_d degrees and still point at the transmitter by the end of the period of illumination. Therefore, the probability of obtaining an interception, or if one or more is obtained, an additional interception during a single period of illumination is the ratio of this permissible phase angle, ϕ_d, to the entire possible 360 degrees, minus the largest integer N that can be contained in this ratio, i.e.

$$P = \frac{\phi_d}{360^\circ} - N = \frac{\theta_r \, t_r}{360^\circ \, t_d} - N \qquad (3)$$

where N constitutes the number of interceptions certain to occur. The quantity $\frac{\theta_r \, t_r}{360^\circ \, t_d}$ may become greater than unity since the direction finder beam may rotate more than once during the period of illumination of the radar. In this manner a number N, of interceptions does occur, in addition to which the probability of getting still another interception is given by P.

18. Next, let the d-f antenna have a finite segment shaped beam width of θ_d degrees, so that at least an approximate bearing will be obtained if the d-f beam even comes within θ_d degrees of the transmitter direction during the period of illumination. In this case the probability obviously is improved as there is greater freedom permissible in the phase of the d-f antenna rotation. At one extreme the trailing edge of the d-f beam may point at the transmitter at the start of the period of illumination, while at the other extreme the leading edge of the d-f beam may not point at the transmitter until the very end of the period of illumination. This is illustrated in Plate 2. Thus, the permissible phase angle has been increased by the width of the d-f antenna beam, so the probability of obtaining a bearing during a single period of illumination is:

$$P = \frac{\phi_d + \theta_d}{360^\circ} - N = \frac{\theta_r t_r + \theta_d t_d}{360^\circ \, t_d} - N \qquad (4)$$

19. This relation is valid regardless of the relative periods of the two (2) antennas. However, in the event that the d-f antenna has a much slower rotational rate than the transmitting antenna it may be more useful to find the probability of obtaining a bearing during a single sweep of the d-f antenna, than of the transmitting antenna. This requires only an interchange of subscripts in the above equation.

20. In the above case uncertainty concerning the true bearing may be as great as θ_d degrees, when only the leading or trailing edge of the segment beam is illuminated, and it is necessary for the entire segment to receive illumination in order to obtain a true bearing by splitting the segment. The situation is somewhat more favorable with the rounded beam shapes encountered with practical antennas as not all of the beam width need receive illumination in order to define the tip of the beam. If it is necessary only to define a fraction y of the beam width to obtain an accurate bearing, there still is left (1-y) θ_d degrees freedom in the phase of the d-f rotation so the probability is only reduced to

$$P = \frac{\theta_r \, t_r + (1-y) \, \theta_d \, t_d}{360^\circ \, t_d} - N \qquad (5)$$

21. There is some room for disagreement concerning what fraction of the beam width must be defined for an accurate bearing but $y = .5$ seems a reasonable and convenient figure, making the probability

$$P = \frac{\theta_r t_r + .5 \theta_d t_d}{360^\circ t_d} - N \qquad (6)$$

22. One other restriction must be placed on this result. It must be assumed that the total radar illumination time, $\theta_r t_r/360^\circ$, is larger than the time required to illuminate $(y \times \theta_d)$ degrees of the d-f antenna pattern, i.e.

$$\frac{\theta_r}{360^\circ} \times t_r > \frac{y \theta_d}{360^\circ} \times t_d$$

Otherwise, the probability relation stated above does not hold. Equation (4) shows that the probability increases with both the beam-width and rotational speed of the d-f antenna. It is not advantageous, however, to increase the antenna beam width since the broader beam makes bearing determination less accurate. It is certainly advantageous to use high d-f antenna rotational speeds provided the following two (2) conditions are satisfied:

(a) That the pulse repetition frequency of the transmitter is high enough so that sufficient pulses are received per revolution of the radar antenna to ensure that the directional pattern of the d-f antenna is adequately outlined on the indicator.

(b) That the d-f antenna can be rotated faster than the transmitting antenna.

23. Condition (a) is important because the precision with which the bearing can be read from the indicator is greatly reduced if the number of pulses appearing on the indicator is insufficient to reproduce the antenna pattern. For instance, if the pulse repetition frequency of the radar transmitter is 60 pulses per second the rotational speed of the d-f antenna should not be much greater than 80 to 100 rpm in order that the resultant indicator pattern may be clearly outlined. This limitation of scanning rate has been determined experimentally and applies to those systems wherein the persistence of the cathode-ray trace is less than the period of one (1) scan, as previously discussed. Two (2) examples of the indicator patterns which might be observed if the d-f antenna were rotated at 90 rpm while receiving a non-scanning radar signal pulsed 60 times per second are given in Plate 3. Condition (b) is ordinarily easy to satisfy. The only exceptions occur when the transmitting antenna employs one (1) of several types of high-speed scanning methods such as spiral scanning, conical scanning, or lobe switching. Under such circumstances the d-f antenna cannot be physically rotated at a rate comparable to the scanning rate of the transmitting antenna. When such rapidly

scanning signals are being received it is difficult to recommend an optimum d-f scanning rate because it depends not only upon the scanning rate and pulse repetition frequency of the transmitter but also upon the position of the direction finder with respect to the field being scanned by the radar transmitter. Therefore, in such a case only general recommendations can be made, such as:

(a) Employ a sufficiently low d-f scanning rate so that the pulse groups appearing on the indicator are spaced closely enough for reasonable bearing accuracy.
(b) Avoid synchronization.

Plate 4 illustrates the type of indicator patterns which might be obtained from a simple lobe switching radar transmitter.

Differential Dipole Antenna System

24. Plate 5 shows a theoretical response pattern of a differentially connected pair of dipoles placed before a flat reflector. Figures (1) and (2) of Plate 22 show typical indicator patterns obtained from a direction finder employing a mechanically rotated antenna system of this type. This differential dipole system is used in direction finders where the antenna rotation is controlled either manually or mechanically, but principally in the former type (e.g., the DBB and DBC). The aural null type direction finder with manual control of the differential dipole antenna rotation is a simple device, but there is often the possibility that an incorrect bearing might be obtained aurally. The reason for this is that the actual antenna pattern is not as ideal as that shown in Plate 4 and might, in some cases, be as poor as that shown in Plate 5 with back radiation and non-symmetrical lobes. It is quite evident that in this case an aural null might be obtained at 0, 100, or 183 degrees. Using a mechanically rotated antenna system with a cathode-ray tube indicator this possibility is ordinarily removed since the true null is quite apparent in most cases (when adequately illuminated). Refer again to Plate 22 which gives typical indicator patterns obtained with a rotating differential dipole antenna and reflector.

25. The limitations of the rotating, differentially connected dipole antenna system for use against scanning radar transmitters are best analyzed from an approach similar to that used for the rotating single dipole antenna. It is evident, upon examination of the response pattern of a differential dipole antenna system (Plate 5), that an accurate utilization of this response pattern requires adequate illumination of the null. In other words, an accurate bearing can not be determined from the null type response pattern unless the pattern is illuminated for a certain number of degrees (say 10 degrees) on each side of null. If it is desired to illuminate 20 degrees of the d-f antenna pattern (10 degrees on each side of the null) the probability that this will occur in one sweep of a scanning radar antenna can be obtained from equation (5) by setting θ_d, the effective beam width of the d-f antenna, equal to this 20 degrees which must be illuminated and by setting y equal to unity, since this entire 20 degrees must be illuminated. Equation (5) thus reduces to

$$P = \frac{\theta_r \, t_r}{360^\circ \, t_d} \quad - N$$

where θ_r = beam width of radar antenna in degrees

t_d = period of one (1) sweep of d-f antenna

t_r = period of one (1) sweep of radar antenna

N = largest integer that can be contained in $\frac{\theta_r\ t_r}{360^\circ\ t_d}$ = number of interceptions

The above equation is the same as equation (3) which was derived for the single beam antenna with infinitesimal beam width. For reception of pulse transmissions it must be stipulated that a certain number of consecutive pulses, n (say about 5), be received during the null illumination. The probability of this happening in one sweep of the radar antenna is the same as that given in the above equation, but it is necessary that the ratio of the transmitter repetition frequency to the d-f scanning rate be high enough so that n or more consecutive pulses are received while the d-f antenna is sweeping through 20 degrees, that is

$$\frac{n}{L} \leqq \frac{20^\circ}{360^\circ} \times t_d \qquad (7)$$

where L is the pulse repetition frequency. It is also necessary that the radar illumination time be long enough so that n pulses are transmitted during this interval, that is

$$\frac{n}{L} \leqq \frac{\theta_r}{360^\circ} \times t_r \qquad (8)$$

Equation (7) can be satisfied if the scanning rate of the d-f antenna is controllable. This serves to emphasize the previous statement that with signals of low pulse repetition frequency and with a short persistence indicator the scanning type d-f antenna must be turned at a relatively slow rate in order to obtain accurate bearings. For an illustration See Plate 7. The null of this pattern is not sufficiently illuminated for accurate interpretation of the bearing. It is assumed that the persistence of the cathode-ray indicator is less than the period of one (1) scan.

26. Several sample calculations of probability are given in Appendix 1 for both the single dipole and differential dipole antenna systems when operating against a scanning radar transmitter. The results of these calculations indicate that the single beam antenna is the more favorable of the two (2). However, the results are not conclusive because of the arbitrary assumptions (such as the required angle of illumination and the d-f antenna beamwidth) which were necessary in order to solve the equations.

Inverse Null Presentation

27. Another type of visual indicator presentation can be employed with the rotating differential dipole antenna system. This type of presentation might be termed the inverse response of the differential dipole antenna and is shown by the dashed curve in Plate 8. This response curve is obtained when the rectified signal voltage is applied as a negative potential on the grid of the deflection amplifier. The bias of this amplifier is adjusted so that the electron beam traces a circle at the periphery of the cathode-ray tube when the antenna pickup is zero. The effect of the antenna pickup is to deflect the beam towards the center of the indicator tube. This type of presentation can be read much more accurately than the null presentation. To prove this point compare Plates 23 and 24 which show both types of indicator patterns. This inverse pattern has the same limitations as the null pattern because it still requires illumination of about 10 degrees on each side of the antenna null and also requires that a sufficient number of pulses be received so that the pattern is clearly outlined. Plate 9 shows the inverse response pattern of the differential dipole system for the same conditions as were imposed for the patterns shown in Plates 3 and 6. A comparison of Plate 3 with Plates 7 and 9 seems to indicate that relatively more pulses per sweep of the d-f antenna are required in order to illuminate the differential dipole response patterns with the same degree of accuracy as the single dipole response pattern.

PERFORMANCE OF THE GONIOMETER TYPE OF AUTOMATIC DIRECTION FINDER

28. Plate 14 illustrates the type of indicator pattern displayed by the automatic bearing indicator (ABI) when the collector system has a figure-of-eight response pattern. It is seen that this pattern is bilateral and requires a sense indication to determine which of the two possible bearings is correct.

29. The goniometer type of automatic direction finder is most useful at medium and high radio frequencies for two (2) principal reasons: first, the type of signals encountered in these frequency bands are usually suitable for rapid bearing determination with this kind of direction finder and, second, the rotating goniometer operates most satisfactorily in these frequency bands.

30. An examination of the indicator pattern, Plate 14, reveals that the pattern must be illuminated for at least 10 degrees on each side of one (1) of the two (2) nulls if a bearing is to be obtained. The probability of this occuring in one (1) sweep of a scanning transmitter is

$$P = \frac{\theta_r \, t_r}{360^\circ \, t_d} \text{ x } 2 - N \qquad (9)$$

where θ_r = beam width of scanning radar transmitter in degrees
t_d = period of one (1) sweep of d-f goniometer in seconds
t_r = period of one (1) sweep of radar antenna in seconds
N = largest integer that can be contained in
$\frac{\theta_r t_r}{360^\circ t_d}$ x 2 = number of interceptions

This equation is very similar to the probability equation for the differential dipole plus reflector, since both are null type systems. The difference between these equations is the factor, two (2), which takes into account the two (2) nulls of the goniometer system as compared to one (1) for the differential dipole system. It should be recognized that the above equation (9) does not give the probability of obtaining a non-ambiguous bearing, since it makes no allowance for the time required to obtain a sense determination.

31. Equation (9) shows that the probability of obtaining a bearing in a certain length of time should increase as the angular velocity of the goniometer is increased. However, it is again necessary to stipulate, when receiving a signal from a pulsed transmitter, that a certain minimum number of pulses is required in order to adequately delineate the goniometer null. This is particularly true when the pulses are of very short duration such as are encountered in radar interception. Figure 1 of Plate 15 shows an ABI pattern obtained when the ratio of goniometer rpm to pulse repetition frequency (of the signal) is too large for accurate bearing determination. Figure 2 of Plate 15 gives an example of an ABI pattern which is well outlined by a radar transmitter (bearing readable to better than ± 2 degrees). Plate 15 presents an accurate picture of the actual indicator patterns except for the angular rotation of the pulse pattern on the indicator which occurs whenever the pulse repetition frequency and the d-f scanning rate are not synchronized.

32. It has been found, from experimental tests, that the ABI pattern, as a whole, is not adequately illuminated by a non-scanning radar transmitter unless one (1) pulse is received at least every 10 degrees of the goniometer rotation. This limiting condition is expressed in equation (10) and is shown as a graph in Plate 16.

$$\frac{1}{t_d} = \frac{L}{36} \qquad (10)$$

where t_d = period of one (1) sweep of d-f antenna

L = pulse repetition frequency of pulsed transmitter

Equation (10) states mathematically that the rotational speed of the goniometer rotor must not exceed the pulse repetition frequency of the received signal divided by 36, if the bearing is to be readable to better than ± 2 degrees. It should be pointed out that the above relation is empirical and holds only if the complete ABI pattern is illuminated. If the received signal is from a scanning transmitter it is possible that only a limited sector of the ABI may be illuminated during each of several successive scans. In this case, relatively more pulses are needed in order to secure an accurate, quick bearing.

33. Equation (10) can also be applied to the scanning, differential dipole plus reflector antenna system since it also has a null-type response pattern. Furthermore, it was illustrated in Plates 7 and 9 that the differential dipole response pattern is poorly outlined on the visual indicator if the antenna scanning rate is too rapid relative to the pulse repetition frequency of the transmitter.

34. In comparing the differential dipole and goniometer type systems, for use in the VHF band, it is found that each has one (1) advantage over the other. The advantage of the differential dipole is its unilateral indication which provides automatic sense determination. The advantage of the goniometer system is its compact form which permits high rotational speeds. With these differences in mind, it is seen that the goniometer type is preferable for use against mcw and icw signals, where high speeds are advantageous, and the differential dipole system is preferable for use against radar transmissions. It should be pointed out that the bearing sensitivity of the differential dipole and reflector system is superior to that of any figure-of-eight antenna array designed for use with a goniometer. This is true provided both arrays are designed for optimum sensitivity, which means that the dipole and reflector array becomes rather large physically at frequencies below 100 megacycles. For some of the original work done on this type of antenna array see Reference (5).

PERFORMANCE OF THE ANTENNA SWITCHING TYPE OF DIRECTION FINDER

35. It might be mentioned here that the CXFF-1 type of phase comparison direction finder is analogous to the rotating, differential dipole antenna direction finder. Although the CXFF-1 system employs a goniometer type of scan the end result is similar to that obtained with the scanning, differential dipole antenna system.

36. For good operation against scanning radar transmitters the d-f antenna switching rate should be determined by two (2) important factors. First, the switching rate should not exceed that value at which only one (1) radar pulse is received by each antenna during one (1) switching cycle. Second, the antenna switching rate should be as rapid as possible in order to minimize the bearing errors which result if the radar antenna is sweeping. As an example, consider a quadrant switching direction finder (e.g., the CXFF) when used against a radar transmitter which has a pulse repetition frequency of 60 pulses per second and scans at a rapid rate. In order that each of the active antennas receive at least one (1) radar pulse per switching cycle, the switching rate must not exceed 60/4 or 15 cycles per second. Since the radar antenna beam is sweeping past the d-f antenna, the error caused by this variation in received signal strength is minimized by not switching at less than 15 cycles per second. It is apparent from this discussion that this type of automatic direction finder must be capable of a definite minimum switching rate (less than 15 cycles per second) and a variable switching rate is highly desirable.

PERFORMANCE OF THE INSTANTANEOUS TYPE DIRECTION FINDER

37. The advantages of the instantaneous type of d-f system are several:

(a) The bearing indication is instantaneous.

(b) The probability of obtaining an indication in one (1) sweep of a scanning transmitter is one, since the antenna system is omnidirectional.

(c) This system eliminates the need for any mechanically moving parts which are required in almost all other types of d-f systems.

38. The requirements for proper operation of this d-f system are that in some types each of two (2) or three (3) receivers must have identical phase shift characteristics and that in all types the two (2) or more directional channel receivers must have identical amplification characteristics. These requirements are difficult to satisfy since the receivers normally employ tuned r-f amplifiers. It has been suggested that tuned r-f circuits can be eliminated if the amplifiers consist of a crystal detector and video amplifier which are preceded by a bandpass filter. Such an arrangement practically eliminates phase-shift difficulties, but is limited to that part of the frequency spectrum where signals are widely separted from one another since selectivity has been sacrificed by the elimination of r-f amplification. Also, the sensitivity of the crystal detector-video amplifier receiver is considerably poorer than that of the superheterodyne type receiver except for extra broad band applications. The reason for this is due to the fact that the efficiency of the crystal as a detector is about 30 db below its efficiency as a mixer in the superheterodyne receiver.

SYNCHRONIZATION PHENOMENA

39. Synchronization between the rotation of the transmitting antenna and the rotation of the d-f antenna can occur if the d-f antenna speed is the same as that of the transmitting antenna, a multiple of this speed, or a sub-multiple of this speed. If exact synchronization occurs it can happen that the d-f antenna will never receive any signals from the transmitter if the d-f antenna is not "looking" at the transmitter position while the transmitting antenna beam is sweeping by the d-f position. However, exact synchronization of the antenna scanning rates is very unlikely, especially since both the transmitter and d-f antenna drive systems ordinarily employ variable speed control. Near-synchronization of the rotational speeds can and does occur frequently, particularly when the d-f antenna rotates at a rate near some multiple or sub-multiple of the transmitting antenna speed. In this case, a relatively long interval of time may elapse between successive bearing presentations on the d-f indicator, but the bearings themselves are read without difficulty. For a more complete discussion of this effect

refer to Reference (4).

40. Another type of synchronization is possible, namely synchronization between the d-f scanning rate and the pulse repetition rate of a radar transmitter. In this case, the synchronization itself causes no difficulties provided that the ratio of pulse repetition rate to d-f scanning rate is large (see equation 10) so that sufficient pulses are received by the direction finder during one scan. If insufficient pulses are received during one scan the d-f indicator will not present a clearly defined bearing indication.

41. An obvious way to eliminate all synchronization difficulties is to employ such a rapid d-f scanning rate that a complete 360 degree scan is completed in a period of time shorter than that of one radar pulse. For instance, in order to complete one scan in the time required to receive a one-half microsecond radar pulse this necessitates using a d-f scanning rate of two megacycles per second. Up to the present time such a rapid scanning rate has not been attempted, and electronic, rather than mechanical methods would be required. The worst practical limitation is the tremendous bandwidth which would be required to build up a useful indicator pattern in a half microsecond.

42. One last significant fact is that the possibility of sweep synchronization through integral rotational rate ratios does not affect the probability of obtaining a bearing during <u>one</u> sweep of a radar. For example, if both the radar and d-f antennas were run at identical speeds, but started with random positions, the fact that an indication might be obtained on each successive scan, or might never be received, would not affect the probability of an indication on the first scan.

Bearing Errors Which Result When Operating a Rotating D-F Antenna Against a Scanning Transmitter

43. Appreciable errors often result when scanning with the maximum lobe type d-f antenna against a scanning transmitter. The reason for these errors is that the signal strength arriving from the transmitter is changing as the d-f antenna sweeps by the azimuth position of the transmitter. At any particular time the received signal will be proportional to the product of the d-f pattern amplitude and the signal amplitude. In this case the pattern which appears on the d-f indicator is not quite symmetrical and gives erroneous bearings. Illustrations of this effect are shown in Plates 10 and 11 for the single dipole antenna system. The line LL represents the field strength of a scanning transmitter over the period during which the d-f antenna sweeps through the signal. For these illustrations the transmitter antenna is assumed to have a radiation pattern as shown in Plate 1 (i.e., 30 degrees wide at the half power points) and the angular velocity of this antenna is assumed to be one-third that of the d-f antenna. Plate 12 shows the relative positions of the transmitting and d-f

antennas at different instants of time during which the receiving position is illuminated by the transmitting beam. An examination of Plates 10 and 11 reveals that the bearing error is 9 degrees when the d-f beamwidth is 60 degrees and about 4 degrees when the beamwidth is 30 degrees. This illustrates the increased accuracy obtained by using the narrower receiving beam. It seems pertinent to mention that, for these same two d-f antenna beams, the indicator response pattern would appear to be the same as those in Plates 10 and 11 if the transmitting beamwidth was halved as well as the ratio of the angular velocities of the d-f and transmitting antennas (i.e., a transmitting beamwidth of 15 degrees and the angular velocity of the transmitting antenna being two-thirds that of the d-f antenna).

44. Plate 13 shows the type of indicator patterns to expect from the differential dipole antenna system when the receiving and transmitting antennas are sweeping simultaneously. The transmitter is assumed to have the same beamwidth as before and the ratio of angular velocities is again assumed to be three to one. The effect of receiving a signal of varying intensity in this case is to cause the patterns to appear quite unsymmetrical. Actually, the position of the pattern null is still the true indication of the bearing. However, an operator would probably be deceived to a certain extent by the unsymmetrical shape of the pattern on each side of the null. For this reason the reception of such a signal is more obvious than is the case with the single beam antenna described above. It is seen that the apparent bearing error is rather small (about 1 degree) when the inverse presentation is used.

45. In view of the above discussion it can be stated that when operating against signals of varying intensity the amount of bearing error is minimized by keeping the ratio of d-f antenna velocity to the transmitting antenna velocity as high as is practicable. The object, of course, is to keep the variation of received signal strength, during the d-f antenna sweep, as small as possible. It is believed that more accurate bearing interpretation can be made by using a long persistence indicator, rather than a short persistence indicator, with the single lobe type of d-f antenna system. Using a long persistence cathode-ray tube, several consecutive indicator patterns will be visible simultaneously, so that more information is available for interpretation. There is no advantage, however, if the repetition rate of the transmitter is not sufficiently high so that each of the successive patterns is not adequately defined on the indicator. For more information regarding the type of bearing error described above see Reference (4).

BASIC INDICATOR REQUIREMENTS

Frequency Response of Deflection Amplifier

46. The frequency characteristic of the deflection amplfier, required with visual indicators, is another important consideration.

[redacted]

In order to maintain optimum signal-to-noise ratio throughout the direction finding system, the cutoff frequency of the deflection amplifier must be governed by the same considerations which determine the receiver bandwidth ahead of the detector stage. Thus, for reception of rectangular radar pulses, optimum signal-to-noise ratio is maintained if the cutoff frequency of the deflection amplifier is equal to that value determined by equation (11)

$$f_c = \frac{0.75}{d} \quad \text{for optimum S/N ratio} \qquad (11)$$

where f_c = cutoff frequency in megacycles
d = pulse width in microseconds.

The basis for this equation can be found in Reference (6) which presents a thorough discussion of band width requirements for pulse reception. If this equation is satisfied, the deflection amplifier is in actuality a video amplifier and the individal radar pulses appear on the cathode-ray tube indicator. In many instances this presentation of the radar pulses on the cathode-ray tube permits identification of the type of signal being received.

47. Another slightly different method of presentation is employed in some d-f systems (e.g. the rotating beam antenna type) intended for use against pulsed signals. This is accomplished by using a deflection amplifier with no extended high-frequency response. This type of amplifier has a low-pass response which effectively filters and smooths short pulses so that they do not appear as such on the cathode-ray tube. Indicator patterns produced by such an amplifier have been shown in Plates 22, 23, 24, and 25. The degree to which the individual pulses are outlined depends upon the width of the pulses and the frequency response of the deflection amplifier. The advantage of this system is the ease with which the bearing can be read because the electron beam traces a solid pattern on the indicator. This advantage is questionable, however, when the following objections to this method of presentation are considered:

(a) The low-pass frequency characteristic of the deflection amplifier requires the acceptance of a poorer peak signal-to-noise ratio than would be obtained if a video amplifier were used for pulse reception.

(b) The smoothing effect produced by the low-pass deflection amplifier eliminates the possibility of identifying the received signal by its appearance on the indicator. Also, if two different radar signals of the same frequency are received coincidentally, this occurrence is much more evident if the indicator shows individual pulses. When the deflection amplifier has a video response characteristic the simultaneous bearing determination of two signals is quite feasible while if the deflection amplifier has low-pass response the simultaneous bearing determination is practically impossible.

Bandwidth Requirements Necessitated by Ultra-High Scanning Rates

48. When a very rapid d-f scanning rate is employed, the bandwidth of the receiving system, at least for reception of cw signals, depends upon the scanning rate and upon directional response of the d-f system. This is because the received signal is modulated by the directional pattern of the direction finder at a rate determined by the d-f scanning speed. For instance, the goniometer type of scanning results in a suppressed carrier type of modulation of the received signal. If the scanning rate were one megacycle per second the minimum receiver bandwidth would be two megacycles per second in order to pass the desired bearing information. For this same case, the deflection amplifier would have to have a response of about 50 times the scanning frequency (i.e., 50 x 1 mc) if the bearing indication on the ABI were to appear reasonably well defined. The necessity for the extended deflection amplifier response is a result of the additional frequencies which are intoduced when the suppressed carrier signal is detected. If it were possible to scan a beam type of d-f system at a rate of one megacycle per second the bandwidth of the I-F amplifier as well as that of the video amplifier would have to be very broad. For example, if the beam width was about 7 degrees, the I-F bandwidth would have to be about 100 megacycles and the video amplifier response would have to be about 50 megacycles for reasonable reproduction of the beam pattern on the indicator.

Linearity of Deflection Amplifier

49. The linearity of the receiver circuits, from the r-f input to the output of the deflection amplifier, has a direct effect upon the shape of the pattern which appears at the indicator. In almost all practical cases it is safe to say that most non-linearity occurs after the second detector, that is, in the video and deflection amplifiers. An example of a non-linear gain characteristic is shown in Plate 17. This gain curve was obtained from an actual UHF direction finder, the CXGA. In this case the deflection amplifier was purposely designed for non-linearity so that the indicator patterns would appear to be more sharp than the actual antenna patterns. In the case of the single dipole direction finder the indicator pattern appears narrower than the antenna pattern and the bearing readability is increased somewhat. For example, see Plates 18 and 19 for patterns obtained with the overall gain curve which is shown in Plate 17. The antenna response patterns for these two examples are those given in Plates 1 and 3b (i.e., 30 degree beam width for Plate 18 and 60 degree beam width for Plate 19). The solid curve represents the pattern obtained from a non-scanning cw transmitter while the dashed curve represents the pattern obtained from a transmitter scanning at one-third the scanning rate of the d-f antenna. The relative positions of the d-f and transmitting antennas for these examples are again as given in Plate 11. It is seen, by comparison of Plates 18 and 19 with Plates 9 and 10, that the amount of error which results from reception of the scanning signal is not reduced by the action of non-linear amplification in the deflection amplifier.

50. The effect of the same non-linear amplification upon the indicator pattern of a differential dipole system is shown in Plate 20. Both direct and inverse patterns are illustrated for an antenna which has a response pattern as given in Plate 5. The inverse pattern is improved by the non-linear amplification, but the readibility of the direct pattern is adversely affected. When the differential dipole system is employed against the same scanning cw transmitter as in the previous illustration the effect of non-linear amplification is shown in Plate 21. By comparison with the patterns of Plate 13, it is evident that the dissymmetry of the direct pattern caused by the scanning signal is made more pronounced by the non-linear amplification characteristic. The inverse pattern, on the other hand, is somewhat improved under these conditions.

51. The linearity of the deflection amplifier has an effect upon all types of d-f indicator patterns regardless of the system employed. Only the most important of these systems have been considered. It can be concluded, from these examples, that the type of non-linear amplification exemplified has the advantages of sharpening the indicated antenna patterns and reducing the amplitude of minor lobes. The possible ill effects of non-linear amplification are to cause unsymmetrical patterns to be more unsymmetrical and to cause amplitude limiting. The latter effect is produced by driving the deflection amplifier to saturation and should be guarded against since it causes the extremities of the indicator pattern to be blunted.

Long Persistence Cathode-Ray Tubes

52. It has been mentioned previously that it is possible, under certain conditions, to obtain more information by use of a long-persistence rather than a short-persistence indicator against signals of varying intensity. The reason is that by integrating the information received during several successive scans a more accurate bearing determination can be made. Aside from this one advantage it is ordinarily not necessary and usually undesirable to employ long persistence if the d-f scanning rate exceeds 15 cycles per second. However, if the d-f scanning rate is much less than 15 cycles per second the use of a long-persistence indicator is desirable in order that the trace made by the electron beam during at least one sweep is visible to the eye.

53. It is often advantageous, where the visual indicator shows individual pulses, to modulate the intensity grid of the cathode-ray tube with the received pulses. In this manner the trace on the cathode-ray tube is made much brighter, during the presentation of each pulse on the indicator, than it would otherwise be. This arrangement serves to improve the presentation and can be used with either long-persistence or ordinary cathode-ray tube indicators.

CONCLUSIONS

54. It is concluded:

(a) That where a direction finder is rotating faster than the radar it is to intercept, the probability of obtaining a bearing in one revolution of the radar increases as the direction finder scanning rate increases, with the limitations stated in (d) and (e) below (Eq (4)).

(b) That where the direction finder is rotating slower than the radar, the probability of obtaining a bearing on the radar in one rotation of the direction finder increases as the direction finder scanning rate decreases (Eq (4)).

(c) That the time required for a particular probability of obtaining an interception is fixed by the period of rotation of the slower of the two devices, making it advisable to operate a direction finder at speeds exceeding the radar speed except where the radar speed is sufficiently high to permit the time for obtaining interception to consist of the direction finder period (Par. 22).

(d) That for accurate bearings enough radial traces must be obtained on the indicator of a rotating system to adequately outline the pattern (Par. 22). In case of the goniometer type direction finder the maximum spacing angle between the traces has been empirically determined to be approximately each 10° (Par. 32).

(e) That the rotational speed of a d-f collector or goniometer cannot exceed a value where the side bands of the received signal, created by such rotation, are "cut-off" by the receiver selectivity (Par. 48).

(f) That a differential dipole-reflector antenna system which might not be suitable for aural null direction finding because the antenna pattern is not free from appreciable back radiation or minor lobes, may be used successfully if a cathode-ray indicator displaying the entire antenna pattern or its inverse is employed. (Par. 24)

(g) That the inverse indicator pattern of the differential dipole-reflector direction finding system can be read more accurately and is less susceptible to errors caused by scanning signals than the direct pattern (Par. 27).

(h) That the goniometer type of direction finding system permits the use of much faster rotational (scanning) speeds than is possible with the present mechanically rotating systems because of the inherent lower mass and size of the goniometer (Par. 34).

(i) That the switching rate of the antenna switching (amplitude comparison) type of direction finder should not exceed that value at which only one radar pulse is received by each antenna while it is connected to the receiver. The pulse repetition frequency of the received signal therefore determines the maximum switching rate (Par. 36).

(j) That the instantaneous type cathode-ray direction finder provides theoretical certainty of bearings on as little as a single pulse, but has thus far been more difficult to develop and maintain than rotating systems because of the necessity of providing accurate amplitude, and when required, accurate phase balance (Par. 37).

(k) That the bearing error, which results when receiving a scanning transmitter with a rotating dipole-reflector antenna system, is minimized by employing a narrow receiving beam and by rotating much more rapidly than the transmitter scanning rate (Par. 43).

(l) That the use of a deflection amplifier which eliminates the identity of individual pulses by integration might prove disadvantageous (Par. 46).

(m) That the advantage of non-linear amplification, as illustrated in this report, is to sharpen the indicator patterns and to reduce the indicated amplitude of minor lobes when direct presentation is employed (Par. 51).

(n) That the disadvantage of non-linear amplification is that it causes unsymmetrical response patterns to appear more unsymmetrical and that it causes amptitude limiting (Par. 51).

(o) That there is no outstanding advantage in the use of either long or short persistence cathode-ray tube screens, but in general if the rotational speed of the direction finder is in excess of 15 rotations per second a short persistence screen should be used and if under, a long persistence screen (Par. 52).

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4. The use of Continuously Rotating Direction Finders Against Signals of Varying Intensity. R.R.L. Harvard University No. 411-158 Div. 15, NDRC.

5. Radio Direction Finding on Wavelengths of 50-100 Centimeters. Part II - On the Use of a Reflector With a Rotating H Aerial System - L.H. Ford, N.P.L. March, 1943 No. 79-B3-12.

6. Principles of Radar - By the Staff of the M.I.T. Radar School - 1944 - pages 4-12 to 4-24.

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8. NRL Report R-2779 - "The Conditions for Certainty of Interception of an Intermittent Signal by a Rotating Directional Antenna." H.D. Arnett.

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SAMPLE PROBABILITY CALCULATIONS

EXAMPLE 1

Assume a radar transmitter with the following characteristics:

Antenna beamwidth, $\theta_r = 20$ degrees
Period of one sweep, $t_r = 10$ seconds (6 rpm)
Pulse repetition frequency, $L = 500$ pulses per second

(a) If the d-f antenna system is a single dipole plus reflector with these characteristics:

Antenna beamwidth, $\theta_d = 30$ degrees
Period of one sweep, $t_d = 1$ second (60 rpm)

Then, the probability of illuminating at least two-thirds (20 degrees) of the antenna pattern in one sweep of the radar antenna is

$$P = \frac{20^\circ \times 10\ \text{sec} + (1-\frac{2}{3})\ (30^\circ \times 1\ \text{sec})}{360^\circ \times 1\ \text{sec}} - N \qquad \text{from eq. (5) Par. 20}$$

$$P = \frac{210}{360} = \frac{7}{12} = .583 \qquad N = 0$$

(b) If the d-f antenna is a differential dipole plus reflector with the same rotational speed ($t_1 = 1$ second), then the probability of illuminating at least 10 degrees on each side of the null in one sweep of the radar antenna is

$$P = \left(\frac{20^\circ}{360^\circ} \times \frac{10\ \text{sec}}{1\ \text{sec}}\right) - N \qquad \text{from eq. (3) Par 17}$$

$$P = \frac{200}{360} = \frac{5}{9} = .555 \qquad N = 0$$

These two results are true providing

$$\frac{\theta_r}{360^\circ} \times t_r \geq \frac{20^\circ}{360^\circ} \times t_d \qquad \text{which is satisfied since}$$

$$\frac{20^\circ}{360^\circ} \times 10\ \text{sec} > \frac{20^\circ}{360^\circ} \times 1\ \text{sec}$$

[redacted]

EXAMPLE 2

Assume the same radar transmitter as in the previous example.

(a) If the d-f antenna is a single dipole plus reflector with these charateristics:

$\theta_d = 30$ degrees

$t_d = 5$ seconds

Then, the probability of illuminating at least two-thirds (20 degrees) of the indicator pattern in one sweep of the radar antenna is

$$P = \frac{20^\circ \times 10 \text{ sec} \neq (1 - \frac{2}{3})\ (30^\circ \times 5 \text{ sec})}{360^\circ \times 5 \text{ sec}} - N \qquad \text{from eq. (5)}$$

$$P = \frac{50}{360} = .139 \qquad N = 0$$

(b) If the d-f antenna is a differential dipole plus reflector with the same rotational speed ($t_1 = 5$ seconds), then the probability of illuminating the null in one sweep of the radar antenna is

$$P = \left(\frac{20^\circ}{360^\circ} \times \frac{10 \text{ sec}}{5 \text{ sec}}\right) - N \qquad \text{from eq. (3)}$$

$$P = \frac{40}{360} = .111 \qquad N = 0$$

TABLE 1.

FACTORS AFFECTING D-F BEARINGS AT VHF, UHF, & SHF

I Scanning Rate of Transmitter

- (a) Fixed antenna (non-scanning)
- (b) Rotating antenna

II Modulation of Transmitter

- (a) Amplitude modulation { mcw, icw, pulse (rate and width)
- (b) Frequency modulation

III Antenna or Radiation Pattern of Transmitter

- (a) Polarization
- (b) Beam width (horizontal directivity)
- (c) Vertical directivity
- (d) Lobe switching

IV. Scanning Rate of D.F.

- (a) Hand rotated
- (b) Automatic (goniometer, antenna switching)
- (c) Instantaneous

V. D-F Indicator and Antenna System

- (a) D-F antenna pattern
- (b) Indication
  - (1) Aural nul
  - (2) Visual (null, maximum, matching)
- (c) Type of sweep, if visual
- (d) Deflection amplifier bandwidth and linearity

TABLE 2.

AVERAGE CHARACTERISTICS OF U.S. NAVAL RADAR

FUNCTION	FREQ.	PRF	PULSE WIDTH	HORIZ. BEAM WIDTH	POLARIZATION	SCANNING RATE (RPM)	TYPE OF SCAN
Shipborne Search	114-120	60	5-10	40	H or V	1-5	CR,M
Shipborne Search	175-225	60	5	20-40	H	0-5	CR,M
Shipborne Search	S-Band	400-1000	1-5	3-12	H or V	0-12	CR,M
Shipborne Search	X-Band	400-2000	1/6-1	2-30	H	0-12	CR,M
Fire Control	S-Band	500-3600	½-1½	2-12	H or V	20-30 cps	LS,C
Fire Control	X-Band	500-3600	½-1½	3/4-12	H or V	20-30 cps	LS,C
Airborne Search	S-Band	300-800	1-3	10	H	12,24	CR,S
Airborne Search	X-Band	300-2000	1/2-2	3-8	H	12,24	CR,S
Airborne Search	X-Band	300-2000	1/2-2	3-8	H	30-60	S

CR - Continuous Rotation
M - Manual
LS - Lobe Switching
C - Conical Scan
S - Sector Scan

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Illustration of the Type of Response Pattern Which Might Be obtained From A Dipole Antenna Placed Before A Parabolic Reflector

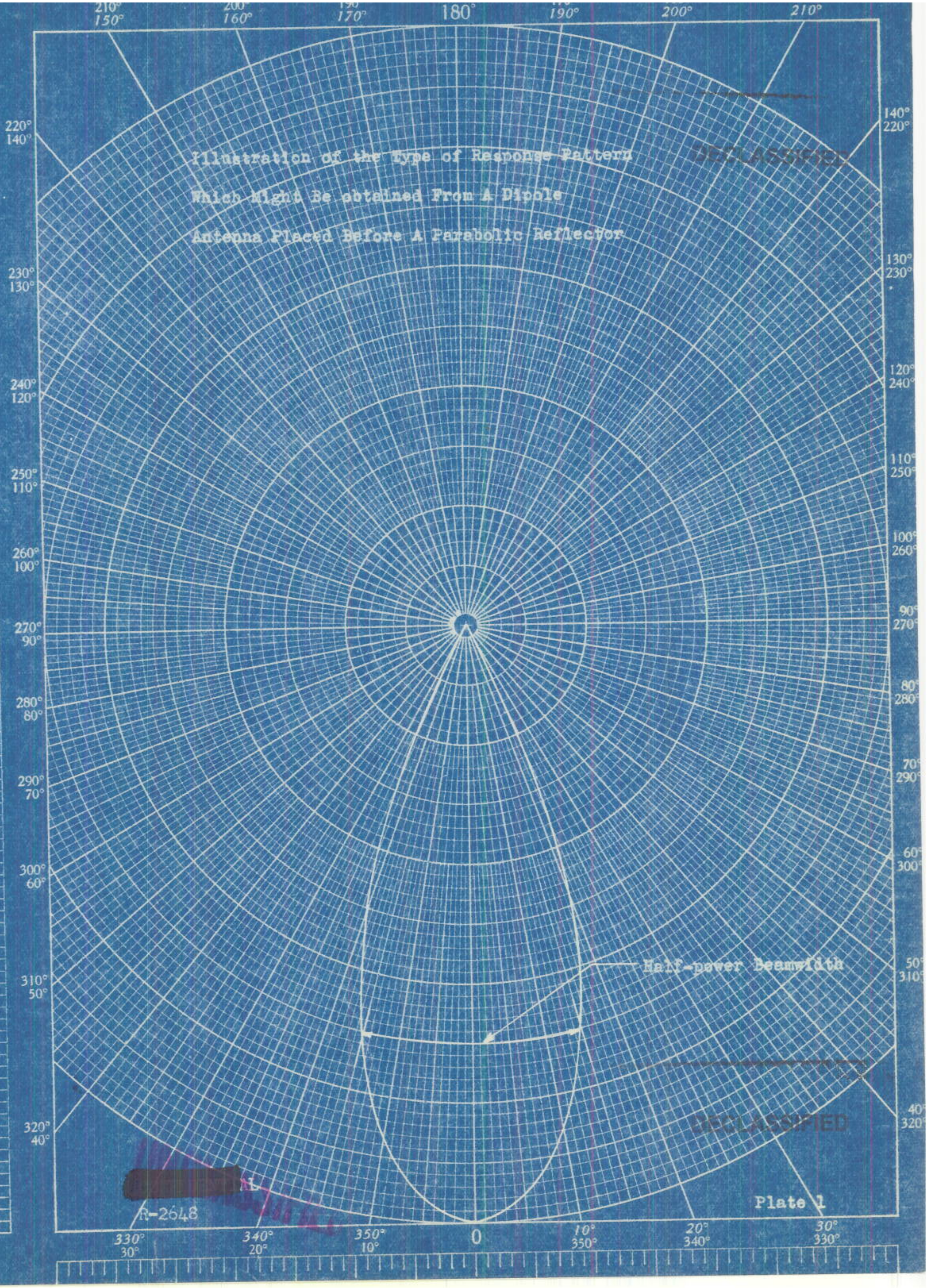

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Plate 1

Limiting Positions of Segment Beams

Bearing only at start of period of illumination

Bearing only at end of period of illumination

Unclassified

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Plate 2

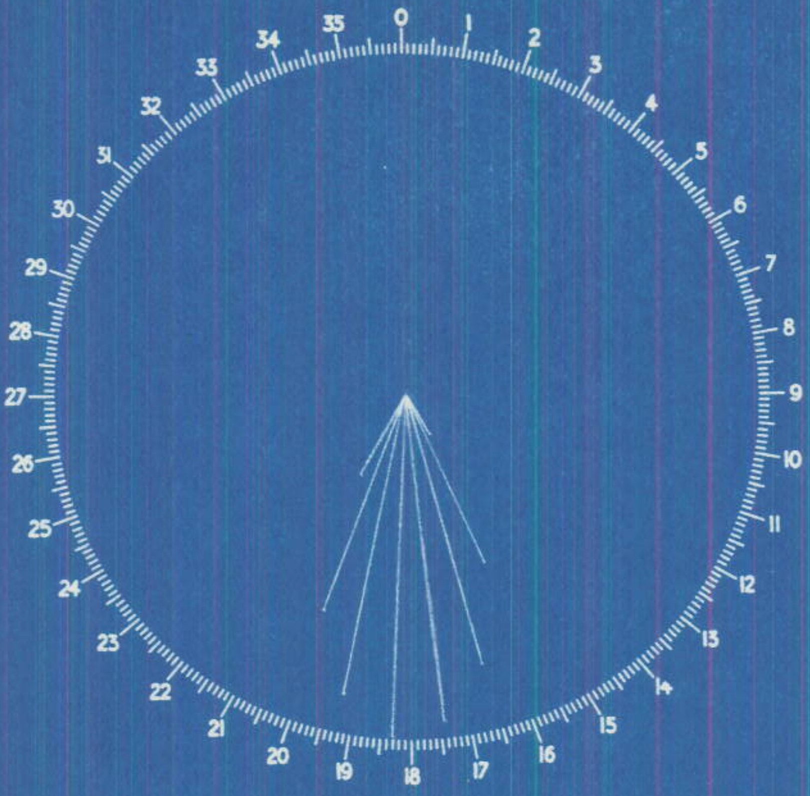
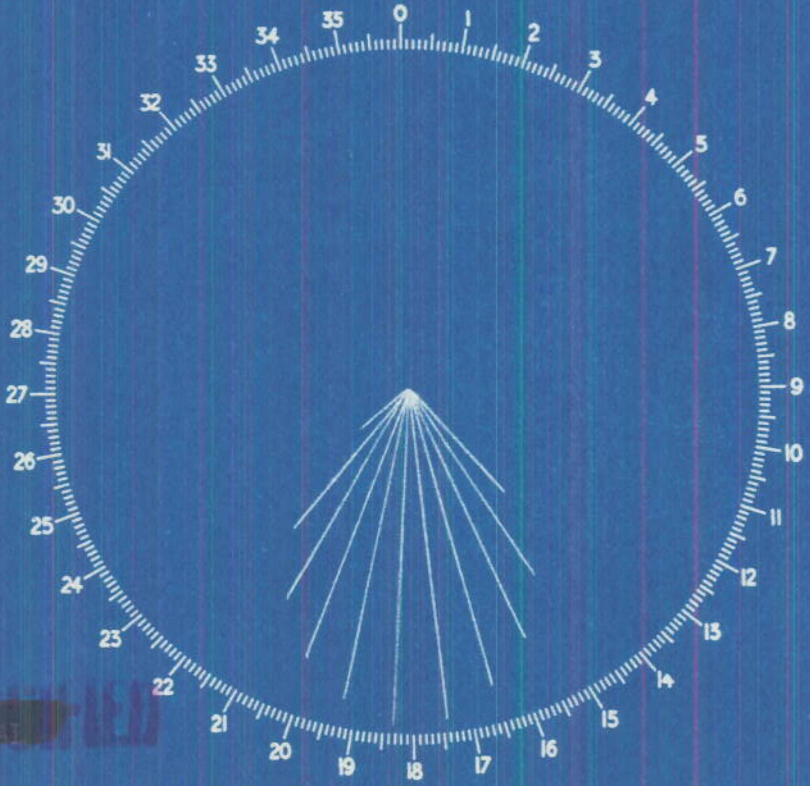


Fig. 1 Indicator Pattern Obtained From A D-F Antenna Scanning at 90 RPM And Receiving a Signal From A Non-Scanning Radar Pulsed 60 Times Per Second. Half-power Beam Width of D-F Antenna is 30 Degrees.



[redacted]

Fig. 2 Indicator Pattern Obtained With Same Conditions As In Fig. 1 Except That Half-power Beam Width of D-F Antenna Is 60 Degrees.

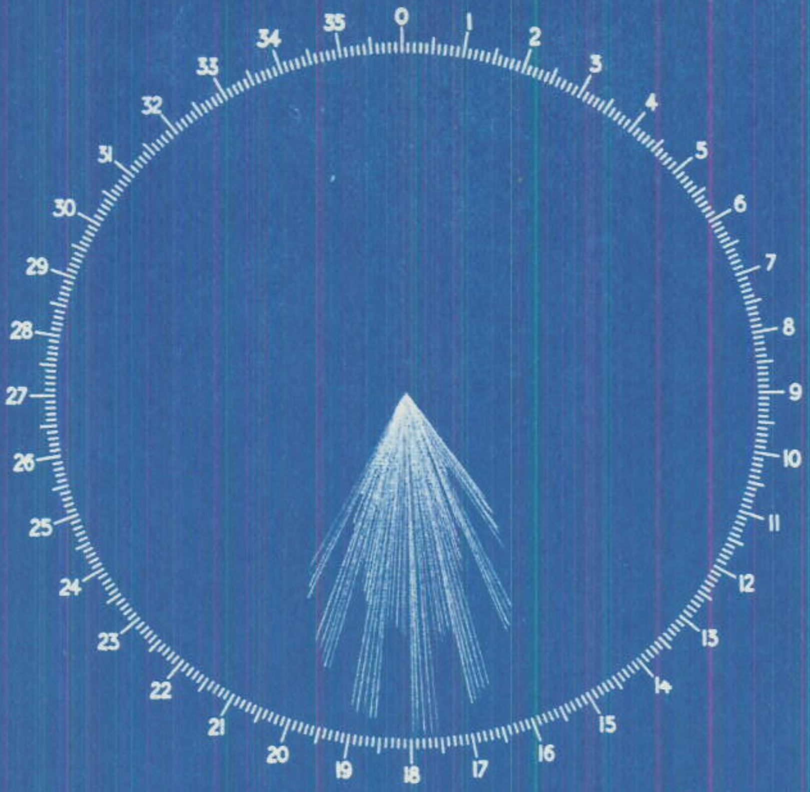


Fig. 1 Indicator Pattern Obtained By Scanning At 90 RPM Against A Simple Lobe Switching Radar Transmitter. Lobe Switching Rate Approximately 100 Per Second, PRF Approximately 500 per Second.

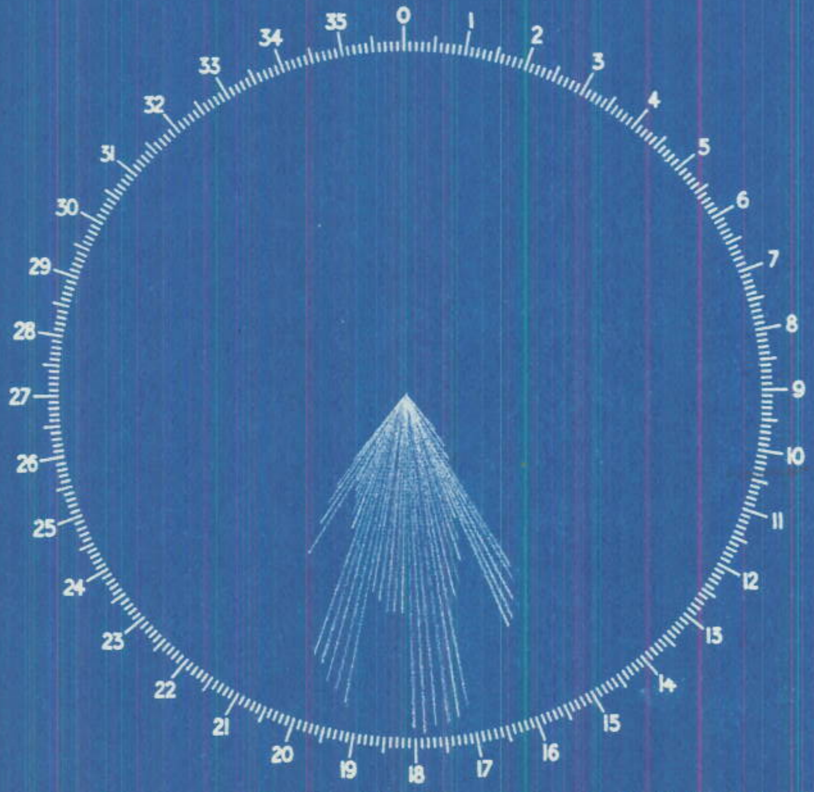
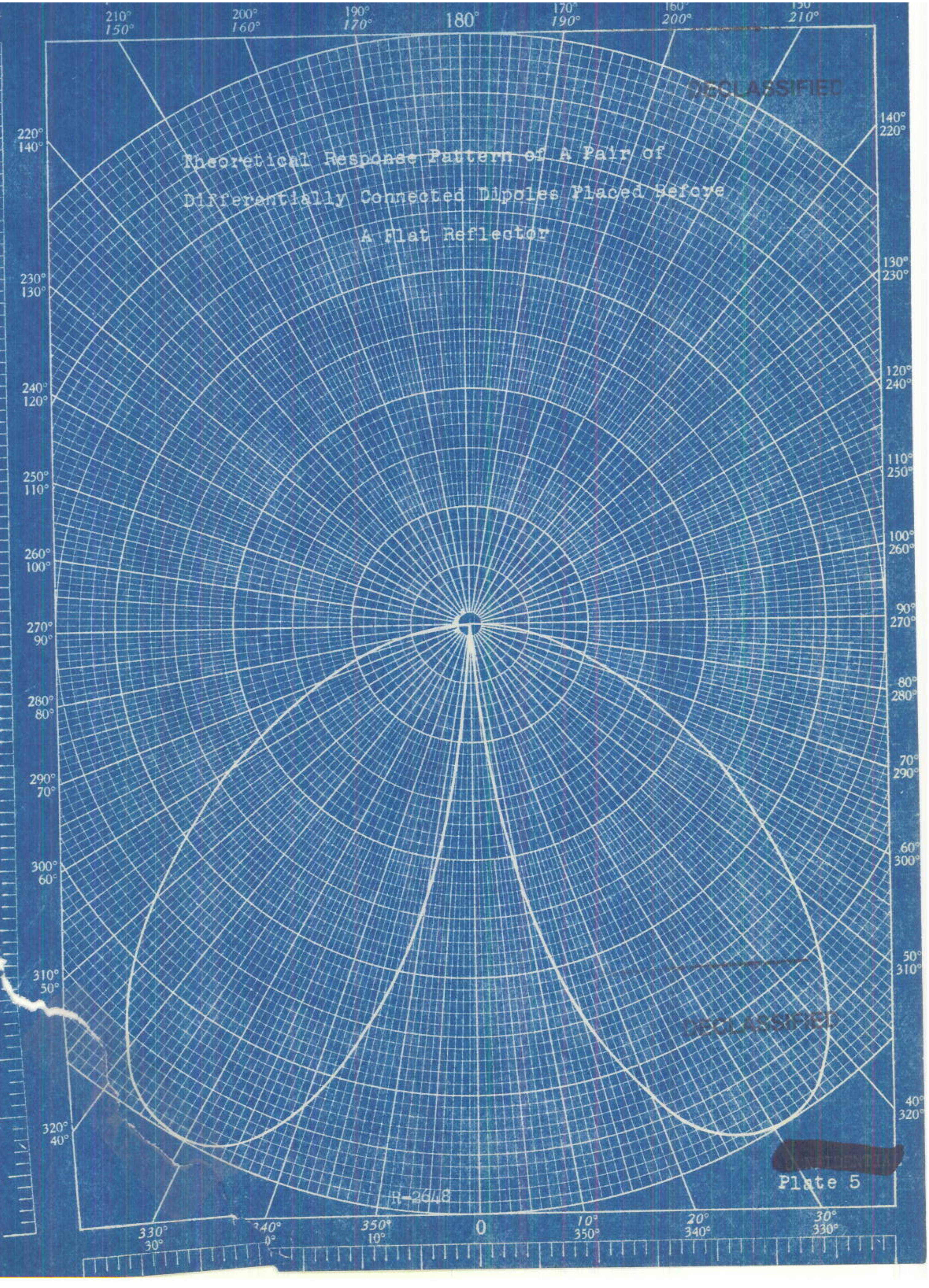


Fig. 2 Indicator Pattern Obtained by Scanning at 180 RPM Against the Same Lobe Switching Radar Transmitter as in (1).



Theoretical Response Pattern of A Pair of Differentially Connected Dipoles Placed Before A Flat Reflector

[redacted]

Plate 5

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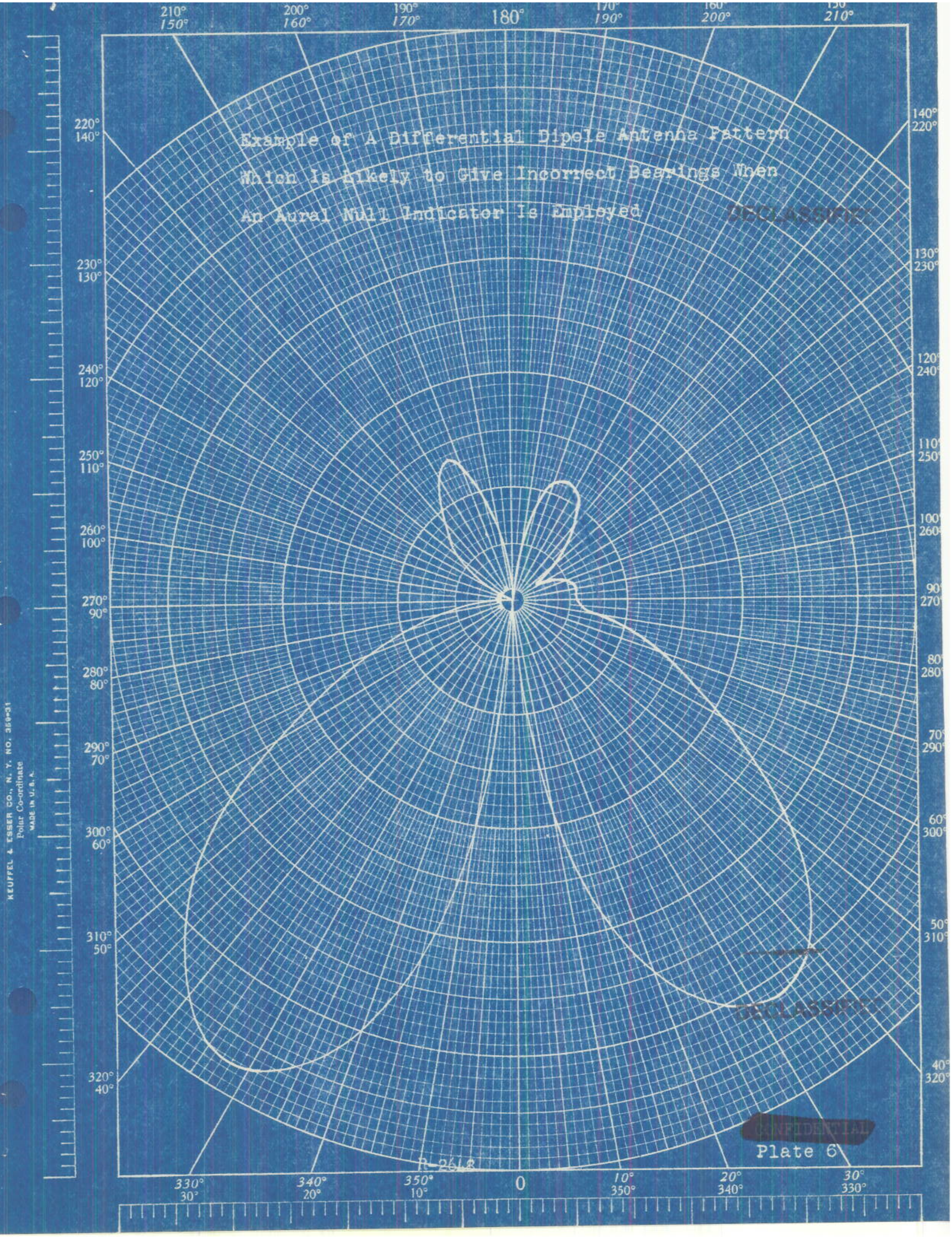

Example of A Differential Dipole Antenna Pattern Which Is Likely to Give Incorrect Bearings When An Aural Null Indicator Is Employed

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Plate 6

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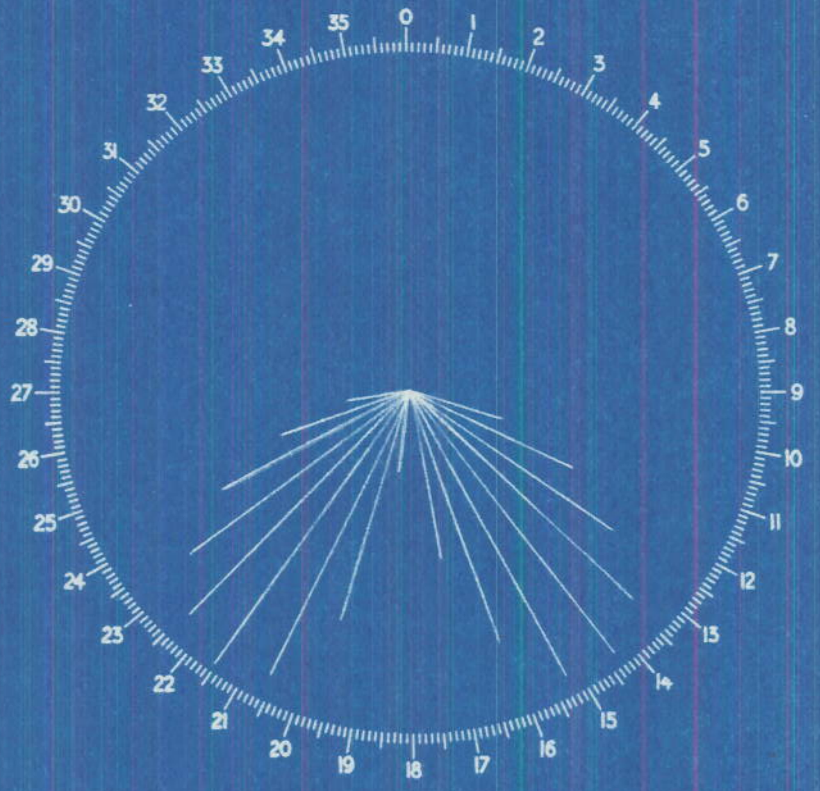

Indicator Pattern Obtained From A Differential Dipole Antenna System Scanning at 90 RPM and Receiving a Non-scanning Radar Signal Pulsed 60 Times Per Second.

Plate 7

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Indicator Patterns Obtained From a Rotating Differentially Connected Dipole Antenna For Linear Amplification

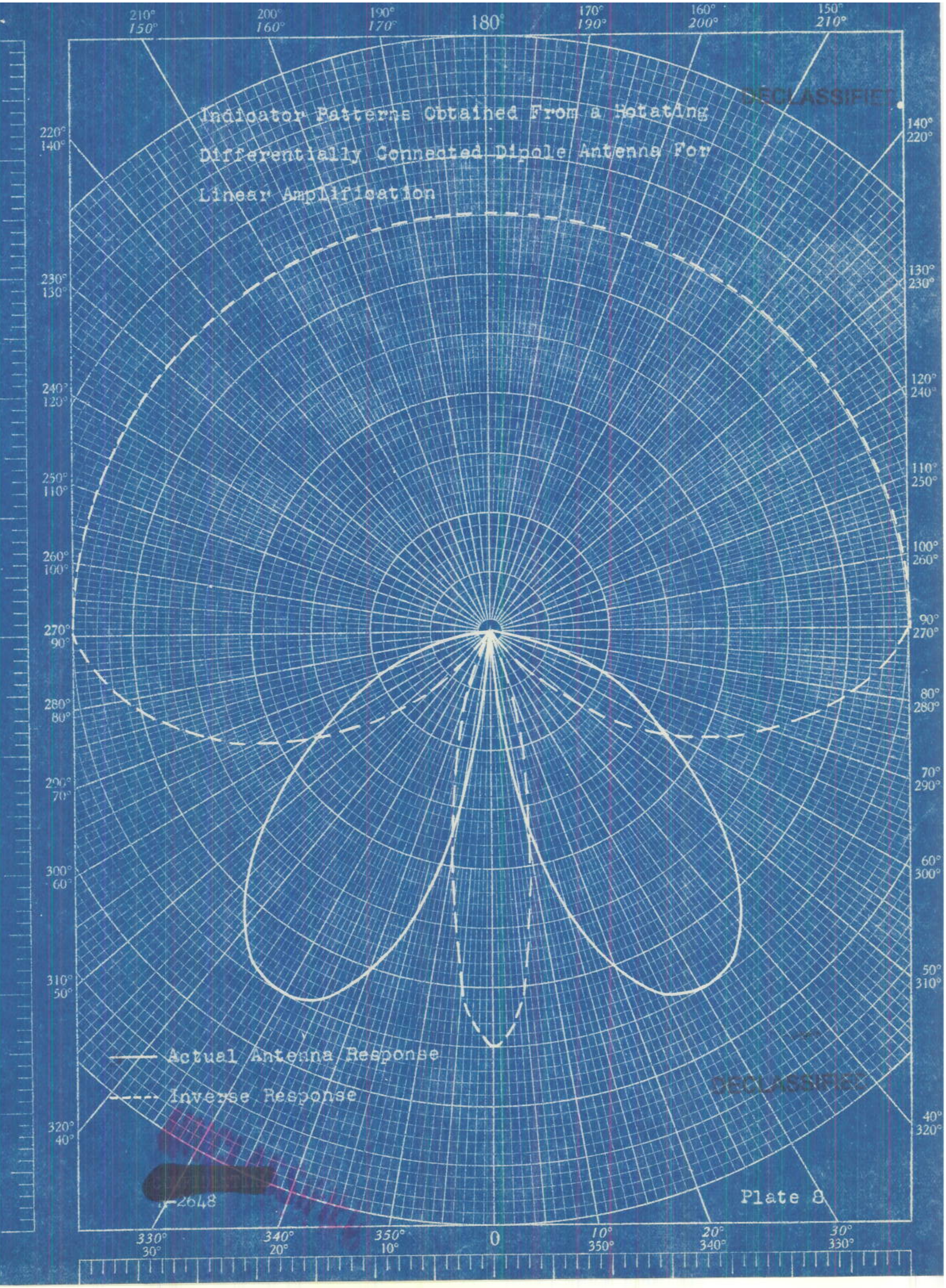

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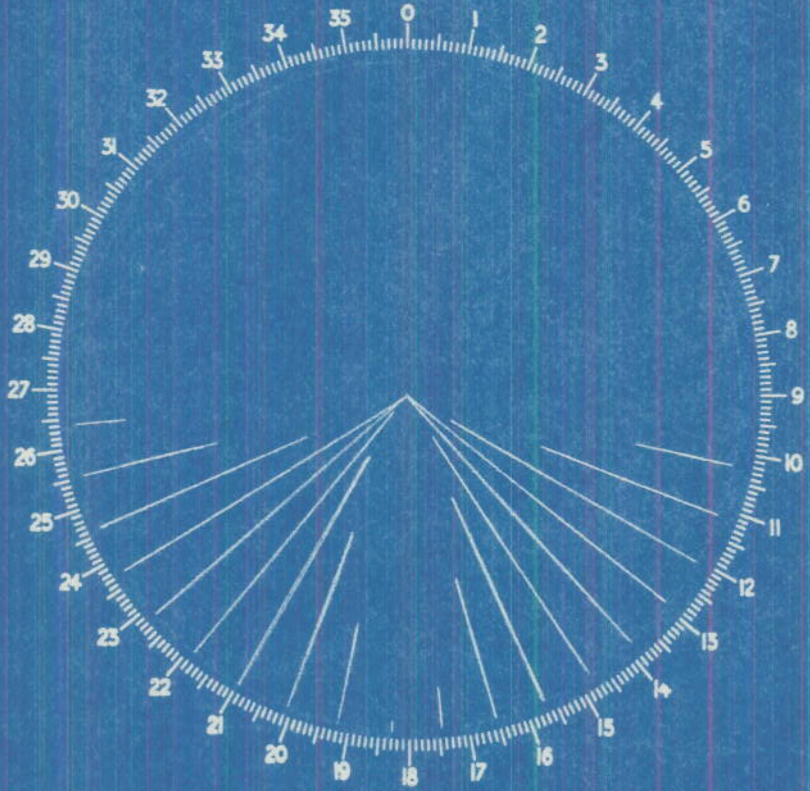
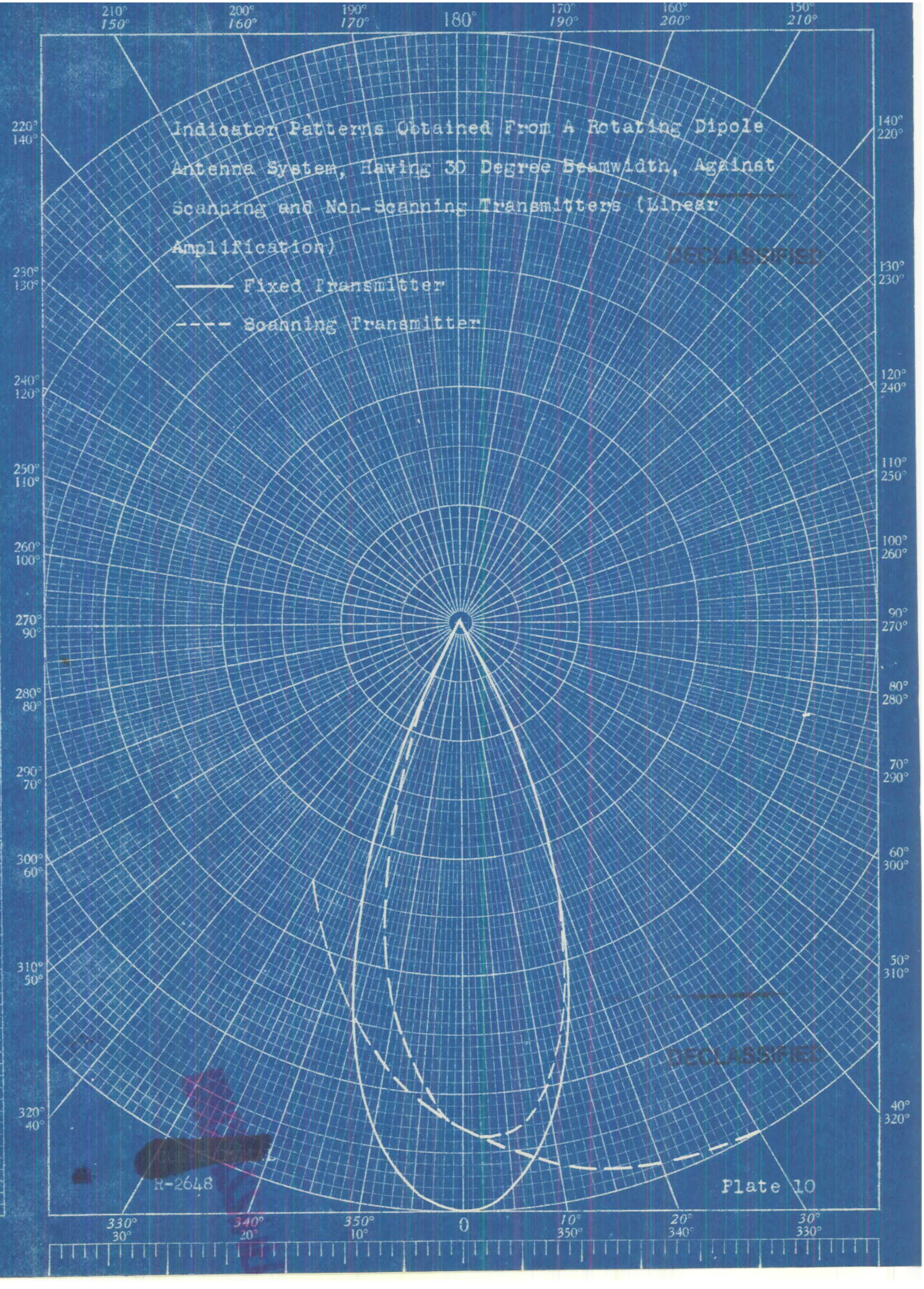
Plate 8



Inverse Indicator Pattern Obtained From A Differential Dipole Antenna System Scanning At 90 RPM And Receiving A Radar Signal Pulsed 60 Times Per Second.

~~CONFIDENTIAL~~



Indicator Patterns Obtained From A Rotating Dipole Antenna System, Having 30 Degree Beamwidth, Against Scanning and Non-Scanning Transmitters (Linear Amplification)

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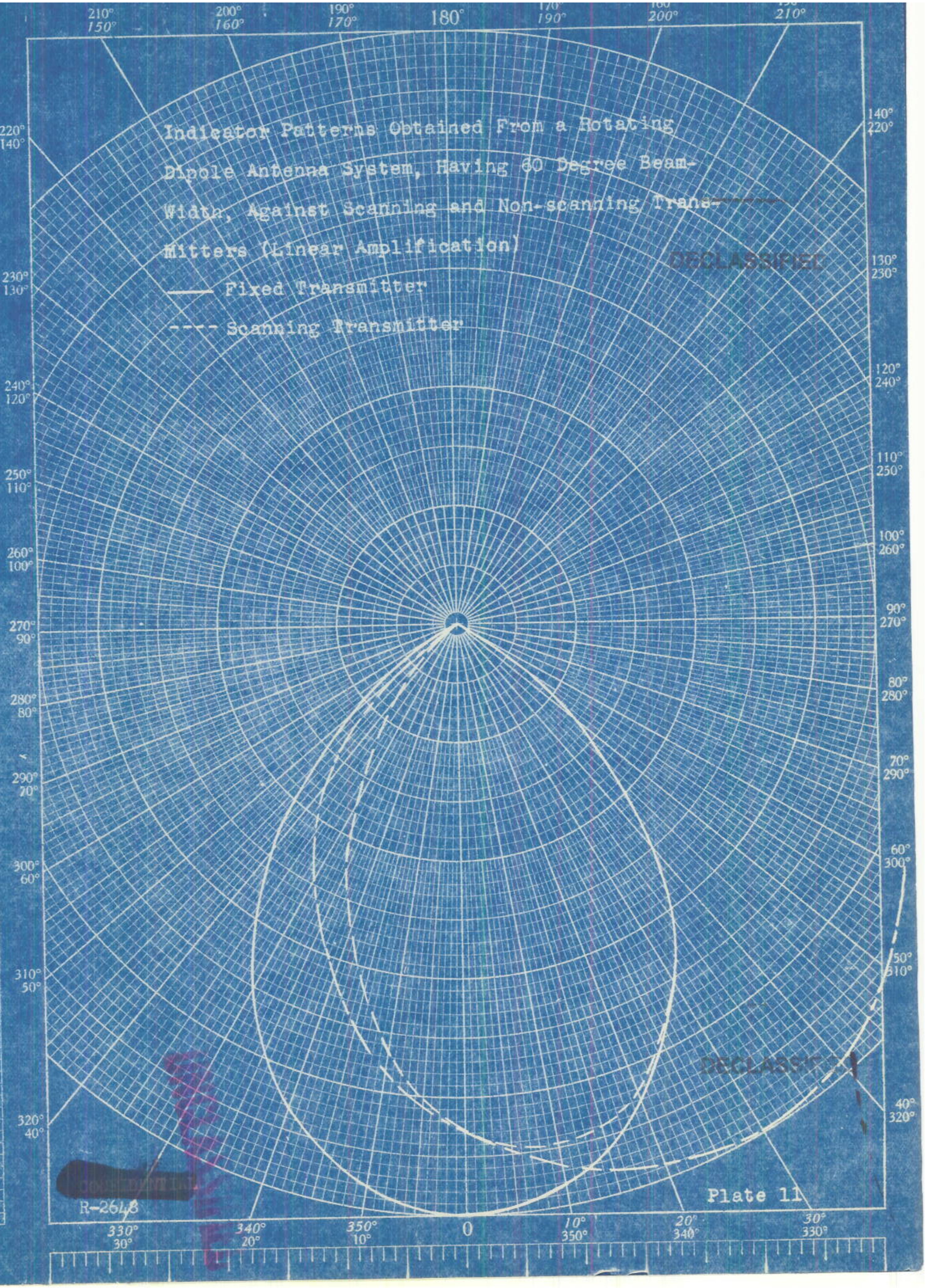
Plate 10

KEUFFEL & ESSER CO., N. Y. NO. 358-31
Polar Co-Ordinates
MADE IN U. S. A.



Indicator Patterns Obtained From a Rotating Dipole Antenna System, Having 60 Degree Beam-Width, Against Scanning and Non-scanning Transmitters (Linear Amplification)

—— Fixed Transmitter

---- Scanning Transmitter

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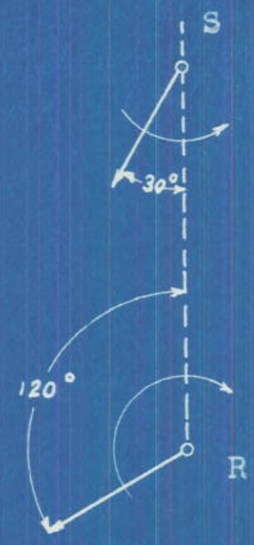
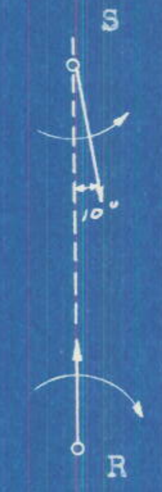
Plate 11

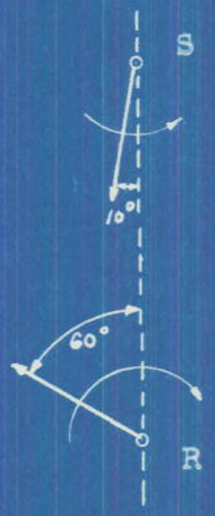
Relative Instantaneous Positions of Transmitting and D-F Antennas For Patterns Given in Plates (8) and (9).



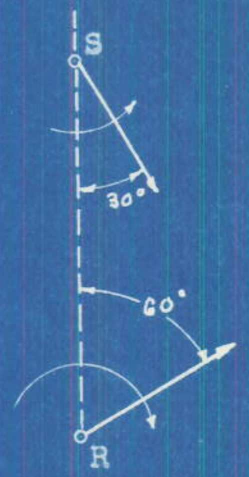
t = 0



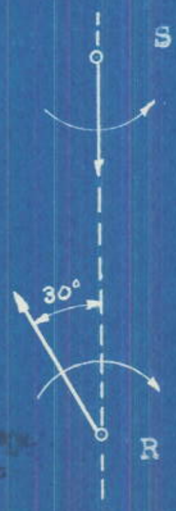
t = $\frac{T}{9}$



t = $\frac{T}{18}$



t = $\frac{T}{6}$



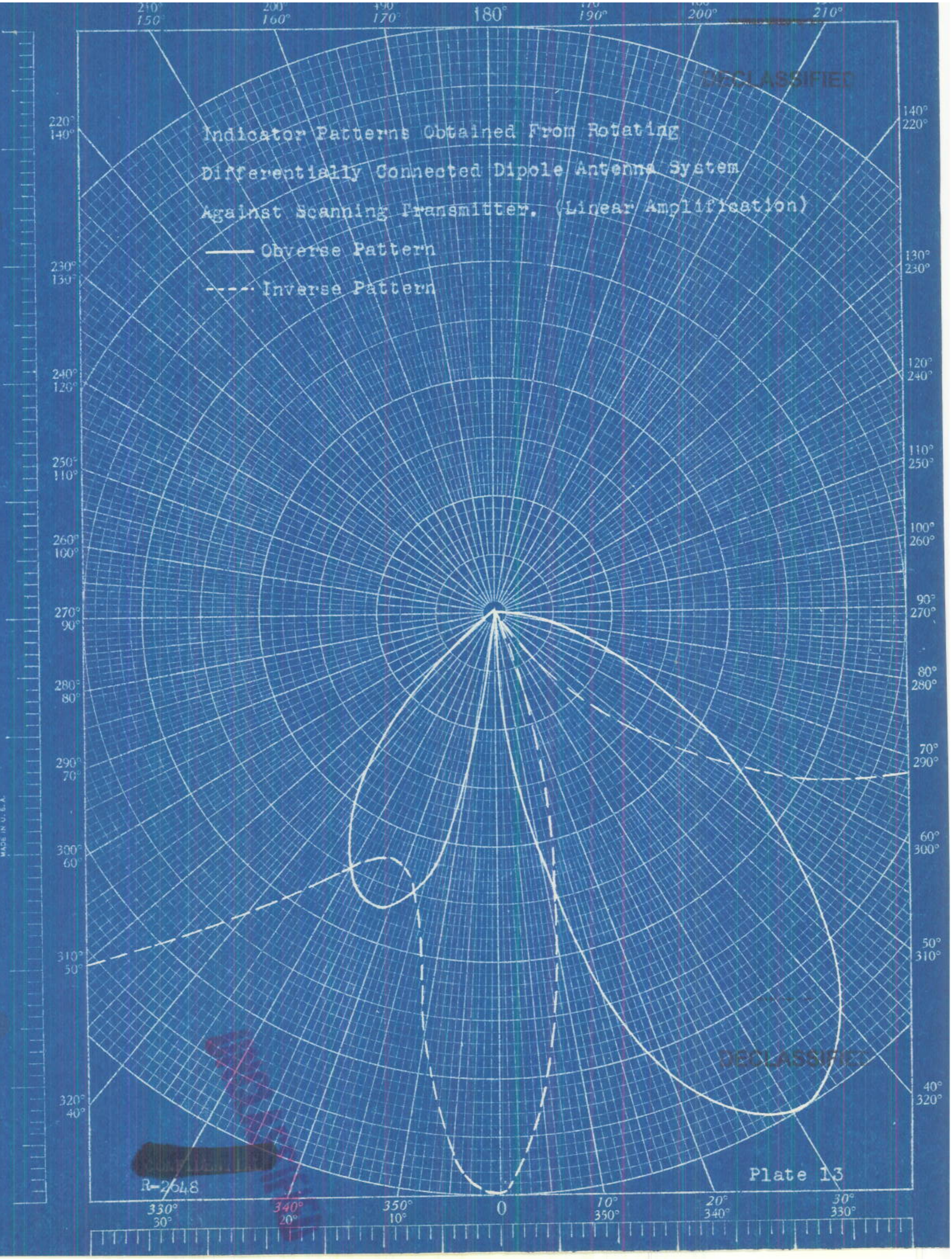
t = $\frac{T}{12}$

S = Transmitting antenna

R = Receiving antenna

T = Time required for transmitting antenna to make one sweep

$$\frac{\text{Angular velocity of S}}{\text{Angular velocity of R}} = \frac{1}{3}$$



Indicator Patterns Obtained From Rotating Differentially Connected Dipole Antenna System Against Scanning Transmitter. (Linear Amplification)

—— Obverse Pattern

----- Inverse Pattern

[redacted]

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Plate 13

ABI Pattern Obtained When a CW Signal Is Received By A Collector System Which Has a Figure-of-eight Response Pattern.

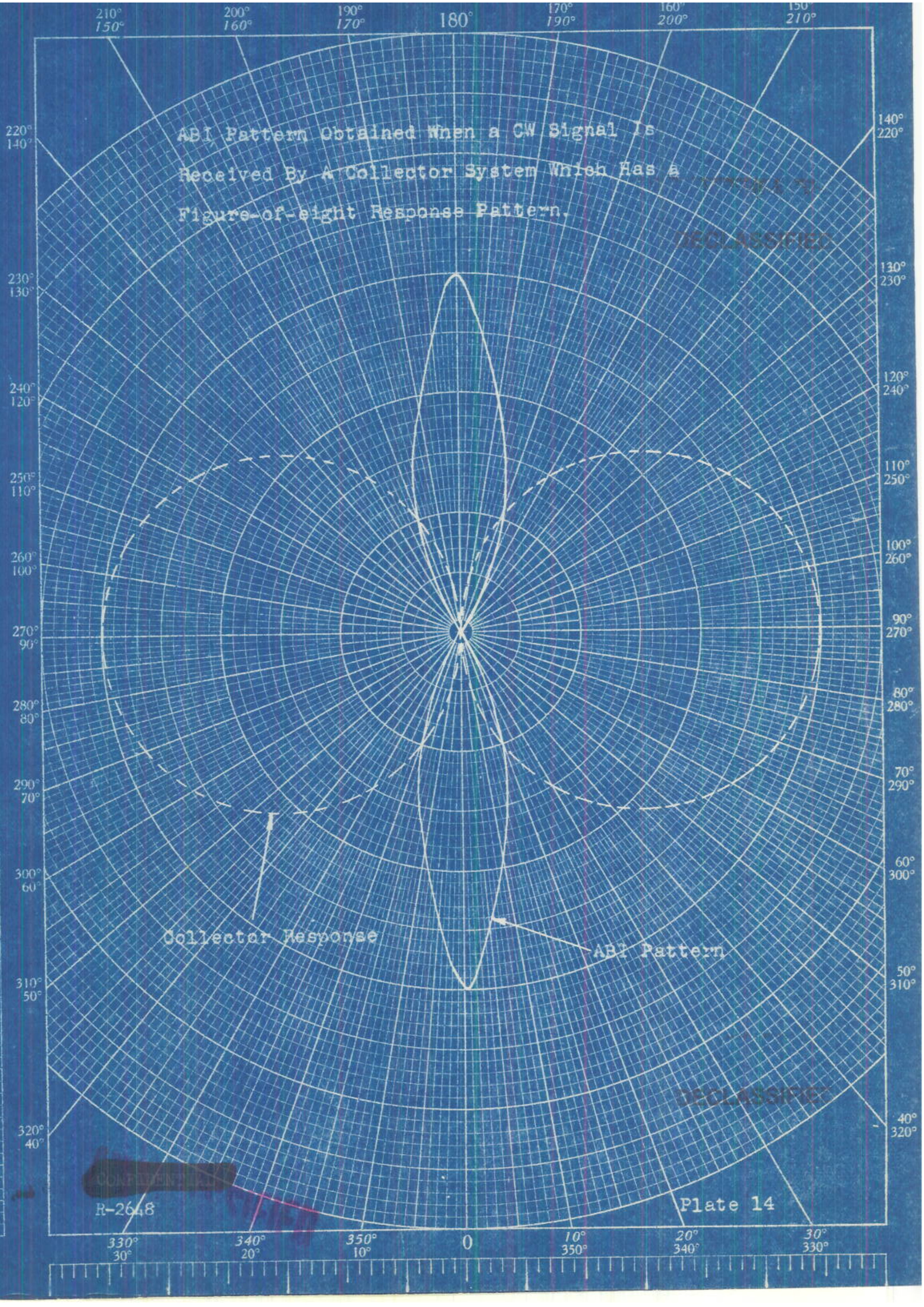

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Plate 14

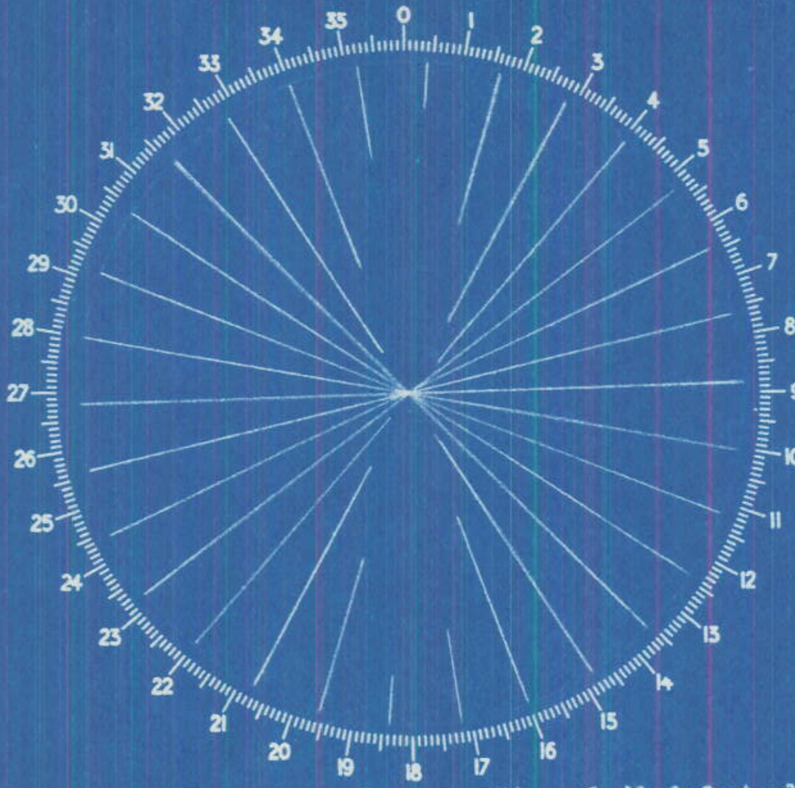
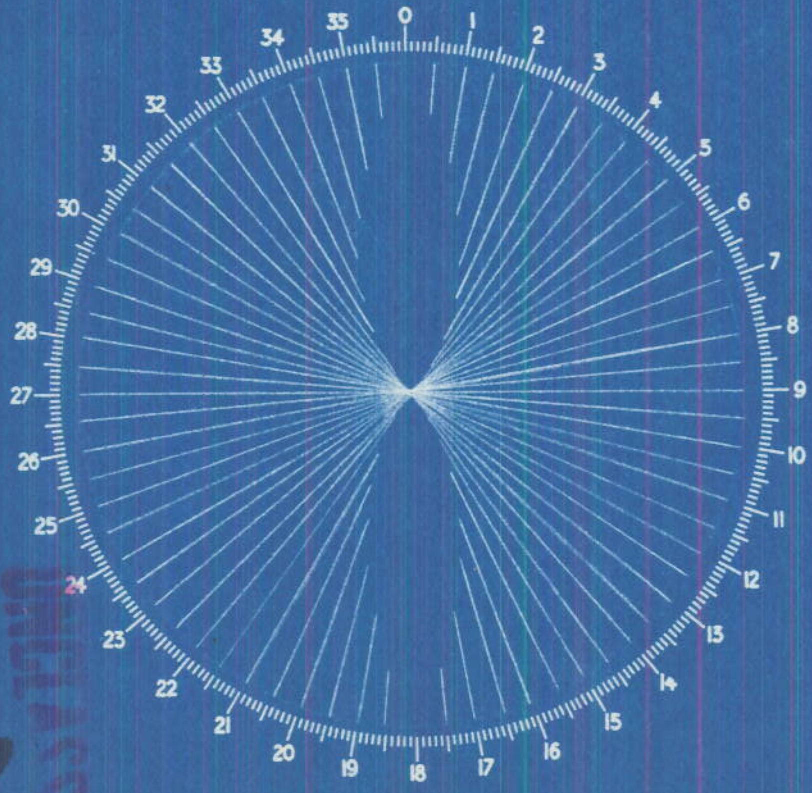


Fig.1 ABI Pattern Produced by a Signal Modulated With Very Short Pulses. Rotational Speed of D-F Antenna is Too Rapid For Accurate Bearing Determination.



[redacted]

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Fig 2 ABI Pattern Produced by the Same Signal as in Fig 1. However, the D-F Antenna Rotational Speed is Less Than One-half its Value in Fig 1.

[redacted]

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Maximum D-F Scanning Rate for Rotating Null Type Systems When Employed Against Pulsed Transmitters With Requirements That Bearing Be Readable to 2 Degrees. Pulse Width of Transmitter Assumed to be Less than 100 Microseconds.

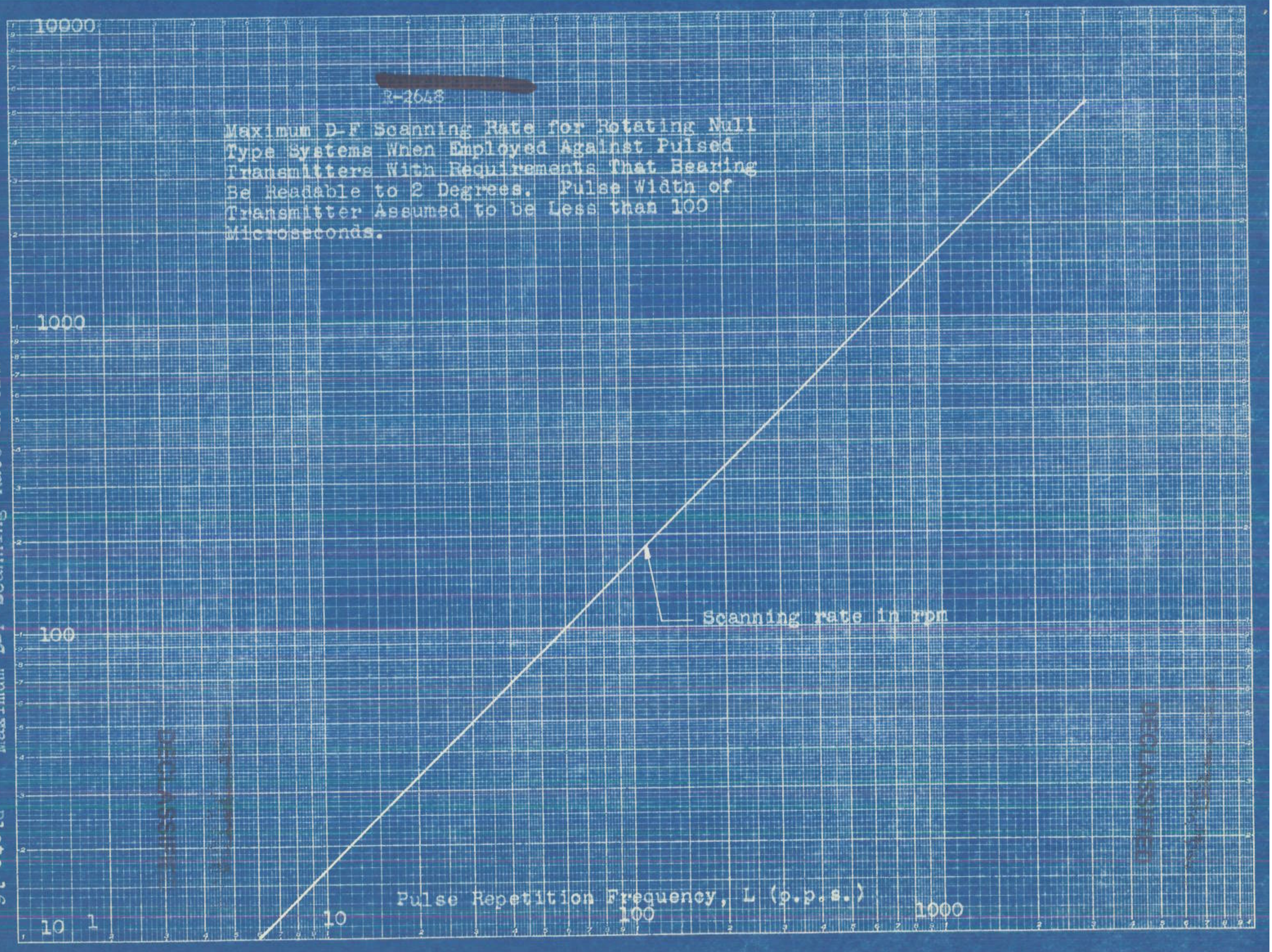
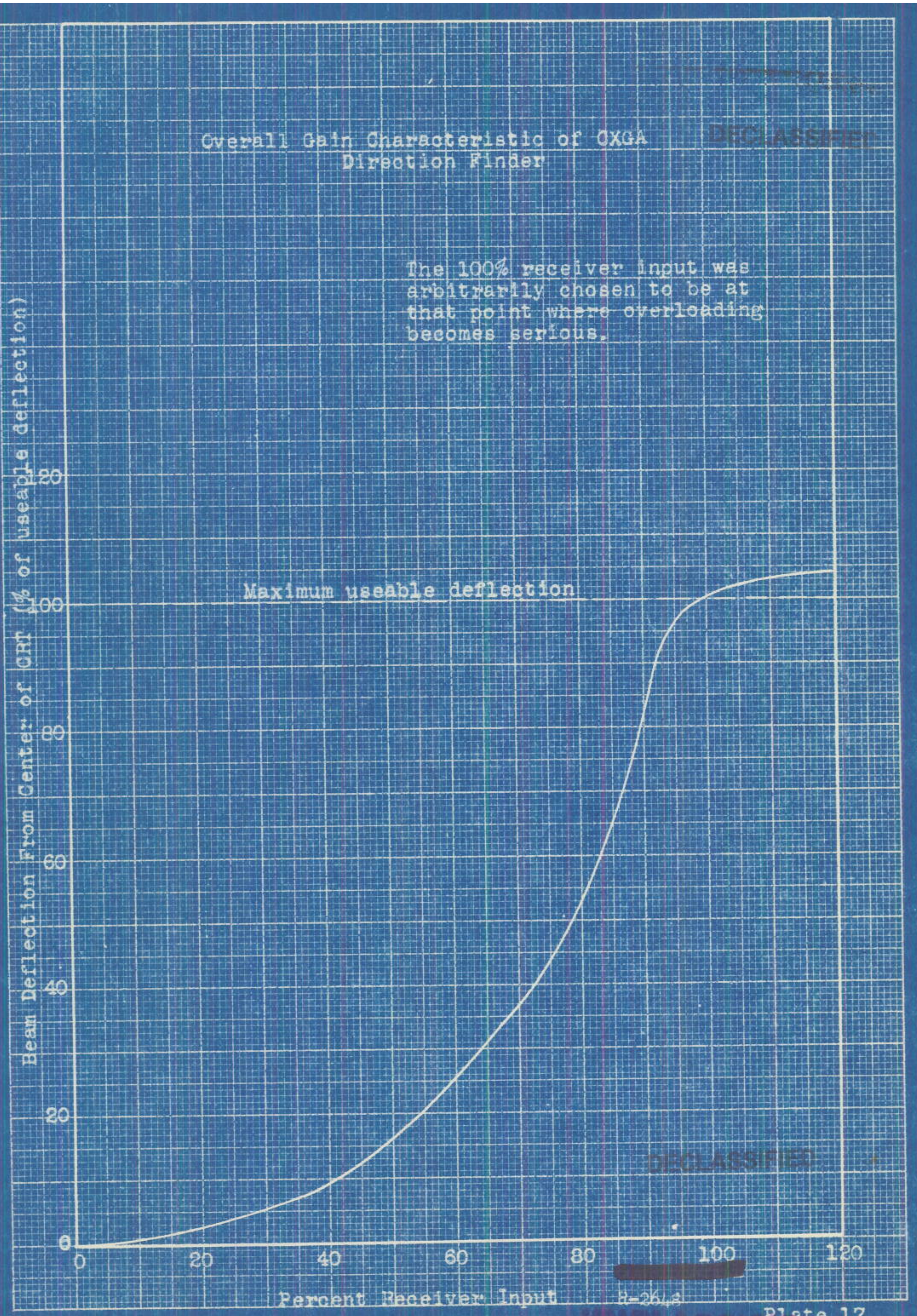


Plate 16

Overall Gain Characteristic of CXGA Direction Finder



The 100% receiver input was arbitrarily chosen to be at that point where overloading becomes serious.

[redacted]

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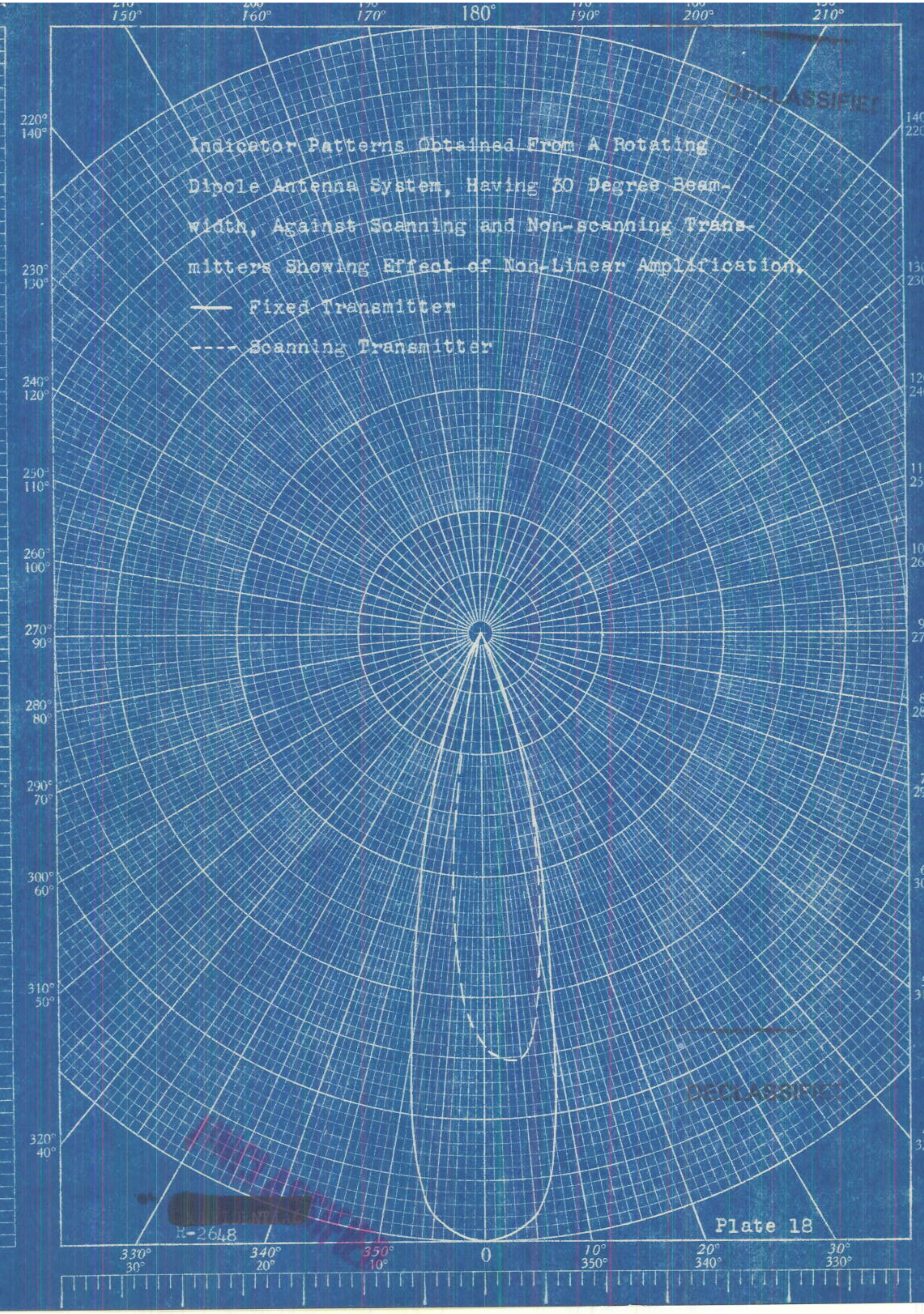
Plate 17



Indicator Patterns Obtained From A Rotating Dipole Antenna System, Having 30 Degree Beamwidth, Against Scanning and Non-scanning Transmitters Showing Effect of Non-Linear Amplification.

—— Fixed Transmitter

---- Scanning Transmitter

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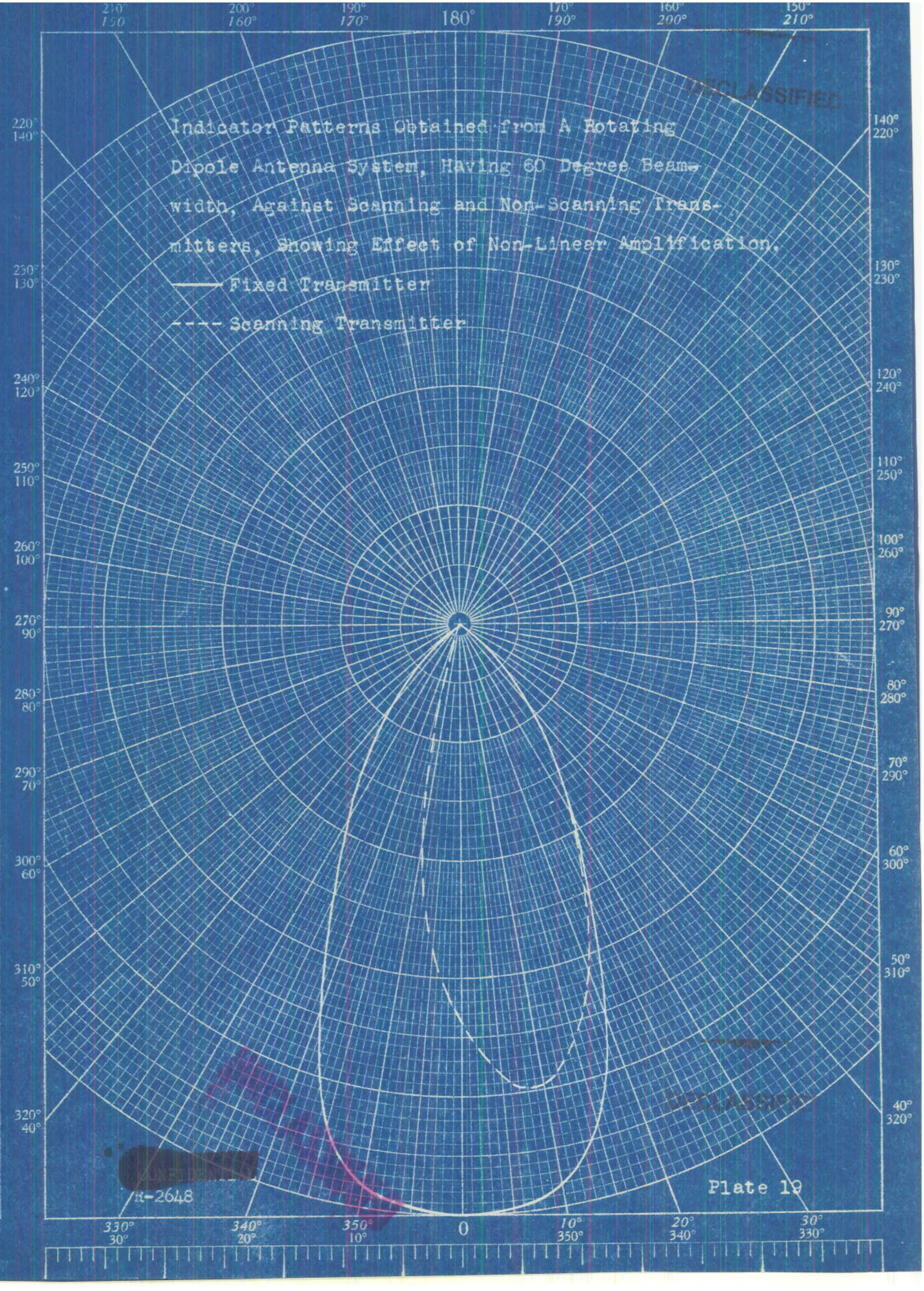
Plate 18



Indicator Patterns Obtained from A Rotating Dipole Antenna System, Having 60 Degree Beamwidth, Against Scanning and Non-Scanning Transmitters, Showing Effect of Non-Linear Amplification.

—— Fixed Transmitter

---- Scanning Transmitter

[redacted]

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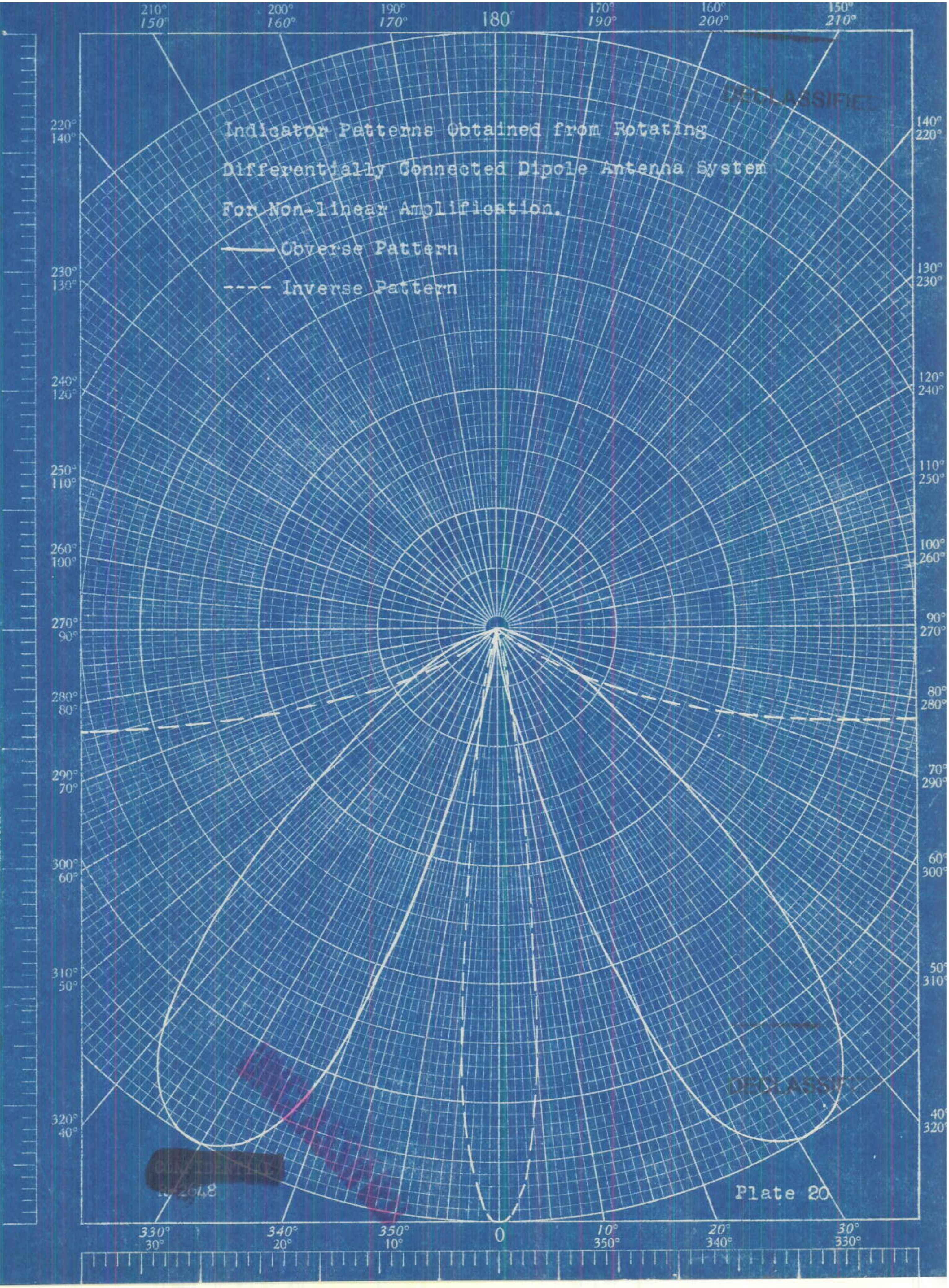
Plate 19



Indicator Patterns Obtained from Rotating Differentially Connected Dipole Antenna System For Non-linear Amplification.

——— Obverse Pattern

- - - - Inverse Pattern

Plate 20

[redacted]

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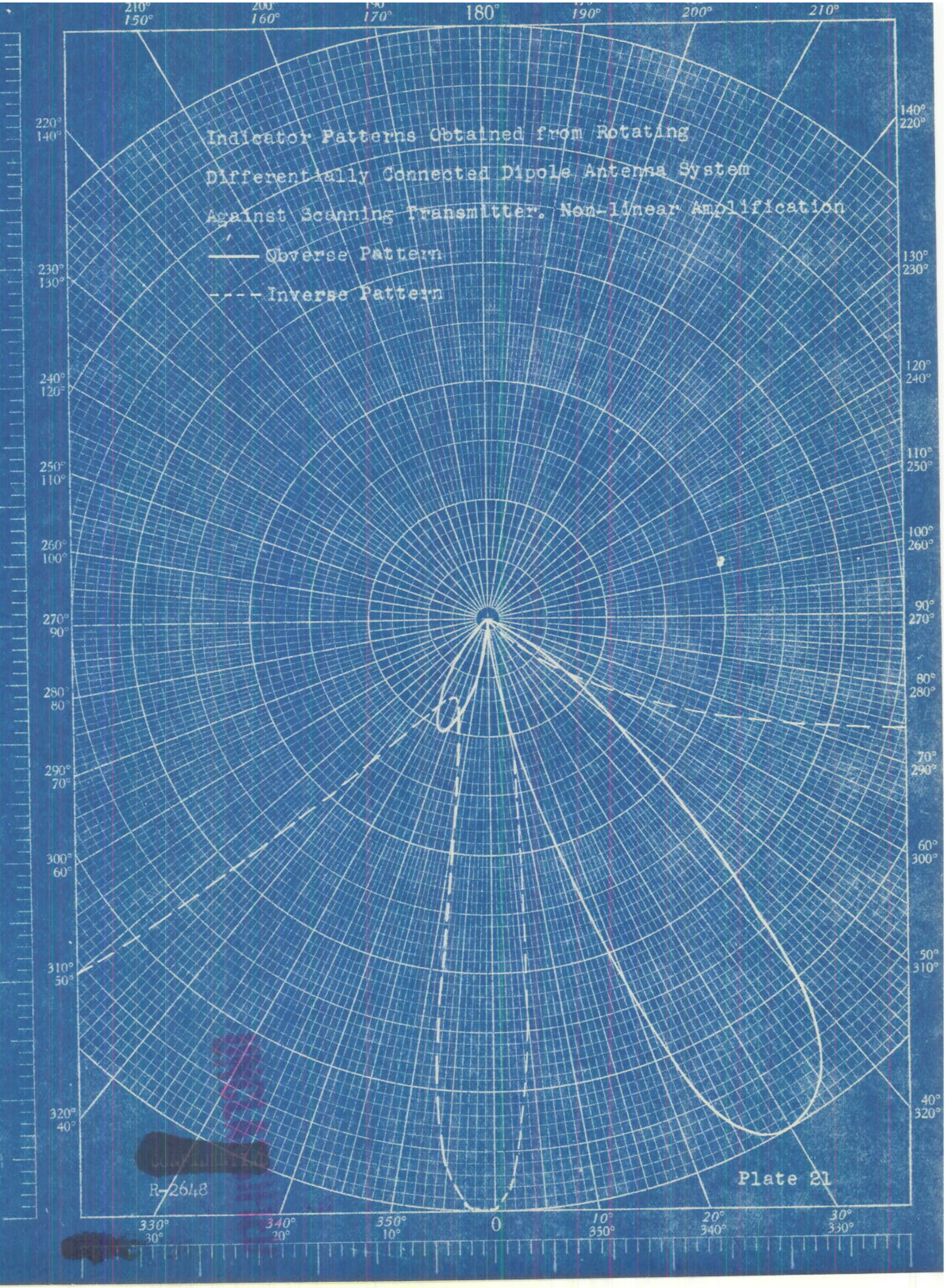

Indicator Patterns Obtained from Rotating Differentially Connected Dipole Antenna System Against Scanning Transmitter. Non-linear Amplification

——— Obverse Pattern

- - - - Inverse Pattern

[redacted]

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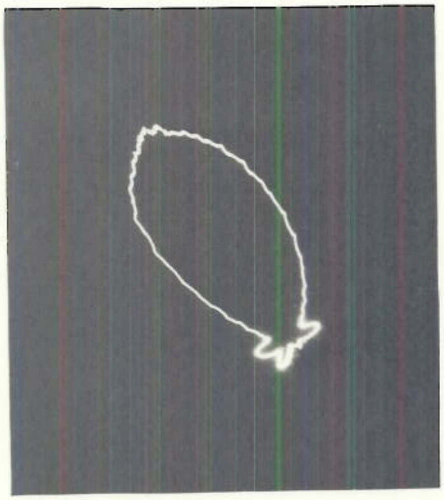
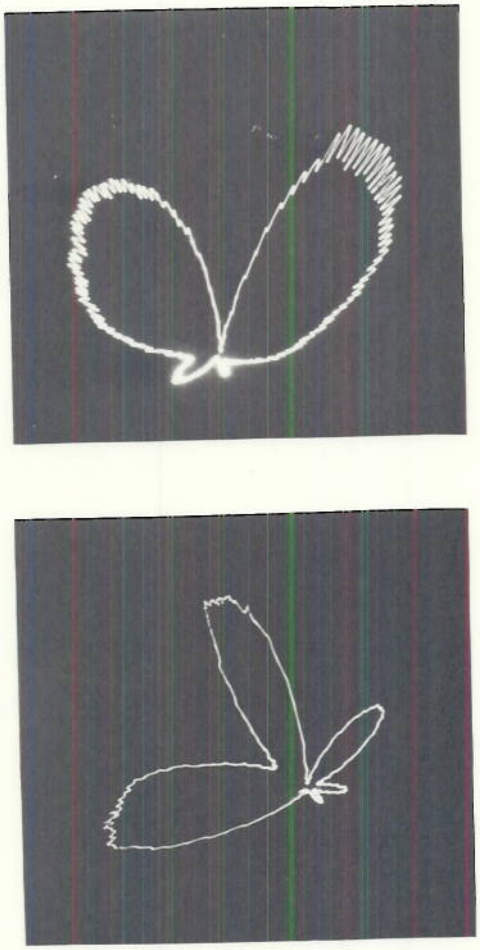
[redacted]

Plate 21

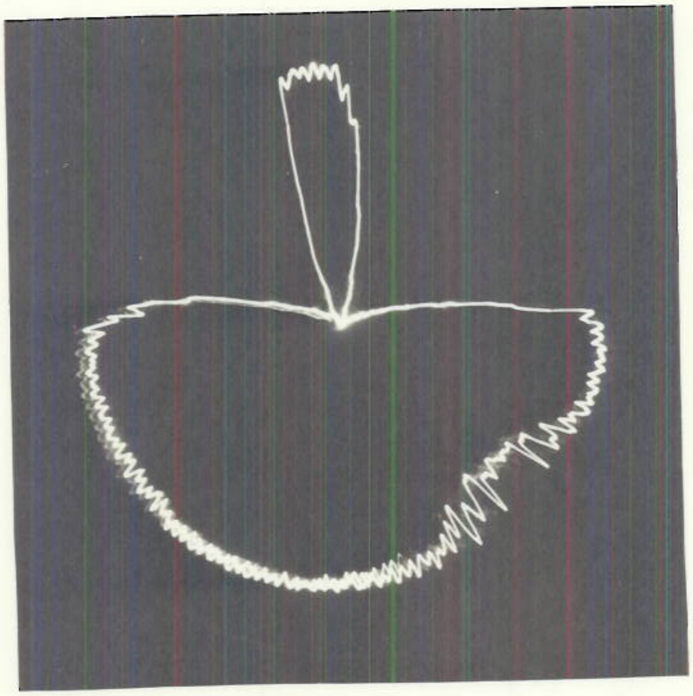


INDICATOR PATTERN PRODUCED BY THE
SINGLE DIPOLE (PLUS REFLECTOR) ANTENNA

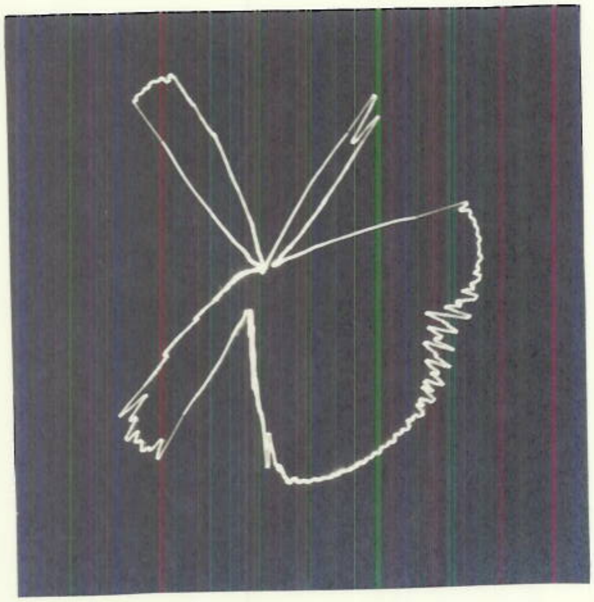
PLATE 22



CXGA INDICATOR PATTERNS PRODUCED BY THE ROTATING DIFFERENTIAL DIPOLE (PLUS REFLECTOR) ANTENNA



INVERSE CXGA INDICATOR PATTERN PRODUCED BY THE ROTATING DIFFERENTIAL DIPOLE (PLUS REFLECTOR) ANTENNA



EXAMPLE OF INVERSE INDICATOR PATTERN OBTAINED WHEN RERADIATION EXISTS AT THE SITE OF THE DIFFERENTIAL DIPOLE ANTENNA

DISTRIBUTION:

BuShips	- 10
CNO (OP-413-B2)	- 3
CNO (OP-413-C3)	- 3
ORI	- 1
NEL,San Diego	- 1
OCSigO,SPSTM-3	- 1
CG, AAF (Attn. Miss Diamond)	- 1
CO,SCEL	- 1
CO,AAF, Watson Lab.	- 1