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RADIO DIVISION II - SEARCH RADAR SECTION

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# A LOBING ARRAY FOR IFF MARK V

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NRL Problem 0-152

## ABSTRACT

A seven element lobing antenna array for IFF Mark V has been designed for installation on the reflector of the Fire Control Radar Mark 12. The dipoles are mounted in a trough-shaped screen 15 inches high by 56 inches long, while the feed system comprises a three-section lober, a polyethylene filled power division transformer, and several lengths of RG-8/U cable. The beam widths in the horizontal plane vary from 15½ to 13 degrees across the 950 to 1150 Mc band, and the sharpness of the main crossover increases from 1.3 to 2.3 db per degree. All false crossovers are 20 db or more below the principal one except at 1000 Mc, where they are 17 db down. The input standing wave ratio is less than 2.5 db except at this frequency, where it reaches 3.1 db. It is estimated that the installed weight of the antenna will be 39 pounds. Eight models are being manufactured at the Naval Ordnance Laboratory for use in evaluation tests of the IFF Mark V system in July 1947.

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## INTRODUCTION

1. As part of the program (NRL problem 0-152) to adapt the IFF Mark V system to fire control radars, the Combined Research Group of the Naval Research Laboratory developed a lobe-switching version of the UPA-3 antenna (described in Reference a) which was later mounted on a Mark 12 radar reflector and tested against ship- and airborne transponders. The antenna performance was satisfactory (Reference b), showing excellent gain and azimuth accuracy, but the false crossovers (in some cases only 16 db below the true one) were quite noticeable.

2. This antenna was nearly $3\frac{1}{2}$ feet high, and, when installed on the top of a Mark 12, could be expected to apply a considerable torque about the elevation axis because of its wind load. It was, therefore, proposed that a dipole array might be used instead. It would have the advantage of smaller dimensions in height and depth, while, with the same horizontal aperture, it could provide equal azimuth accuracy. At the same time, it was possible that the level of the spurious crossovers might be reduced further. Of course, the array would have less gain, but this did not seem to be a critical item in the IFF Mark V system.

3. The lobing array was visualized as consisting of perhaps seven vertical dipoles on a more or less flat screen, which would, however, be shaped somewhat in the vertical plane to reduce the E plane beam width as much as possible. Except for the center element, each pair of dipoles would require a separate phasing line and r-f switch. The CRG capacity switch (Reference c) was ideally suited for the construction of such a lober.

4. A problem was assigned by the Bureau of Ordnance for the development of a lobing array (References d and e), and the work progressed steadily until the end of the war, when it seemed unlikely that the antenna would ever be needed. However, in the Spring of 1946 fleet tests were planned for the Summer of 1947 in which the Mark V IFF system would be given thorough trials and evaluation. Models of all components were required, and, as no steps had been taken to procure antennas of the type described in Reference (a), the array was completed as quickly as possible. At the present time the eight models needed for the tests are being constructed by the Naval Ordnance Laboratory.

## DESIGN OF THE ARRAY

5. <u>General Method of Pattern Calculation</u> -- The main beam of a dipole array can be shifted to the right or left by advancing the phase of the dipoles on one side of center and retarding it on the other. However, the best pattern is obtained when the phase is made to increase in equal steps from one element to the next across the aperture, as this distribution generates a plane wave front. Plate 1A shows a set of currents meeting this requirement. The amplitudes of the currents are symmetrical about the center, while their phases increase by $2\psi$ per radiator from



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left to right. The radiation field of the k-th pair of radiators from the center is

$$E_k(\theta) = 2 I_k \cos\left( \frac{2\pi k d}{\lambda} \sin\theta + 2k\psi \right)$$

where d is the spacing between elements. Making the substitution

$$u = \frac{\pi d}{\lambda} \sin\theta,$$

the complete horizontal pattern is

$$F(u) \equiv E(\theta) = \frac{I_o}{2} + \sum I_k \cos 2k(u + \psi)$$

Now if this antenna were fed with the radiators all in phase, the pattern would be

$$F_o(u) = \frac{I_o}{2} + \sum I_k \cos 2ku$$

so that

$$F(u) = F_o(u + \psi)$$

as illustrated in Plate 1B. Thus in calculating the pattern of a lobing array, the optimum distribution of current amplitudes may first be determined for the corresponding non-lobing array. Then the pattern $F_o(u)$ must be displaced a distance $\psi$ equal to half the phase shift between radiators to obtain the pattern $F(u)$ for the lobing array. Finally, $E(\theta)$ is obtained by working back through the transformation:

$$u = \frac{\pi d}{\lambda} \sin\theta.$$

6. Determination of Optimum Current Distribution -- The optimum current distribution for the unlobed array was determined by a method described by C. L. Dolph in Reference (f). It was computed as follows: Let

$$x = \cos u$$

then

$$\cos 2u = 2x^2 - 1,$$
$$\cos 4u = 8x^4 - 8x^2 + 1,$$
$$\cos 6u = 32x^6 - 48x^4 + 18x^2 - 1,$$

and

$$F(u) = G(x) = \tfrac{1}{2} I_o + (2x^2-1) I_1 + (8x^4 - 8x^2 + 1) I_2 + (32x^6 - 48x^4 + 18x^2 - 1) I_3.$$

Now the ideal pattern for a 7-element array is given by

$$T_6(z) = \cos 6V,$$

where

$$z = \cos V$$

and

$$z = ax,$$

where $T_6(a)$ is equal to the desired ratio of main beam to side lobe level.

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Thus

$$T_6(z) = 32(ax)^6 - 48(ax)^4 + 18(ax)^2 - 1$$

By equating G (x) to $T_6(x)$ and comparing coefficients of equal powers of x, the relative values of the currents may be determined, once a has been fixed by side lobe requirements. In the present case $T_6(a)$ was set equal to 34.6 (30.8 db), and a came out to be 1.26. Then it was found that

$$I_3 = 4.0 : I_2 = 8.88 : I_1 = 13.8 ; I_o = 15.84$$

or

$$I_o : I_1 : I_2 : I_3 = 1: 0.87: 0.55: 0.25.$$

It was known from the theory of the method that such a set of current ratios, if calculated with sufficient accuracy, should reduce all side lobes to a level exactly 30.8 db below the main beam, and that the beam width would be the minimum obtainable under this condition. However, the actual theoretical pattern (Plate 2) deviated somewhat from the ideal, as the currents had been rounded off to two significant figures. While the average level of the side lobes was 30.8 db as predicted, one of them reached 29.8 db.

7. Determination of Optimum Crossover Level and Dipole Spacing -- After the proper current distribution had been established, it was necessary to decide on the phase shift between radiators ($2\psi$) and the dipole spacing (d). The quantity $\psi$ had to be calculated from the desired beam shift, which in turn was fixed by a compromise between the increasing sharpness of crossover and decreasing antenna gain as the crossover level was lowered. The curve shown in Plate 3A was useful in this respect; here a portion of the pattern $F_o(u + \psi)$ was plotted against $u + \psi$. If u was taken as zero, the curve gave the crossover level, $F_o(\psi)$ as a function of $\psi$, and by taking u as plus and minus one degree, the sharpness of crossover in db per degree of u could be determined. Before converting this into db per degree of $\theta$, it was necessary to know the dipole spacing so that the relation $u = \frac{\pi d}{\lambda} \sin \theta$ could be used.

8. It was desirable to make the dipole spacing as large as possible, as this improved the antenna gain and would tend to reduce the difficulties with coupling between dipoles. But as $d/\lambda$ was increased, more and more of the pattern F(u) was included in $E(\theta)$ until the geometrical lobe at u = 180 degrees began to appear. The larger the beam shift, the larger this lobe became, for a given value of spacing. In calculating a maximum safe value for d, it was assumed that the main crossover would never be lower than 5.6 db; the geometrical lobe was permitted to rise to the 20 db level, as the reflecting screen could be counted on to provide a signal reduction of at least 10 db. From these considerations (Plate 3B) it was found that u = 126 degrees had to correspond to $\theta$ = 90 degrees at the high end of the band, and that the best dipole spacing was 7-3/16 inches.

9. It was estimated from preliminary measurements that $\psi$ , as realized by an actual phasing line, would vary across the band approximately as follows: $\psi_{950} = 0.86\ \psi_{1050}$ ; $\psi_{1150} = 1.16\ \psi_{1050}$ . Then the position and sharpness of crossover were calculated for three values of $\psi_{1050}$ :

TABLE I

| | Crossover Level, db | | | Sharpness of Crossover db/deg. | | |
|---|---|---|---|---|---|---|
| $\psi_{1050}$ | 950 | 1050 | 1150 | 950 | 1050 | 1150 |
| 14.9° | 2.22 | 3.0 | 4.27 | 1.23 | 1.67 | 2.25 |
| 16.0 | 2.54 | 3.5 | 4.80 | 1.36 | 1.88 | 2.38 |
| 17.1 | 2.90 | 4.0 | 5.5 | 1.48 | 1.92 | 2.57 |

It was felt that $\psi_{1050}$ = 16.0 degrees represented the best compromise between a broad crossover at 950 Mc and a low one at 1150 Mc. To summarize, the dipole spacing was taken as 7.19 inches, and the phase shift between adjacent radiators as 32 degrees at midband.

10. Theoretical Patterns -- After the parameters of the array had been fixed, theoretical patterns were drawn up for three frequencies (Plates 4, 5, and 6). The 3 db beam widths were found to be 16.5°, 14.9°, and 13.6° at 950, 1050, and 1150 Mc, respectively, with all side lobes and spurious crossovers at least 29.8 db down from the main beam.

11. Power Division Transformer -- The design of the power division transformer is illustrated in Plate 7. After the power to be supplied to each radiator had been calculated, the input impedances at various junctions were arranged to be inversely proportional to the required power division. Then these impedances were realized by the use of double quarter-wave transformers.

12. Capacity Switch -- Since a capacity type r-f switch for $L_x$ band had already been developed by the Combined Research Group (Reference c), it was adapted for use in lobing the present antenna. Its method of operation may be understood by reference to the schematic of Plate 8A. When the rotor R meshes the insulated stator C' and the grounded stators E,E', the section of line C'B' is loaded with a sufficiently great capacity to make it equivalent to an open circuited quarter-wave stub, with the result that point B' is grounded. On the other side, the shorted stub DB is tuned to parallel resonance with the section of line BC, so that point B is not loaded by the switch. Thus the power passes without mismatch entirely into line F. With the rotor in the other position, of course, line F' is connected with the input.

[redacted]

13. Schematic of Lober -- The method of incorporating this switch into a lober for the seven element array is shown in Plate 8B. In practice the three sections of the lober were mounted one above the other and driven from a common shaft, but they were drawn side by side for clarity. With the line shorted on the right as shown, the power proceeds up the left side of each section and is divided, at the left end of the phasing line $L_1$, $L_2$, or $L_3$, between a pair of radiators symmetrically placed with respect to the center line of the antenna. Clearly the right hand radiator of each pair lags the left hand one by $360^\circ L_i/\lambda$ , where $L_i$ is the electrical length of the particular phasing line. By reference to Plate 1A it is seen that it was necessary to make

$$360^\circ L_1/\lambda_{1050} = 4\psi = 64^\circ$$

$$360^\circ L_2/\lambda_{1050} = 8\psi = 128^\circ$$

$$360^\circ L_3/\lambda_{1050} = 12\psi = 192^\circ$$

from which the equivalent air line lengths were found to be

$$L_1 = 2.00 \text{ inches}$$

$$L_2 = 4.01$$

$$L_3 = 6.01$$

These were inconveniently great for mechanical reasons, and lines 1.125, 2.25, and 3.375 inches long were used instead; their electrical lengths were brought up to the proper value by introducing long Mycalex insulators. As the dielectric constant of the Mycalex was somewhat in doubt, the lengths of these slugs were determined empirically as described in a later paragraph.

14. Impedance Match of Lober -- Each section of the lober had to feed two 51.5 ohm cables in parallel and was matched to its input line by double quarter-wave transformers as shown in Plate 8B. These sections as well as the switch itself were tuned for midband (1050 Mc) and it was expected that at that frequency the output power would divide evenly between the two dipoles, while the input line would be perfectly matched. However, at other frequencies the switch no longer provided a perfect short or open, and the matching sections were no longer exact quarter waves. For this reason it was desirable to check admittance through the lober. The shorted side of the switch was taken as a starting point, since the transmission line loop was (at least at midband) broken at this point. Calculated admittances at several points are listed in Plate 9. The values used for the susceptances of the switch itself at points B and B' have been taken from computations in Reference (c).

[redacted]

Power division ratios and input standing wave ratios are plotted in Plates 10, 11, and 12, along with the experimental values that were obtained later.

15. Vertical Pattern, Gain -- Preliminary experiments indicated that vertical beam widths of about 45 degrees at 3 db could be obtained with very modest dimensions in height and depth by bending the screen into a flat trough. Photographs of the final array (Plates 13 and 14) illustrate the form of reflector used. On the assumption that the vertical beam width would be 45 degrees, the horizontal beam width 15 degrees, and the crossover 3.5 db, the gain at midband was estimated at 10.8 db over a dipole.

## CONSTRUCTION AND TEST

16. Dipoles -- It was desired for mechanical reasons to build the feed system for the array from RG-8/U cable insofar as possible. This meant that the radiating elements had to be of the unbalanced type and suitable for matching to 51.5 ohms over a 20 percent band of frequencies. Previous experience with Mark III IFF arrays (Reference g) indicated that sleeve dipoles probably would meet the electrical requirements, so that the dipole problem became largely one of mechanical design.

17. Plate 15 is an assembly drawing of the final version of the dipole, while Plates 16 and 17 are photographs showing assembled and exploded views of an experimental model. The features of greatest interest are the cable bend, feed point arrangement, and dielectric rain cover. The 90 degree corner in the cable was made by cutting the dielectric down to the inner conductor in a 45 degree plane and then simultaneously twisting and bending the inner conductor the required amount. As the cable was inserted into the tubing forming the outer conductor, a small strip of polyethylene was forced into the corner with it. Then heat was applied externally until the dielectric melted together. In the feed point region the cable was passed through a close fitting polyethylene insulator, which was recessed to ensure centering of the upper part of the dipole. This was secured to the inner conductor by means of a four-sided pin and a nut. A polystyrene "hat" was slid down over this part of the assembly and screwed to the body of the radiator to weatherize it. As the volume of air enclosed was extremely small, it was considered that breathing would be negligible. In the experimental model, the top of the hat was cut off to permit adjustment of the dipole length.

18. Preliminary experiments showed that a 2 to 1 ratio of diameter between lower and upper sections of the radiator gave the maximum impedance bandwidth. Tapering at the feed point failed to improve the match appreciably and was eliminated for mechanical reasons. By adjusting the sleeve lengths it was possible to match a single dipole on the screen with a standing wave ratio of 1 db or less from 950 to 1150 Mc. With the other six dipoles in place and terminated by 51.5 ohm loads, each one could be matched to about 2 db. Finally, if all seven were fed through the power division transformer, most of the dipoles

[redacted]

could be held to 2 db over the band by individual and repeated adjustments. In practice, however, the elements were set at equal lengths and all adjusted together for optimum pattern.

19. <u>Screen</u> -- In determining the dimensions of the trough-shaped reflector, the maximum desirable height was taken as 15 inches, and the dimensions and angles involved were varied over a considerable range subject to this limitation to obtain the maximum directivity. With the sides of the trough 4 inches wide and inclined at 45 degrees, the average vertical beam width over the band was 45 degrees. Although a solid aluminum sheet was used for experimental purposes, the production models are to be punched with vertical slots 3/4" x 2-3/4" spaced 1-1/4" horizontally on centers, as shown in Plate 18. Since these openings were considerably less than a tenth wave in the H plane, they were expected to have no appreciable effect on either pattern or match.

20. <u>Power Division Transformer</u> -- The experimental power divider was of molded construction and contained no air spaces except for the two type N connectors visible in the photograph (Plate 19). These were eliminated in the final drawings (Plate 20) where the input was changed to a modified type HN jack. The power division of the transformer was not checked on matched loads, as it would have required making up special cables, but tests with the lober, described in paragraph 27, indicated satisfactory operation.

21. <u>Lober</u> -- Plate 21 shows the lober and transformer mounted on the back of the array; the lober housing appears in the lower part of the picture. In the close-up view (Plate 22), the motor at the left is a 1/40 H.P. Bodine which operates on 115 volts, 60 cycles, single phase, at 1725 R.P.M. Then from left to right may be seen r-f sections 3, 2, and 1, and the video and I-R blanking switches. Plate 23 shows the arrangement of the lines within the third section. The input at the left is connected through 43.7 ohm lines to the capacity switch and then through 31 ohm sections to the phasing line and the two output channels at the right. The Mycalex slug for increasing the electrical length of the phasing line is clearly visible. Within the switch itself, the rectangular insulated stators, flanked by triangular grounded stators, are connected across the main line to shorted stubs in the square brass blocks. Plate 24 is an exploded view of the component parts of the first section of the lober, and Plate 25 is an assembly drawing of the complete unit. In aligning each section, four items had to be checked:

(1) Useful angle in each lobing position.
(2) Phase difference between output channels.
(3) Input standing wave ratio.
(4) Power difference between output channels.

Each of these adjustments is described in one of the following paragraphs.

[redacted]

22. As the rotor is turned towards the edge of a lobing position, the signal level on each output line suddenly shifts away from its steady value. The limit of the useful angle was taken arbitrarily as the point where this deviation reached 1/2 db. When the lober was first tested, the signal began to vary at as little as 20 degrees from the center position; the difficulty was traced to coupling between sections of the lober, and was eliminated by grounding the rotor shaft to the switch housing in several places with sliding contacts. The useful angle then was found to be in the range of 90 to 145 degrees, depending on the length of the phasing line, the frequency, and the angle to which the plates of the rotor were cut. The best overall compromise was effected by using a 170 degree rotor, which gave in the worst case a minimum usable angle of 108-1/2 degrees. It was considered safe to use 100 degrees of this in the actual presentation. Later tests with the complete array, however, showed that the pattern was constant for an angle of 116 degrees or more, so that a slightly greater period of operation might have been used.

23. The phase shift between output terminals was adjusted by changing the length of the Mycalex slug until the design value was obtained at midband. The dielectric constant of the particular sample of Mycalex used was found to be 5.1 by determining that a 7/16 inch line filled with it gave a good match to 51.5 ohms when a 1/16 inch inner conductor was used. Slug lengths calculated on this basis were very nearly correct.

24. The input standing wave ratio was reduced to a minimum over the band by varying the shorted stubs at the switch.

25. While the first and third sections of the lober divided power quite evenly between their outputs, some difficulty was experienced with the second section in this regard. At first the signal passing through the phasing line was about 4 db stronger than the "direct" one at the low end of the band and about 1 db weaker at the high end. This was explained by the fact that the phasing line was approximately 3/8 of a wave long; the susceptance of the quarter-wave line at the far end of it was reflected at the input end as a conductance greater or less than unity, depending on the sign of the susceptance. Power differences of the same sign but considerably smaller magnitude had been predicted theoretically. No means was discovered for eliminating this effect, but it was possible to make the power division equally bad (2.7 db) at the two ends of the band by changing the inner conductor through the Mycalex slug to 0.050 inches and the diameter of the conductor leading to the insulated stator from 0.188 inch to 0.150 inch.

26. Final data for each section of the lober is given in graphical form in Plates 10, 11, and 12, along with theoretical values for standing wave ratio and power difference.

27. <u>Tests of Feed System</u> -- When the lober adjustments had been completed, the entire feed system was assembled and tested, with 51.5 ohm loads replacing the dipoles. The power distribution was checked (Plates 26, 27, and 28) and found to be quite close to the intended ratios. However, the outer line on each side of the array was a little weak.

28. The phase distribution was obtained by trimming the cables leading from the transformer to the lober until, at midband, each of the elements was phased just as far ahead of the center one for one lobing position as it was behind it for the other. Unfortunately this criterion could not be met at the ends of the band, for the lines to the various dipoles passed through different numbers of quarter-wave transformers, whose phase shift is a function of frequency. In spite of this, the phase fronts were sufficiently straight that the azimuth patterns were acceptable.

29. <u>Dipole Adjustment</u> -- Each dipole showed an optimum match over the band when the lengths of the upper and lower sections were set at 1-5/16 and 2-13/16 inches respectively, but the azimuth patterns could be improved by increasing these dimensions. The lengths finally chosen as a compromise between pattern and input standing wave ratio were 1-3/4 and 3-1/2 inches.

30. <u>Impedance Matching</u> -- When the feed system and dipoles were in final form, the overall match was approximately 3 to 4 db all across the band. Fortunately the impedance points were fairly well grouped on the Smith chart, and the insertion of a short series transformer brought the standing wave ratio well within 3 db except in the immediate neighborhood of 1000 Mc. The transformer was built into a type HN jack, as indicated in Plate 29.

<u>PERFORMANCE</u>

31. <u>Patterns, Gain and Match</u> -- Final horizontal patterns of the lobing array are shown in Plates 30 to 41. The first three of these cover 360 degrees at 950, 1050, and 1150 Mc; the next nine patterns extend from 280 to 080 degrees and cover the band in 25 Mc steps; Plate 42 gives the details of the crossover region. Vertical patterns were taken at three frequencies (Plates 43, 44, and 45). Finally, the impedance at the input terminal of the antenna is shown in Plate 46. Performance data is summarized in the following table:

[redacted]

## TABLE 2

## ELECTRICAL CHARACTERISTICS OF LOBING ARRAY

## FOR IFF MARK V

| Frequency, Mc | 950 | 1000 | 1050 | 1100 | 1150 |
|---|---|---|---|---|---|
| Horizontal Beam Width (3 db): Lobed Left | $15^\circ$ | $14\frac{1}{2}^\circ$ | $12\frac{1}{2}^\circ$ | $13^\circ$ | $13^\circ$ |
| Lobed Right | $15\frac{1}{2}$ | $14\frac{1}{2}$ | 13 | 13 | 13 |
| Main Crossover, db | 2.5 | 2.9 | 4.0 | 4.3 | 4.8 |
| Sharpness of Crossover, db per degree | 1.44 | | 2.00 | | 2.19 |
| Maximum Side Lobe, db | 21.5 | 20 | 21.2 | 25.8 | 22.4 |
| Maximum Spurious Crossover, db. | 24.8 | 20 | 27.2 | 31 | 25.3 |
| Back Lobe, db | 34 | | 28.5 | | 25 |
| Lober Angular Range for Constant Pattern: Lobed Left | $116^\circ$ | | $124^\circ$ | | $122^\circ$ |
| Lobed Right | 123 | | 120 | | 122 |
| Maximum Cross-Polarized Signal, db | | | 24 (at $347^\circ$) | | |
| Vertical Beam Width (3 db) | $48^\circ$ | | $42^\circ$ | | $39^\circ$ |
| Standing Wave Ratio, db | 1.4 | 3.1 | 2.2 | 1.2 | 1.2 |
| Measured Gain over Dipole at Crossover, db | 7.8 | | 8.6 | | 8.5 |
| Gain Calculated from Beam Widths and Crossover Level | 10.8 | | 10.2 | | 9.9 |

32. Discussion -- A serious effort was made to keep all spurious crossovers 20 db or more below the main one, and this was accomplished for most of the band. However, the differential could not be increased beyond 17 db in the immediate neighborhood of 1000 Mc, where, it will be noted, the second section of the lober was badly mismatched. On the other hand, the main crossover data were in very close agreement with the theoretical values given in Table 1. The vertical patterns indicated that the beams were centered some 10 degrees above the horizon. This cut the gain by as much as 1 db at the high end of the band, but otherwise did no damage. In fact, the reduction in the amount of energy reflected from the water might actually improve the vertical coverage.

## MECHANICAL DESIGN

33. Weatherizing -- As indicated earlier, it was felt that an all-dielectric feed system offered several important advantages over rigid air line:

(1) Reduced Weight
(2) Ease of Construction and Installation.
(3) Weatherproof without Pressurizing or Drying.

These were offset slightly by cable attenuation, which, fortunately, amounted to less than 0.6 db for the lengths involved. Obviously the capacity switch itself could not be filled with dielectric, and its diameter was so great that polyethylene-filled quarter-wave lines would not reach around it. As a result the entire lober had to be kept dry by means of silica gel dessicator tubes. Every Mark V IFF antenna must be provided with a low-pass filter for protection against S and X Band radiation. In the present case, this unit was made up from CRG Drawing Number C-1647, which is the 6.3 inch filter in a 7/8 inch air line fitted with type HN jacks at either end. Because of the air dielectric design, the filter is to be mounted inside the director, where it will not be exposed to the weather.

34. Reflector Design -- The assembly drawings of the antenna (Plate 18) show that the punched screen was backed by 6 stiffeners, two of which matched the heavy ribs in the Mark 12 radar screen and formed the main support. The dipoles were mounted against a 2 inch channel, and 1 inch angles were attached to the corners of the trough for torsional rigidity. Since the lober was nearly as heavy as the entire screen assembly, it was mounted directly from the radar antenna ribs and tied to the IFF structure only for stiffness. All members were fabricated from 1/16 inch 24ST aluminum sheet. The weights were estimated as follows:

| | |
|---|---|
| Dipoles ---------------------------- | 5-1/4 lbs. |
| R-F Cables ------------------------- | 3-1/8 lbs. |
| Lober ------------------------------ | 13-3/8 lbs. |
| Transformer ------------------------ | 1 lb. |
| Screen ----------------------------- | 4-1/2 lbs. |
| Braces ----------------------------- | 6-3/4 lbs. |
| Clamps, Screws, Nuts, etc. --------- | 5 lbs. |
| Total ------------------------------ | 39 lbs. |

## CONCLUSIONS

35. The antenna described in this report has good patterns and match over most of the 950 to 1150 Mc band, and should be quite satisfactory for use during the Mark V IFF evaluation tests next summer. When and if large scale production is contemplated, further work should be directed toward improving the antenna characteristics in the neighborhood of 1000 Mc. For the present, however, the time and effort involved would scarcely be justified.

36. It is quite possible that the overall weight could be reduced substantially by more careful mechanical design.

## REFERENCES


(a) CRG Report No. 77: "Lobe-Switching Antenna for Surface Use".

(b) CRG Report No. 64: "Tests of Mark V IFF Installation with USN Mark 12 Fire Control Radar at Naval Research Laboratory Chesapeake Bay Annex".

(c) CRG Report No. 54: "A Wide-Band Capacity Switch".

(d) BuOrd ltr (Re4f) S67 Ser. 009249 of 30 April 1945 to Director, NRL, (Secretary Radio Problems Priorities Board) requesting assignment of Problem 0-152 R-S: "Antenna for Fire Control Identification System Using IFF Mark V".

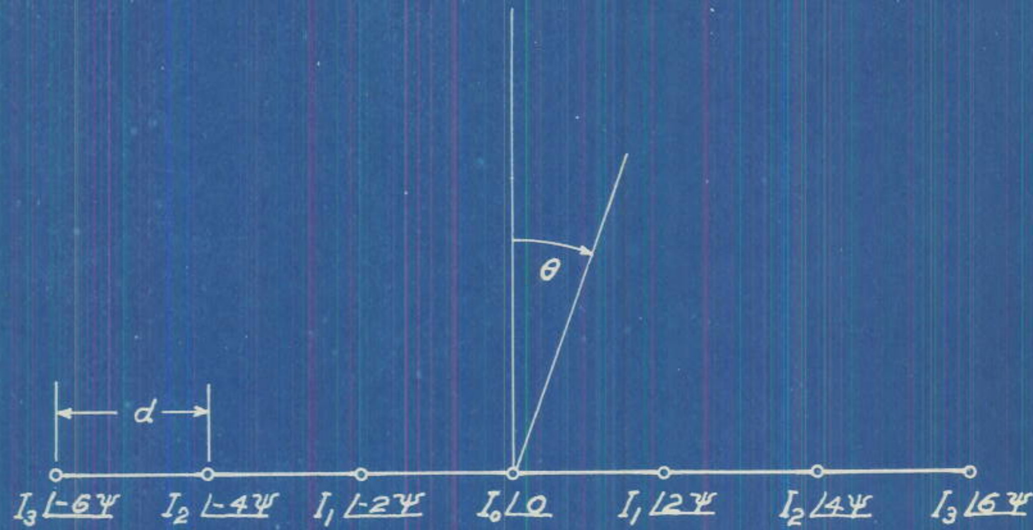
(e) NRL Problem Assignment ltr S-S67/89(700) Ser. No. 4933 to BuOrd (Re4f) dated 1 May 1945, assigning Problem 0-152 R-S.

(f) CRG Report No. 82: "On the Optimum Current Distribution for Broadside Arrays".

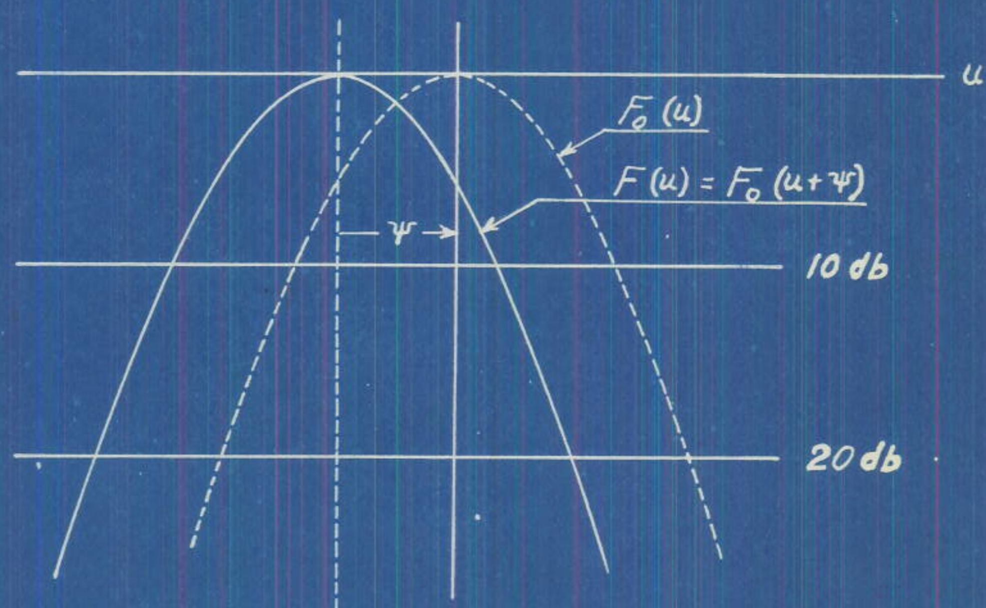
(g) NRL Report R-2349: "A Lobe Switching Mark III IFF Array for Mark 4 Radar Equipment".



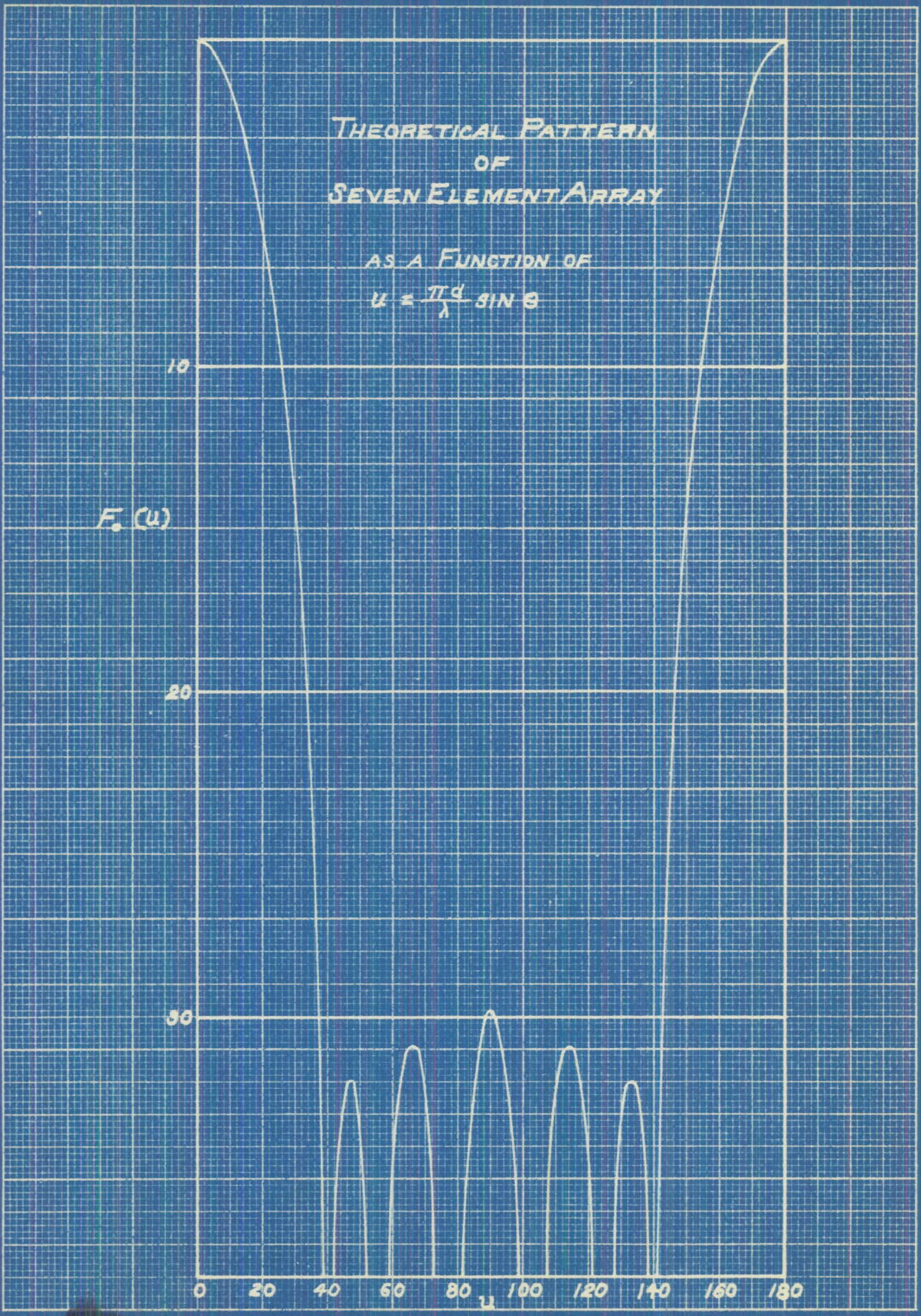

[redacted]

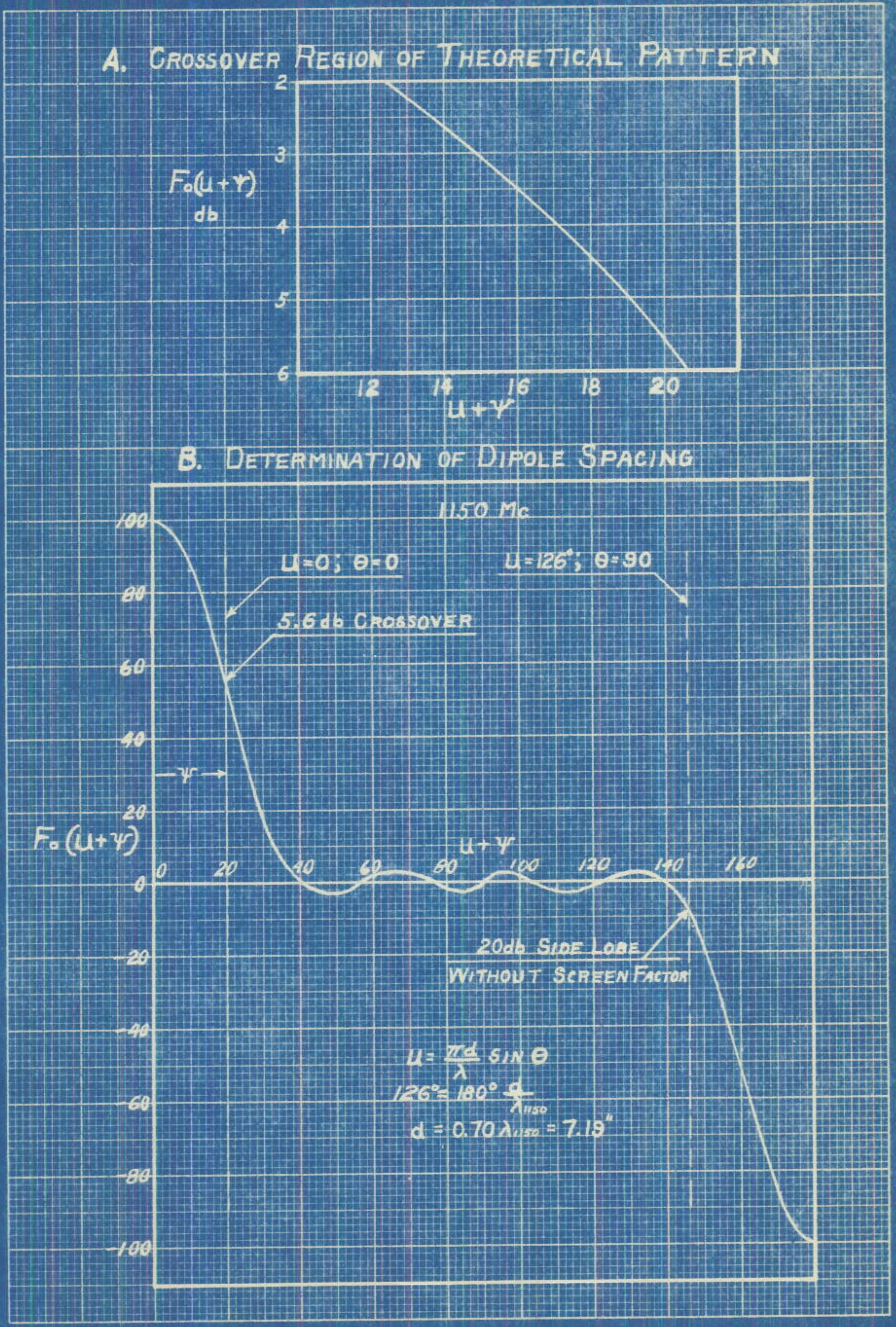



A. THEORETICAL CURRENT DISTRIBUTION

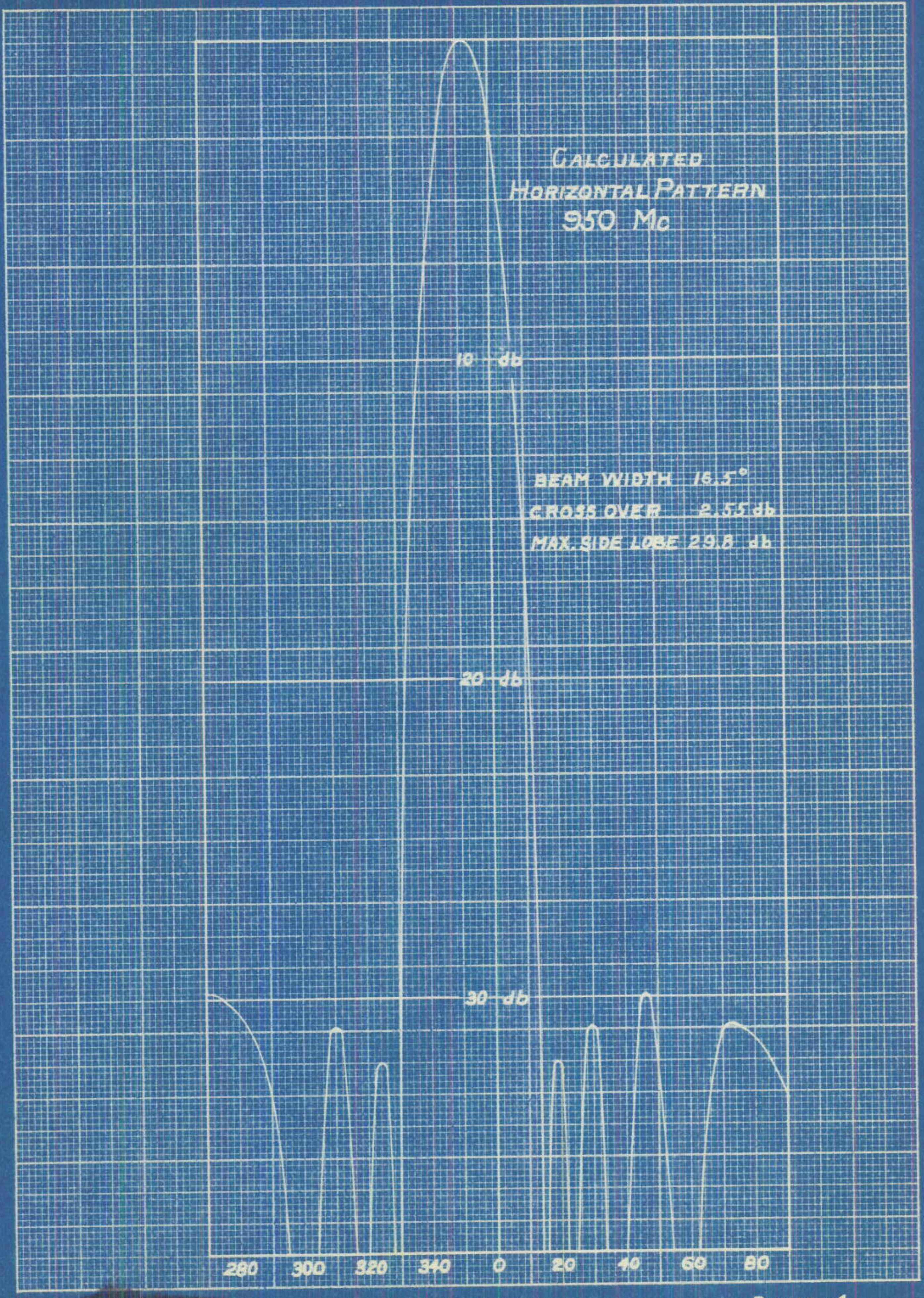



B. BEAM SHIFTING OF THEORETICAL PATTERN

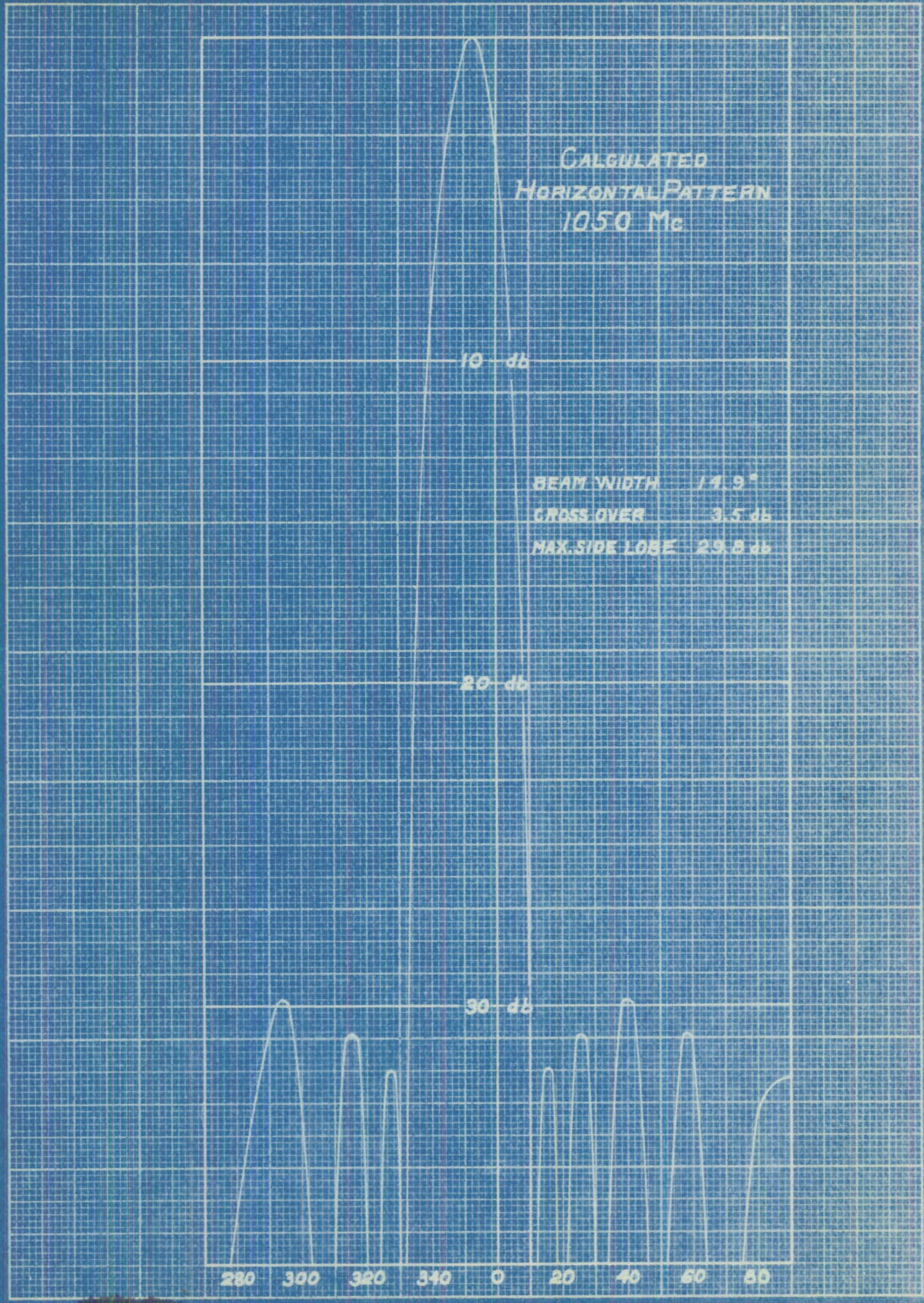

THEORETICAL PATTERN
OF
SEVEN ELEMENT ARRAY
AS A FUNCTION OF
u = πd/λ SIN θ
10
20
30
F₀ (u)
0
20
40
60
80
100
120
140
160
180
u



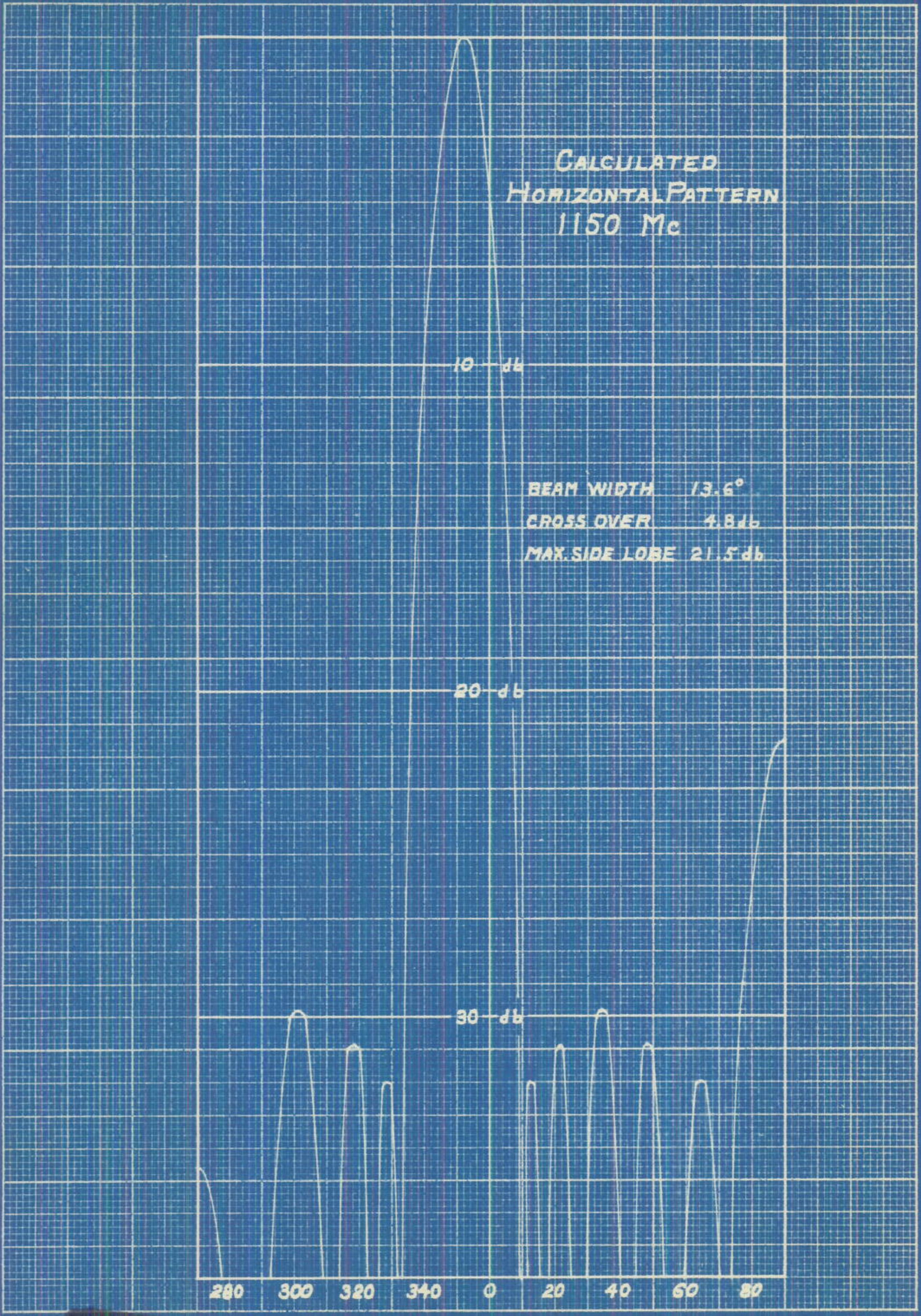
A. CROSSOVER REGION OF THEORETICAL PATTERN
Fo(u+ψ) db
2
3
4
5
6
12
14
16
18
20
u+ψ
B. DETERMINATION OF DIPOLE SPACING
1150 Mc
u=0; θ=0
u=126°; θ=90
5.6 db CROSSOVER
100
80
60
40
20
0
-20
-40
-60
-80
-100
Fo(u+ψ)
—ψ→
u+ψ
0
20
40
60
80
100
120
140
160
20db SIDE LOBE
WITHOUT SCREEN FACTOR
u = πd/λ SIN θ
126° = 180° d/λ1150
d = 0.70 λ1150 = 7.19"

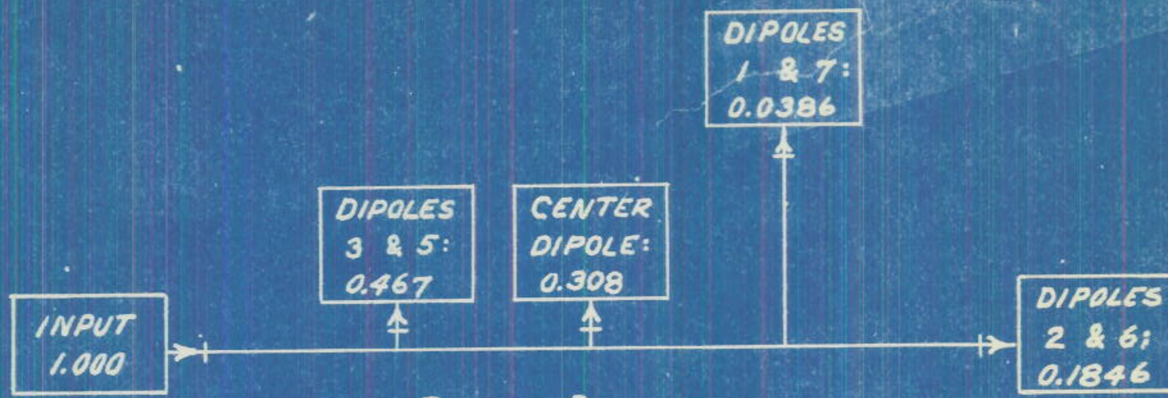



CONFIDENTIAL



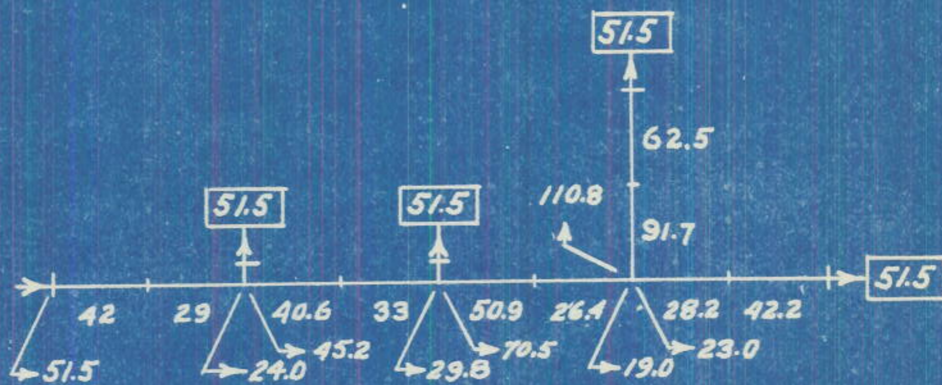
CALCULATED
HORIZONTAL PATTERN
1050 Mc
10 db
20 db
30 db
BEAM WIDTH 14.9°
CROSS OVER 3.5 db
MAX. SIDE LOBE 29.8 db
280
300
320
340
0
20
40
60
80


CALCULATED
HORIZONTAL PATTERN
1150 Mc
10 db
20 db
30 db
BEAM WIDTH 13.6°
CROSS OVER 4.8db
MAX. SIDE LOBE 21.5db
280
300
320
340
0
20
40
60
80

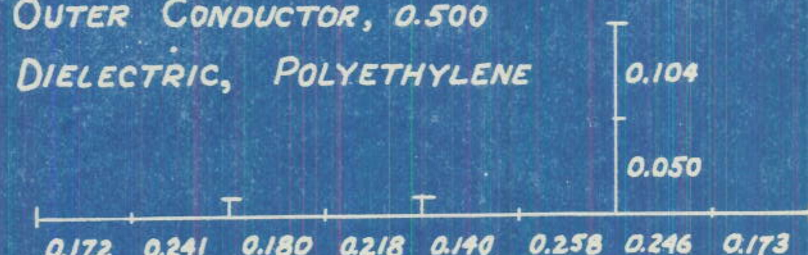



A. POWER DIVISION

CORRESPONDING TO THEORETICAL CURRENT DISTRIBUTION

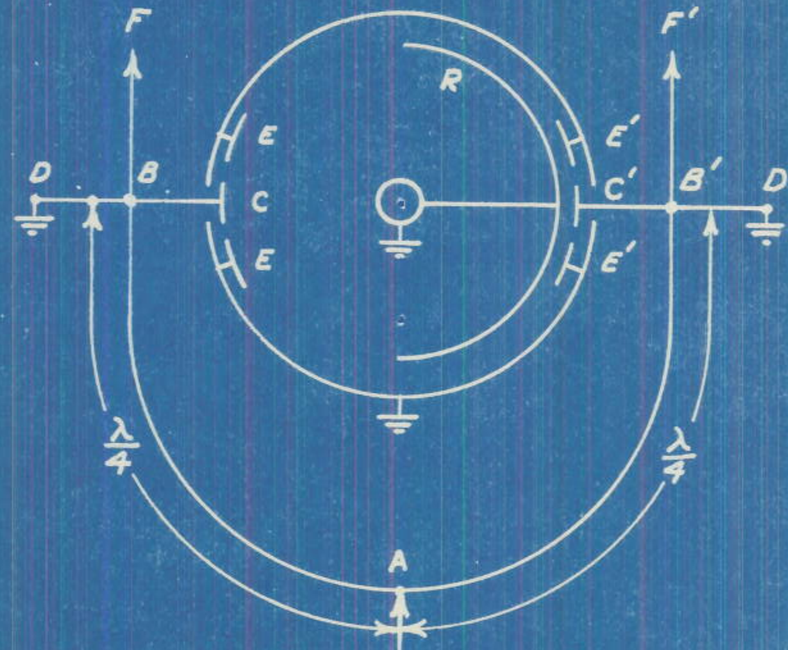



B. INPUT IMPEDANCES & QUARTER-WAVE TRANSFORMERS

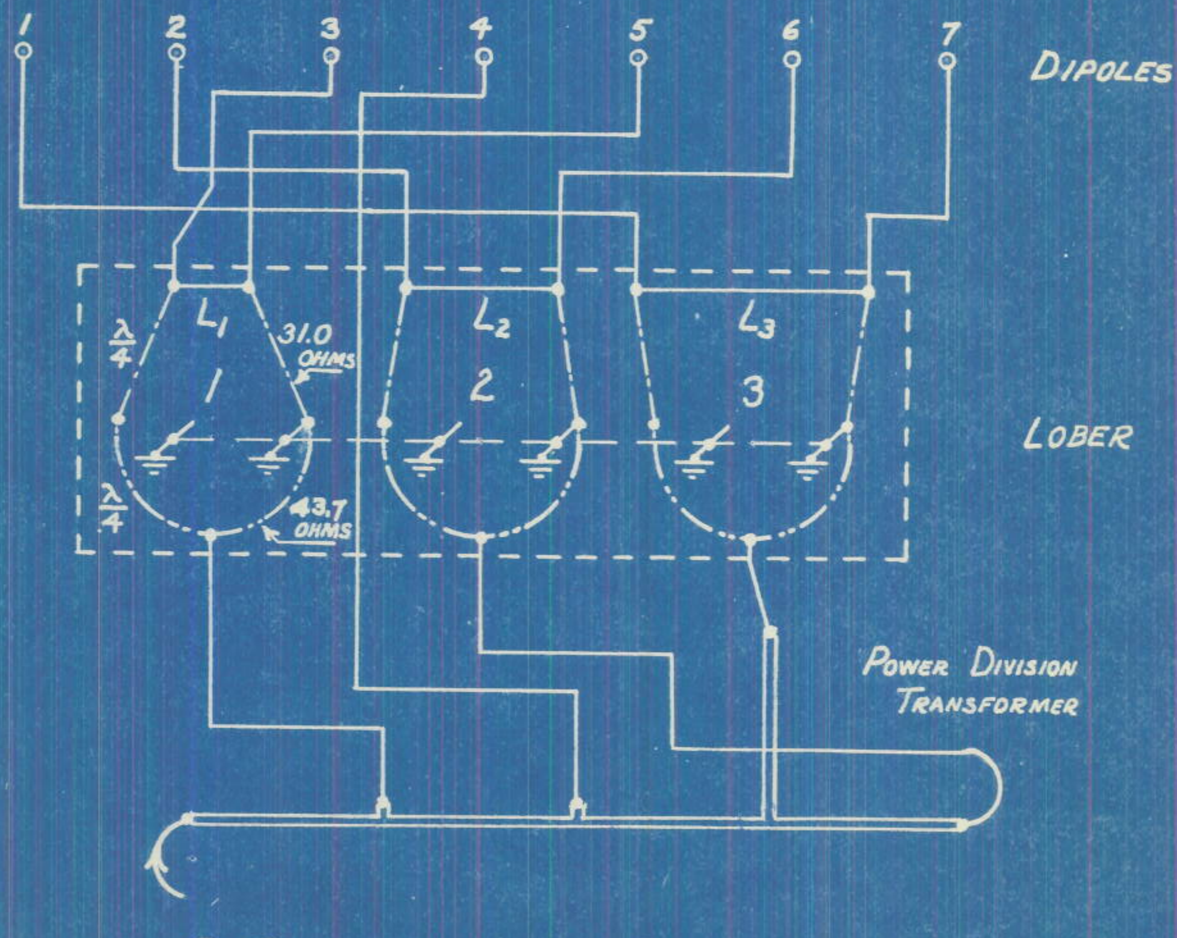



C. INNER CONDUCTOR DIAMETERS

## POWER DIVISION TRANSFORMER



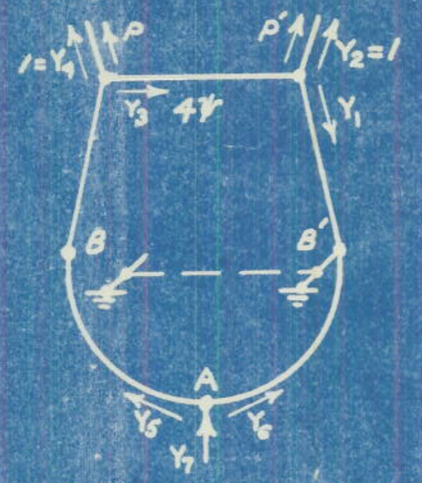

A. SCHEMATIC OF CAPACITY SWITCH




B. SHEMATIC OF FEED SYSTEM

CONFIDENTIAL

# CALCULATED POWER DIVISION AND INPUT ADMITTANCE OF LOBER




ALL ADMITTANCES
REFERRED TO
51.5 OHM LINE

## GENERAL DATA

| FREQUENCY, Mc | 950 | 1000 | 1050 | 1100 | 1150 |
|---|---|---|---|---|---|
| SWITCH ADMITTANCE | | | | | |
| OPEN (B) | -j.234 | -j.122 | 0 | +j.122 | +j.234 |
| CLOSED (B') | +j 15.4 | +j 32.8 | Inf. | -j 32.8 | -j 15.4 |
| ADMITTANCE $Y_1$ | -j.362 | -j.180 | 0 | +j.180 | +j.362 |

## SECTION 1

| | | | | | |
|---|---|---|---|---|---|
| 4ψ | .153 λ | .165 λ | .178 λ | .182 λ | .206 λ |
| $Y_3$ | .70 + j.04 | .84 + j.06 | 1.00 | 1.10 - j.16 | 1.07 - j.38 |
| P/P', db | 1.5 | 0.75 | 0 | -0.4 | -0.3 |
| $Y_5$ | 0.74 + j.10 | .88 + j.12 | 1.00 | 1.05 + j.03 | 1.01 - j.01 |
| $Y_6$ | -j.236 | -j.118 | 0 | +j.118 | +j.236 |
| $Y_7$ | .74 - j.24 | .88 | 1.00 | 1.05 + j.09 | 1.01 + j.23 |
| INPUT SWR, db | 2.95 | 1.1 | 0 | 0.8 | 2.0 |

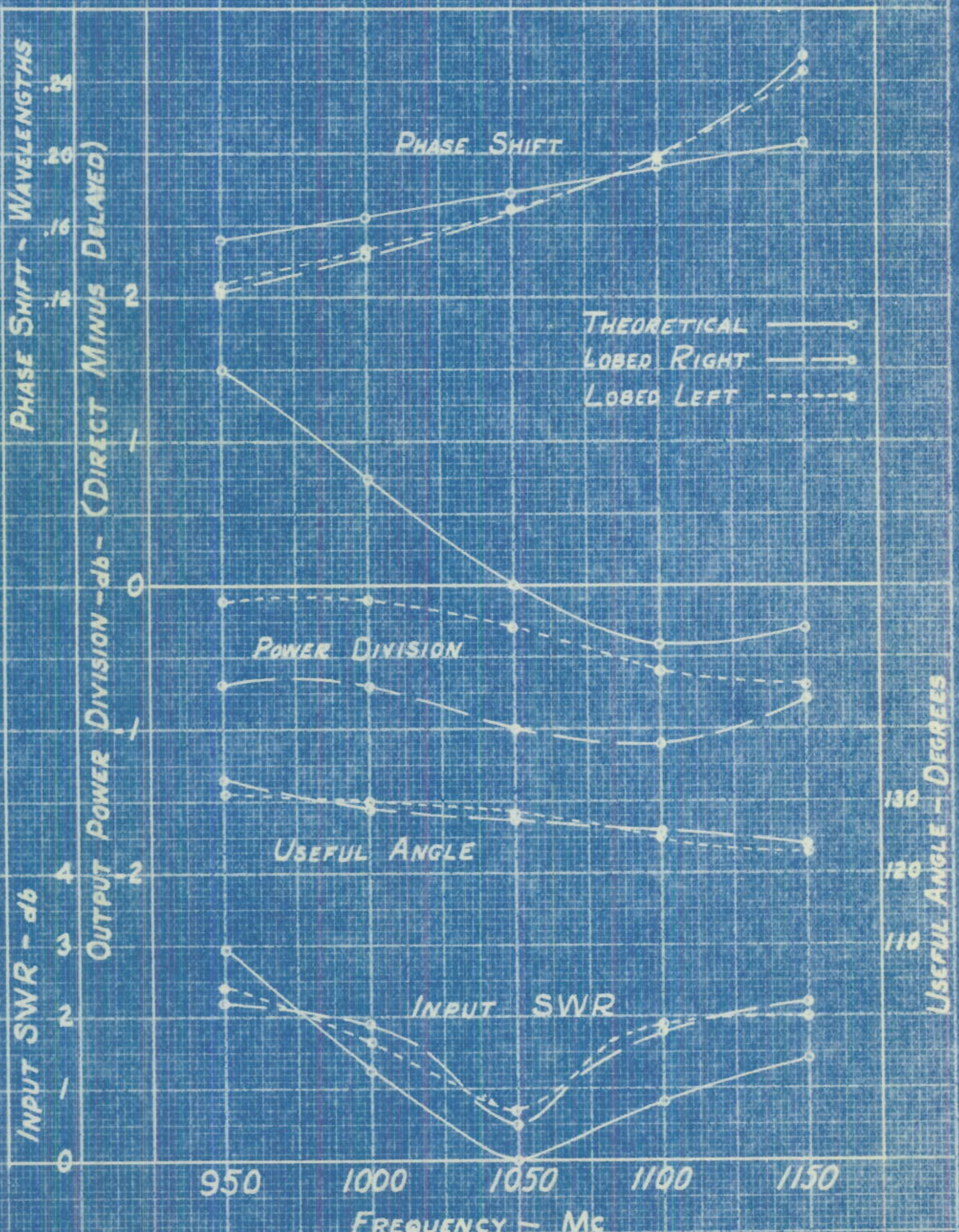
## SECTION 2

| | | | | | |
|---|---|---|---|---|---|
| 4ψ | .306 λ | .331 λ | .356 λ | .383 λ | .411 λ |
| $Y_3$ | 1.13 + j.36 | 1.15 + j.12 | 1.00 | 0.83 + j.03 | 0.73 + j.16 |
| P/P', db | -0.5 | -0.6 | 0 | 0.8 | 1.4 |
| $Y_5$ | 0.73 + j.29 | 0.97 + j.24 | 1.00 | 0.90 - j.09 | 0.87 - j.08 |
| $Y_6$ | -j.236 | -j.118 | 0 | +j.118 | +j.236 |
| $Y_7$ | 0.73 + j.05 | 0.97 + j.12 | 1.00 | 0.90 + j.03 | 0.87 + j.16 |
| INPUT SWR, db | 2.75 | 0.55 | 0 | 0.95 | 1.90 |

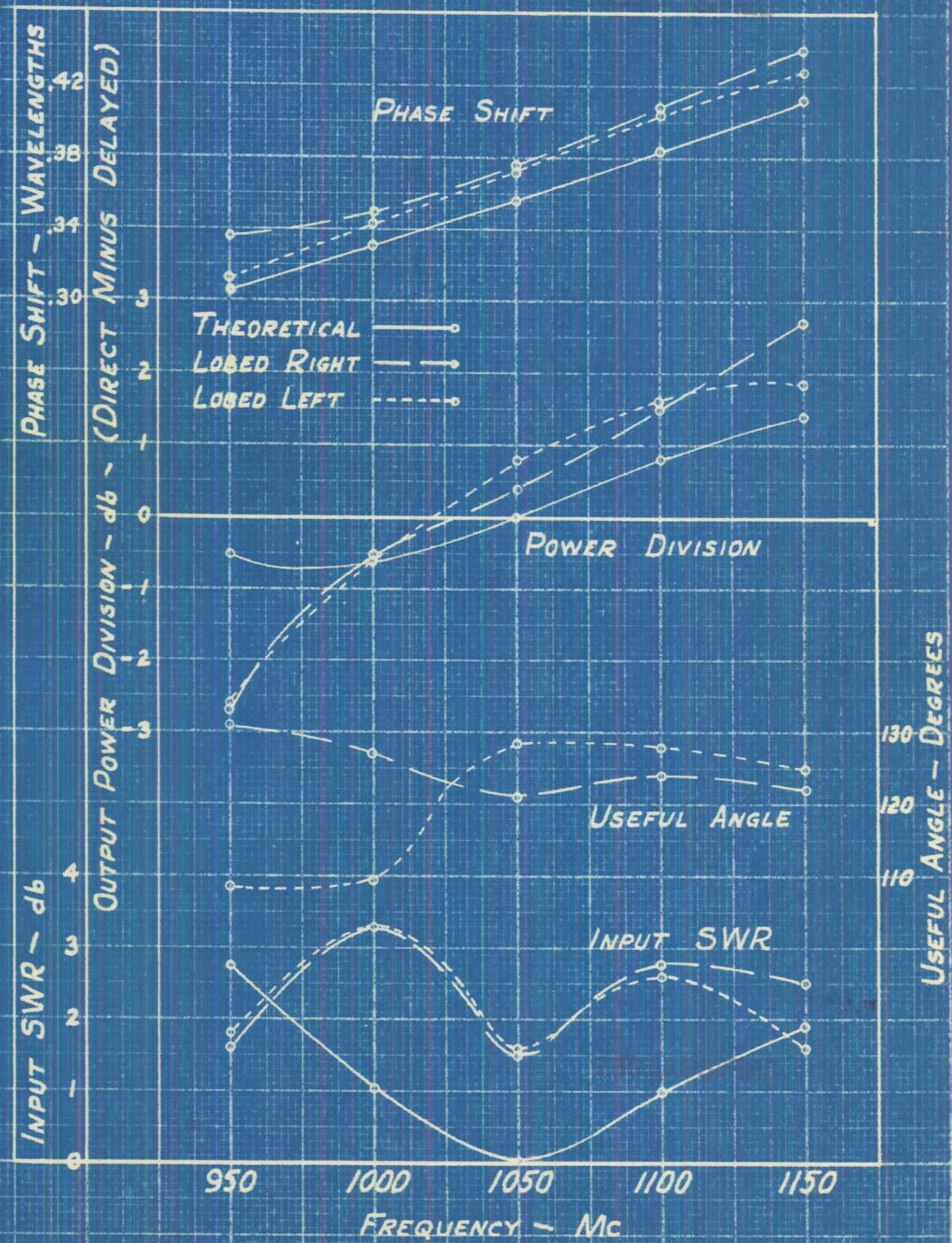
## SECTION 3

| | | | | | |
|---|---|---|---|---|---|
| 4ψ | .458 λ | .496 λ | .533 λ | .575 λ | .617 λ |
| $Y_3$ | 1.21 - j.34 | 1.10 - j.18 | 1.00 | 1.17 + j.11 | 1.44 - j.05 |
| P/P', db | -0.8 | -0.4 | 0 | -0.7 | -1.6 |
| $Y_5$ | 1.02 + j.26 | 1.03 + j.11 | 1.00 | 1.04 - j.17 | 0.88 - j.38 |
| $Y_6$ | -j.236 | -j.118 | 0 | +j.118 | +j.236 |
| $Y_7$ | 1.02 - j.02 | 1.03 - j.01 | 1.00 | 1.04 - j.05 | 0.88 - j.15 |
| INPUT SWR, db | 0.2 | 0.2 | 0 | 0.6 | 1.8 |

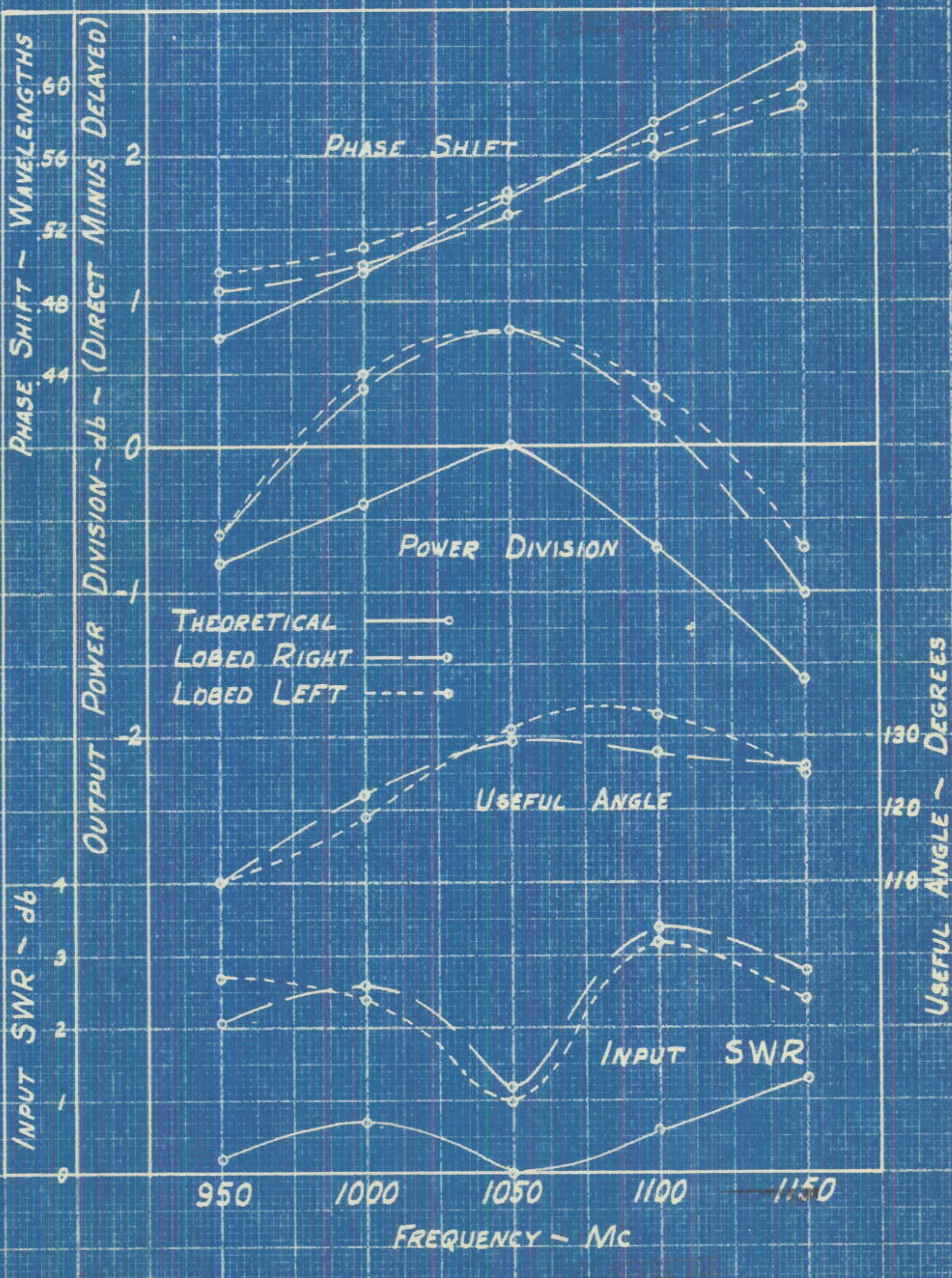
# ELECTRICAL CHARACTERISTICS OF FIRST SECTION OF LOBER

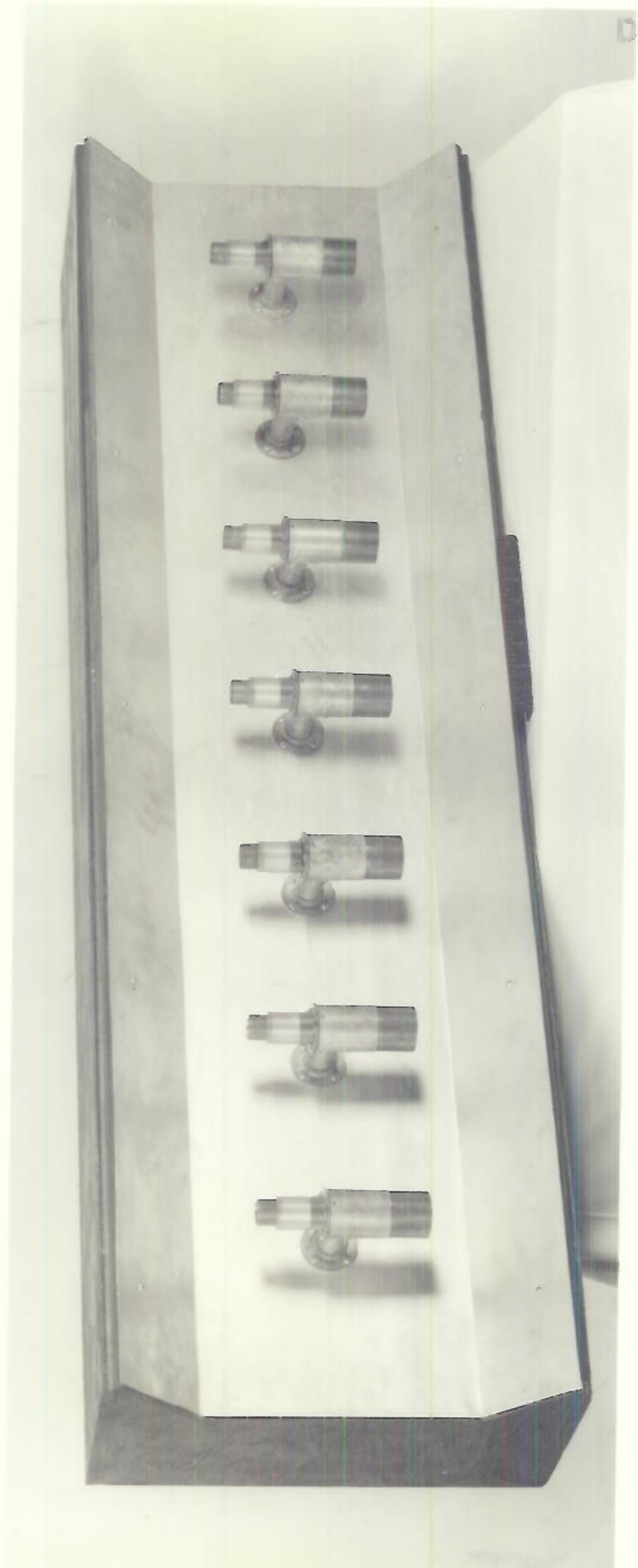


## ELECTRICAL CHARACTERISTICS OF SECOND SECTION OF LOBER



# ELECTRICAL CHARACTERISTICS OF THIRD SECTION OF LOBER





DECLASSIFIED



PLATE 13

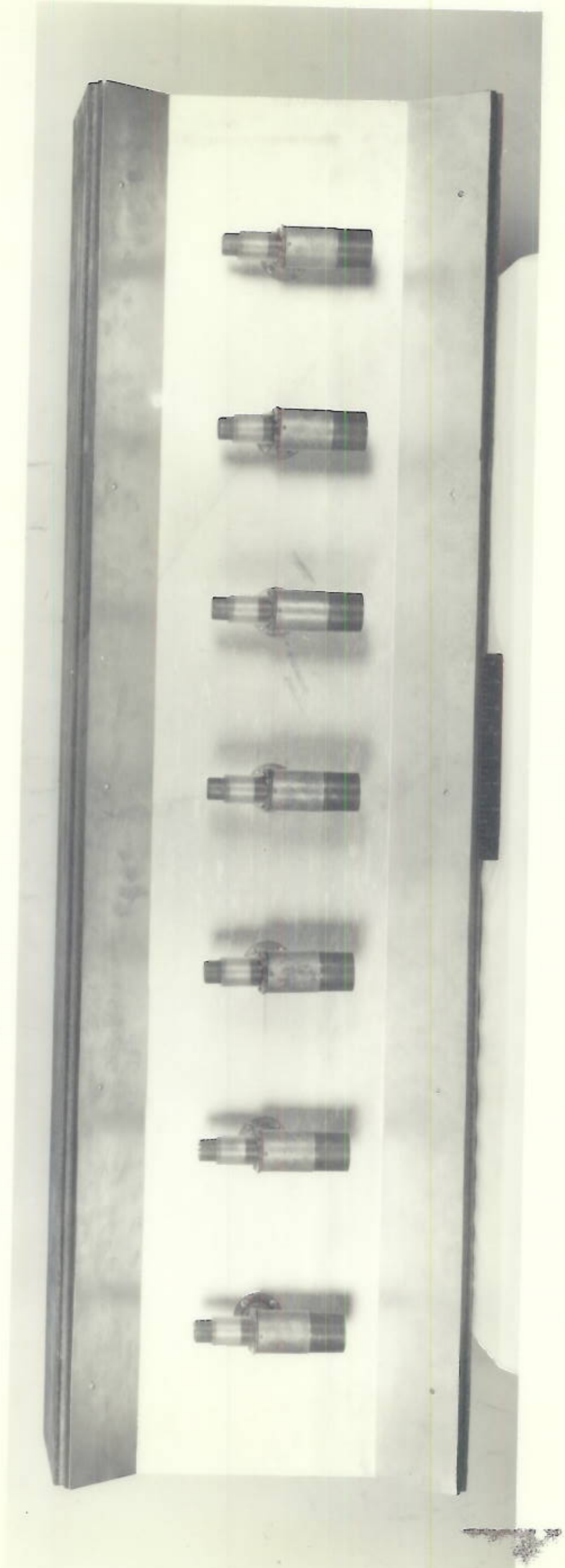
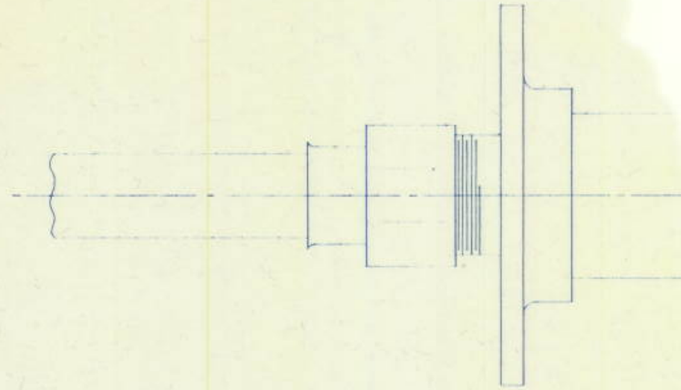
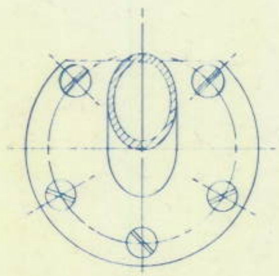




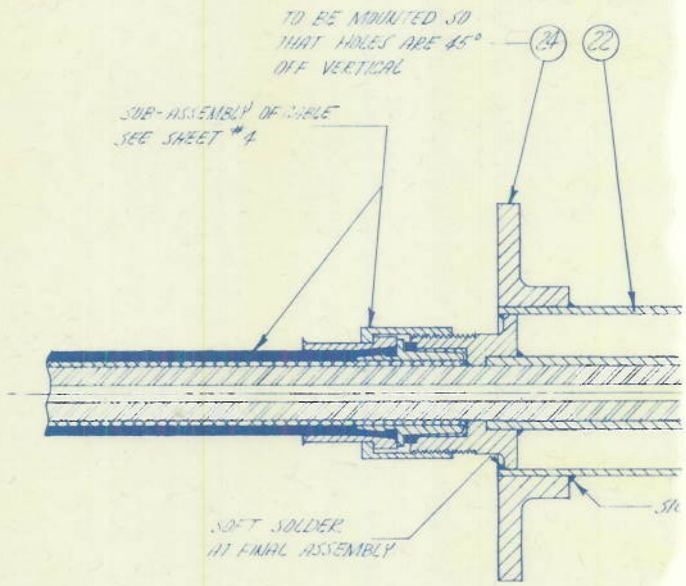


PLATE 14





VIEW AA

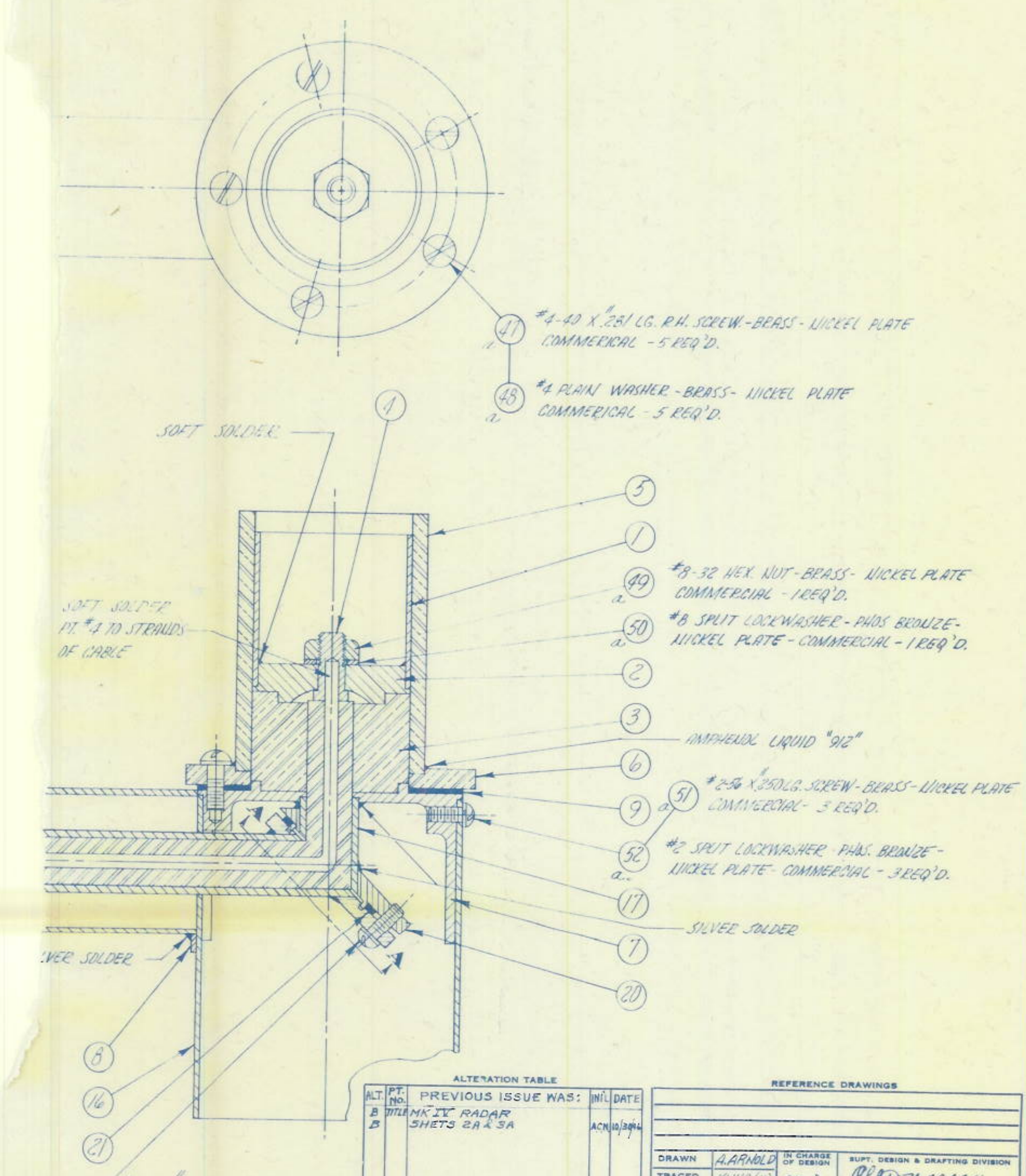



— ASSEMBLY —



[redacted]

[redacted]




ALTERATION TABLE

| ALT. | PT. No. | PREVIOUS ISSUE WAS: | INIT. | DATE |
|---|---|---|---|---|
| B | TITLE | MK IV RADAR | ACN | 10/30/46 |
| B | | SHETS 2A & 3A | | |

SYMBOLS AND THEIR EQUIVALENT TOLERANCES (UNLESS OTHERWISE NOTED)

SYMBOL 1 ...... ± .0005 SYMBOL 3 ...... ± .0050

REFERENCE DRAWINGS

| | | | |
|---|---|---|---|
| DRAWN | A. ARNOLD | IN CHARGE OF DESIGN: CRS. | SUPT. DESIGN & DRAFTING DIVISION |
| TRACED | KLUG (X) | | FOR DIRECTOR W.C. Carter |
| CHECKED | | | COMDR. U.S.N.R. |
| APPR'V'D | | | |

NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

RADIATOR FOR MK V IFF
ON
MK XII RADAR
ASSEMBLY

SCALE 24 IN = 1 FT. DATE JULY 19, 1945

R-3026

PLATE 15

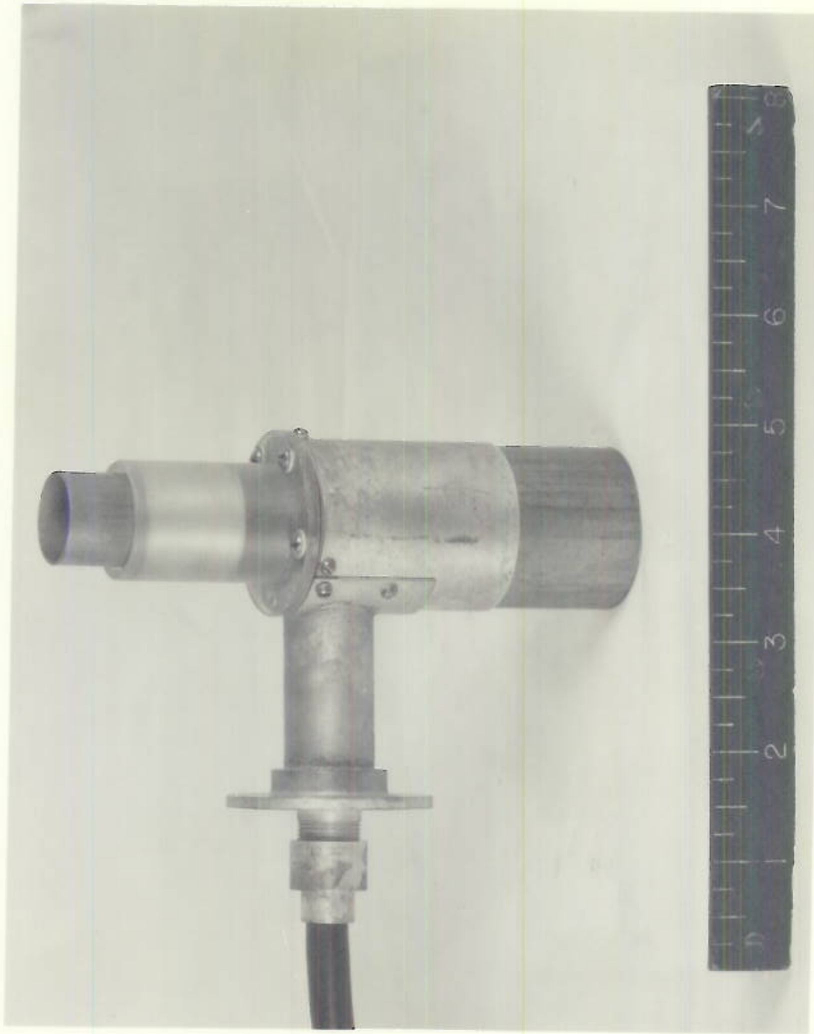
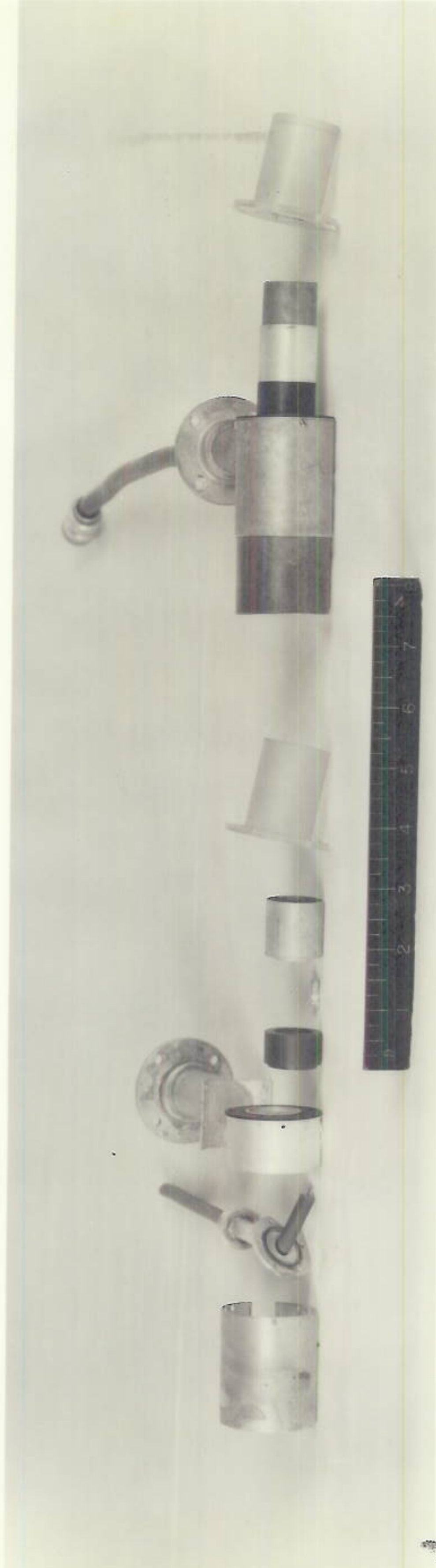







PLATE 16

DECLASSIFIED

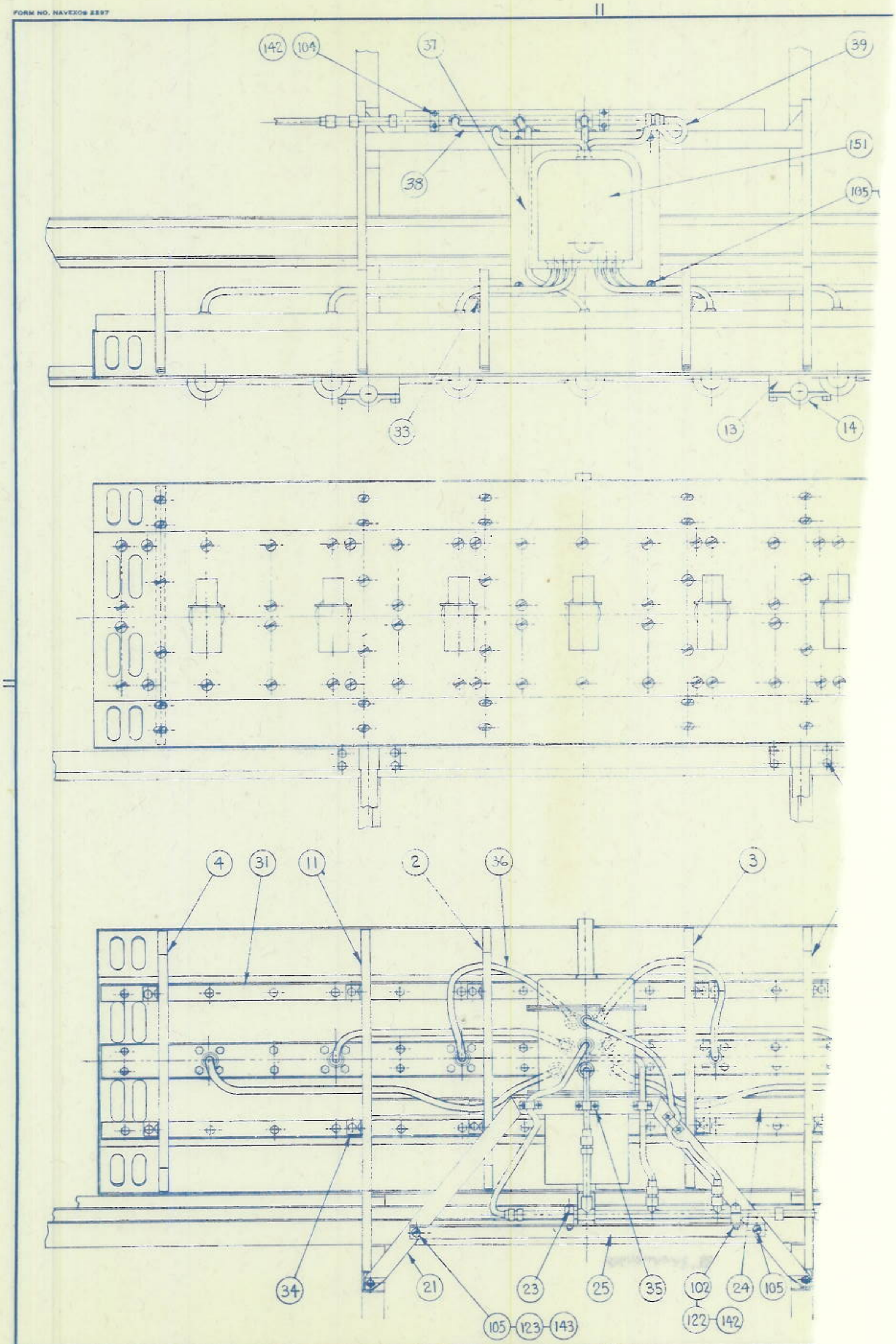


DECLASSIFIED

CONFIDENTIAL

PLATE 17

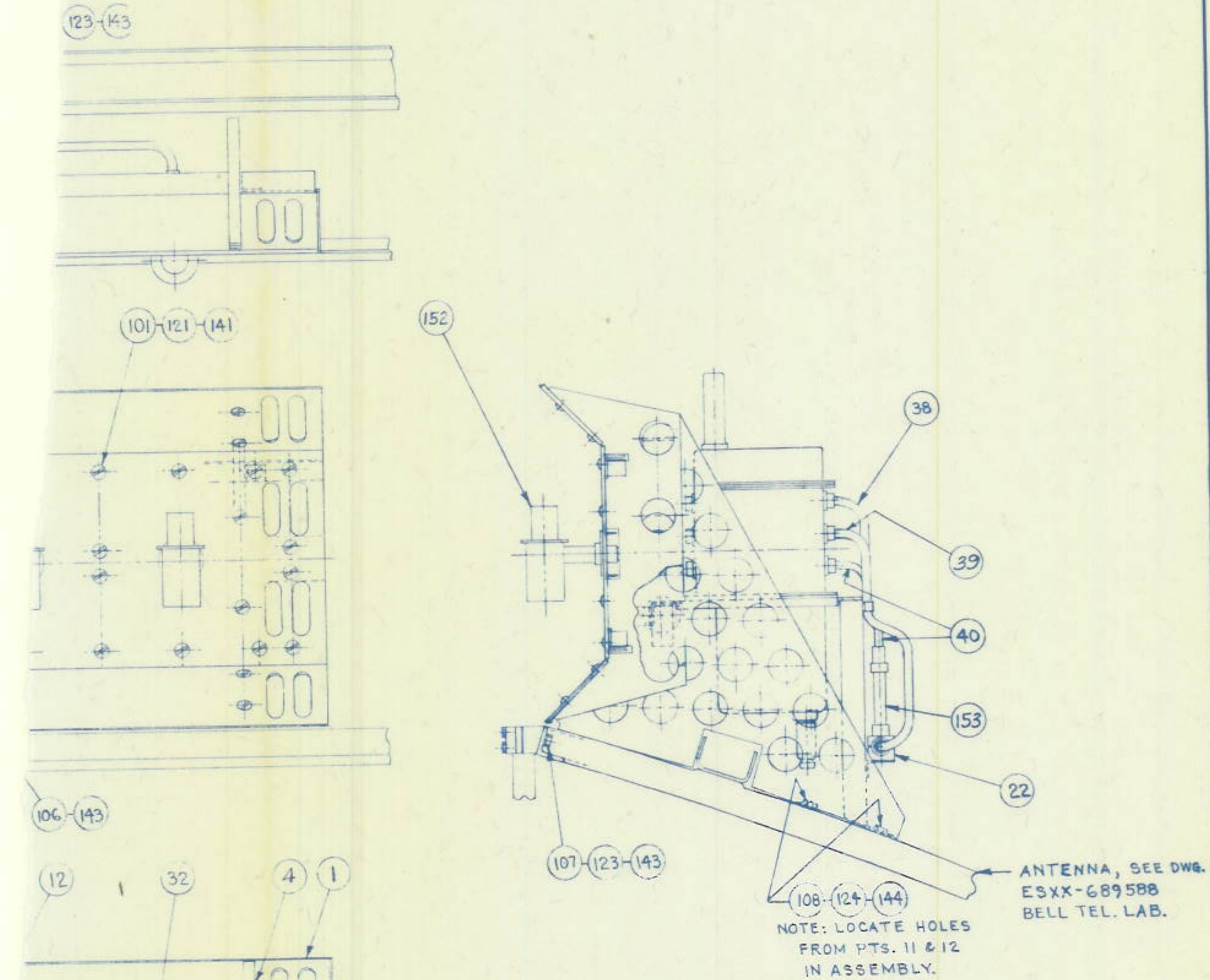
FORM NO. NAVEXOS 2297






[redacted]

NOTE:- ANODIZE ANTENNA SCREEN & MOUNTING STRUCTURE, IN ASSEMBLY AND FINISH ENTIRE UNIT WITH ZINC CHROMATE PRIMER AND NAVY GRAY PAINT.




NOTE: LOCATE HOLES FROM PTS. 11 & 12 IN ASSEMBLY.

ALTERATION TABLE

TOLERANCES UNLESS OTHERWISE SPECIFIED
1 PLACE DECIMAL = ± .1
2 PLACE DECIMAL = ± .01
3 PLACE DECIMAL = ± .005
DIMENSIONS IN INCHES

| REFERENCE DRAWINGS | | |
|---|---|---|
| RA 24F 243 | | |
| RA 47F 223 | | |
| RA 66F 335 | | |
| RA 47F 224 | | |
| DRAWN | ALEKS | IN CHARGE OF DESIGN |
| TRACED | | |
| CHECKED | J.L.B. | C.R.S. |
| APPR'V'D | C.A. Lundquist | |

SUPT. DESIGN AND DRAFTING DIVISION
[signature]
FOR DIRECTOR
COMDR. U.S.N.

NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

# LOBING MK. V-IFF ANTENNA

ASSEMBLY

SCALE 3IN. = 1FT. DATE OCT. 21, 1946

RA 66F 351A

6 SHEETS

PLATE 18

R-3026

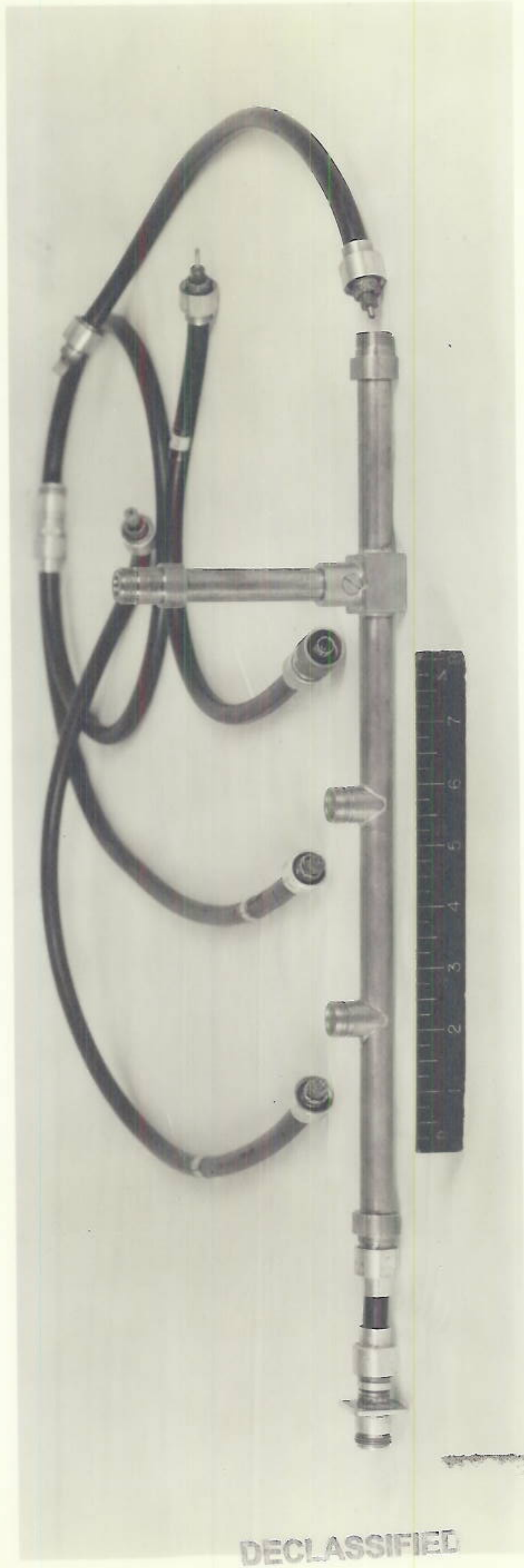
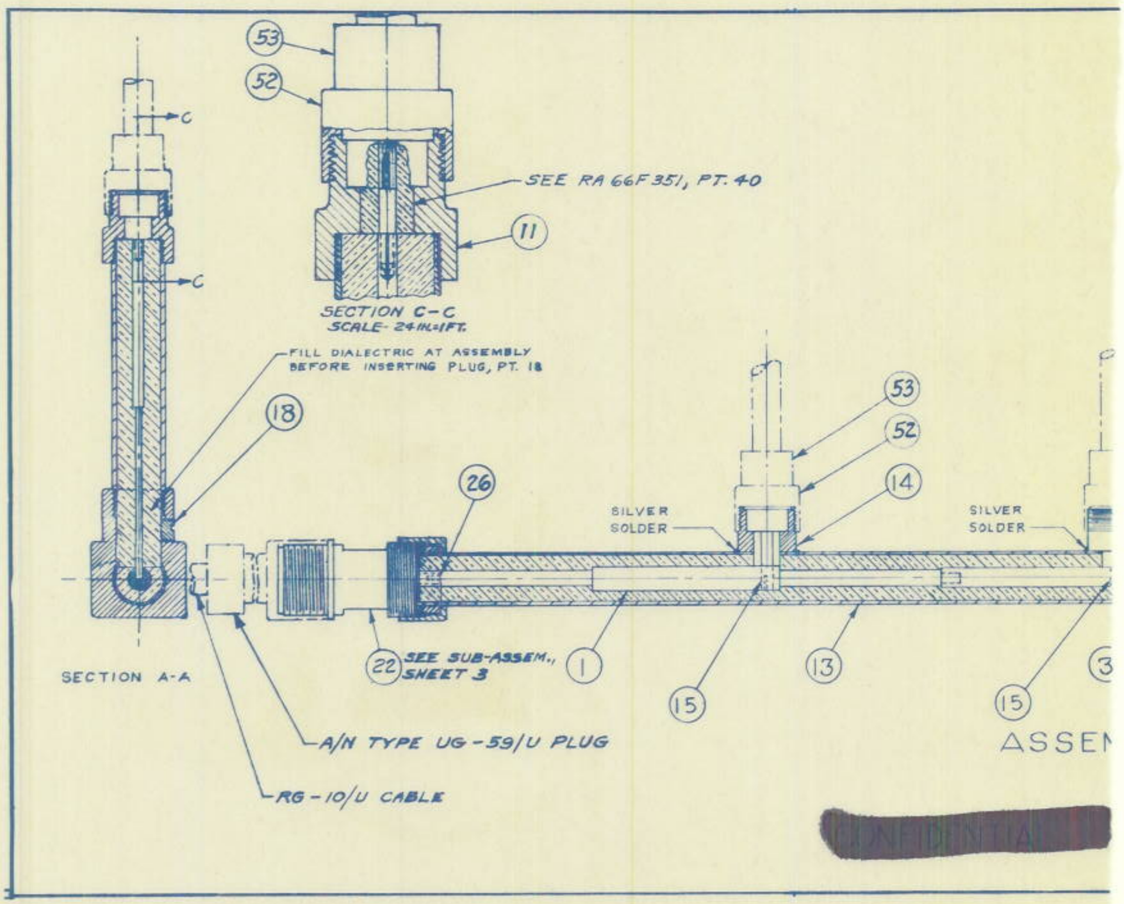




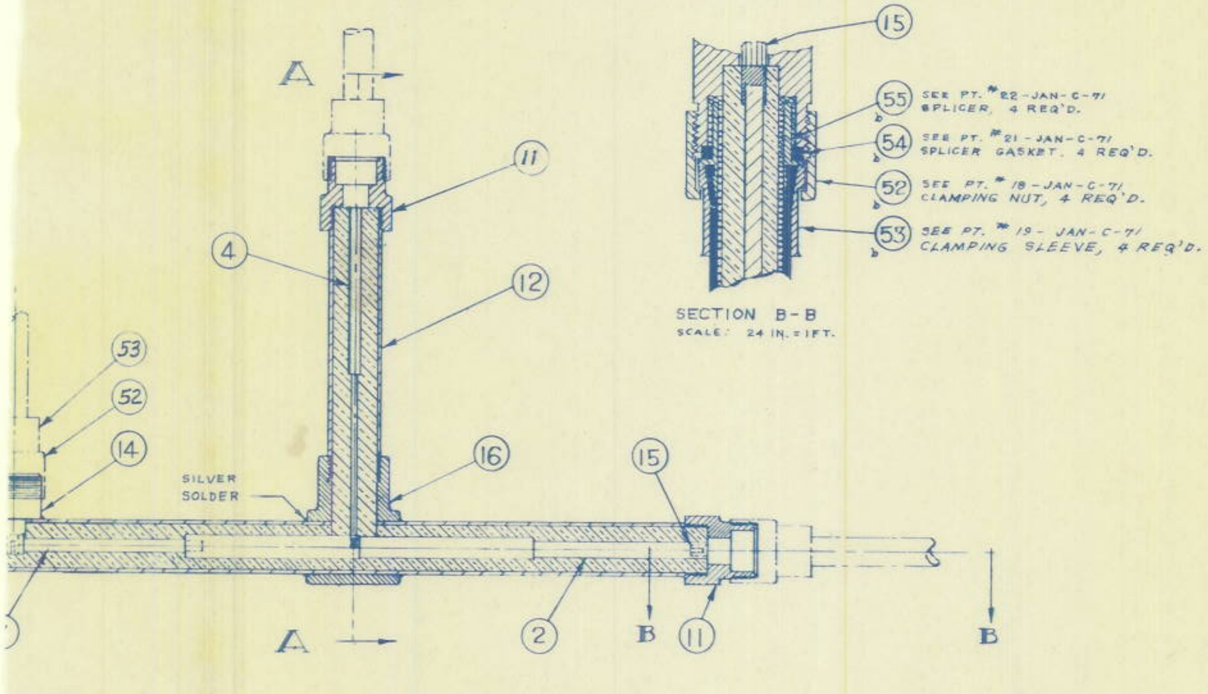


PLATE 19


53
52
SEE RA 66F351, PT. 40
11
SECTION C-C
SCALE- 24 IN.=1FT.
FILL DIALECTRIC AT ASSEMBLY BEFORE INSERTING PLUG, PT. 18
18
26
SILVER SOLDER
14
SILVER SOLDER
SECTION A-A
22
SEE SUB-ASSEM., SHEET 3
1
15
13
15
A/N TYPE UG-59/U PLUG
RG-10/U CABLE
ASSEM
[redacted]



[redacted]

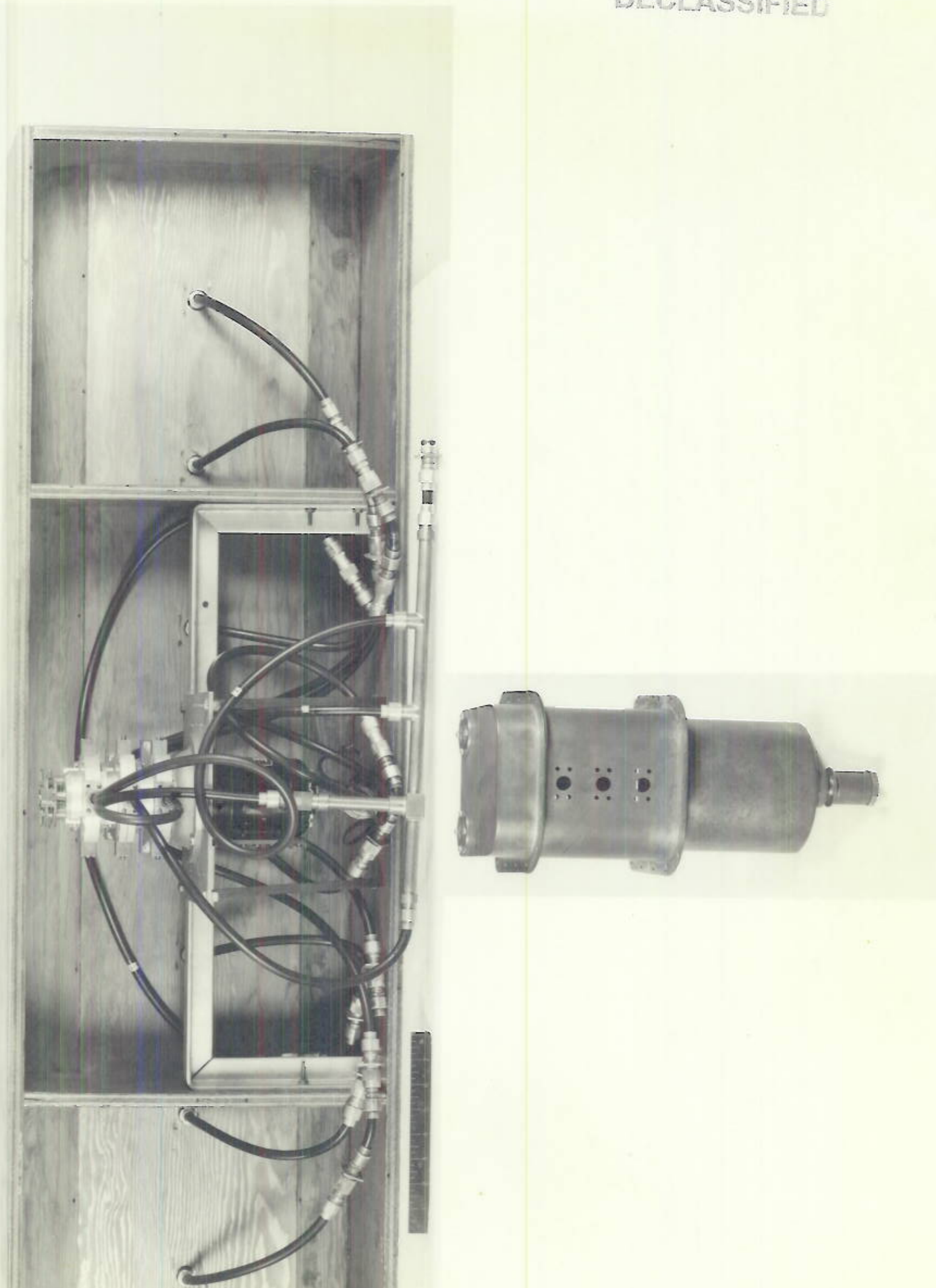



MBLY

R-3026

PLATE 20

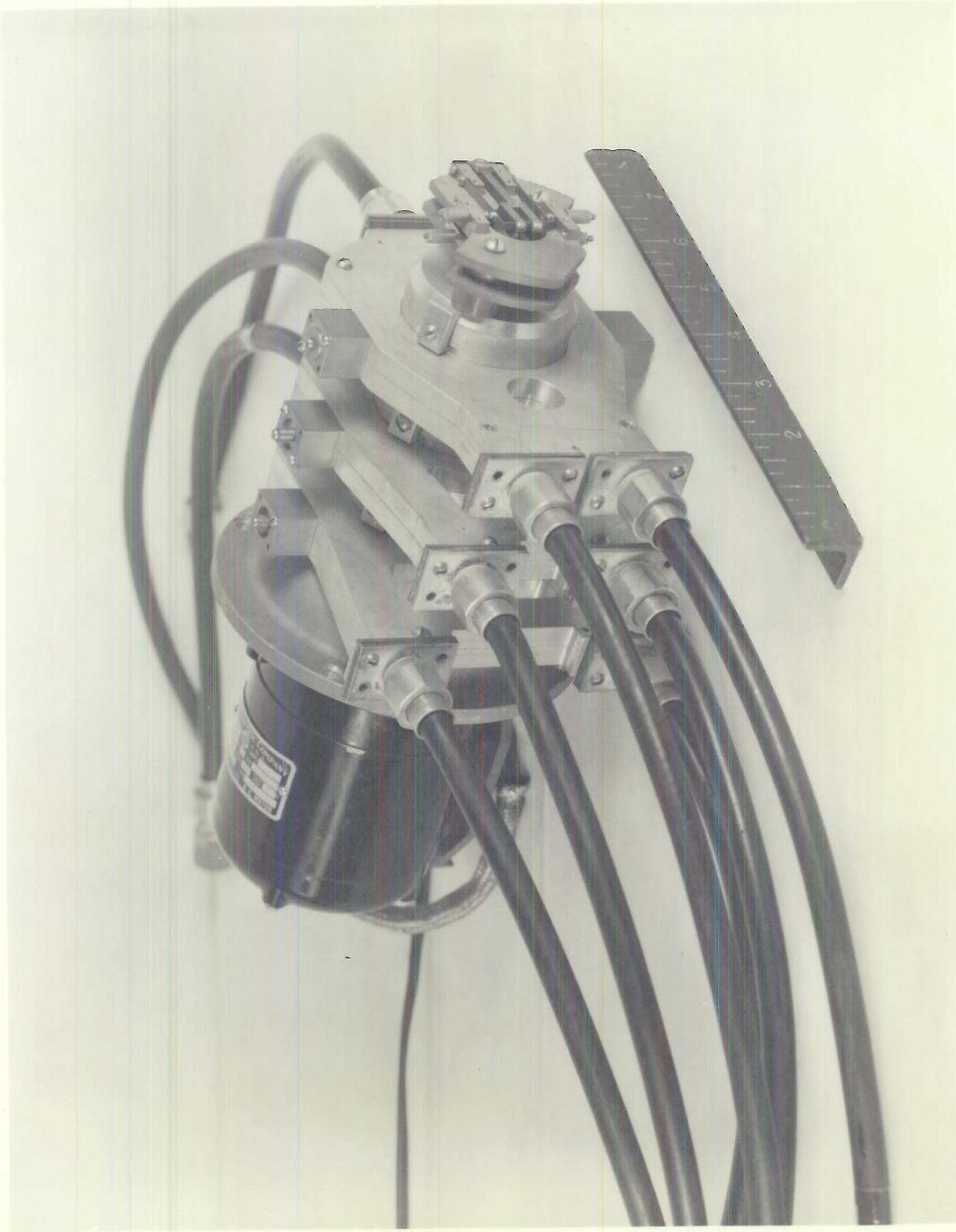
DECLASSIFIED



CONFIDENTIAL

DECLASSIFIED

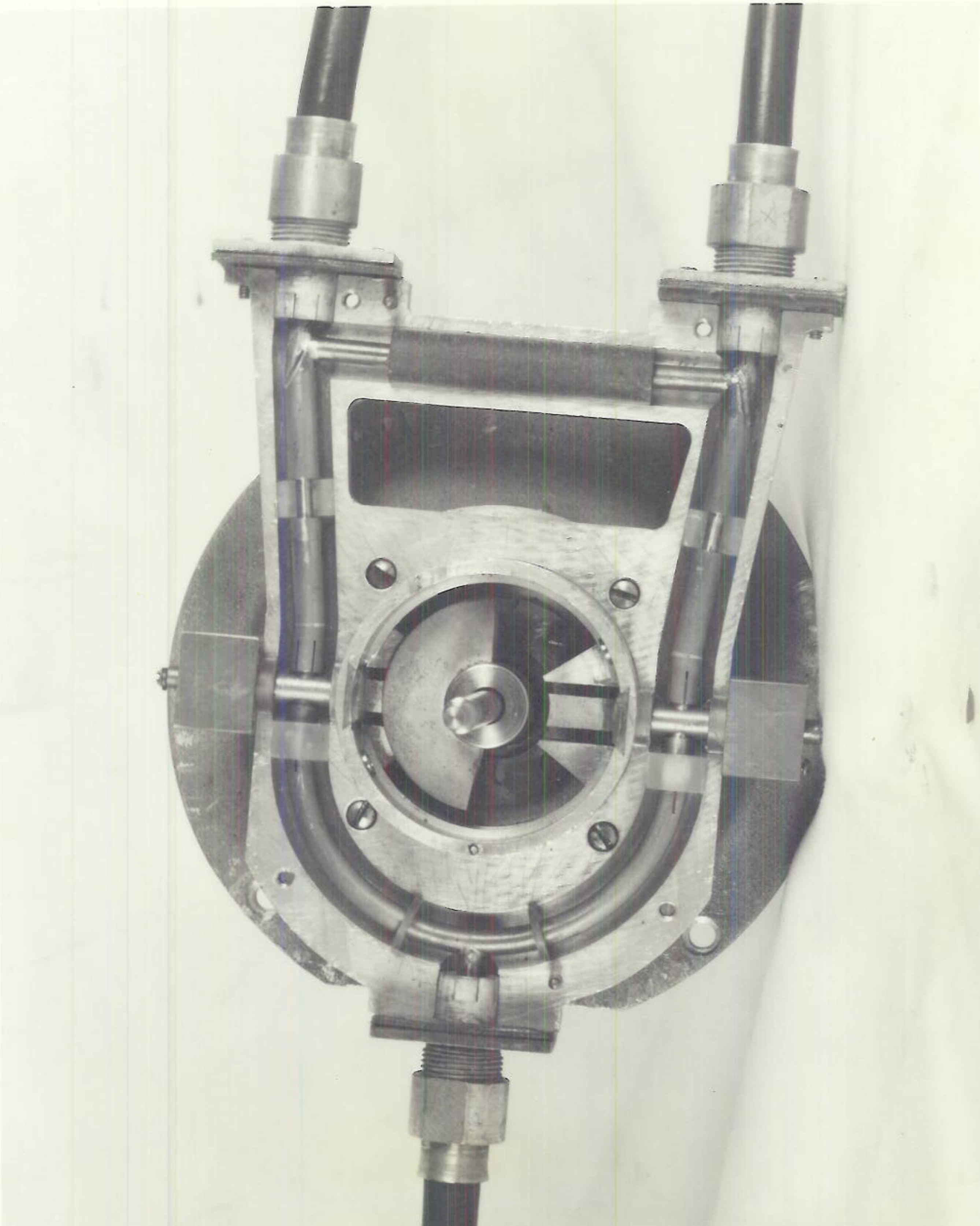
PLATE 21





DECLASSIFIED

PLATE 22



DECLASSIFIED



PLATE 23

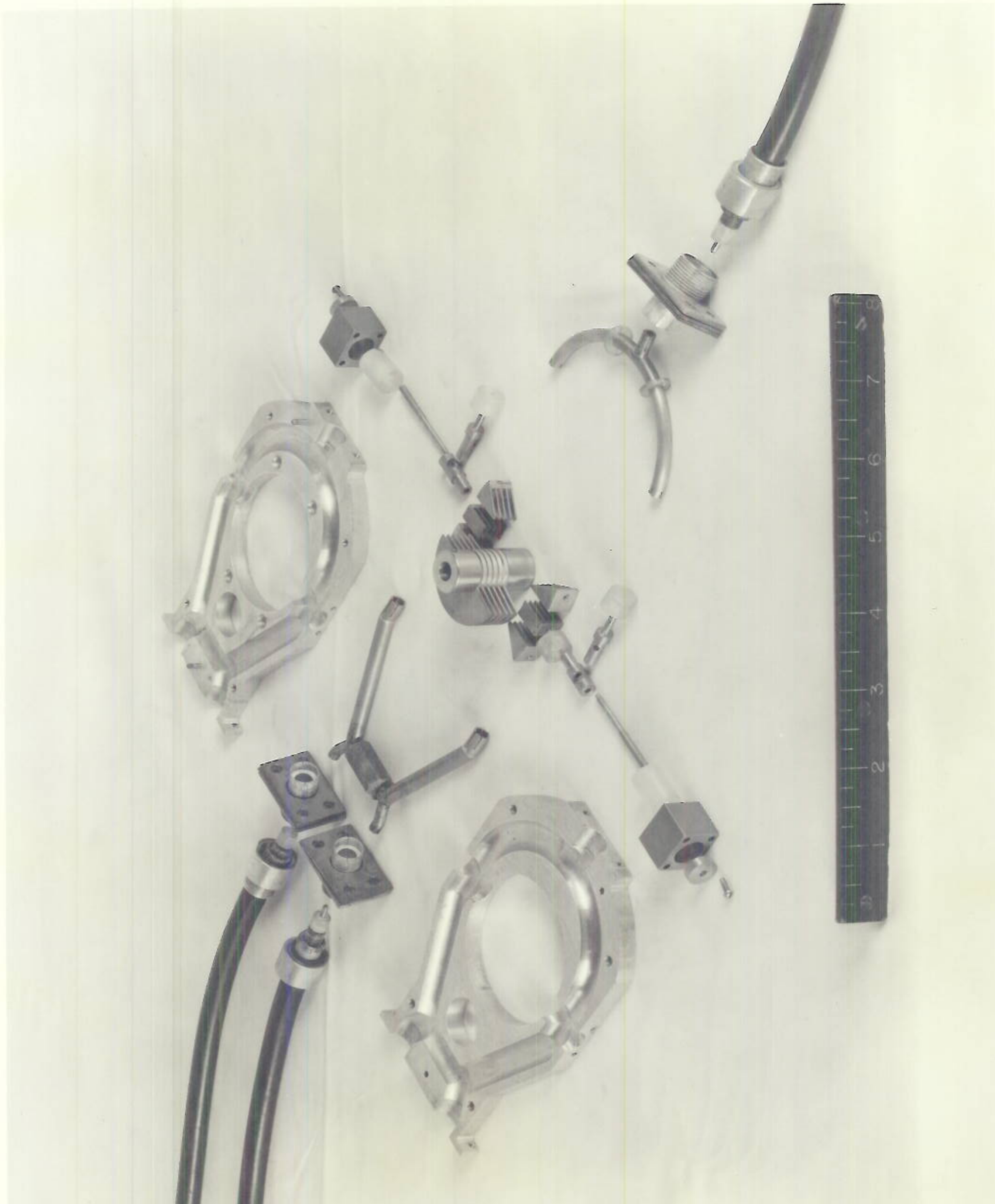
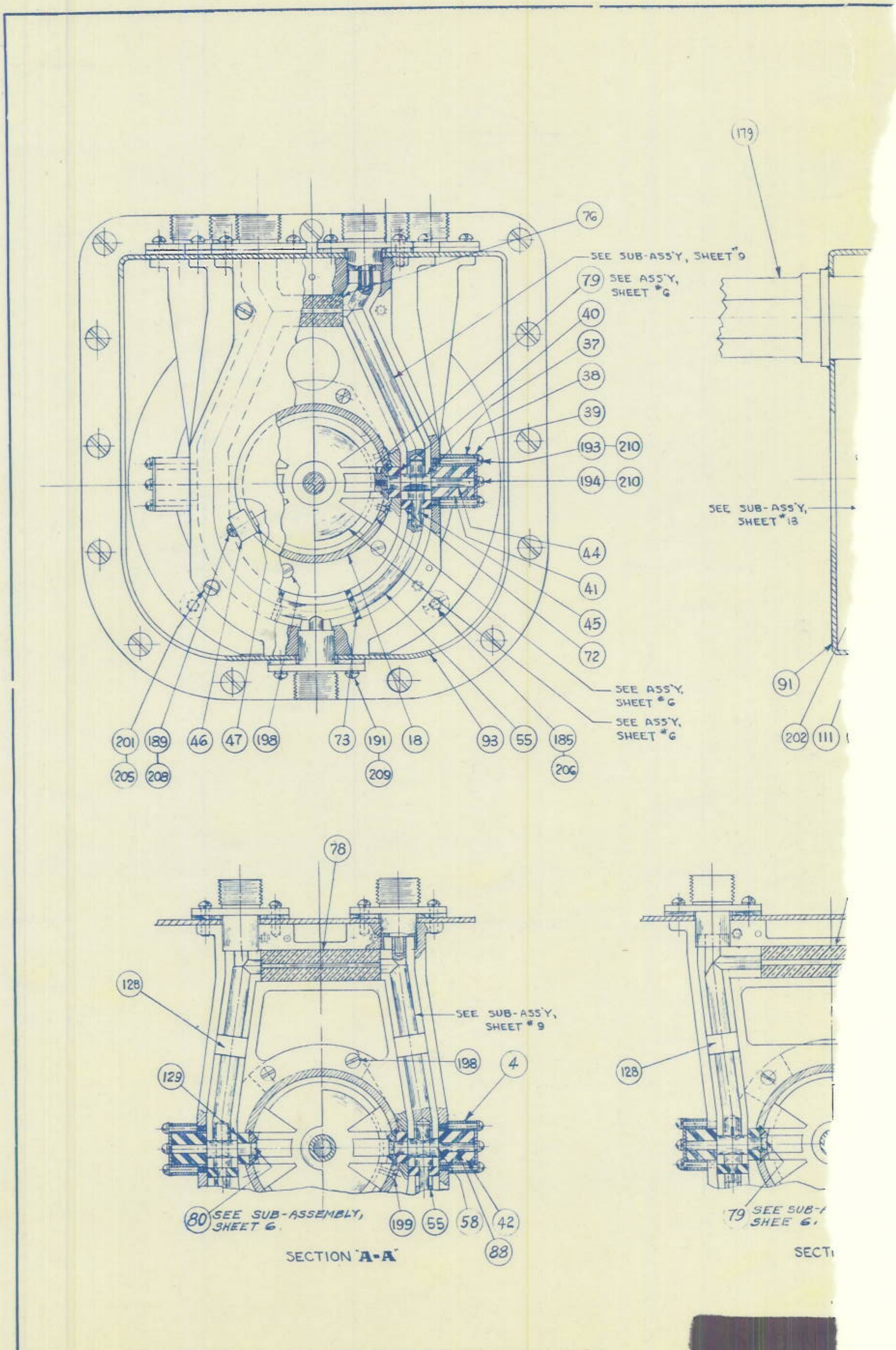




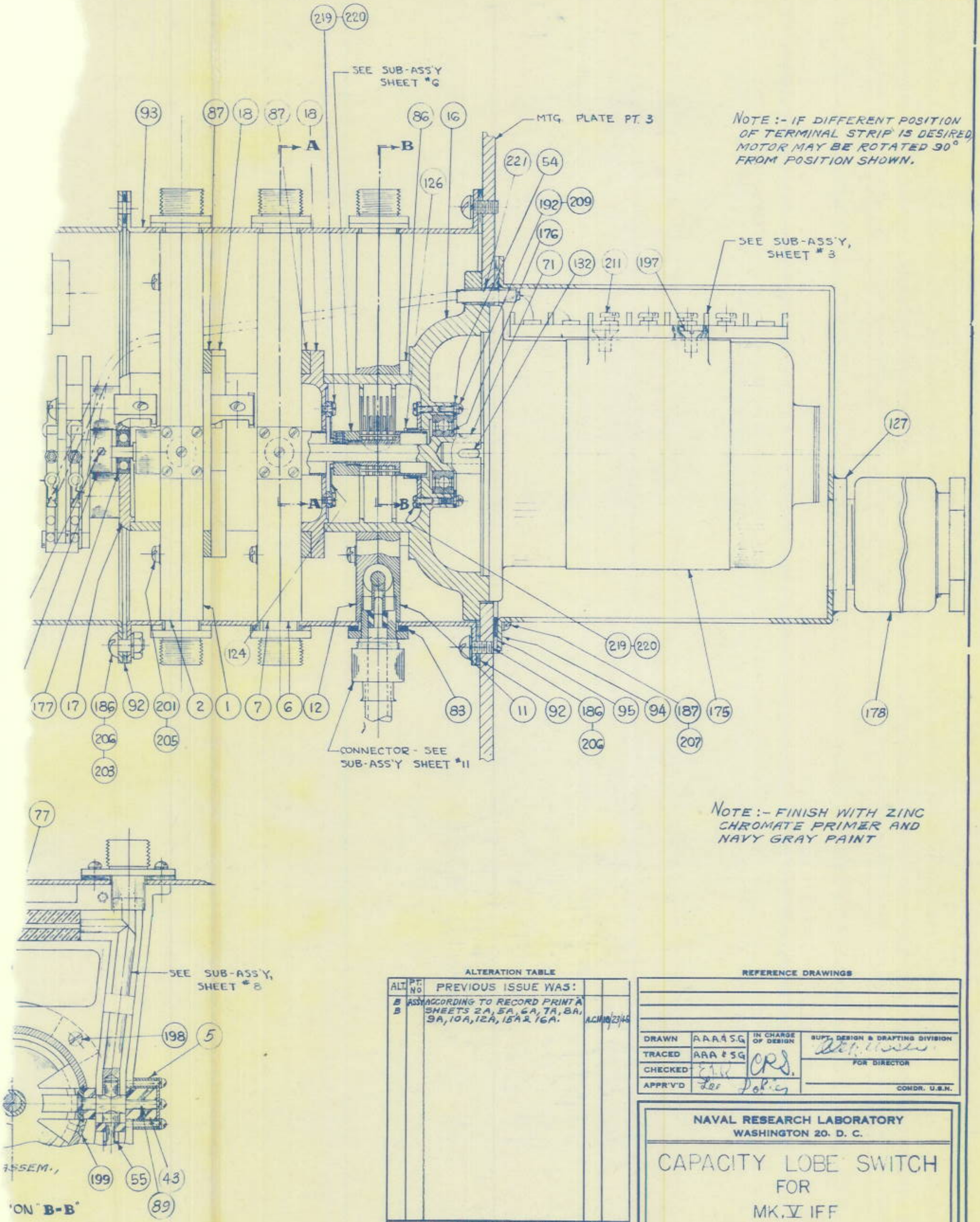



PLATE 24



76
SEE SUB-ASS'Y, SHEET #9
79 SEE ASS'Y, SHEET #6
40
37
38
39
193 210
194 210
44
41
45
72
SEE ASS'Y, SHEET #6
SEE ASS'Y, SHEET #6
201 205
189 208
46
47
198
73
191 209
18
93
55
185 206
179
SEE SUB-ASS'Y, SHEET #13
91
202
111
78
128
SEE SUB-ASS'Y, SHEET #9
129
198
4
80 SEE SUB-ASSEMBLY, SHEET 6.
199
55
58
42
88
SECTION "A-A"
128
79 SEE SUB-/
SHEE 6,
SECT


[redacted]




NOTE :- IF DIFFERENT POSITION OF TERMINAL STRIP IS DESIRED, MOTOR MAY BE ROTATED 90° FROM POSITION SHOWN.

NOTE :- FINISH WITH ZINC CHROMATE PRIMER AND NAVY GRAY PAINT

**ALTERATION TABLE**

| ALT. | PT. NO | PREVIOUS ISSUE WAS: | |
|---|---|---|---|
| B B | ASSY | ACCORDING TO RECORD PRINT A SHEETS 2A, 5A, 6A, 7A, 8A, 9A, 10A, 12A, 15A & 16A. | A.C.M. 10/23/46 |

SYMBOLS AND THEIR EQUIVALENT TOLERANCES (UNLESS OTHERWISE NOTED)

SYMBOL 1 ...... ±.0005 SYMBOL 3 ...... ±.0050

**REFERENCE DRAWINGS**

| | | | |
|---|---|---|---|
| DRAWN | A.A.A. & S.G. | IN CHARGE OF DESIGN | SUPT. DESIGN & DRAFTING DIVISION |
| TRACED | A.A.A. & S.G. | C.R.S. | FOR DIRECTOR |
| CHECKED | E.J.R. | | |
| APPR'V'D | | | COMDR. U.S.N. |

**NAVAL RESEARCH LABORATORY**
**WASHINGTON 20. D. C.**

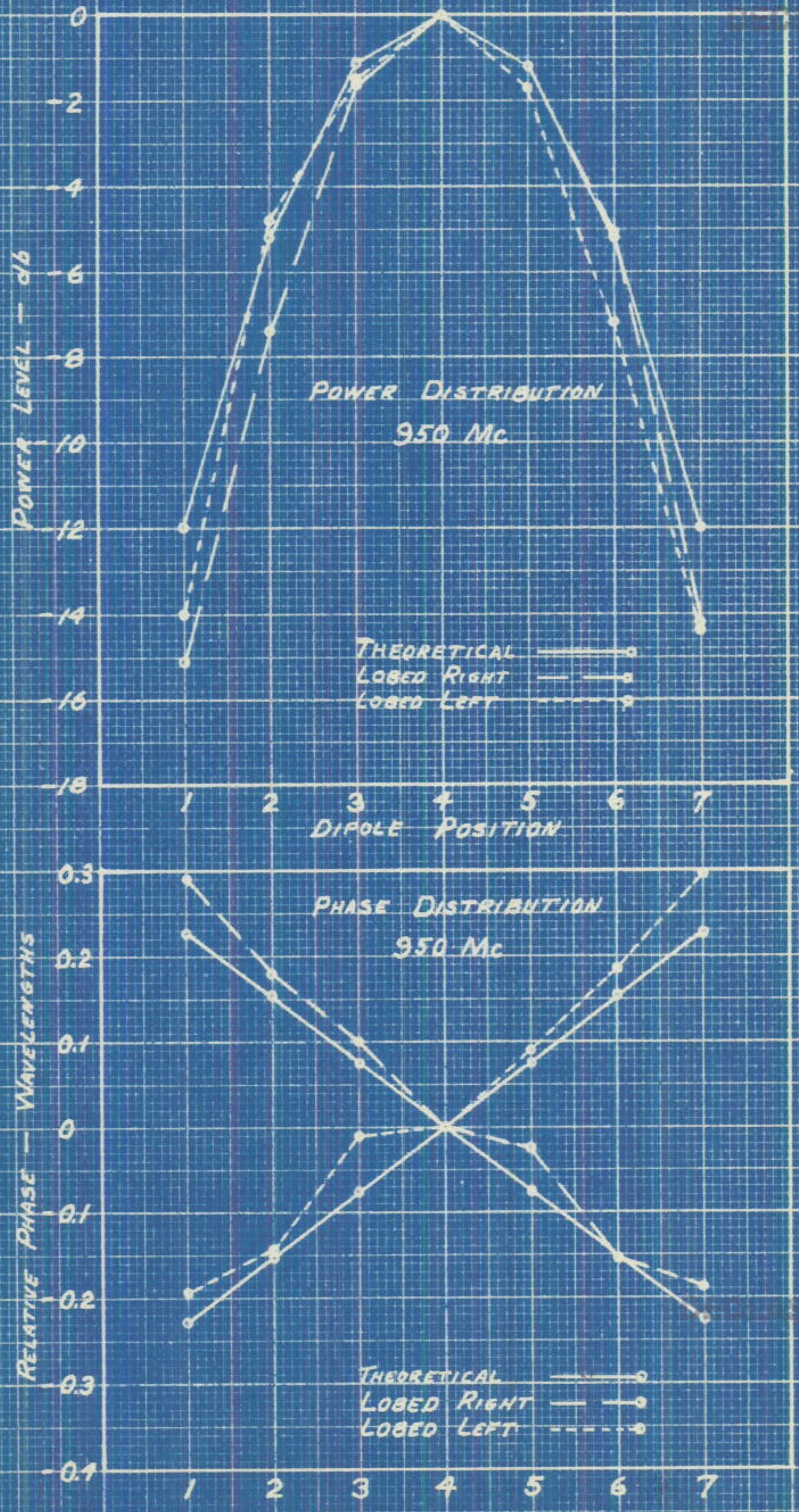
CAPACITY LOBE SWITCH
FOR
MK. V IFF
ASSEMBLY

SCALE FULL SIZE    DATE JULY 15, 1945

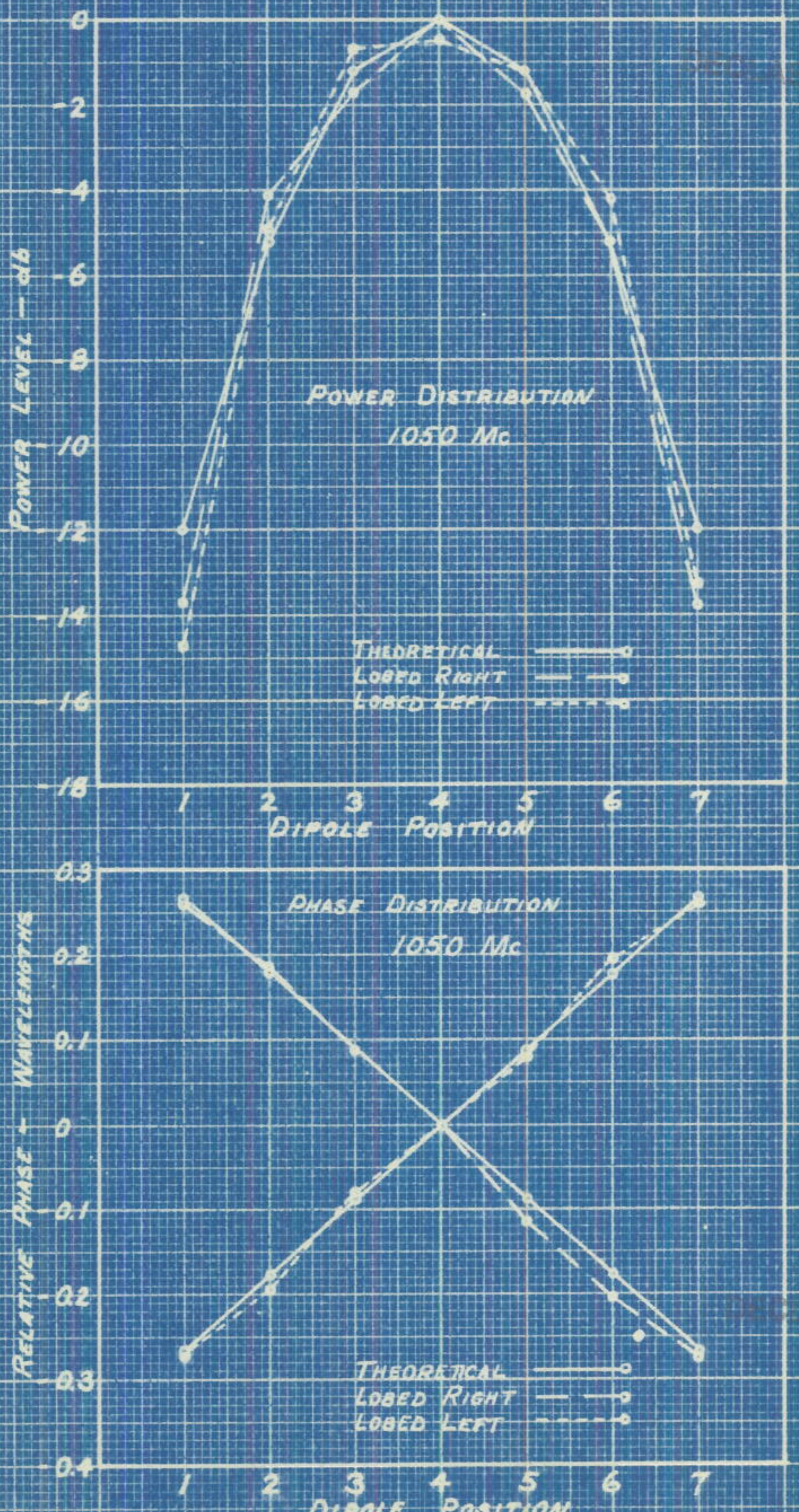
R-3026

PLATE 25

## Power and Phase Distribution Supplied by Feed System To 51.5 Ohm Loads



POWER AND PHASE DISTRIBUTION SUPPLIED BY FEED SYSTEM
TO 51.5 OHM LOADS




R-3026

PLATE 27

POWER AND PHASE DISTRIBUTION SUPPLIED BY FEED SYSTEM TO 51.5 OHM LOADS

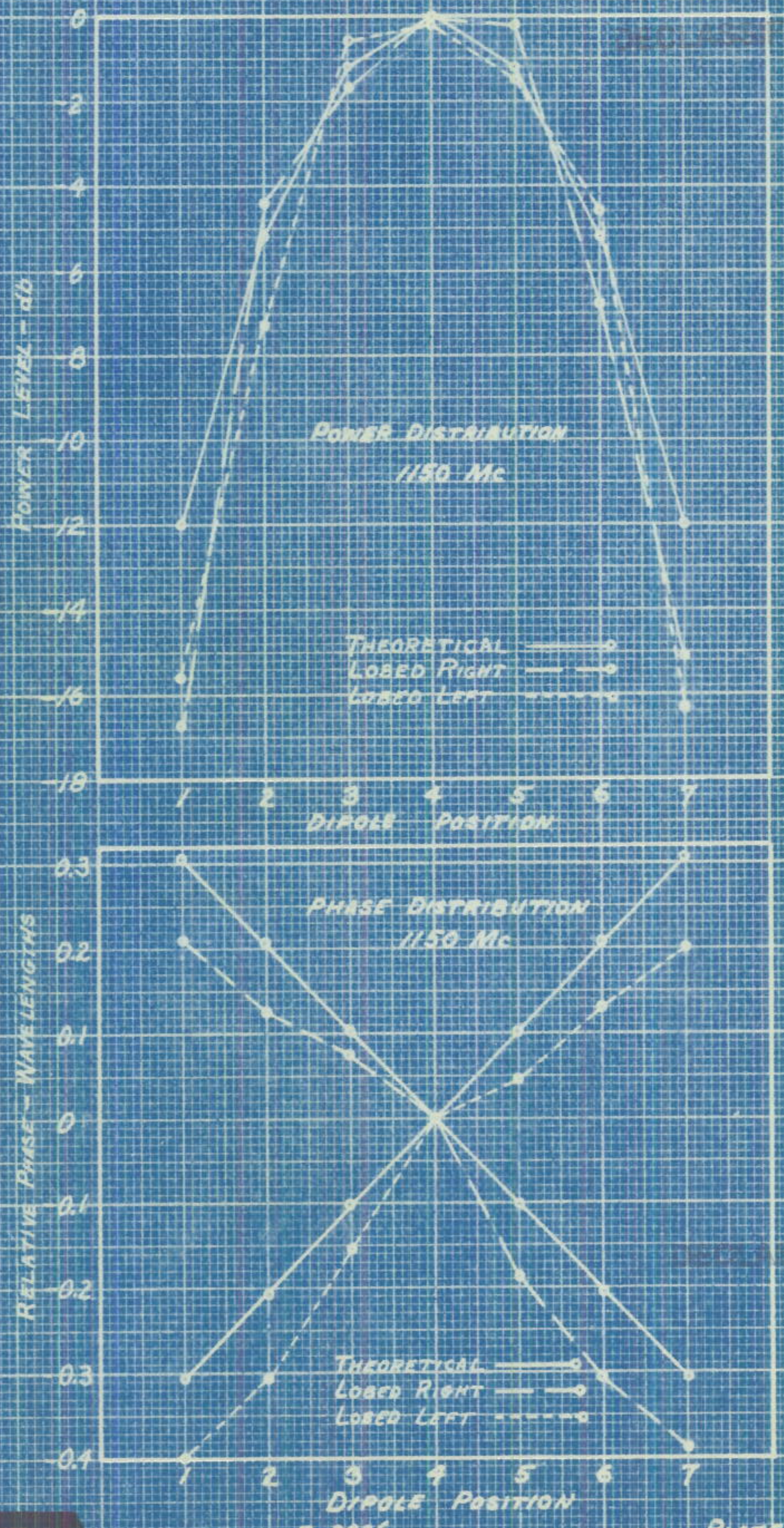



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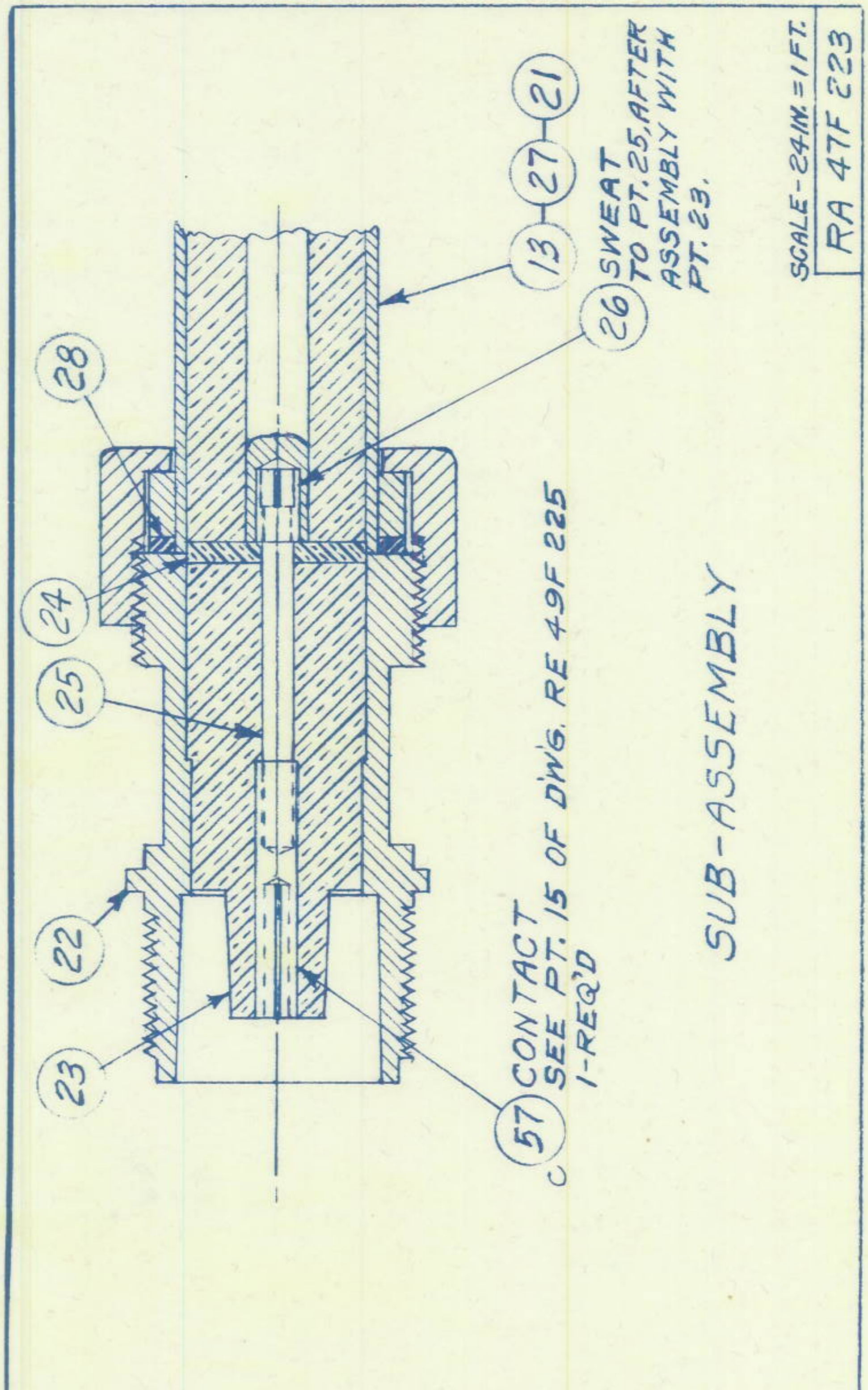
PLATE 28




[redacted] R-3026 PLATE 29

DECLASSIFIED

UNCLASSIFIED

# Complete Azimuth Pattern of Lobing Antenna for IFF Mark V at 950 Mc

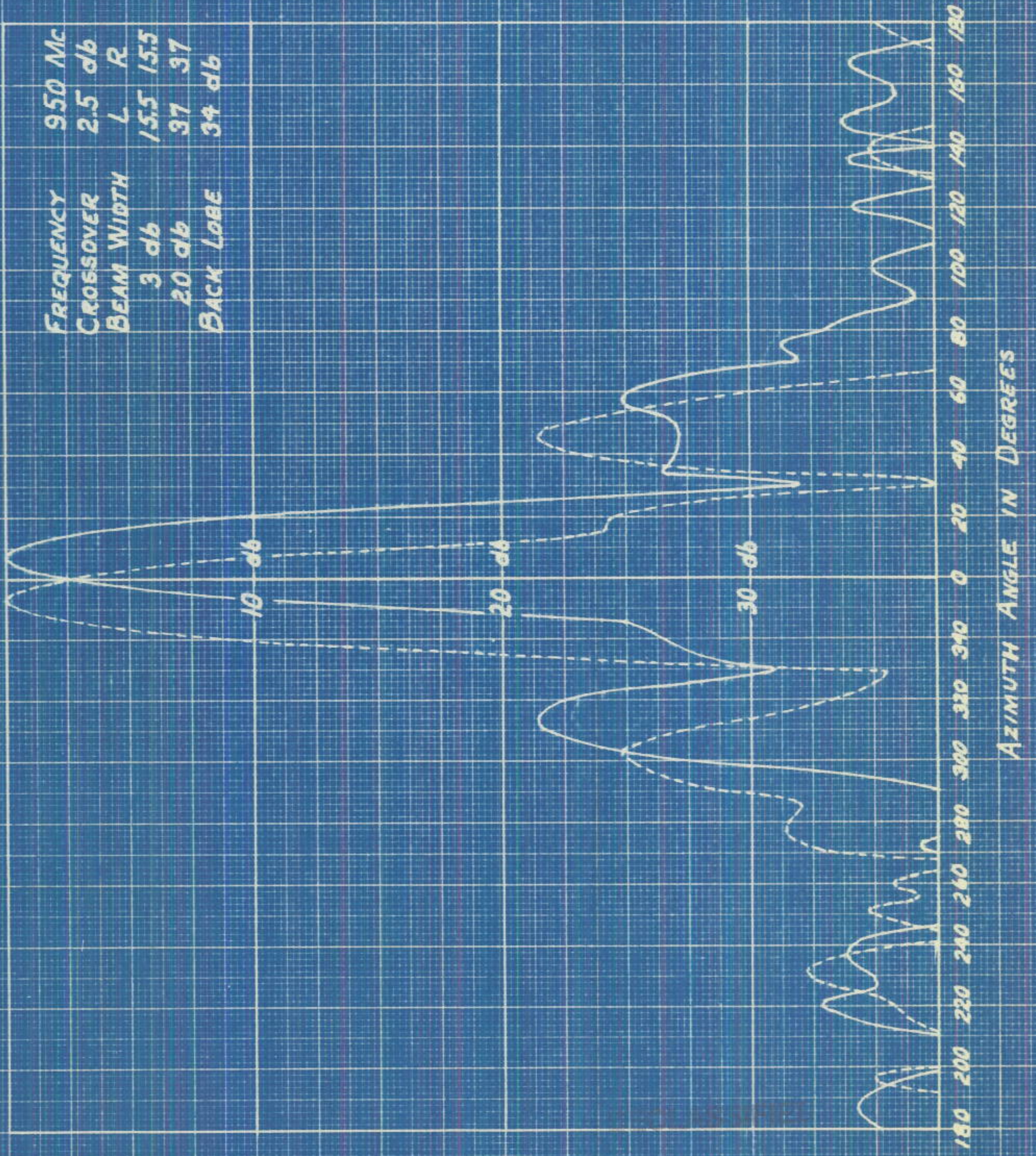



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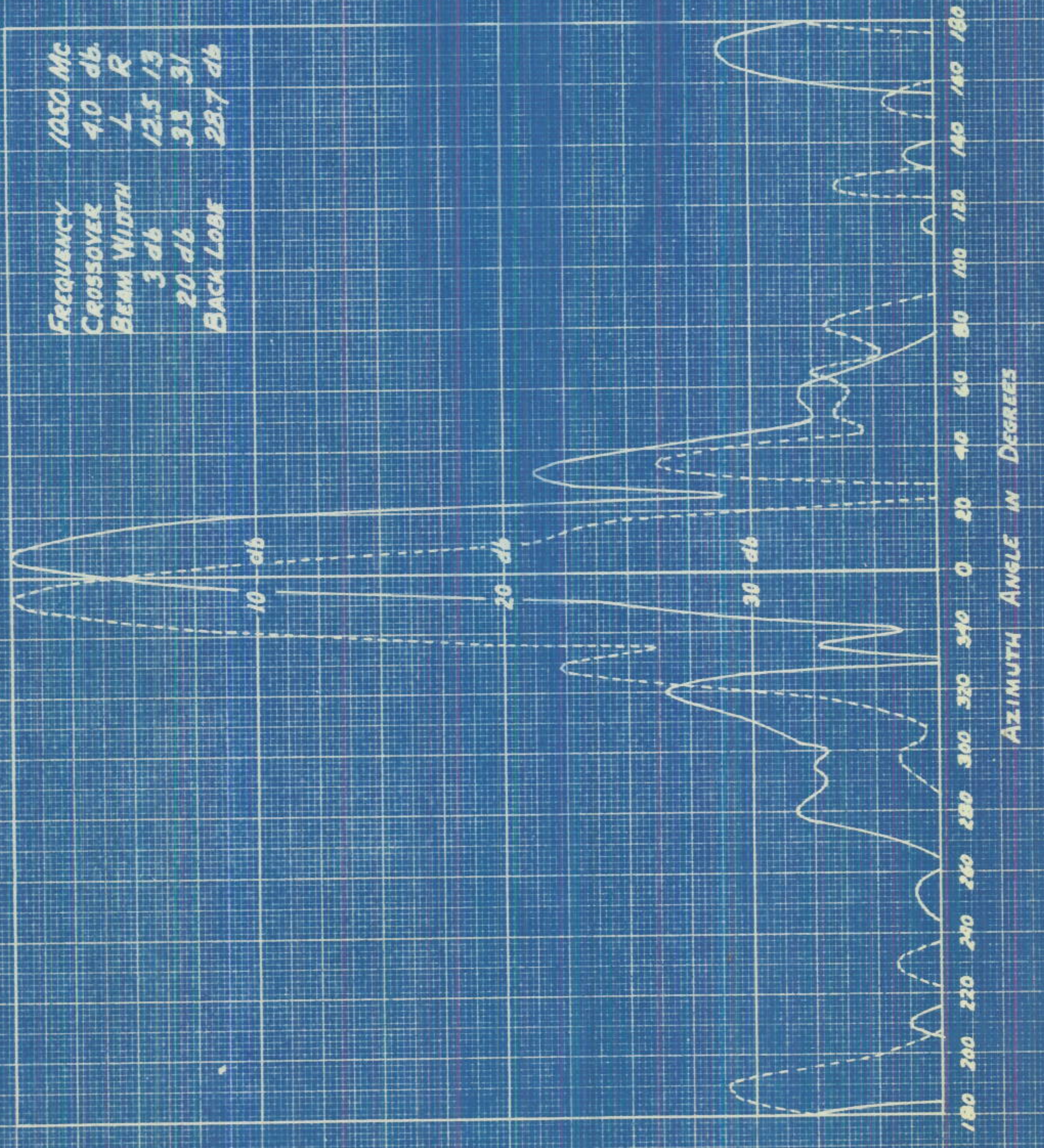
PLATE 30

## Complete Azimuth Pattern

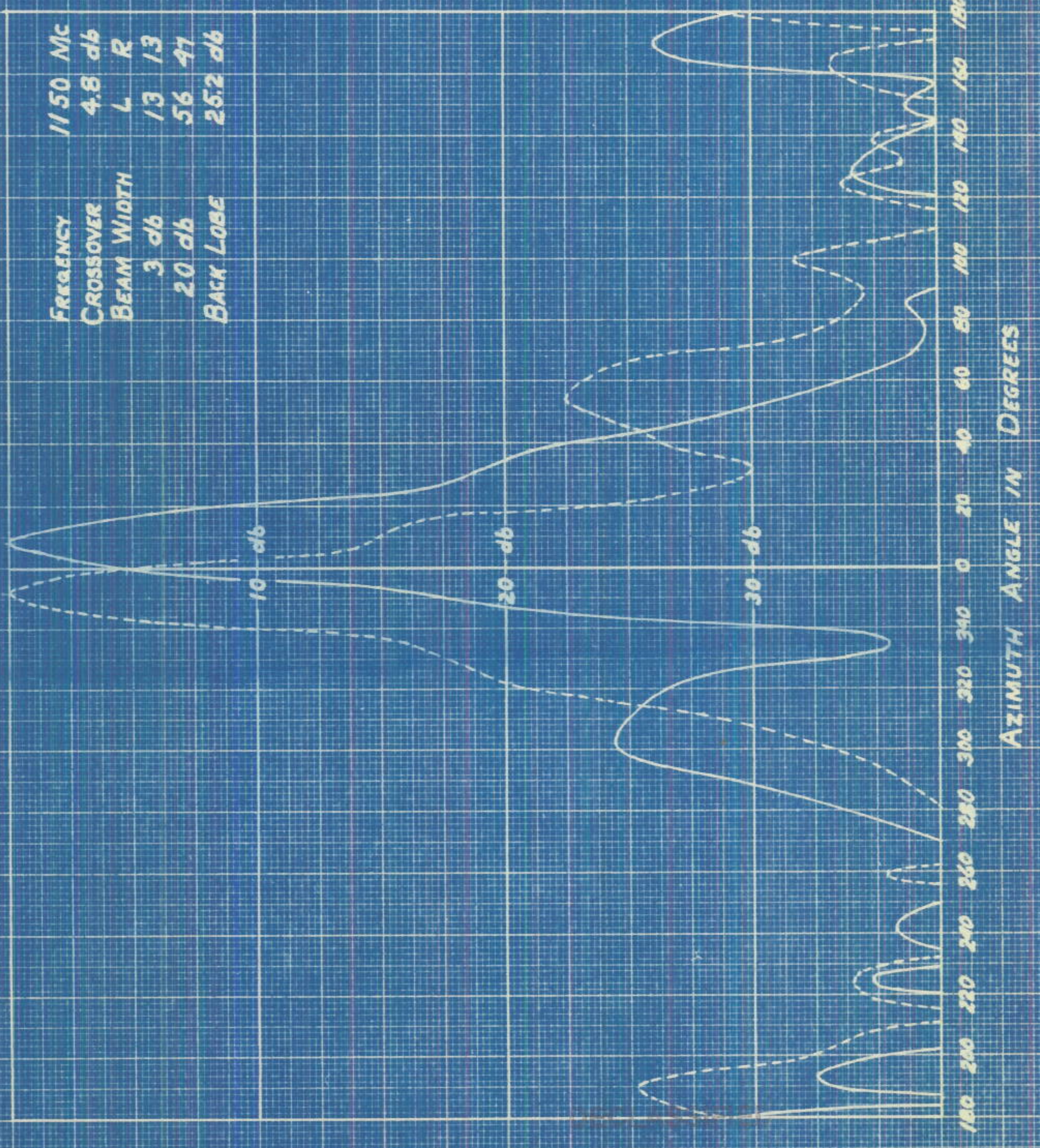
## of Lobing Antenna for IFF Mark V

## at 1050 Mc

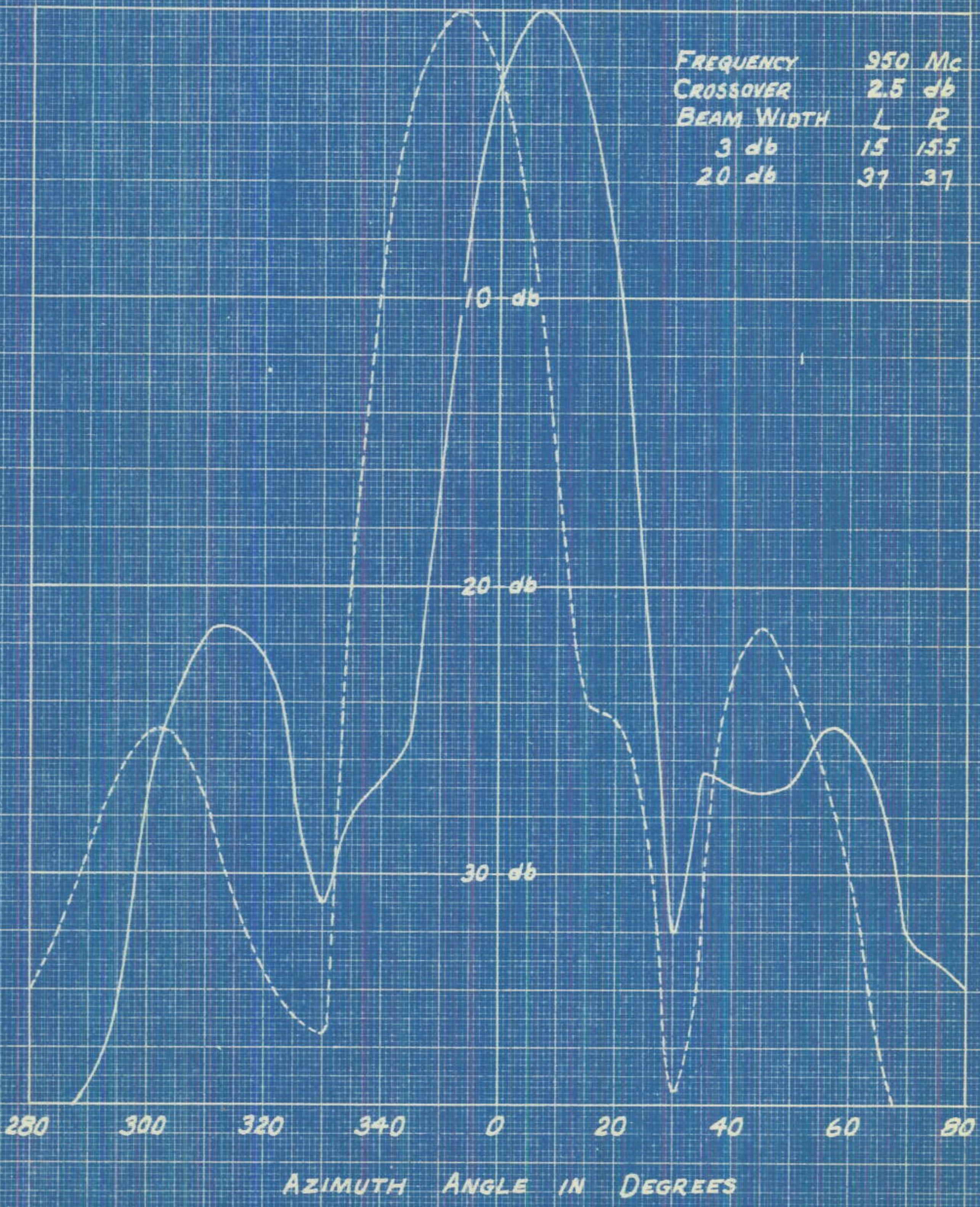


UNCLASSIFIED

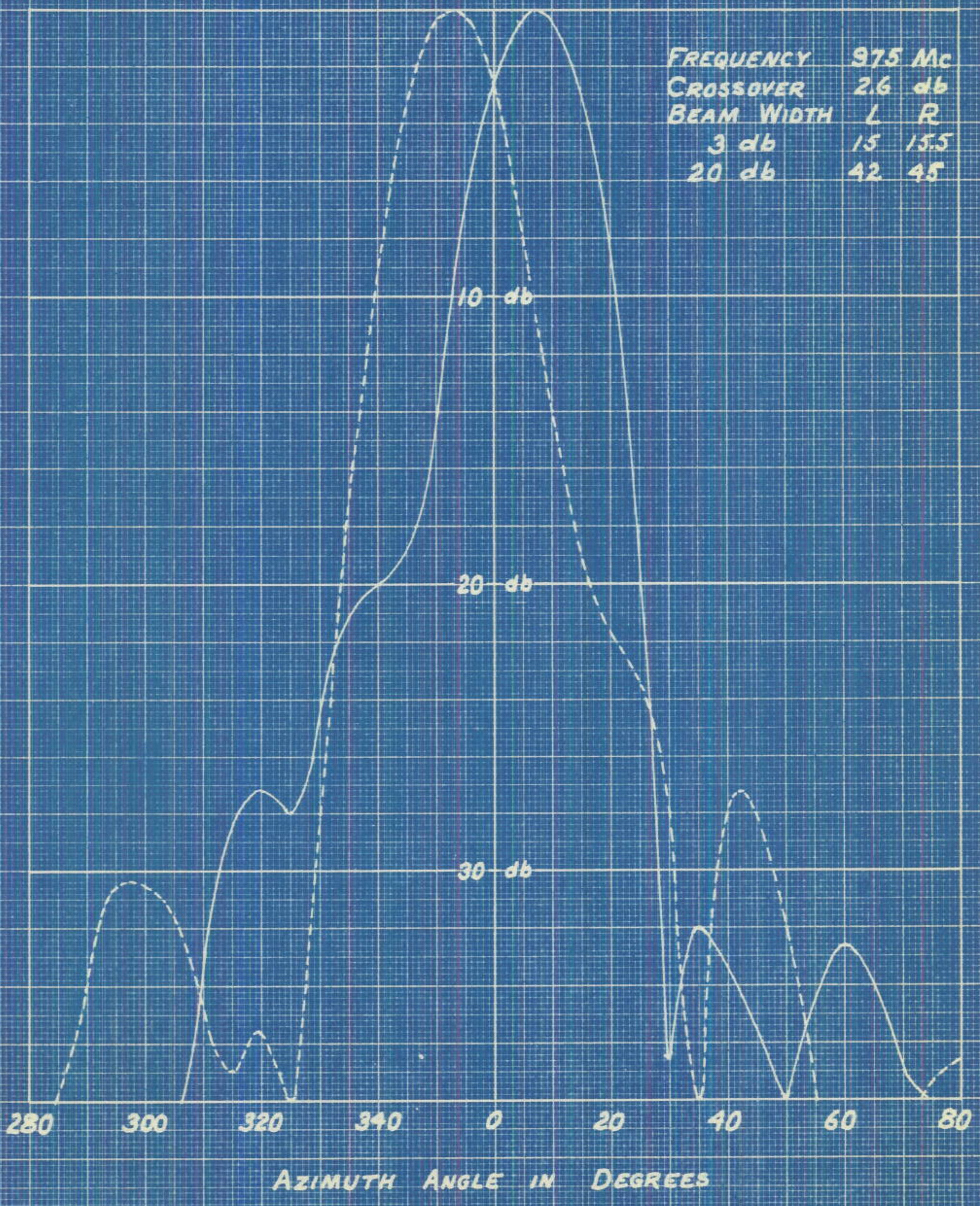
# Complete Azimuth Pattern of Lobing Antenna for IFF Mark V at 1150 Mc



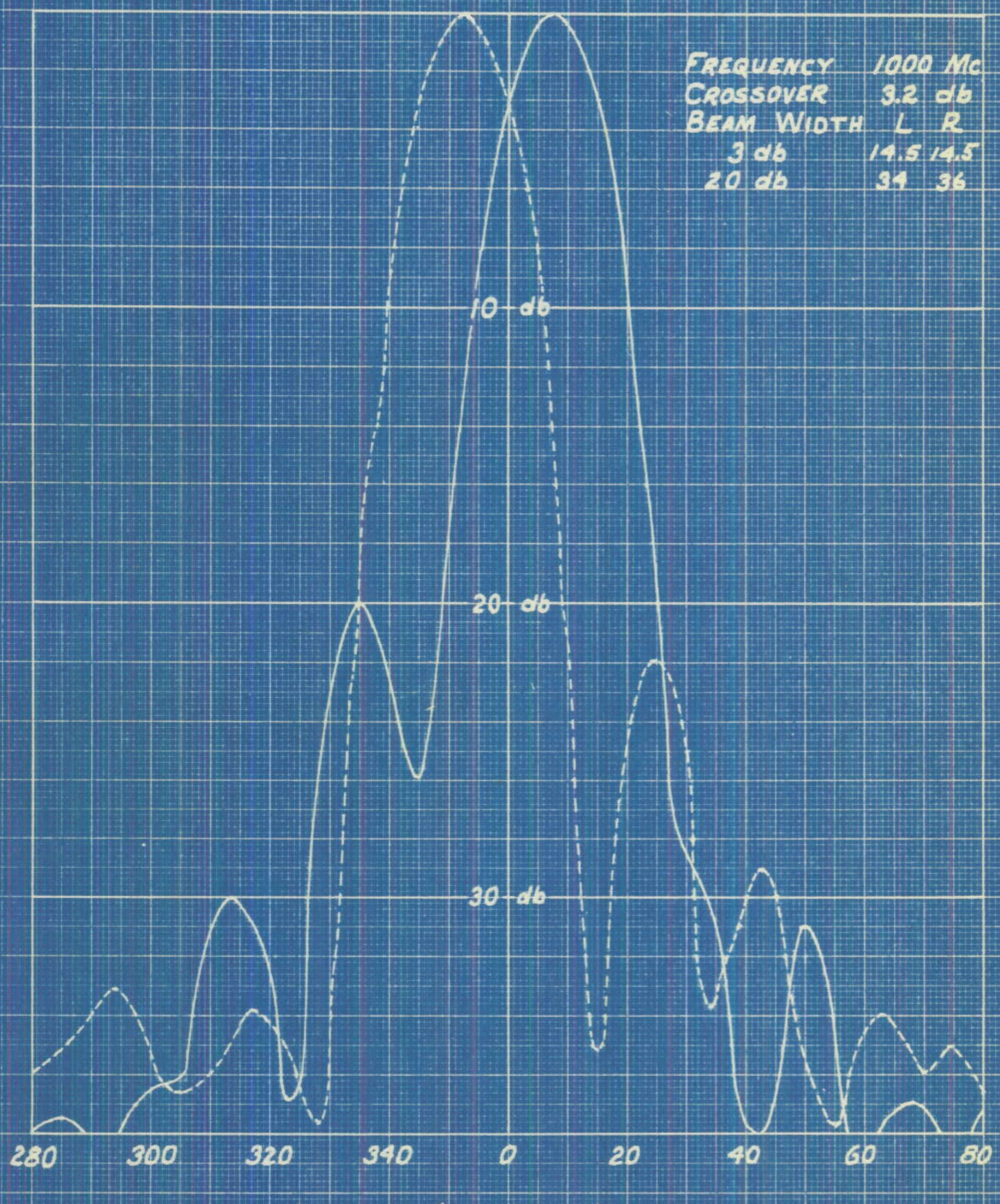
HORIZONTAL PATTERN OF LOBING ANTENNA FOR IFF MARK V



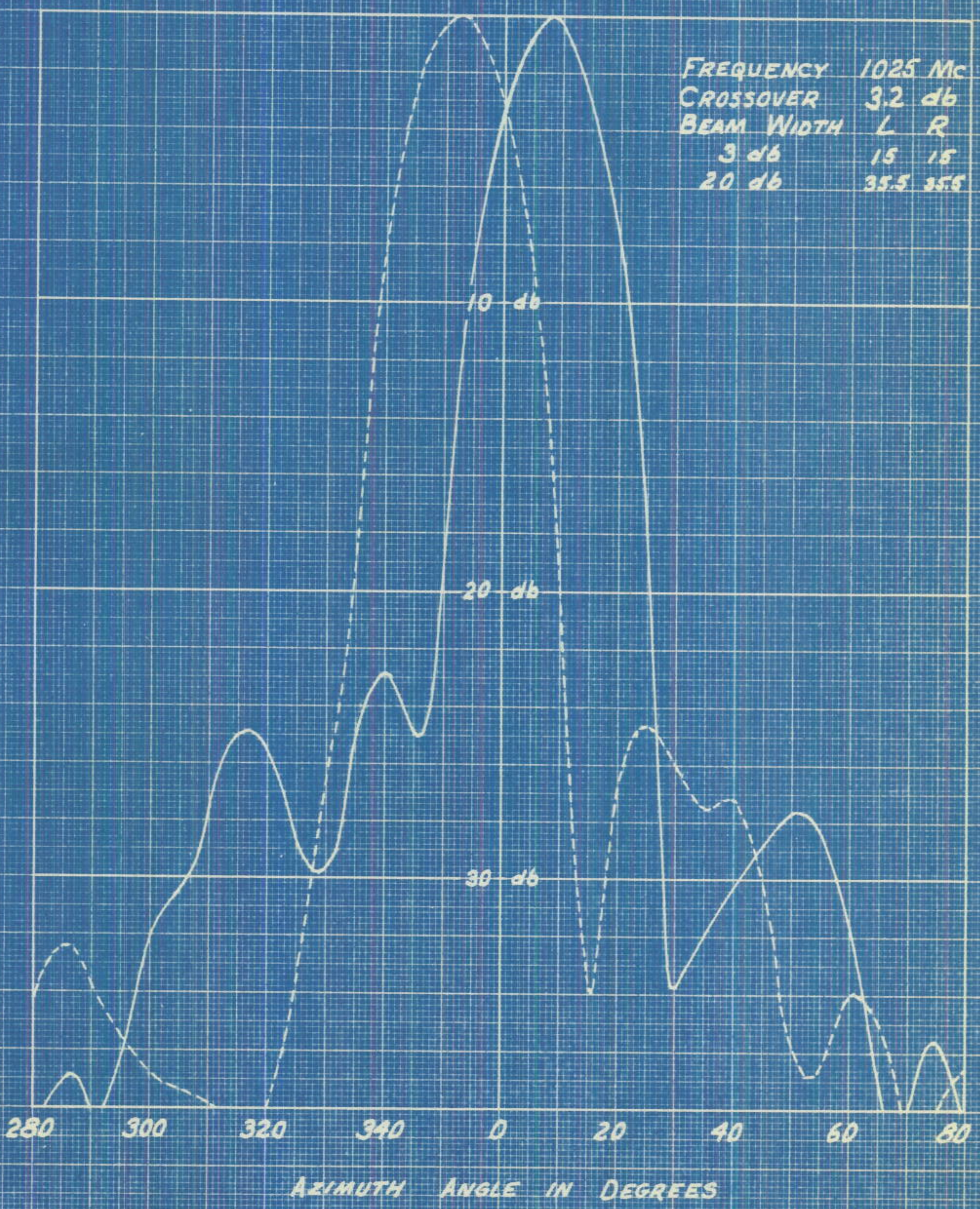
## HORIZONTAL PATTERN OF LOBING ANTENNA FOR IFF MARK V



# HORIZONTAL PATTERN OF LOBING ANTENNA FOR IFF MARK V



HORIZONTAL PATTERN OF LOBING ANTENNA FOR IFF MARK V



## HORIZONTAL PATTERN OF LOBING ANTENNA FOR IFF MARK V

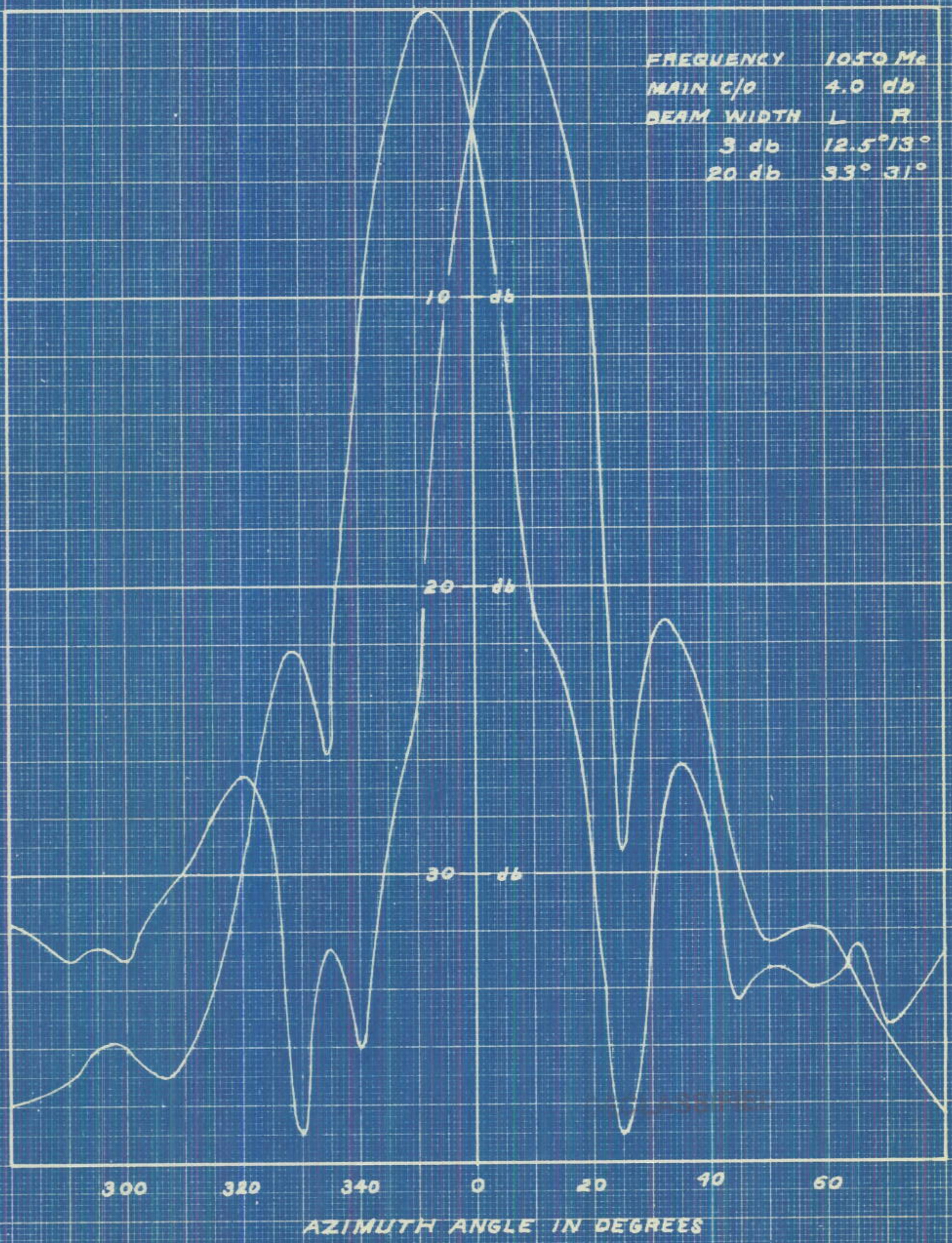



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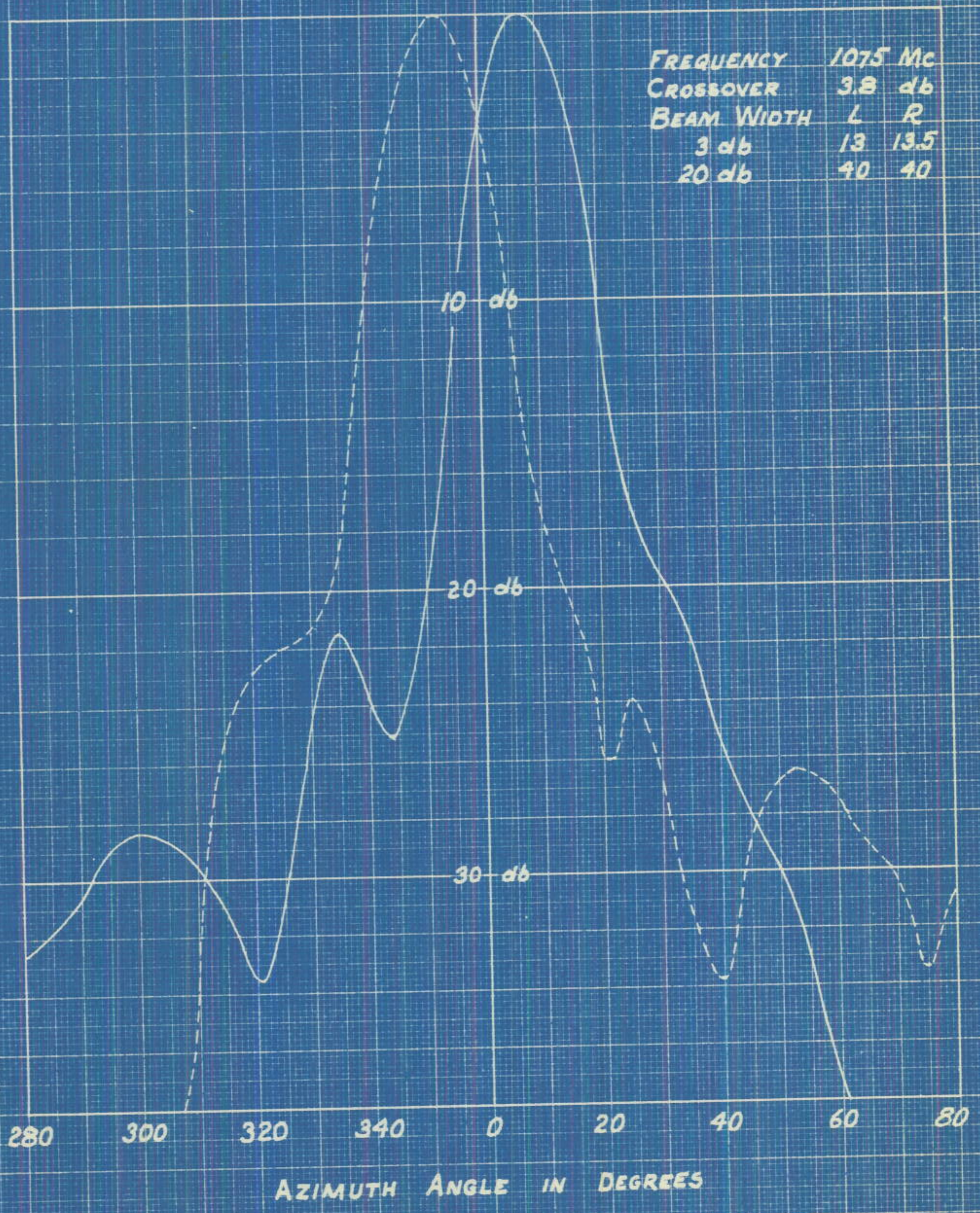
PLATE 37

HORIZONTAL PATTERN OF LOBING ANTENNA FOR IFF MARK V



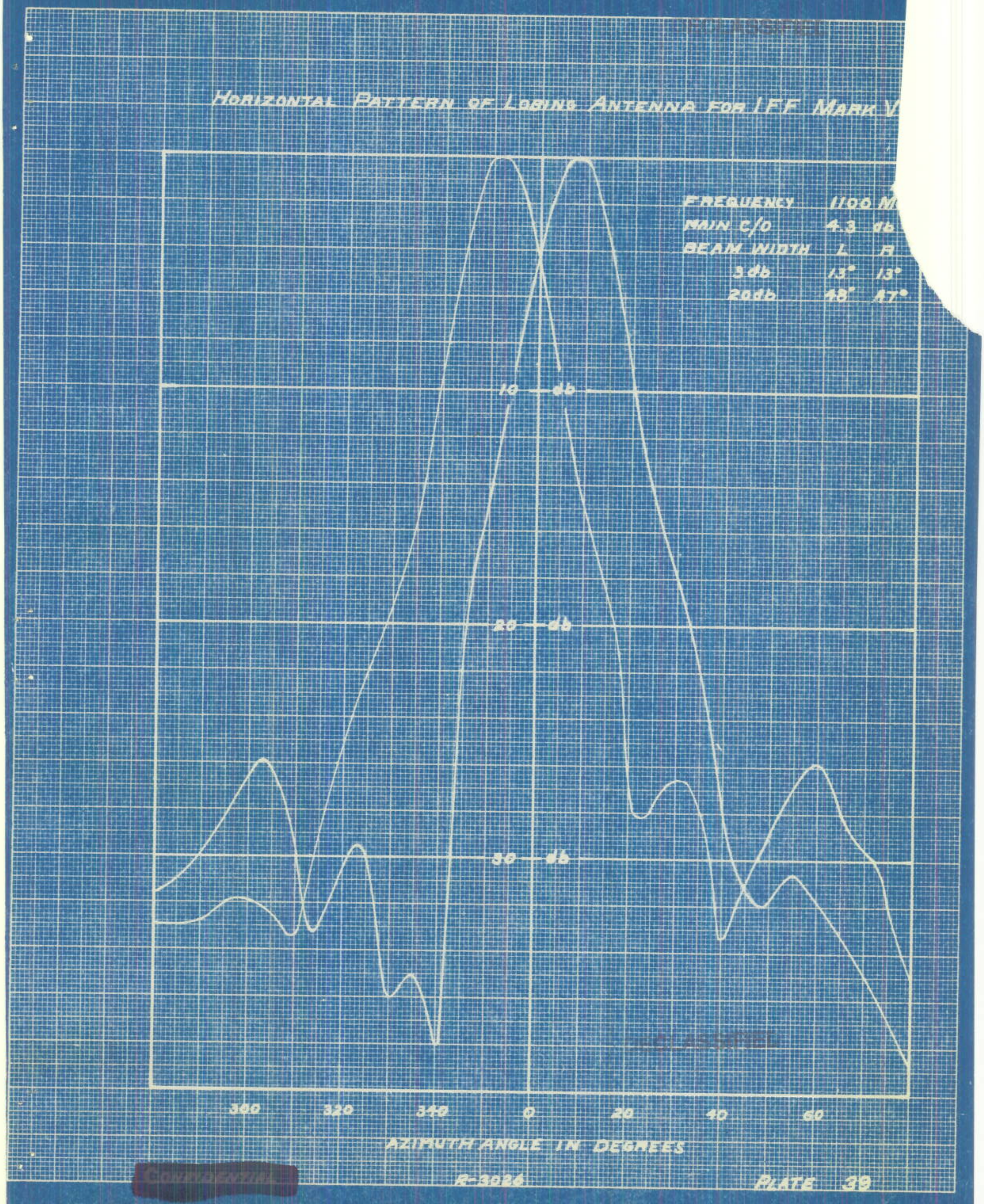

UNCLASSIFIED
HORIZONTAL PATTERN OF LOBING ANTENNA FOR IFF MARK V
FREQUENCY 1100 M
MAIN C/O 4.3 db
BEAM WIDTH L R
3 db 13° 13°
20db 48° 47°
10 db
20 db
30 db
UNCLASSIFIED
300
320
340
0
20
40
60
AZIMUTH ANGLE IN DEGREES
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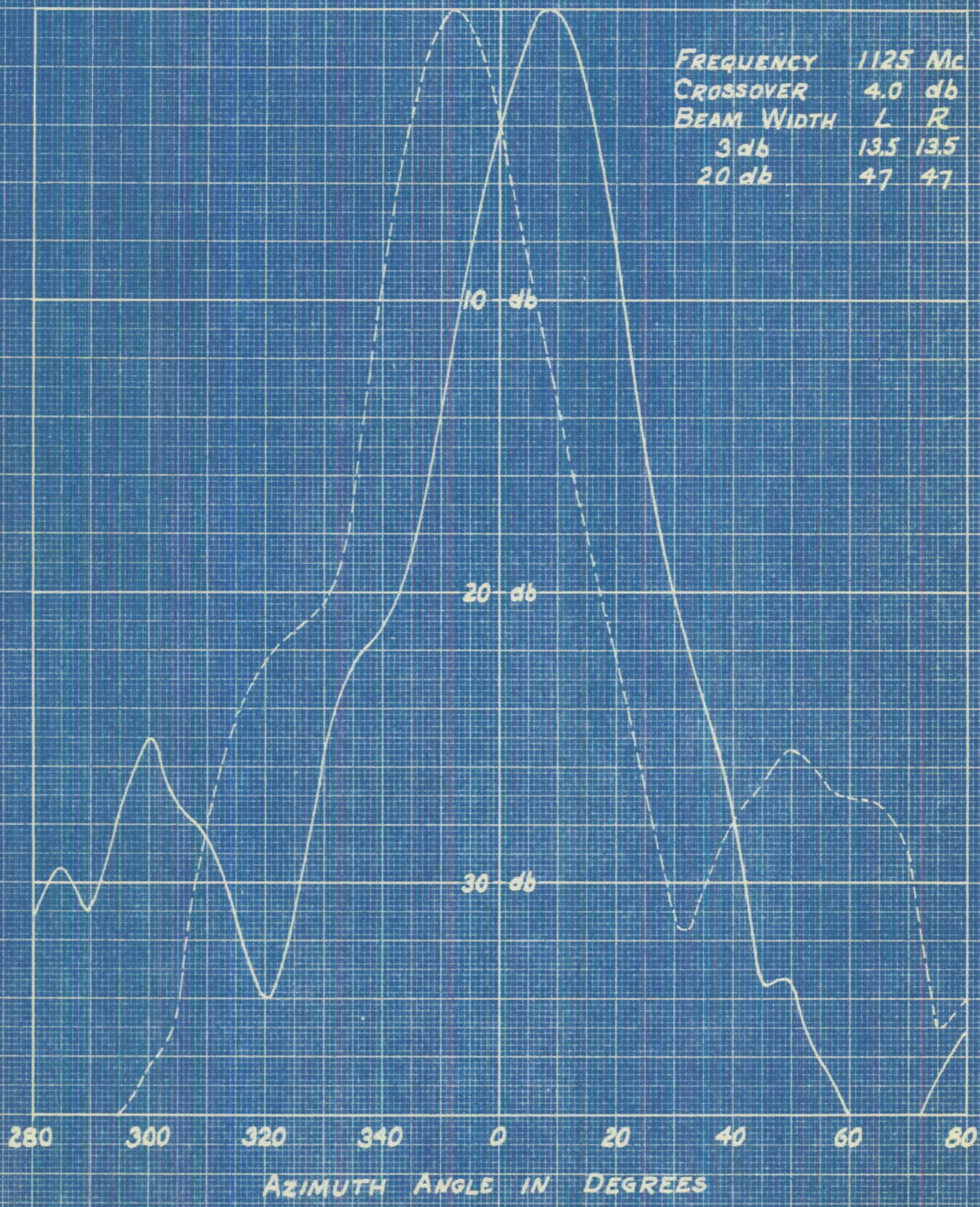
PLATE 39

# HORIZONTAL PATTERN OF LOBING ANTENNA FOR IFF MARK V



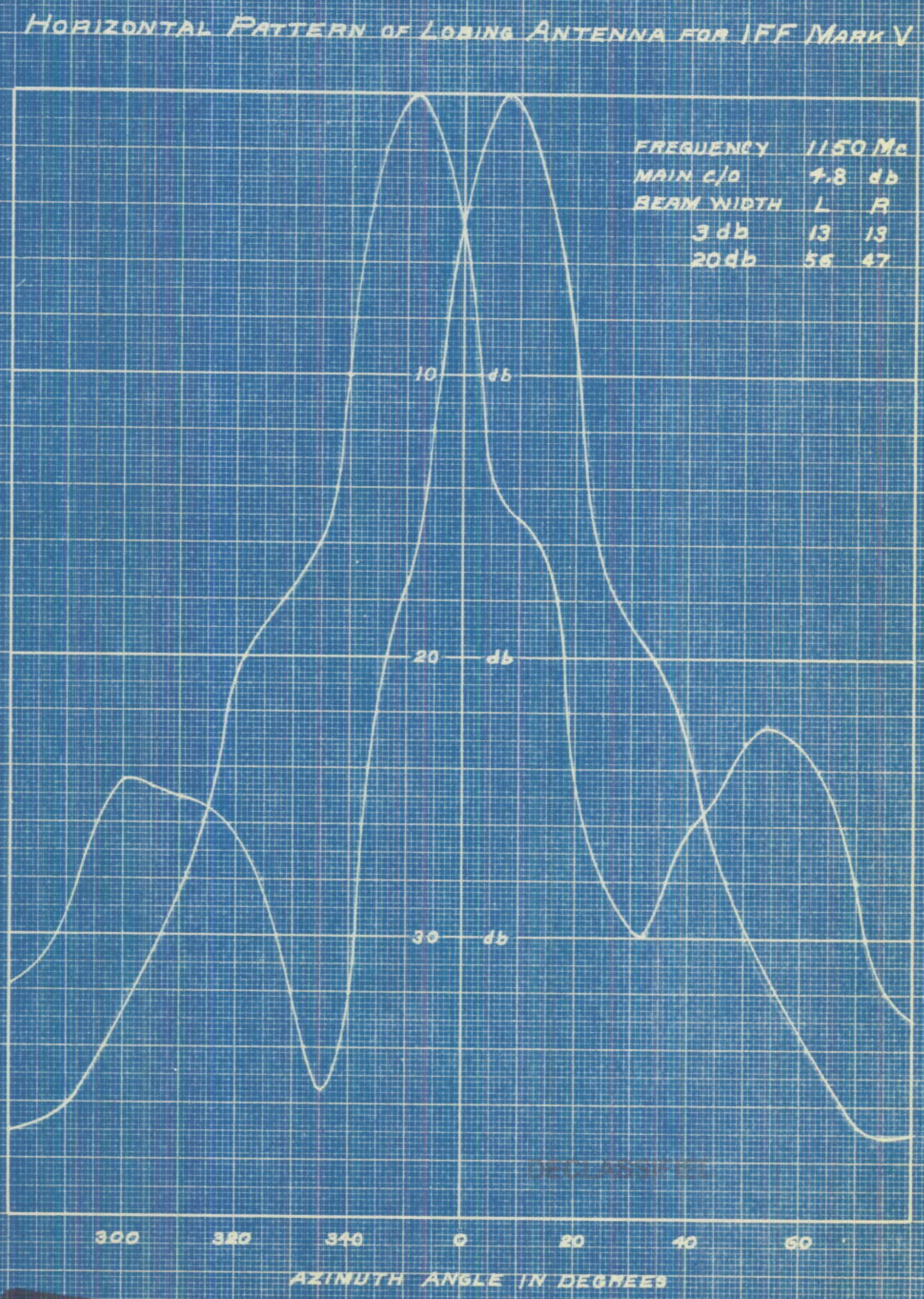









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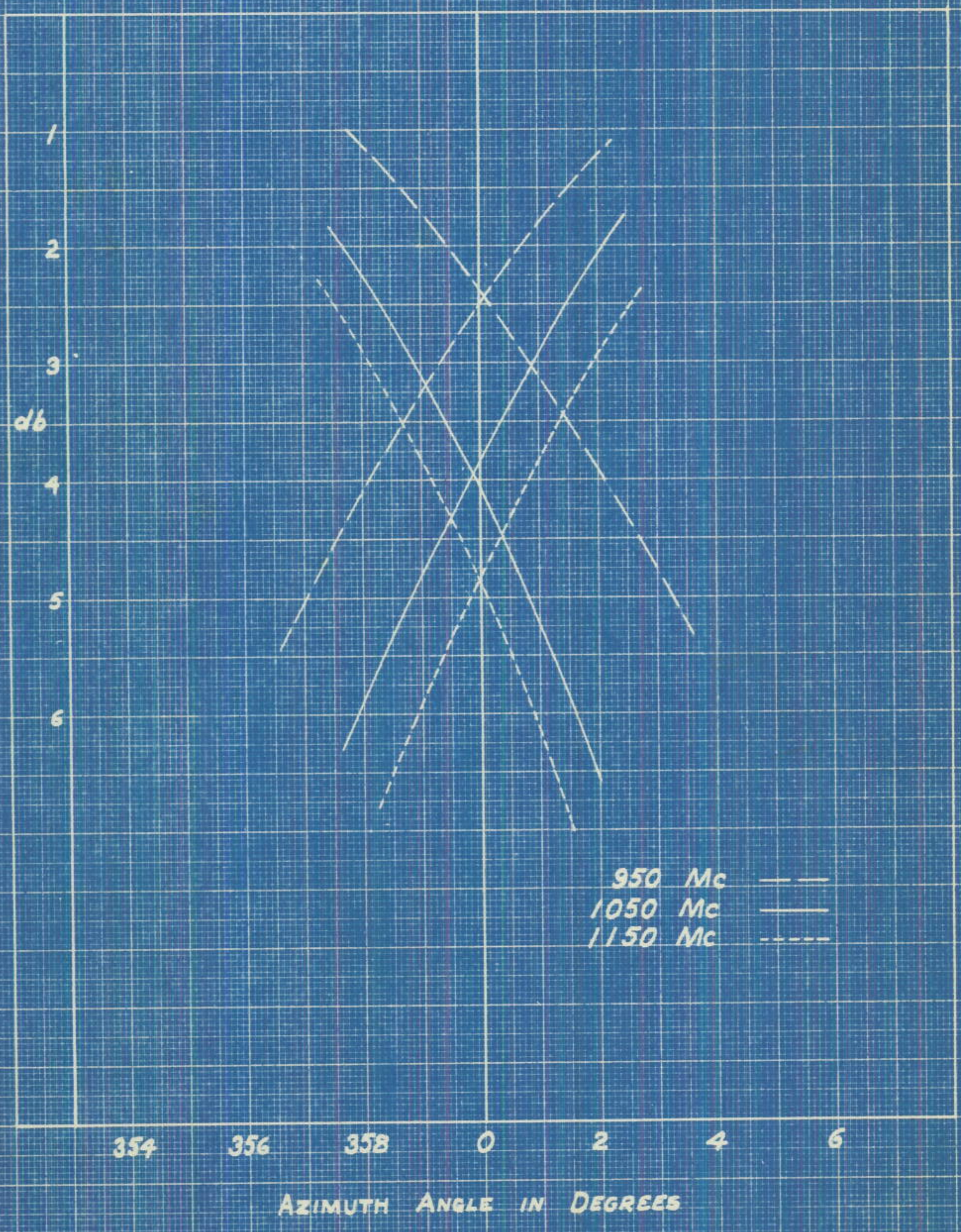
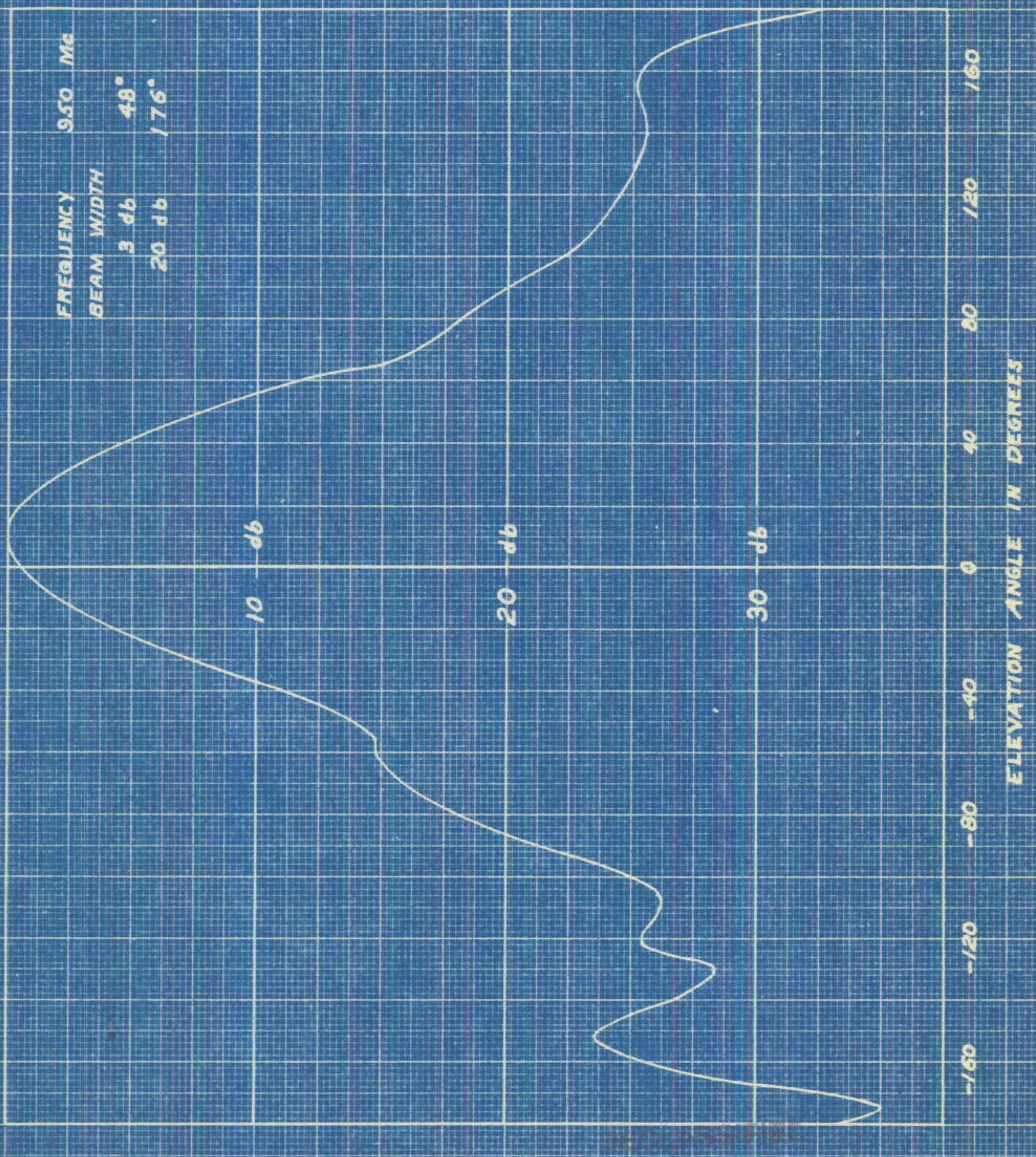
PLATE 41

Variation of Main Crossover with Frequency

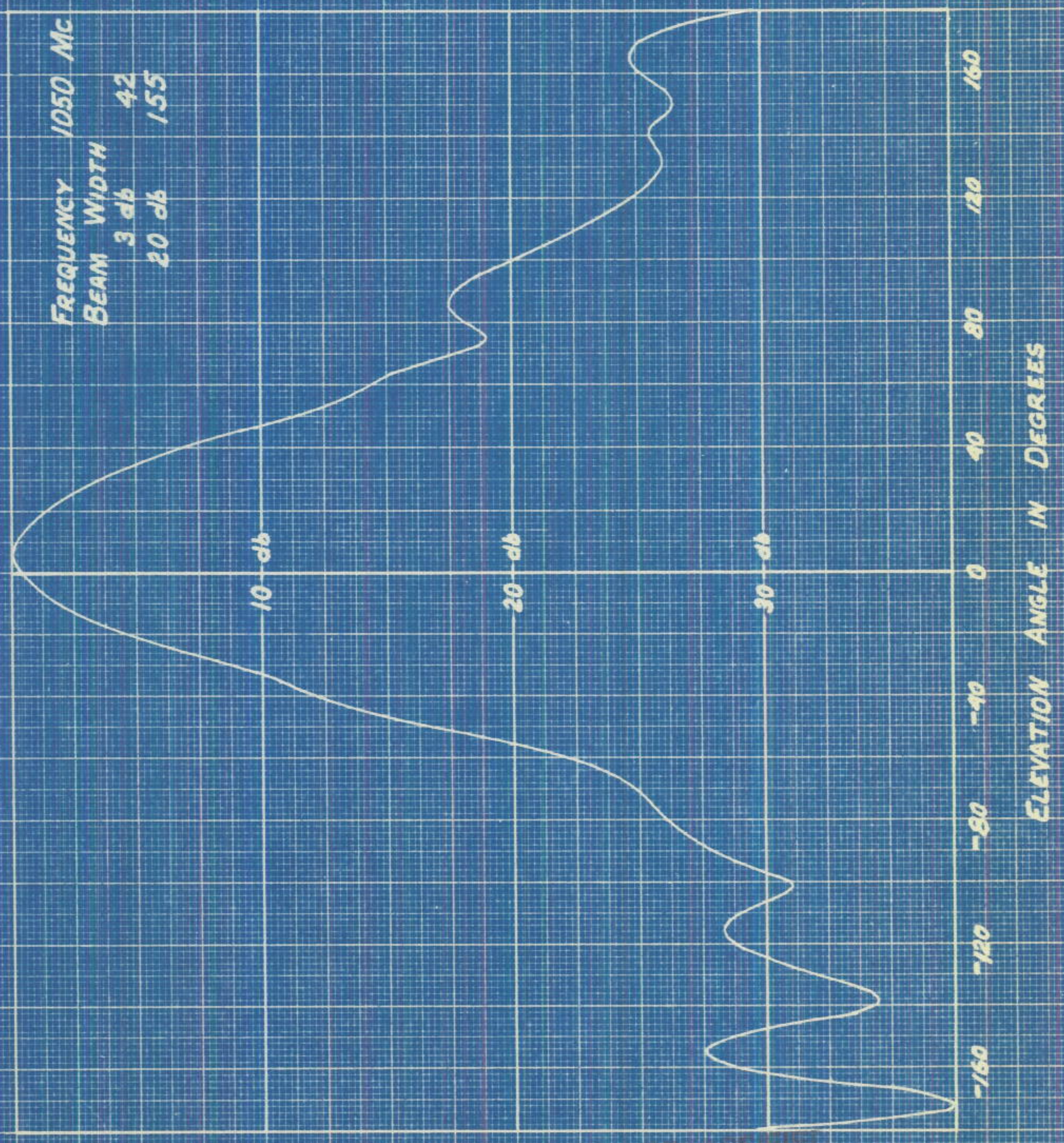


# VERTICAL PATTERN OF LOBING ANTENNA FOR IFF MARK V

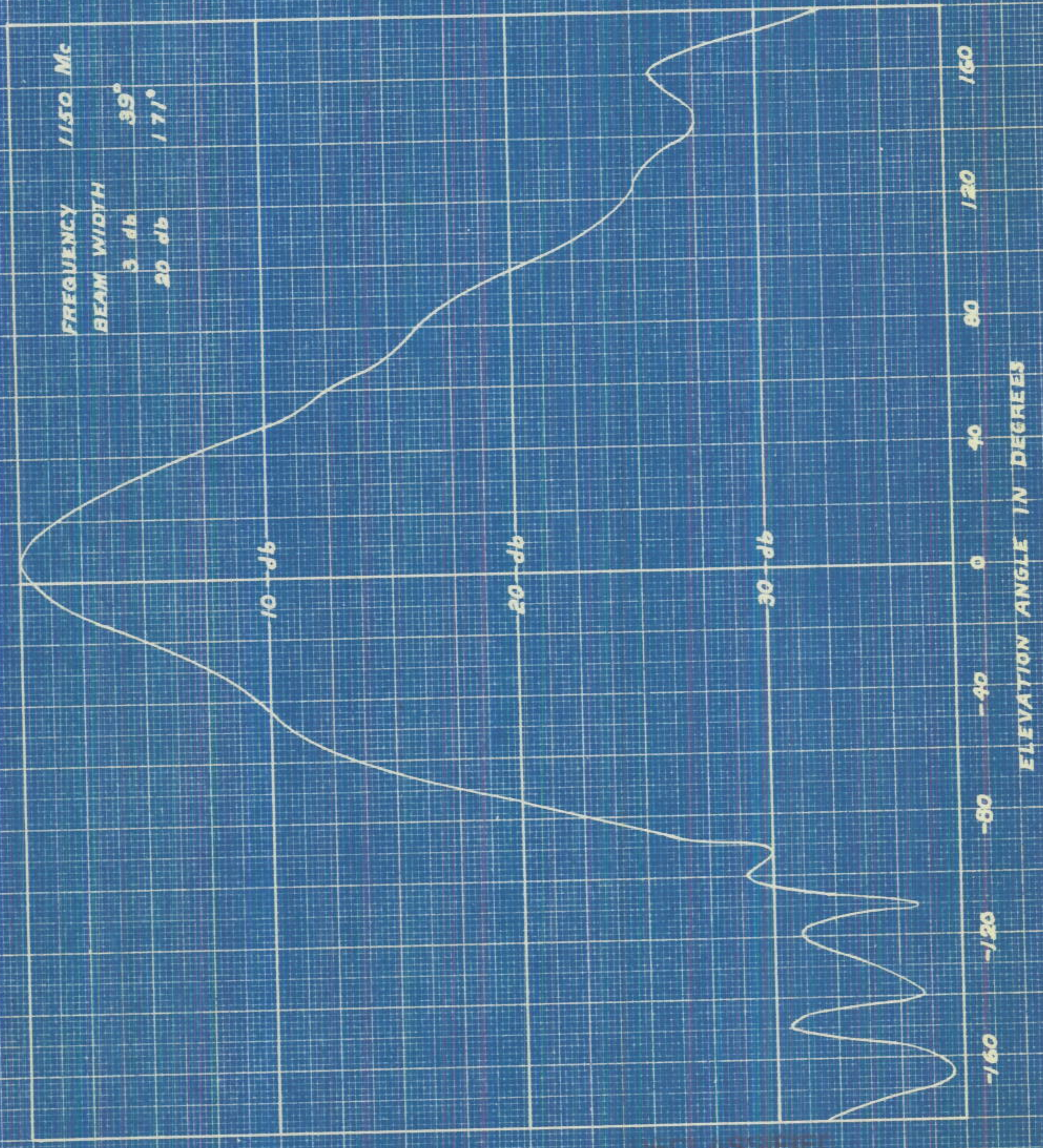
## AT 950 Mc

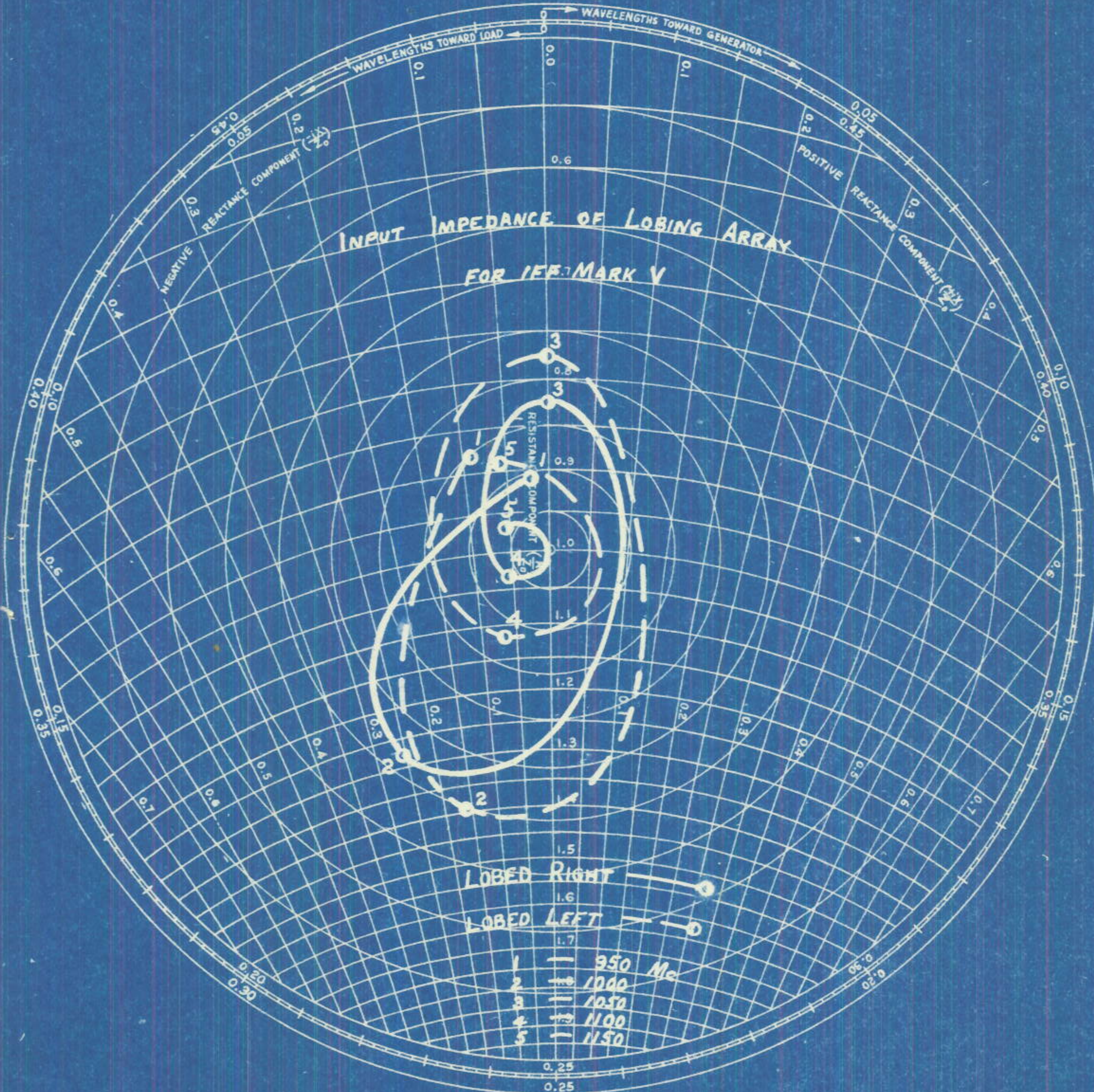


# Vertical Pattern of Lobing Antenna for IFF Mark V at 1050 Mc



# VERTICAL PATTERN OF LOBING ANTENNA FOR IFF MARK V AT 1150 Mc




INPUT IMPEDANCE OF LOBING ARRAY
FOR IFF MARK V
WAVELENGTHS TOWARD GENERATOR
WAVELENGTHS TOWARD LOAD
NEGATIVE REACTANCE COMPONENT
POSITIVE REACTANCE COMPONENT
RESISTANCE COMPONENT
LOBED RIGHT
LOBED LEFT
1 — 950 Mc
2 — 1000
3 — 1050
4 — 1100
5 — 1150