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Radio Division - Transmitter Section

NOTES ON THE DESIGN OF FLAT SCREENS FOR UHF DIRECTIVE ANTENNAS

by

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ABSTRACT

An investigation has been made to determine the effects of screen size, element spacing from the screen, and type of screening upon the amounts of back radiation and pattern distortion in the case of an antenna array consisting of parallel elements equally spaced from a flat reflecting surface. Measurements were taken using a half wave dipole and a flat reflecting screen and the results permitted the determination of the optimum screen size and type of screening for the case of an array with a flat screen. Measurements were made at 400 Mc and conclusions reached would not necessarily be applicable for frequencies widely differing from this.

A method of predicting the amount of distortion which will exist in an antenna pattern is described. (Distortion is defined as deviation from the theoretical pattern for an infinite perfectly reflecting screen.)

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APPENDICES

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AUTHORIZATION

1. This investigation was carried out under the authority granted in reference (a). Since general design information was obtained in this investigation, the results should prove helpful in the design of directive UHF antennas using a flat screen, especially where it is necessary to reduce the back radiation to a practical minimum.

Reference: (a) Naval Research Laboratory Problem N7R-C.

INTRODUCTORY

2. In the case of screen type antennas, there are various reasons why the measured field strength pattern is somewhat different from the pattern calculated from the geometric and electrical properties of the antenna. Among these reasons are the following:

(a) A theoretical calculation assumes an infinite screen, but measurements indicate that the dimensions of screen demanded by practical considerations fall short of simulating an infinite screen.

(b) A theoretical calculation also assumes a perfectly reflecting screen, and again practical considerations often require a type of screening which is not perfectly reflecting.

3. In addition to distortion of the field strength pattern, back radiation is obtained as a result of the screen being of finite size and not perfectly reflecting. Some of this back radiation is due to leakage through the screen, because it is a mesh rather than a continuous sheet; whereas some is due to the finite size of the screen, i.e., the electromagnetic field may be diffracted around the edges and currents may flow from the front of the screen around the edges onto the back, with the result that radiation occurs in the backward direction. Measurements have been made to determine the effect of screen size on the amounts of pattern distortion and back radiation. Measurements were also taken to determine the relative effectiveness of various types of screening. Measurements were made at 400 Mc, using a single dipole antenna and a flat reflecting surface. The results obtained, however, are applicable to the design of more complicated antenna arrays.

DESCRIPTION OF MEASUREMENTS

4. The final results were obtained from field strength measurements at certain positions with respect to a radiating system and from the power fed to the radiating system. Sketches of the experimental setups can be found on Plates 2 and 3. All of the experimental work was done at 400 Mc. The radiating system consisted of a half-wave dipole located in the desired positions with respect to the various types of screen and will be described in more detail for each type of measurement. The relative powers fed to the radiating system were obtained from slotted-line measurements. The field strength detector consisted of a dipole feeding a receiver. To

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determine the relative magnitude of a given field strength the following procedure was used. With the pickup dipole in the field which was to be measured, the energy absorbed by it was carried to the receiver by a concentric transmission line and a certain response of the receiver was obtained. The same receiver response was then obtained by using a signal generator to feed the receiver and adjusting the attenuator of the signal generator. Since the attenuator was calibrated in microvolts and since the voltage applied to the receiver by the pickup dipole and transmission line system was directly proportional to the field strength, it is evident that relative values of field strength could be obtained by this method.

5. When the position of the radiating dipole was changed with respect to the screen, or in other cases when the type of screening was changed, the input impedance of the radiating dipole also changed causing varying amounts of power to be fed to it. In the results the measured values of field strength have been corrected to give the relative values for the same radiated power.

6. Among the several types of measurements made were those of field strength due to a dipole placed at various distances from the edge of a solid aluminum screen. Field strengths were measured throughout the 180° from directly in back of the screen to directly in front of it (see Plate 1). Measurements in the angular region 90°-180° show how the distance of the dipole from the edge affects the amount of back radiation. Distances of the dipole from the other three edges were great enough so that radiation in back of the screen could be considered to be due only to the one edge. In the angular region 0°-90° the measurements showed how the pattern of a dipole with a screen varied with the size of the screen.

7. A sketch of the experimental setup for these measurements is given on Plate 2. In the sketch the screen is oriented so that radiation in the $180^\circ-\beta$ direction is being measured. See Plates 1 and 2 for angular designation of direction. The pickup antenna was located forty to seventy feet away. This distance was great enough to smooth out the interference pattern due to the propagation and also the interference pattern due to diffraction around the edge of the aluminum screen. The distance was kept as small as was consistent with the above mentioned considerations in order to minimize the error introduced by reflection from surrounding objects. Checks were made and the magnitude of this reflection was found to be small enough to permit significant results to be obtained. See paragraph 14.

8. The radiating dipole was located one-tenth wavelength from the plane of the screen and at the desired distance from the edge. For each orientation of the screen, field strength readings were taken for various distances of the dipole from the edge of the screen. The dipole was vertical and thus parallel to the edge of the screen.

9. As is shown in the sketch of Plate 2, the oscillator and the transmission line feeding the dipole were located so that the screen was between them and the pickup antenna. This was to minimize errors introduced

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by reflections from the oscillator, power supply, etc., and by radiation from the outside of the transmission line and the transmitter cabinet. Checks indicated that errors from these sources were negligible.

10. Data taken on the next type of measurement were not very extensive. It was an attempt to determine how the spacing of the dipole from the plane of the screen affected the back radiation. The experimental setup was the same as that described in paragraph 7. The field strength was measured as the dipole spacing from the screen was varied for several combinations of angular direction and distance of the dipole from the screen edge.

11. It should be noted that in the two types of measurement described above a solid aluminum screen was used. This was to assure that the effects measured were not due in any way to radiation leaking through the screen. Following these measurements, an attempt was made to determine the effects of different types of screen on back radiation. To make these measurements it was necessary to eliminate the effect of the finite size of the screen; i.e., to eliminate any effect of the edges. This was accomplished by using the type of screen under consideration to cover one end of a box 3' x 4' in cross section and about 8' long. See Plate 3. The rest of the box was covered with a fine wire mesh, Type B of Plate 5. Measurements showed that this type of screen permitted very little energy to leak through. The radiating dipole was placed inside this box and one-tenth wavelength from the end which was covered by the type of screening under measurement. The pickup dipole was placed outside the box in a position as shown on Plate 3. Relative field strengths as recorded in Table 2 are those measured at the detector position for the various types of screening used to cover the end of the box. The same amount of power was fed to the dipole in all cases. It should be noted that with the arrangement described above the field strength measured could be the result neither of diffraction nor of currents flowing around the screen edges.

12. These relative field strengths, however, are not exact measurements of the amount of radiation that would leak through were the different types of screen used as the reflectors for a given antenna array. This is due to the fact that a standing wave exists inside the box and the standing wave ratio changes as different types of screen are used to cover the end of the box. There are several ways in which this difficulty could have been avoided, In order to eliminate the standing wave the box could have been made very long and an absorbing material could have been used to prevent any energy from being reflected. Another solution would have been to eliminate the box and make screens of very large dimensions in order to remove the effect of the edges. Neither of these schemes was practical under the circumstances.

RESULTS

13. It is hoped that the results of these measurements can be used in the design of antennas, particularly in cases where it is desired to minimize back radiation and distortion in the antenna pattern. As pointed out in paragraph 2, two of the factors which contribute to back radiation and which cause the measured pattern of an antenna to deviate from the theoretical pattern are that the reflecting screen is not infinite in extent and that

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it usually is not a perfectly reflecting surface.

14. Curves showing radiation in various directions as a function of the distance of the dipole from the edge of the screen which in this case consists of a solid aluminum sheet are shown in Plates 6 and 7. Experimental points are joined by straight lines to prevent the confusion that would exist should smooth curves be used. It will be noticed that in the angular region in back of the screen (90°-180°) the field strength decreases with increase in the distance of the dipole from the screen edge. This is as would be expected. The important thing to note is that the rate of reduction in back radiation is much smaller beyond 0.4λ than it was up to this point. Increases in field strength shown by some of the curves beyond this point are principally due to reflections of the front radiation from surrounding objects. Checks indicated that these reflections were of the right magnitude to produce such increases. Careful consideration shows that the conclusions drawn from these measurements are not affected appreciably by the presence of errors due to these reflections. The significance of data taken in the angular region in front of the screen (0°-90°) is discussed in the paragraphs following.

15. On Plate 8 the data are replotted to show the field strength patterns for the dipole at various distances from the edge of the screen. Curves are plotted for distances of the dipole up to 0.8λ from the edge. The power input to the dipole is the same in each case. These curves are useful in predicting how an actual field strength pattern of an array will compare with a theoretical pattern. This will be discussed in paragraphs 18 and 19.

16. On Plate 9 some of these patterns are replotted so that each has a field strength in the 0° direction of 100 relative volts per meter. A theoretical pattern for a dipole with an infinite screen is also plotted. As would be expected the shapes of the curves approach the shape of the theoretical curve as the distance of the dipole from the edge is increased.

17. As pointed out in paragraph 14, the rate of reduction in field strength in the angular region 90°-180° is much less beyond 0.4λ than up to that point. Correspondingly, in Plate 9 the curves show that beyond this point the rate of improvement in the pattern is considerably less than in the region 0.1λ to 0.4λ. It may be concluded that in designing an antenna array with a flat screen the overlap, i.e., the distance the screen extends beyond the last element on either end (see Plate 4), should be about 0.4λ in order to minimize back radiation and distortion of the field strength pattern. The low rate of improvement beyond this point would make impractical any further extension of the screen for a $\lambda/10$ spacing of the dipole from the screen.

18. To demonstrate an application of these results to antenna design, let us consider an antenna array consisting of two vertical elements spaced 0.5λ apart horizontally and mounted 0.1λ from a rectangular screen. The general practice is to make the overlap of such an amount that angle μ, Plate 4, is about 50°, i.e., the overlap is about 0.12λ. For most applications this size screen would be sufficiently large. Assume however that it

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is desired to reduce the back radiation and pattern distortion to a practical minimum. (Distortion is taken to mean deviation from the theoretical pattern for an infinite screen.) The curves of Plates 6 and 7 indicate that the overlap should be increased to 0.4λ . The curves on Plate 8 may be used to indicate the degree that the pattern distortion is reduced by this increase of overlap. If one assumes that the two elements are fed in phase and carry currents of equal magnitude, then the distortion of the field strength pattern is most apparent in a direction parallel to the screen and perpendicular to the vertical elements, i.e., the 90° direction. For the case where the overlap is 0.12λ the field strength due to the element closest to the end is 76 and that due to the other element is 33. These values may be obtained directly or by interpolation from the curves on Plate 8. The field strengths, however, are approximately 180° out of phase due to the spacing, so the resultant in this direction is approximately 43. In a direction perpendicular to the screen the two field strengths are in phase and add directly giving a value of 305. The ratio of field strengths in the two directions, parallel to the screen and perpendicular to the screen, is thus computed to be 0.14. Proceeding in the same way for the case in which the same array utilizes a screen with an overlap of 0.4λ the corresponding ratio is found to be 0.02. The ratio for a theoretical pattern (assuming infinite screen) would of course be zero. The accuracy of these figures is not good due to the difficulty in interpolating between curves of the type shown on Plate 8. It does show, however, that considerable improvement is obtained by increasing the screen overlap from 0.12λ to 0.4λ. For a more accurate quantitative comparison, the method described in paragraph 20 below could be used.

19. The use of the curves of Plate 8 in predicting the distortion of an antenna pattern is not strictly accurate, since the curves for a dipole with a screen will depend not only on the distance of the dipole from one edge but also somewhat on the overall size of the screen. The curves are sufficiently good to indicate approximately the distortion obtained.

20. A method for predicting actual patterns suggests itself. For the size screen to be used in the final antenna, separate field strength patterns are taken with a dipole in the various positions where the elements would be in the final array. The curves should be plotted on the basis that the same amount of current exists at the antinode point of the dipole in each case. If the array consists of M parallel elements, equally spaced from the screen (see Plate 4), the field strength pattern can be then calculated from the formula

$$E = K\sqrt{\sum_{m} k_m^2 + 2\sum_{\substack{mn \\ m \neq n}} k_m k_n \cos(\alpha_m - \alpha_n)}$$

$$k_m = C_m C^1_m$$

Where C^1_m is the function of θ represented by the field strength pattern for the dipole in the position of the m^{th} element in the array.

[redacted]

C_m - The current in the m^{th} element of the array is proportional to C_m.

$\sum_m k_m^2$ - means a summation of all the k_m^2 from $m=1$ to $m=M$.

$\sum_{\substack{mn \\ m\neq n}} k_m k_n \cos(\alpha_m - \alpha_n)$ indicates a double summation. It is the summation of terms of the form $k_m k_n \cos(\alpha_m - \alpha_n)$ using all the possible combinations of m and n, as m and n each run from 1 to M except the cases in which m=n. Also, a term of the form $k_p k_q \cos(\alpha_p - \alpha_q)$ is to be considered identical with a term of the form $k_q k_p \cos(\alpha_q - \alpha_p)$. They are not to be considered to make up separate terms in the summation. In general, there will be $\left(\frac{M^2-M}{2}\right)$ terms in the summation.

$$\alpha_m = \frac{2\pi D_m \sin\theta}{\lambda} + \phi_m$$

D_m = The distance from the first element to the m^{th} element. See Plate 4.

ϕ_m = The angle by which the current in the m^{th} element leads that in the first.

λ The wavelength.

θ The angle with respect to the perpendicular to the reflecting screen. See Plate 4.

D_m and λ must be measured in the same units.

K - This factor is a constant and may be set equal to 1 for convenience in calculating a field pattern.

21. The derivation of this formula differs only very slightly from the derivation of equation (19), page A-8 of NRL Report No. R-2253, "Improved Antenna for Model YL(XBC) Radio Beacon Equipment". One assumption made is that phase differences between the field strengths in a given direction due to the various elements with a screen are equal to the corresponding phase differences in the field strengths due to the elements alone. This is correct for the theoretical case in which an infinite reflecting screen is assumed. Some error may be introduced by making this assumption for the case of a finite screen. Careful consideration of this assumption shows that errors introduced by it should be small.

22. The theoretical pattern for such an array assuming an infinite perfectly reflecting screen can be calculated from the formula

$$E=K\sqrt{(1-\cos\gamma)\left(\sum_m k_m^2 + 2\sum_{\substack{mn \\ m\neq n}} k_m k_n \cos(\alpha_m - \alpha_n)\right)}$$

where in this case

$$\gamma = \frac{2\pi S \cos\theta}{\lambda}$$

$\frac{S}{2}$ is the spacing of the elements from the screen.

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k_m - the current in the m^{th} element is proportional to k_m.
All other quantities are as defined in paragraph 20.

23. Table 1 shows the effect of changing the distance of the dipole from the plane of the screen. As the spacing from the screen increases, the back radiation increases. The data are far from complete, since only two directions of radiation and two distances of the dipole from the edge of the screen were used. It seems reasonable to assume, however, that the trends shown by the more complete data taken for 0.1λ spacing would indicate what to expect for the other spacings. One thing should be noted: As the spacing of the dipole from the screen is increased, the directivity of the antenna pattern is decreased, at least in the range of spacings used in these measurements. This can be shown by using the formula of paragraph 22. Table 1 suggests that, as the spacing from the screen increases, the back radiation increases. If the ratio of the field strength in the backward direction to the field strength in the forward direction were examined then this ratio would increase with increasing spacing from the screen.

24. The relative effectiveness of various types of screening is shown on Table 2. The table shows relative field strength with various types of screen as measured with the experimental set up described in a previous section in paragraph 11. Due to the fact that there was a standing wave inside the box and that the standing wave ratio changes with the type of screen used, it cannot be said that the figures of Table 2 represent the relative amounts of radiation that would leak through to the back if the various types of screen were used as reflectors for an antenna array. It will be noticed that for types A and B the relative field strength is approximately the same as that for the solid aluminum screen. It is evident from this that this figure represents the amount of field strength contributed by the current on the outside of the transmission line from the transmitter and by leakage in other parts of the apparatus, since there could be no appreciable transmission through the solid aluminum sheet. Type C screening permits considerably more radiation to leak through than either type A or type B. It seems reasonable to assume that other types of perforated metal sheet would be as effective as type A provided that the percentage of the metal removed is not much greater than for type A. In all the types of screening used there was good electrical contact at the joints of the mesh.

25. Returning to the example of paragraph 18, the most practical thing to use as screening material for the antenna would appear to be the perforated metal. This type has the advantage of being strong mechanically as well as having good reflecting properties. Also, a perforated metal screen has the advantage that it weighs less and offers less wind resistance than a solid sheet.

SUMMARY

26. Data taken on screen size indicate that screens for flat arrays should extend approximately 0.4λ beyond the last element on either side. Curves show that up to 0.4λ the rates of reduction in the amounts of back

[redacted]

radiation and pattern distortion are quite a bit higher than beyond this point. It can be concluded that any additional extension beyond 0.4λ would not justify the added weight, size, wind resistance, etc.

27. Curves plotted from the data can be used in limited cases to predict the amount of distortion in patterns of antenna arrays due to the fact that the screen is not infinite. Also, a method is described by which actual antenna patterns can be predicted by taking patterns of dipoles using the size screen to be used in the completed array.

28. Data taken indicate that as the spacing of the dipoles from a given screen is increased the ratio of back radiation to front radiation is increased.

29. Concerning the data taken on different types of screening, an important result obtained is that a perforated metal sheet is a considerably better type of screening than a wire mesh whose holes are of approximately the same size as the holes in the perforated metal.

[redacted]

TABLE 1

VARIATION OF FIELD STRENGTH WITH SPACING OF DIPOLE FROM THE SCREEN

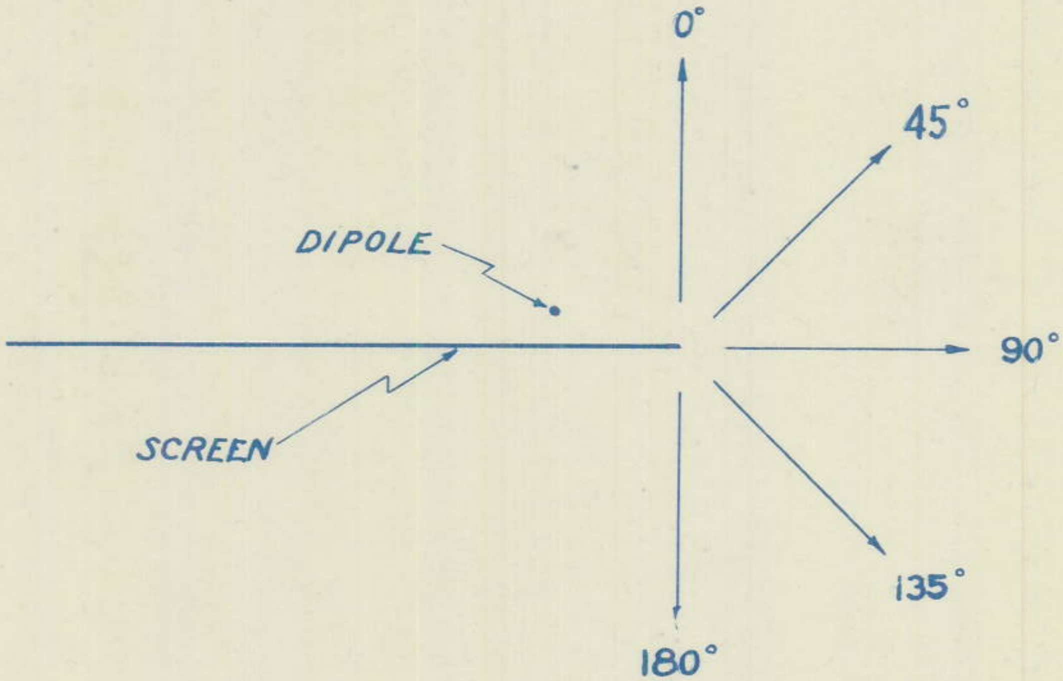
Distance of dipole from screen edge	Direction of Radiation	Spacing of dipole from screen	Relative Field Strength
.20λ	120°	.05λ	87
.20λ	120°	.10λ	100
.20λ	120°	.20λ	104
.20λ	140°	.05λ	78
.20λ	140°	.10λ	89
.20λ	140°	.20λ	87
.30λ	120°	.05λ	40
.30λ	120°	.10λ	45
.30λ	120°	.20λ	49
.30λ	140°	.05λ	33
.30λ	140°	.10λ	39
.30λ	140°	.20λ	39

TABLE 2

LEAKAGE THROUGH DIFFERENT TYPES OF SCREENING

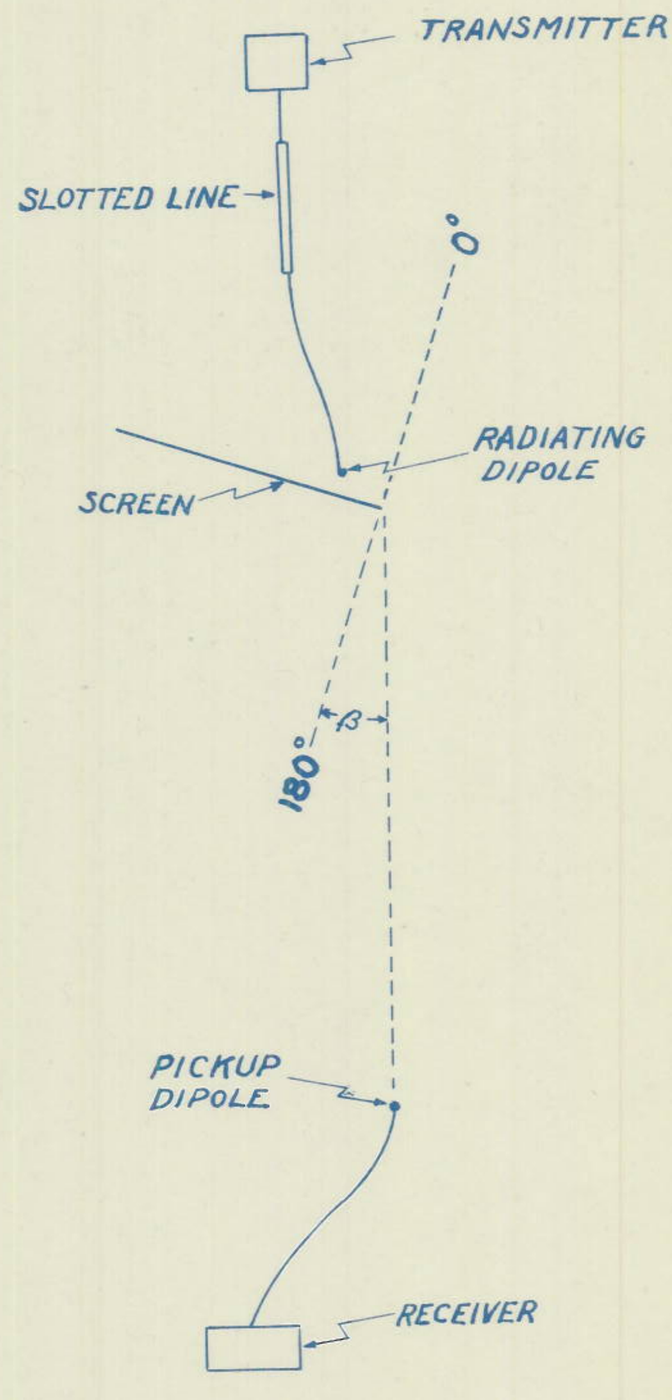
Type	Description	Relative Field Strength
	Aluminum Sheet	2.2
A	Metal Cane	1.7
B	Wire Screen, 16 mesh per inch	2.0
C	Hardware Cloth, 4 mesh per inch	6.6
D	Hardware Cloth, 2 mesh per inch	22.1
E	Same as D, alternate strands removed	108
F	Poultry Netting	181

[redacted]



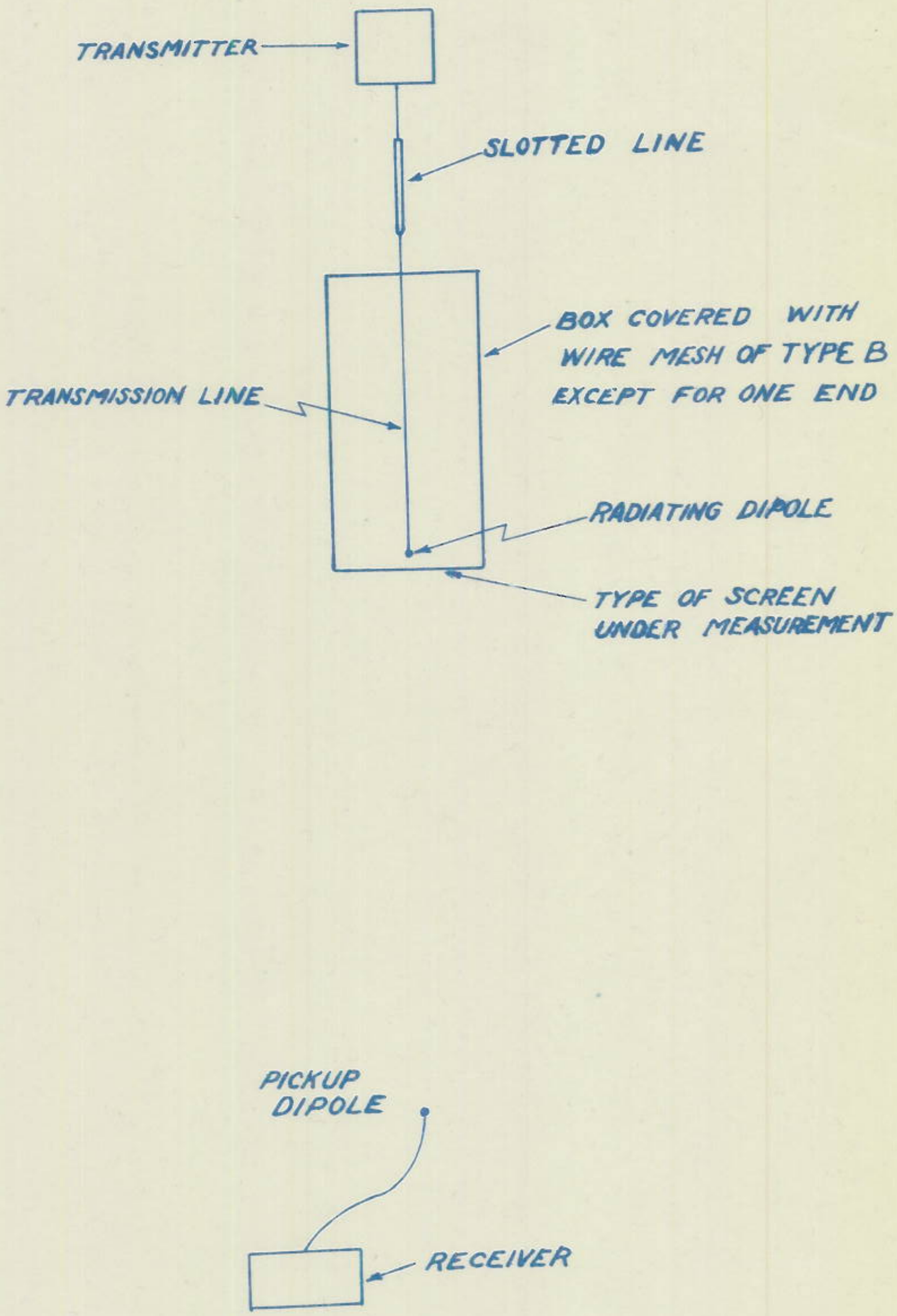
ANGULAR REGION OF 180°
THROUGHOUT WHICH FIELD STRENGTH WAS MEASURED

PLATE 1



BLOCK DIAGRAM OF EXPERIMENTAL SETUP

PLATE 2



BLOCK DIAGRAM OF EXPERIMENTAL SETUP
PLAN VIEW

PLATE 3

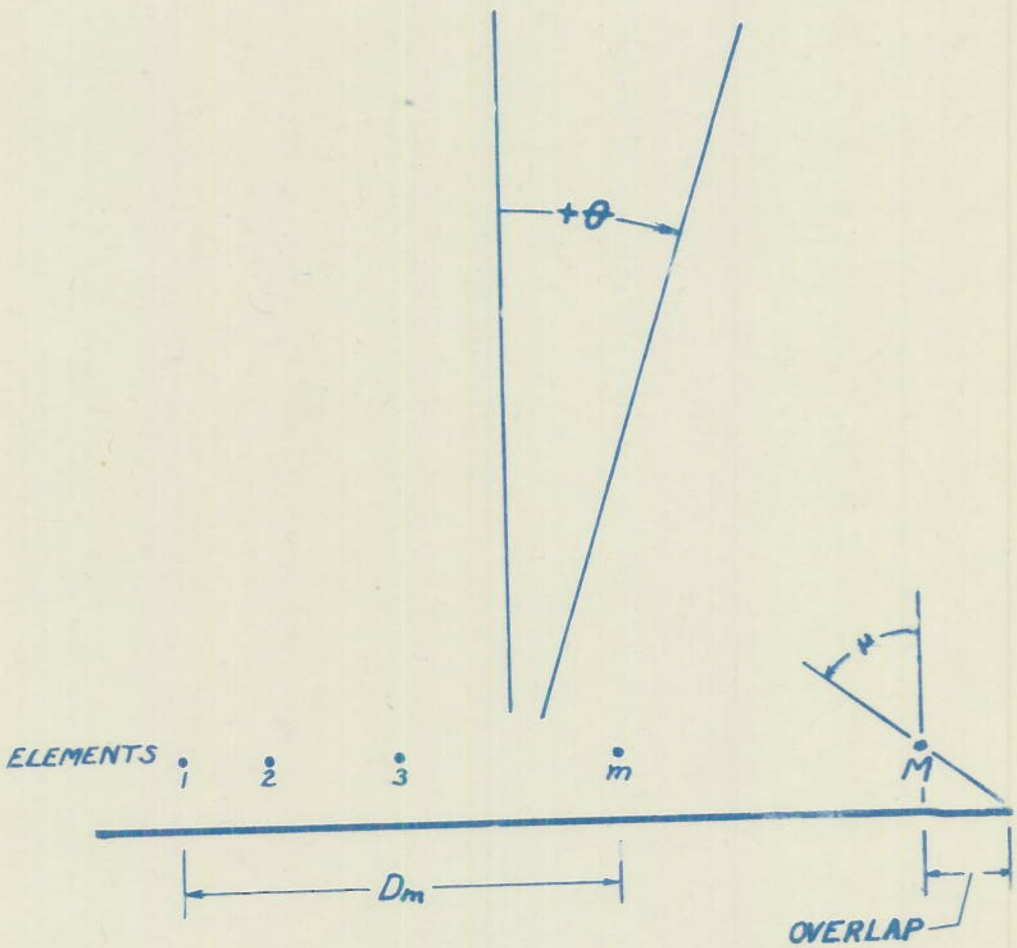
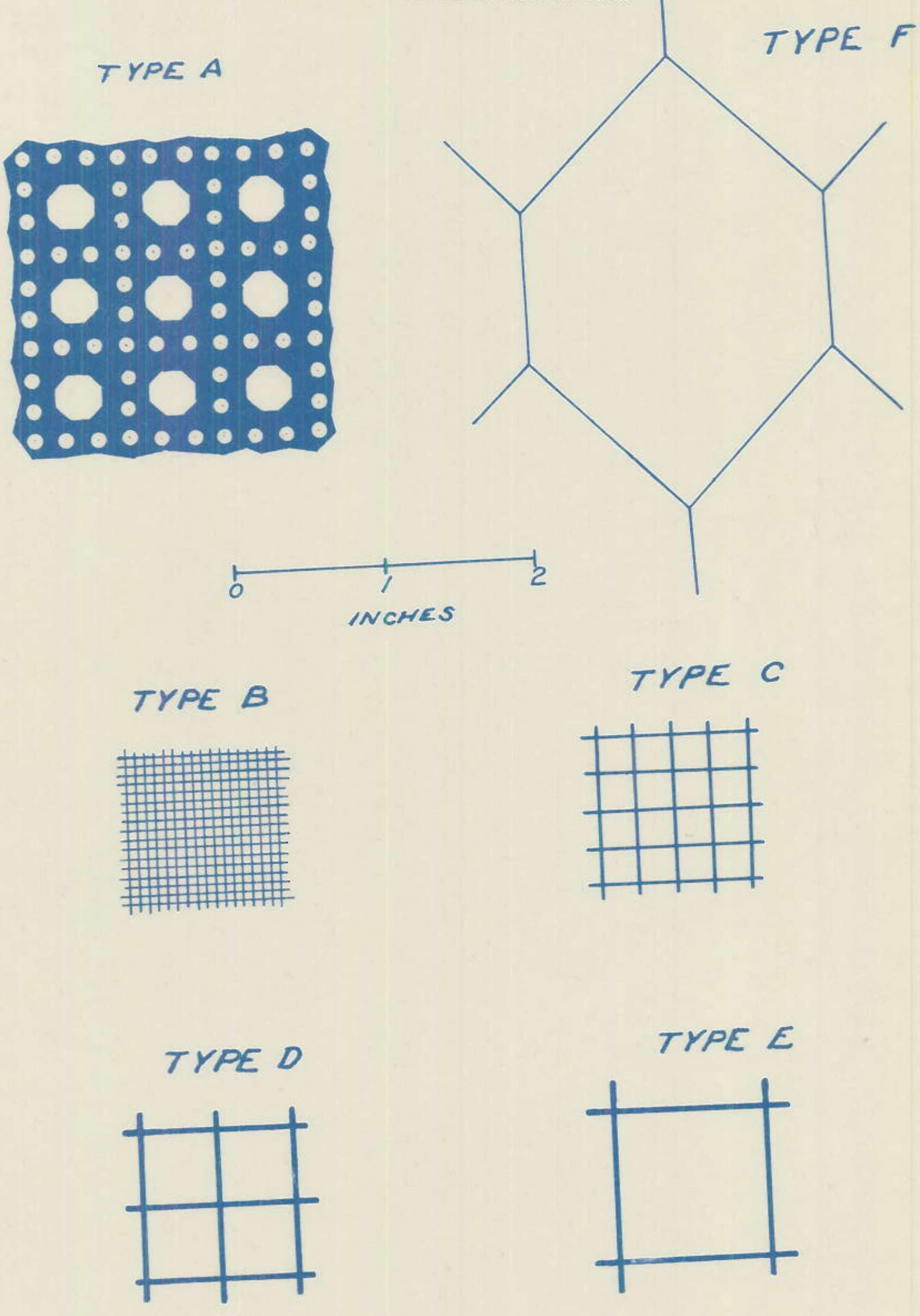


DIAGRAM OF ARRAY WITH FLAT SCREEN

PLATE 4



TYPES OF SCREENING USED IN MEASUREMENTS

FIGURES ARE SHOWN FULL SIZE

PLATE 5

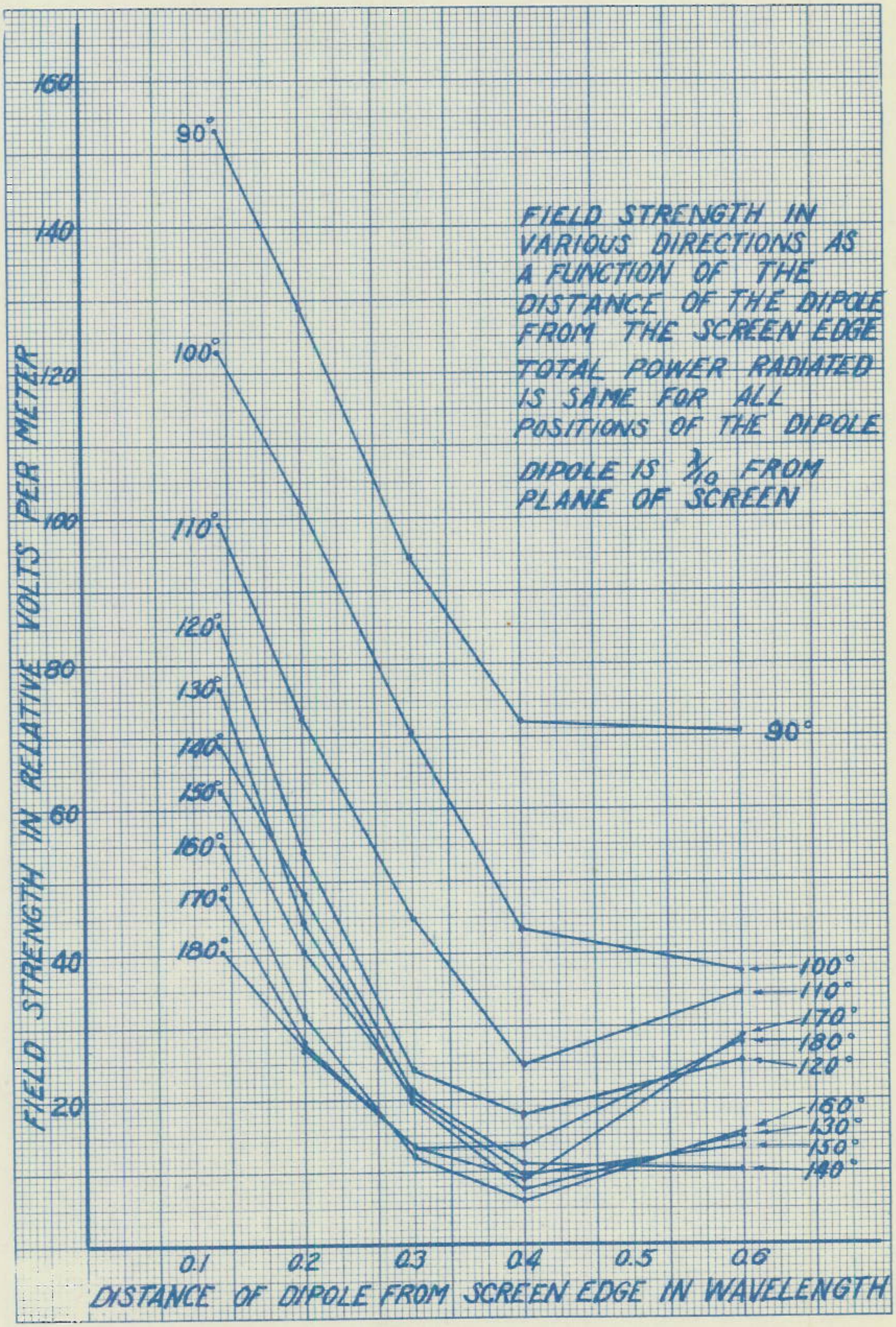


PLATE 6

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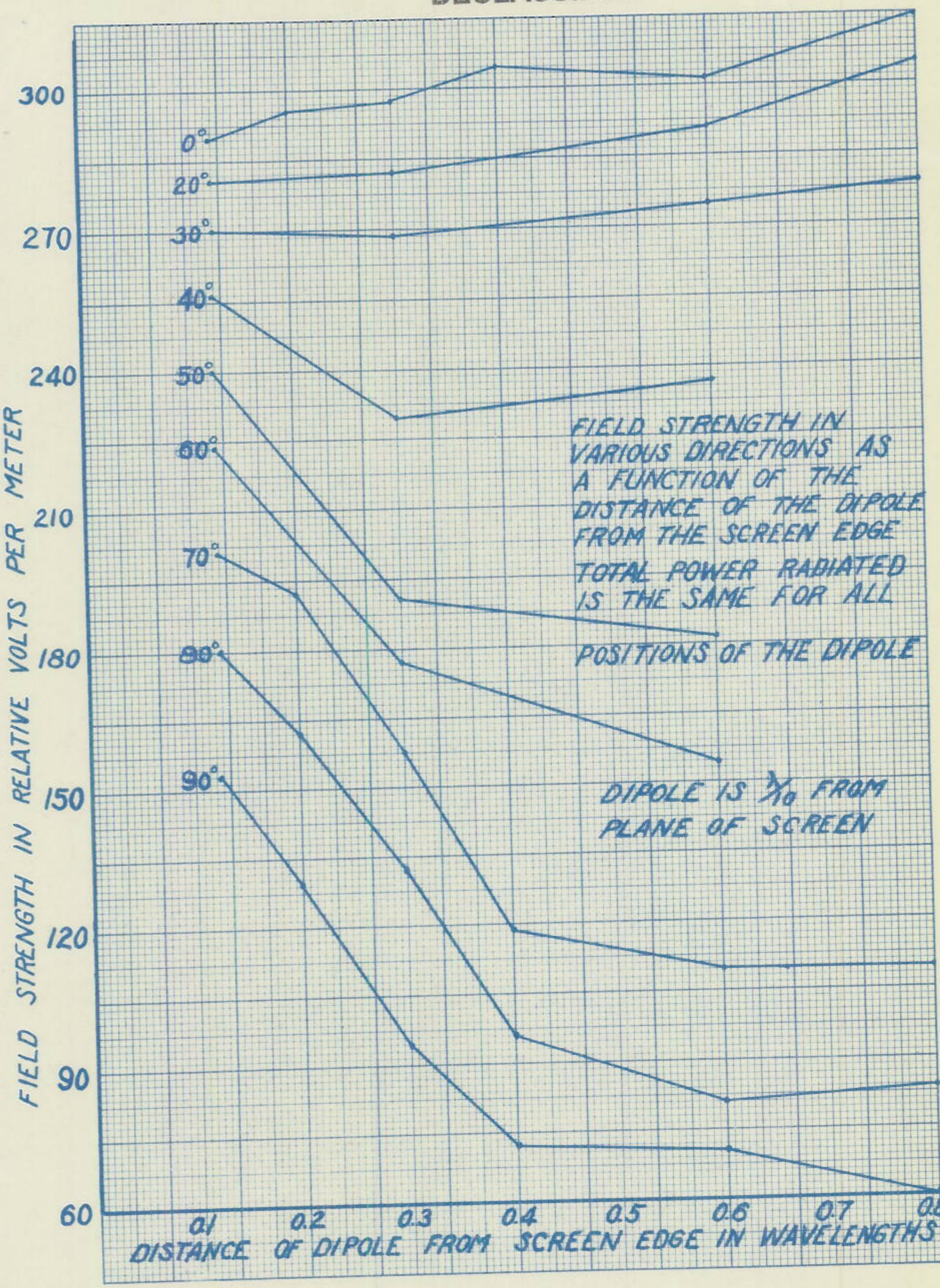

PLATE 7

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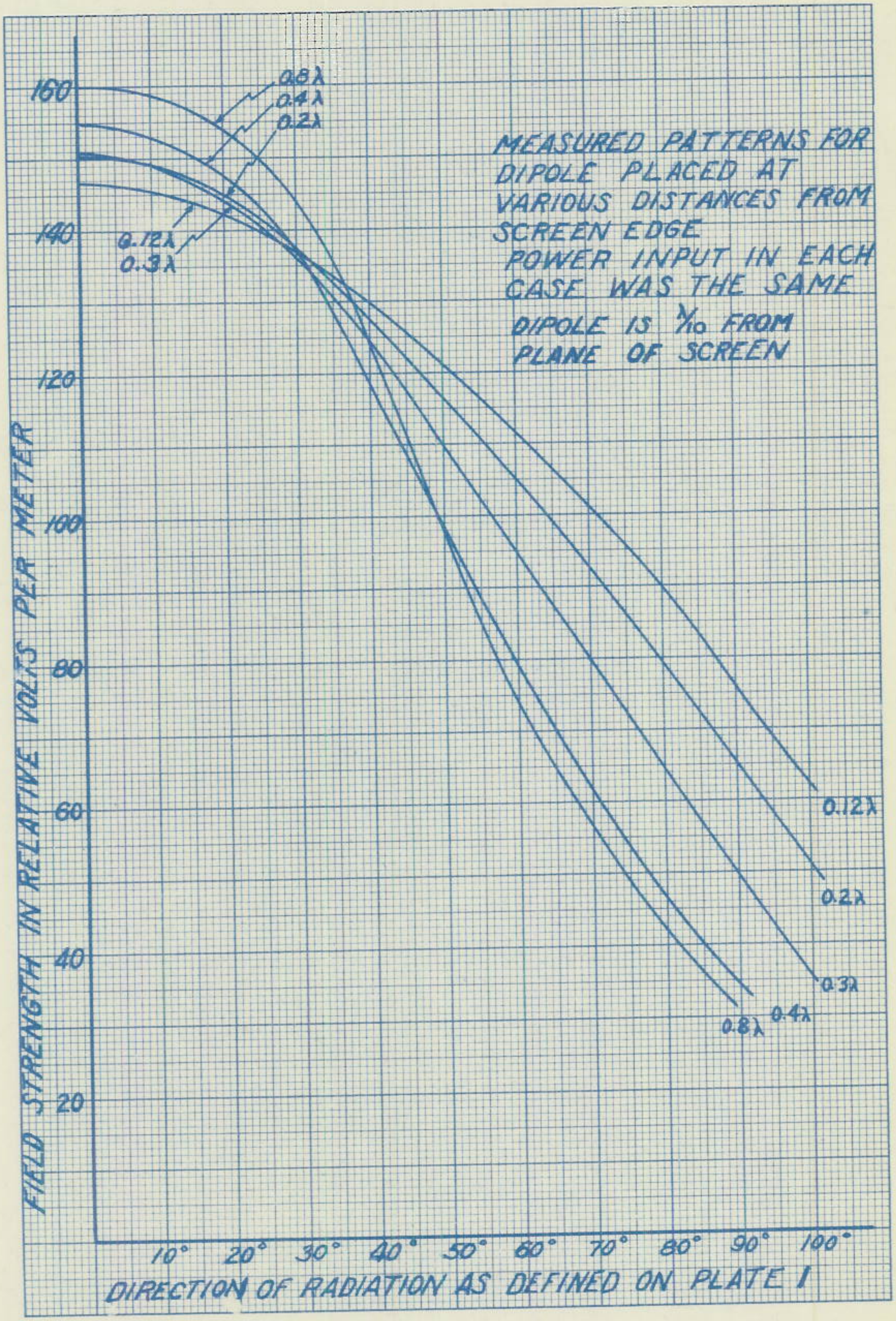
MEASURED PATTERNS FOR DIPOLE PLACED AT VARIOUS DISTANCES FROM SCREEN EDGE
POWER INPUT IN EACH CASE WAS THE SAME
DIPOLE IS λ/10 FROM PLANE OF SCREEN
0.8λ
0.4λ
0.2λ
0.12λ
0.3λ
160
140
120
100
80
60
40
20
FIELD STRENGTH IN RELATIVE VOLTS PER METER
10° 20° 30° 40° 50° 60° 70° 80° 90° 100°
DIRECTION OF RADIATION AS DEFINED ON PLATE I

PLATE 8

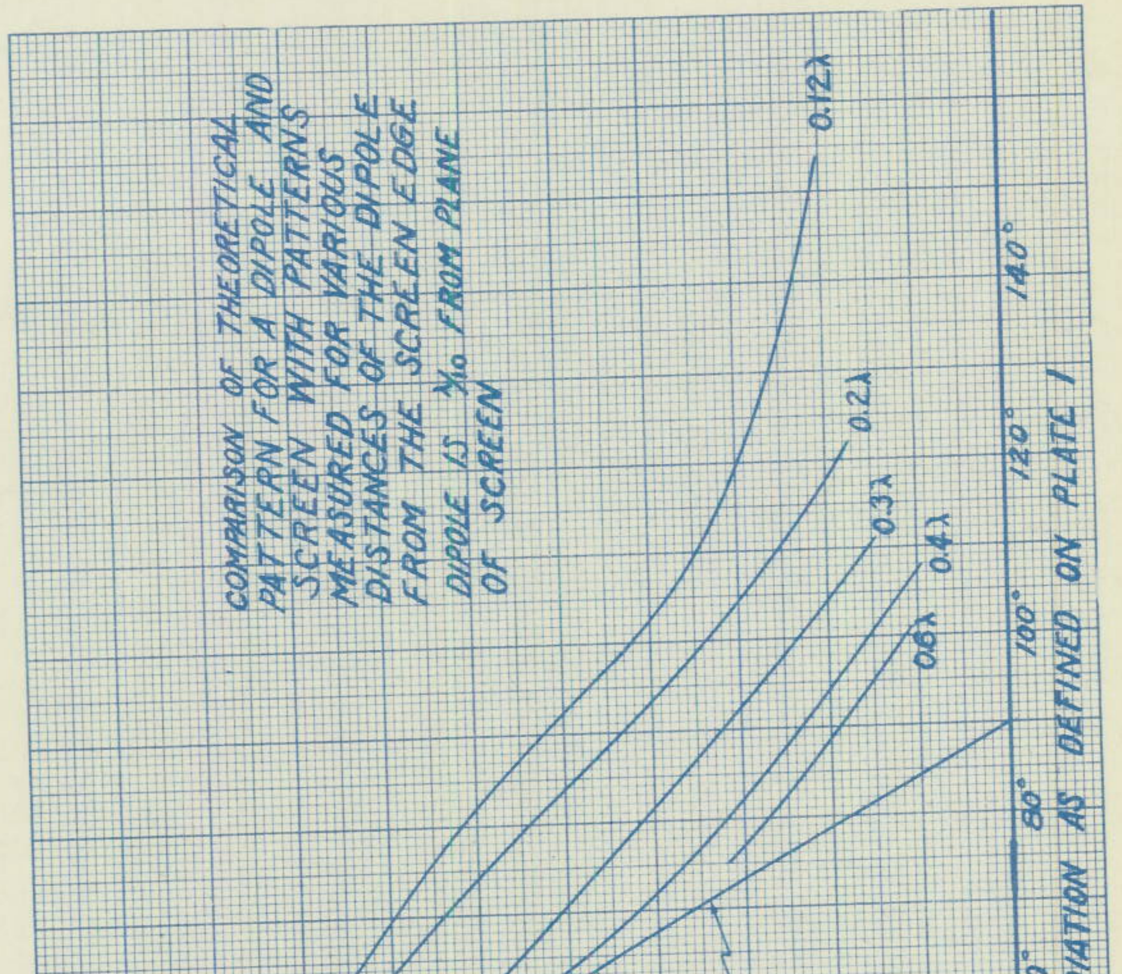
COMPARISON OF THEORETICAL PATTERN FOR A DIPOLE AND SCREEN WITH PATTERNS MEASURED FOR VARIOUS DISTANCES OF THE DIPOLE FROM THE SCREEN EDGE
DIPOLE IS ⅒ λ FROM PLANE OF SCREEN
0.12λ
0.2λ
0.3λ
0.4λ
0.6λ
THEORETICAL CURVE
20°
40°
60°
80°
100°
120°
140°
DIRECTION OF RADIATION AS DEFINED ON PLATE I
100
90
80
70
60
50
40
30
20
10
FIELD STRENGTH RELATIVE VOLTS PER METER

PLATE 9

DISTRIBUTION LIST

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