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# NAVAL RESEARCH LABORATORY REPORT

FR-2900

EVALUATION OF MODEL CXFF  
RADIO DIRECTION FINDER  
(Federal Telecommunications Laboratories)

By

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-Report R-2900-

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SHIP-SHORE RADIO DIVISION  
RADIO COUNTERMEASURES SECTION

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ABSTRACT

The Navy Model CXFF radio direction finder, developed by the Federal Telecommunications Laboratories of New York, under Bureau of Ships Contract N7ss-30834 was tested to determine the soundness of its operating principles and its suitability for Naval use. The equipment, covering the frequency range 140 - 600 Mc, employs four separate antenna arrays supported by and in front of square flat screens, arranged for mounting as a quadrangle around a ship's mast. The antenna outputs are alternately switched, by electronic means, to the input of a common receiver, the video output of which is synchronously switched through suitable amplifiers and a differentially connected variable resistive network, to a cathode ray tube. Arrangement is such that the output of each antenna appears as a flat topped "pip", the "pips" from the four antennas appearing simultaneously. Bearings are obtained by matching "pip" heights by an adjustment of the attenuator, its calibration being in terms of angular bearing. The equipment being developmental, various changes and presumed improvements were made by the contractor during the progress of the test. The tests indicated that the equipment was strictly laboratory material, not mechanically suitable either as a manufacturing prototype or for Naval use in its present form. Electrically, it was found to function as intended but to be subject to variable and difficult-to-control instrumental errors as high as fifteen degrees. The equipment successfully demonstrated the principle of operation, but whether additional developmental work could translate it into prototype equipment suitable for Naval use, might be open to question.

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## INTRODUCTION

1. The Federal Telecommunications Laboratories of New York, under Bureau of Ships contract NKss-30834 developed a radio direction finder equipment (designated as Model CXFF) covering the frequency range 140-600 Mc, in which bearing indications were obtained by comparing the amplitude of signal received from two of four fixed antennas possessing substantially cosine directivity through 180 degrees, mounted in a quadrangle around a ship's mast. The bearing indication is obtained by the adjustment of a differential attenuator in the receiver output circuit to obtain equal output from the two antennas under comparison, this attenuator being calibrated in terms of azimuth. The system is similar to the British Type FV-1 developed during the war, excepting that it has been refined to include rapid automatic switching of the antennas and a cathode ray output presentation. The operating principle demonstrated by the CXFF equipment was later employed in the so called PONY program, excepting that in this latter system it is proposed to mount the four antennas in strategic divorced locations on the superstructure of the vessel instead of as an assembly surrounding a mast. The tests covered by this report were intended to determine the operating characteristics of the CXFF system.

## STATEMENT OF PROBLEM

2. The Naval Research Laboratory was requested by BuShips, reference 1, to test the Model CXFF direction finder for its suitability for use in the Naval Service. Extensive tests have been carried out by this Laboratory at its Flue Plains Site and at the Federal Telecommunications Laboratories field location, Great River, Long Island, New York. The equipment, particularly in its early stages was difficult to test because of repeated mechanical and electrical failures, causing much delay and skepticism on the part of both Federal and NRL engineers as to the validity of data. However, the data submitted herewith, while not complete in all details, is considered accurate within normal experimental limits.

## PRINCIPLES OF OPERATION

3. The CXFF direction finder is designed to indicate the direction of a source of r-f energy in the 140 to 600 megacycle range. The system uses four directional antennas arranged at right angles so as to cover the complete azimuth. Bearing indications are obtained by comparing the amplitudes of voltages induced in adjacent antennas. Sense is automatically given by the determination of the pair of antennas receiving energy.

4. The 360 degrees of azimuth are divided into four sectors. Each sector is subtended by the overlapping response patterns of a pair of adjacent antennas. The general function of the system is to allow one antenna at a time to pass energy to the receiver. The

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(1)

receiver takes the energy from each antenna as it receives it in cyclic order, and places it in its proper position along the time base trace which is visible as a horizontal trace on the cathode ray tube indicator screen. The amplitudes of the various antenna responses can then be compared. The energy from any antenna always appears on the same part of the screen because the horizontal sweep frequency and the antenna switching actions are automatically synchronized.

5. By adjusting the gains of the two detector channels at the output of the receiver, the voltage amplitudes of any two antenna responses can be adjusted to equality. The gain controls are ganged and fitted with a dial, from which bearings are read.

6. Plate 1 shows a simplified functional outline drawing of the system.  $S_1$  indicates the electronic antenna switch, which successively switches each antenna to the input of the receiver.  $S_2$  indicates the detector switching, which commutates the detectors in synchronism with  $S_1$ . Since only two antennas receive energy at any one time from any one signal, alternate sections of  $S_2$  may be connected to the same detector.

7. The switching actions of  $S_1$  and  $S_2$  are accomplished electronically, as described later. The switching voltages are developed by a mechanical square wave generator, also described later in this report.

#### DESCRIPTION OF EQUIPMENT

##### Sizes and Weights:

8. The complete CXFF equipment consists of three basic units:

Collector System (Including four 50 ft. cables)	Weight 92 Lbs.
Receiver/Indicator Unit (21" x 21" x 21")	Weight 128 Lbs.
Power Unit and Cables (21" x 19" x 12")	Weight 109 Lbs.

##### The Collector System:

9. The collector system is composed of four antennas each of which consists of a vertical dipole spaced from a metallic reflector approximately three (3) feet square. The elements which form the antenna itself are connected through two coaxial cables, with a  $Z_0$  of 25 ohms each, to a balance box attached to the rear of the shield. The balance box converts the balanced voltage from the antenna to an unbalanced voltage suitable for feeding the input of the electronic r-f switch.

10. The radiation pattern of each antenna is intended to be a cosine response for 180 degrees of azimuth, the shield being intended to prevent pickup from the rear. The shield design is compact and

thus some back radiation will probably be present up to frequencies of 300 megacycles. However, this should not interfere with bearing determination, as the back radiation, if small, would easily be distinguishable from the voltages in the antennas which receive energy directly.

11. The four antennas are designed to be mounted symmetrically around the mast of a ship to form a square, each antenna shield being at right angles to its neighbors.

#### The Receiver/Indicator Unit

12. The receiver is of the conventional super-heterodyne design excepting for the r-f section and the input circuits. The input circuits comprise four GL-446A grounded grid vacuum tubes, the plates of which are connected in parallel across the first tuned r-f circuit. The cathodes are resistive coupled to the four antennas respectively while the grids are cyclically blocked by voltages from a square wave generator. These four tubes in combination form the Electronic Antenna Switch. The plates of the switching tubes feed into the input of an r-f amplifier, which uses a GL-446B tube, which in turn feeds a type GL-446A mixer tube. Double tuned circuits are used for both the input and output circuits of the r-f amplifier, making four tuned circuits ahead of the mixer. A type GL-446A tube is used as a tuned grid/tuned plate first oscillator. All tuning is by means of ganged transmission lines, the six lines being circular in shape so that the shorting bars may be attached to a tuning control shaft.

13. After amplification and detection, the signal is fed to the first i-f amplifier stage which employs a type 9003 tube in a conventional i-f amplifier. This is followed by two more identical i-f amplifier stages. The last i-f stage employs a type 6AG5 tube. The intermediate frequency is 15 megacycles, and the i-f band width is one megacycle at the 3 db point.

14. The signal from the i-f amplifier is fed to two second diode detector channels whose outputs feed separate cathode follower stages. The cathode load resistors in the cathode-follower stages are potentiometers, ganged in such a manner as to decrease the voltage output of one cathode follower stage while increasing the voltage output of the other. This enables the signals which are fed to the following amplifier to be adjusted to the same voltage level, thus indicating bearing on the attenuator dial. From this final amplifier stage the signal goes to the video amplifier, and then to the vertical deflecting plates of the cathode-ray oscilloscope,

15. Square wave switching of the two detectors to the i-f amplifier permits each detector to conduct alternately as adjacent antennas are connected to the input of the receiver through the r-f electronic

switching previously described. In this manner, the energy from one detector circuit is always conducted through one attenuator section, while the energy from the other detector circuit is always conducted through the other attenuator section. The detectors are switched by application of negative square waves to their plate circuits. When the negative square wave is applied to the plate of the detector being blocked, a positive square wave is simultaneously applied to the corresponding cathode. This keeps the d-c level in the cathode circuit, due to the initial electron current, from changing and causing audio square waves to be generated because of the switching action. If the d-c level in the cathode circuit is maintained, by application of the positive square wave, no voltage change will occur on the cathode follower grid which follows the detector cathode, and hence the only thing affecting this grid is the signal from the detector circuit.

16. In addition to the video circuit arrangement, the outputs from the two detectors are connected in parallel to an audio amplifier, employing a type 6AG7 vacuum tube, the output circuit of which is intended for operation into 600 ohm head telephone receivers to permit aural monitoring of the received signals. As there will always be a signal in at least one of the two antenna channels and their respective detectors, aural reception is substantially omnidirectional. All the square wave switching voltages are obtained from a motor-driven commutator assembly contained in the receiver cabinet. A variable-speed motor is employed to drive this commutator and a field rheostat on the panel permits the switching rate to be varied from approximately 52 to 61 complete antenna cycles per second.

#### Power Unit:

17. There are several power supplies incorporated within the Power Unit. One power supply is designed to deliver 2000 volts d-c at 2 ma. for operation of the cathode-ray tube. Two other supplies are regulated to supply 300 volts d-c at 150 ma. One of these supplies is used to supply the video amplifier chassis with power for the video section, and 110 volts a-c to the 24 volt d-c motor power supply in the square wave generator chassis. This 24 volt power supply consists of a 28 volt transformer supplying a bridge type selenium rectifier.

18. The power supply is controlled by a switch on the front panel of the receiver. Indication of operation and adequate fusing are provided.

#### POWER REQUIREMENTS

19. The equipment is designed to operate from a 115 volt, 60 cycle single phase supply line and required approximately 110 watts at 94 percent power factor for operation.

#### FIELD OBSERVATIONS AT CONTRACTOR'S LABORATORY

20. The original tests conducted at Great River, Long Island, in-

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icated that the operation of the equipment (an early version of the Serial #1 unit) was unsatisfactory in the following respects:

- (a) The motor driving the mechanical square wave generator was overloaded and would not turn with sufficient speed to keep the equipment in synchronization.
- (b) The antenna switching square wave used for synchronizing the sweep circuit allowed locking-in on either its leading or trailing edge. This was later corrected by differentiating the switching pulse.
- (c) The coupling between the gear mechanism, used in tuning, and the brushes was not properly pinned to the shaft resulting in a gradual slippage and ultimately in complete misalignment of the receiver. This was partially repaired at Great River.
- (d) The transmission line tuning circuit brushes introduced noise due to contact irregularities and the brush holders caused back-lash in tuning. New brushes were said to be in preparation.
- (e) The transmitter used at Great River operated on C.W. or with sine wave modulation only, resulting in apparently satisfactory cathode ray tube bearing display. The only Rader signals heard were of the long duty cycle type and did not show up the indicator's ability to display short pulses. The system overloaded before the "minimum usable radius" of the indicator tube had been reached.

21. The Laboratory, thereafter, submitted suggested improvements and corrective actions to the contractor, that were considered desirable before the equipment was submitted to the Laboratory for further tests.

#### FIELD TESTS AT NRL

22. The Model CXFF (Serial #1) received at NRL on January 2, 1945, was essentially the same as had previously been observed at Great River. Few of the proposed improvements had been made in the gear. Extensive field checks were conducted at NRL between January and July 1945 under the CXFF problem. These tests indicated that several major mechanical and electrical faults existed in the equipment. The following comments cover those faults which should be carefully considered by the Bureau of Ships in writing specifications for future quadrant switching direction finders.

- (a) The original set of tuning brushes was still a part of

the equipment. F.T.L. informed NRL that this condition would be rectified. A factory representative was to install new brushes at NRL during the progress of the tests. However, the Serial #1 gear was returned after testing (July 15, 1945) with the original set of tuning brushes still installed. This fault, which caused erratic sensitivity and high tuning noise, considerably hampered test work and gave the equipment a poor showing at demonstrations.

- (b) The commutator used for generating the square wave did not prove satisfactory. As the commutator became worn (after 8 hours running time) sparking developed at the gaps causing transient voltages that were at times larger than the intended square wave. When this sparking occurred on the brush from which the synchronization voltage was obtained, the equipment locked-in on the wrong quadrant or jumped from quadrant to quadrant in a random manner. The contractor sent a representative to NRL to correct the trouble but no simple solution could be found. The contractor (through Mr. Clark) indicated that several electronic and photo-electronic systems of switching had been tried but that the mechanical method seemed to be the simplest and most reliable. The NRL engineers are not in agreement with this statement.
- (c) The intensity, or rather the contrast between base line and pip intensity, for normal radar pulses as seen on the indicator screen is completely unsatisfactory. In developing the Model CXGA and Model DBM direction finders, NRL found that if intensity control is not used to brighten the scope trace during a received pip, narrow band detected output will provide better scope displays than the broad band video type of circuits used in the Model CXFF. As an example of the undesirable character of the indicator it is pointed out that on one occasion radar transmission originating within a mile of the CXFF could not be found by visual search with the indicator. It was necessary to first tune in the signals using the earphones and only then could the faint traces of the pips be seen on the cathode-ray tube.
- (d) All r-f cable work was of poor quality. The Type N connectors were not assembled according to Naval specifications resulting in poor grounding which caused unbalance, leakage and intermittent operation. This type of trouble is very dangerous from an operational point of view since too often simple ohmic checks will not trace or even indicate where the trouble is. Although no controlled

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polarization error checks were made, it seems that double shielded antenna cables, such as RC/9- would be justified to reduce stray pickup. A second set of cables were received in February 1945. This new set proved satisfactory for all tests run.

- (e) It should be pointed out that one of the advantages of quadrant switching direction finding has been largely lost in the CXFF. This supposed advantage was that since no phase comparison was attempted in this method of direction finding, the length of cable was not important. This is true to some extent but it should be remembered that the mismatch loss due to cable termination varies between

$$M_{\max} = 10 \log_{10} \frac{(S_1 S_2 + 1)^2}{4 S_1 S_2}$$

$$\text{and } M_{\min} = 10 \log_{10} \frac{(S_1/S_2 + 1)^2}{4 S_1/S_2}$$

where

$M_{\max}$  = Maximum loss due to the cable mismatches

$M_{\min}$  = Minimum loss due to the cable mismatches

$S_1$  = Standing wave produced at the receiver end of the cable

$S_2$  = Standing wave produced at the antenna end of the cable.

As the length of cable varies the loss fluctuates between  $M_{\max}$  and  $M_{\min}$ . Tests indicated that  $S_1$  went as high as 10 at 600 megacycles and  $S_2$  at the same frequency was 3. Therefore,  $M_{\max}$  would be 9 decibels and  $M_{\min}$  would be 1.4 decibels. This is a difference of 7.6 decibels, or a voltage ratio of 2.4 to 1 which could conceivably cause large bearing errors. Even if the cables were cut to the close tolerance necessary to eliminate this difficulty, the variation in  $S_1$  and  $S_2$  for different antenna and receiver inputs would give difficulties. As an example, the value of  $S_1$  for the four receiver input (see Plate 21) varies enough to cause a shift from 9 decibels for the  $M_{\max}$  down to 8.6 decibels. To be sure this is only a voltage change of 5 percent but this is a detectable difference in terms

of resultant bearings.

- (f) The filament transformer was under-designed causing a complete breakdown of equipment and much delay.
- (g) The padding adjustments in the receiver's oscillator tank showed a tendency to short out. This circuit is very difficult to service.
- (h) The drive shaft for the tuned-lines was too small resulting in an elastic torsion type of backlash.
- (i) The receiver tracking adjustments were far too difficult to make for Navy use.
- (j) Set screws throughout the equipment are too small. Pins should have been used in many cases.
- (k) The r-f switch balance controls were inaccessible from the outside of the cabinet.
- (l) Component markings were absent in almost all cases. Schematic diagrams were not complete, making the all-too-frequent servicing very difficult.
- (m) The voltage dividing networks associated with the cathode ray tube were not well designed. Adjustment of intensity and focus were difficult to make for mechanical and electrical reasons. The potentiometer resistive elements were under-sized causing overheating which produced changes in the voltages on the cathode ray tube resulting in drifts in the image and range of control. The complete supply and control circuit had to be rebuilt during the tests.
- (n) The method of indicating which quadrants are under comparison was quite complicated from the operator's view point. The indicator lights were not well-installed which caused frequent burn-outs and shorting of connecting wires. The method of assembly was such that a complete panel breakdown was necessary to perform any repairs on the indicating light circuits.
- (o) Considerable difficulty was had with the power supply. There were three voltages regulated circuits in the unit. The rather novel negative voltage circuit required repeated repairs.
- (p) The cabling between receiver and power supply was more complicated than Naval design should allow. If high voltage leads cause extensive cabling complication,

techniques such as those used on the Model DEF's indicator would be more desirable.

- (q) The final antenna assembly which was not received until June, had some definite faults. First, the pass band was from about 200 to 700 megacycles instead of from 140 to 600 megacycles. A slight scaling up of the entire antenna system should allow this difficulty to be remedied without seriously affecting the pattern shapes. The second fault is in the mechanical assembly. It was necessary to repair several "cold" solder joints in the dipoles and baluns. To make these repairs it was necessary to drill holes in the polystyrene end plates so that they could be removed. This procedure destroyed the water-tight integrity of the units and made the repair operation difficult. It is doubtful if the present water-tight design of the antennas is desirable.

23. Because the many unsatisfactory features of this Serial #1 equipment precluded the conduct of any meaningful tests, this equipment was returned to the contractor on 15 July 1945.

24. The second equipment, Serial #2, was received by NRL on 13 June 1945. Several improvements had been made over the Serial #1 equipment, but many faults were still present. Each of the points discussed under paragraph 22 will be taken up under the same sub-paragraph designations to show to what extent the Serial #2 equipment was improved over the Serial #1.

- (a) The tuning brushes used in the Serial #2 equipment were far superior to the original ones. Some tuning noise was still present but was not annoying. No backlash caused by poor brush design was evident.
- (b) The square wave generator was greatly altered in the second equipment. Considerable simplification of the commutator has led to much more reliable mechanical construction. However, the switching circuits failed after ten hours operation.
- (c) No noticeable improvement was made in the intensity control circuits to allow better display of Radar signals. Until such changes are made the equipment is of no value to the Navy as an operational instrument.
- (d) The set of r-f cables received with the second equipment were assembled according to Naval specifications and were satisfactory for all tests run.

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- (e) The problem of mismatch loss versus cable length and termination did not improve with the second equipment. The electrical lengths of the short cables running between front panel and r-f switch were different enough to cause trouble at the high end of the band. Considerable improvement could be had by properly terminating the cable at the switch input. There is no advantage of using resistively terminated lines on a receiver input if the termination is not made as good as possible. NRL experience has shown that, with very little care, the termination of the cables could have standing wave ratios as low as 2:1. The high value of 10:1 found in the switch input at 600 Mc is unacceptable.
- (f) No trouble was experienced with the filament transformer of the second model.
- (g) The padding adjustment in the receiver's oscillator circuit gave no trouble in the second equipment. However, no attempt has as yet been made to align or adjust any of the controls in the transmission line circuits of the equipment.
- (h) The backlash caused by overload of the drive shaft was completely corrected in the Serial #2 equipment. The tuning is very smooth and much more acceptable than in the original equipment.
- (i) No changes of any consequence were made in the mechanical facilities for receiver tracking.
- (j) Set screws have given no trouble in the Serial #2 equipment.
- (k) Facilities have been provided for balancing the r-f switch without removing the equipment from its cabinet.
- (l) There was no improvement in component marking or schematic drawings for the second equipment.
- (m) The voltage dividing networks for the cathode ray tube failed after one hundred hours of service.
- (n) The method of indicating which quadrants are under comparison was greatly simplified in the second equipment. The two "blocks" of output under measurement are automatically displayed at the center of the cathode ray scope. This is accomplished by a switching arrangement similar to that used originally to control the quadrant indicating lights.

- (o) The power supply gave no trouble during the tests on the Serial #2 equipment.
- (p) No improvement had been made in the power cabling between the power supply and receiver.
- (q) The antenna assembly supplied with the Serial #2 equipment was identical to the final assemblies supplied for the Serial #1 equipment. "Cold" solder joints are the main electrical fault in the antennas. The use of soft solder for holding mechanical members that are under stress and vibration should never be allowed.

25. While this second (Serial #2) equipment was still far from acceptable as Naval equipment, it did operate sufficiently well to permit tests to be conducted.

#### ANTENNA CHARACTERISTICS

26. The antennas were tested for Frequency Coverage, Pattern Shape and in connection with the overall instrumental error of the equipment. No tests of Pick-up Factor or Efficiency were made at the time of these tests, but this will be done in connection with the evaluation work being done on a large number of different direction finders under Problem Sl051R-C and will be reported under this latter problem.

27. Prior to the conduct of detailed tests of the antenna, spot checks were made to assure that all antennas were electrically similar. Thereafter tests were made on but one antenna, the other three antennas being left physically in position and electrically terminated to maintain them in their working status.

28. In making spot checks on the antenna system it was noted that as a result of the four frames being bolted together in electrical contact, circulating currents resulted that greatly distorted the antenna pattern and produced serious back lobes. This effect is shown by Plate 1 in which the pattern of one antenna at 200 Mc both with the reflectors in electrical contact and insulated are depicted. As a result of this discovery the four frames were electrically insulated from each other and all data in this report were obtained under this condition.

29. Plates 2 to 7 inclusive, show the antenna patterns for 150, 300, 400, 450, 500 and 600 Mc respectively. These patterns are considered excellent, all of them approaching the ideal circular shape and possessing negligible minor lobes. However, as has been pointed out, all these data were obtained and are shown on a relative basis and give no indication of the efficiency or Pick-up Factor of the

antennas.

30. While there is every reason to believe that the Pick-up Factor of the antennas is quite uniform down to a frequency of 250 Mc as indicated by the Standing Wave ratios obtained and shown by Plates 13 and 14, these plates illustrate the fact that the antennas are not of optimum design for the frequency range 140-600 Mc but rather cover the range 250-700 Mc. However, as this is practically the same percentage coverage as the 140-600 range, a redesign of the antennas in these particulars should not be too difficult.

#### RECEIVER CHARACTERISTICS

31. The electrical characteristics of the receiver designed and furnished as part of the CXFF equipments are shown by Plates 8 to 12 inclusive. These data were actually taken on Serial #1 equipment although tests indicated that no substantial difference existed in the characteristics shown between Serial #1 and #2 equipments. On each of these plates, comparative data for the respective performance characteristics of the Navy Model RDO receiver are also shown (as dotted curves). This comparison is shown as a matter of pertinent interest, in as much as this latter receiver was the only equipment available in production at the time that covered a comparable frequency range. All data are for pure CW inputs with an output of signal plus noise to noise ratio of twenty (20) decibels at the video circuit output. No audio frequency characteristics were measured.

#### Sensitivity

32. The receiver sensitivity both as measured by the F.T.L. engineers at their Laboratory and by the NRL. . are shown on Plate 8. It will be noted that the respective measurements show good agreement as to variation with frequency but that the F.T.L. measurements are about ten (10) decibels more favorable than those of NRL. It is possible that at least six (6) decibels of this discrepancy could be the result of differences in the measurement techniques employed by the respective laboratories. The remaining four (4) decibels is considered within the limits of accuracy that might be expected for measurements such as those in question.

33. With respect to measurement techniques, it is the standard and most meaningful practice to consider receiver sensitivity in terms of the voltage delivered by an antenna that will produce a standard output under standard noise conditions. In practice this voltage is delivered through the antenna impedance, which, at the higher frequencies is taken as fifty ohms. Accordingly, receiver Sensitivity is defined as: the number of microvolts, in series with the specified antenna impedance, required to produce a 20 decibel

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signal plus noise to noise ratio in the (video) output of the receiver. At the lower frequencies practically all signal generators are calibrated in terms of open circuited voltage or the voltage appearing at the input of their internal impedance. Higher frequency signal generators, such as those used in the measurements reported herein (Measurements Corp. types 50 and 84 by the F.T.L. and a Navy Model LAF by NRL) have an internal impedance of fifty ohms (simulating the antenna impedance) and are calibrated in terms of the voltage appearing at the end of their output cable when terminated in fifty ohms. Thus, their attenuator readings are six (6) decibels below the true driving voltage existing at the input to their internal impedances and if employed directly will yield values of received sensitivity six (6) decibels too low or make the receiver appear more sensitive than it really is. In the data shown on Plate 8, the NRL sensitivity values have been corrected for this factor, but it is not known whether the F.T.L. took similar action, which might account for at least six (6) decibels difference in the sensitivity figures obtained by the two organizations.

34. It will be noted from Plate 8 that the sensitivity is quite "flat" throughout the frequency range of the receiver but is somewhat low (high in numerical value), probably resulting from the fact that the input tubes are resistively coupled to the transmission lines. Similarly, these measured values give no indication of the mechanical suitability of the design, such as to whether the multiplicity of tuned lined r-f circuits will remain quiet in operation and "in track" over any appreciable period of time. This was commented on in paragraph 24.

35. It will also be noted that Plate 8 gives no indication of the value of Standard Output employed in the measurement of sensitivity. This was omitted as being rather meaningless for a cathode ray tube presentation and of no consequence where the criterion of performance is signal plus noise to noise ratio and the overall gain is sufficient. The gain of the Model CXFF receiver was sufficient to result in approximately one quarter inch of "grass" from the noise and as a matter of record, a a-c output of five volts from the detector was employed as a reference Standard Output level.

#### Selectivity

36. The selectivity of the receiver is shown on Plate 9. While this is the i-f selectivity only, at the frequencies in question the r-f selectivity adds little, if any, to the over-all selectivity, so that these data may be considered as representing the latter. This selectivity is considered to be quite good, the Shape Factor (6/60 db) being but 2.2 and the Acceptance Selectivity shown by the "nose" of the curve being quite regular with the "cleft" being of minor amplitude.

### Image Response

37. The Image Response is shown on Plate 10. While its average value of forty (40) decibels is not exceptional, it is considered quite good for receivers in the frequency range in question, and adequate.

### Noise Factor

38. Plate 11 is a power plot of the "nose" selectivity of the receiver used in the measurement and computation of the Noise Factor which is shown on Plate 12. It will be noted that this factor averages approximately 25 decibels, as compared to the "perfect" value for matched wide band receivers of three (3) decibels. This is not considered good and results (at least in part) from the use of aperiodic input circuits to the r-f tubes. The discrepancy between the F.T.L. and the NRL Noise Factor data is a direct result of the discrepancy in sensitivity measurements shown on Plate 8 and commented on above.

### Model RDO Receiver Comparisons

39. The Sensitivity, Selectivity, Image Selectivity and Noise Factor of the Model RDO receiver are shown on Plates 8, 9, 10 and 12 respectively in order to permit direct comparison with the Model CXFF receiver. The frequency range 140 to 600 Mc that is covered by the CXFF in one band requires two bands of the Model RDO so that its performance curves all show a discontinuity at 300 Mc. While the performance comparisons are generally self explanatory, the following general comments are offered. The poor sensitivity of the Model RDO in the high band is the result of the use of a crystal instead of a vacuum tube mixer in this band. The poorer Selectivity of the RDO is the result of the employment of a 30 Mc i-f frequency instead of the 15 Mc frequency used in the CXFF. The Shape Factor of the RDO (2.3) is practically the same as the CXFF, indicating otherwise good design. The poorer Image Selectivity of the RDO is the result of the use of but two "butterfly" type tuned circuits preceding the mixer as compared with five tuned lines used in the CXFF.

40. However, these electrical performance comparisons should not be accepted as being indicative of the relative quality or suitability of the two receivers, in as much as such data do not cover the many intangible factors involved in quality or the suitability of an equipment for Naval use. In this connection, it is believed that the CXFF receiver would require a complete redesign before it could be considered as being suitable for Naval use and there is no way of even approximating what such a redesign would do to the over-all performance.

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## EQUIPMENT PERFORMANCE

41. In checking the performance of the equipment the availability of personnel and equipment did not permit the measurement of over-all sensitivity of the system; although, assuming normal efficiency for the antennas and "baluns", it is believed that directional indications could be obtained on field intensities down to approximately 100 microvolts per meter. This information will be obtained and included in a forthcoming report on Problem S1051R-C.

42. However, tests were made of the Instrumental Error inherent in the equipment and data on these errors are shown by Plates 15 to 20 inclusive for 150, 200, 300, 400, 500 and 600 Mc respectively. It will be noted that these errors run as high as fifteen (15) degrees and, as might be expected from the principle of operation of the system, are highest at the ninety degree points where the two adjacent antennas whose outputs are under comparison are receiving the greatest signal differential. Unfortunately, as indicated by the plates, the instrumental errors vary markedly with frequency, so that the difficulty cannot be corrected by any fixed adjustment in the system or of the azimuth scale.

43. An additional factor, not indicated by the plates involves a variation of the observed bearing with received signal intensity and/or variation of the gain control of the receiver. This condition involves so many variables that it is impossible to submit meaningful quantitative data in the premises, but bearing shifts as high as eight degrees have been observed.

44. In connection with the general subject of the Instrumental Errors indigenous to the system of direction finding exemplified by the CXFF equipment, there are certain inherent features of the design and operation that either preclude or make difficult the obtainment of negligible instrumental errors. Before describing these features, it is believed desirable to outline the basic principle of operation of the system.

45. The four antennas are connected to the receiver input through four grounded grid vacuum tubes, which are electronically switched (by grid blocking methods) in a circularly manner. The signal from each antenna is thus passed through the receiver progressively. The i-f output of the receiver feeds two cathode followers through additional electronic switches synchronized with the antenna switches. To follow the switching progression, consider the antennas as numbered 1 to 4 inclusive and the cathode followers as A and B. The switching progression would then be: 1A, 2B, 2A, 3B, 3A, 4B, 4A, 1B, 1A etc. The cathode follower outputs connect to the vertical deflection plates of the cathode ray indicator through a differentially connected variable voltage divider calibrated in terms of bearings from zero to ninety degrees. With a

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system such as this, the following conditions of design and operation must be met in order for the instrumental error to be zero:

- (a) The taper of the voltage dividing bearing indicator must be identical with the "taper" of the respective antenna patterns with respect to azimuth of received signal.
- (b) The antenna patterns must not change with frequency
- (c) The patterns of the four antennas must be identical.
- (d) The gain of the receiver and cathode followers must not vary with signal level.
- (e) The standing wave ratios of the four antenna systems down to and including the receiver input circuits must be identical at all frequencies.
- (f) The electrical length of the four lines connecting the antennas to the receiver must be identical at all frequencies (assuming that unity standing wave ratio cannot be achieved for the system).
- (g) The four r-f input and the two cathode follower output tubes must be maintained with identical gain at all times.

46. A survey of the above list of factors affecting the inherent instrumental error of the CXFF equipment as well as the stability of these errors will indicate the weaknesses of a system of this type. While no attempt was made to break down the possible magnitude of maximum errors chargeable to each of the above factors, due to their numbers and complexity, the existence of the instrumental errors shown by Plates 15 to 20 inclusive indicates the design, maintenance and operating difficulties indigenous to the CXFF system.

#### CONCLUSIONS

47. It is concluded:

- (a) That the CXFF equipment (as exemplified by both Serials #1 and #2) is not in its present form mechanically suitable for Naval use.
- (b) That extensive mechanical redesign of the CXFF equipment would be necessary before it could be considered suitable for Naval use.

- (c) That the CXFF equipment in its present embodiment is suitable as a means of demonstrating that the amplitude comparison method of direction finding, employing fixed antennas, can be made to operate with limitations as to accuracy and stability.
- (d) That modification or redesign of certain of the electrical features of the CXFF equipment would be necessary before the equipment could be considered as being electrically suitable for Naval use.
- (e) That there is considerable doubt as to whether the CXFF equipment or any equipment employing similar operating principles, could ever be made to operate with extreme accuracy over an appreciable range of frequencies without excessive design, installation, maintenance and operating difficulties.
- (f) That, in spite of the excessive instrumental errors of the CXFF equipment, it is possible that the flexibility inherent in the design, that permits the antennas to be mounted in electrically strategic locations in a Naval vessel, might so reduce the errors indigenous to location as to make the instrumental errors acceptable.
- (g) That amplitude matching types UHF and VHF direction finders, while, eliminating certain of the difficulties experienced with phase matching types, are subject to difficulties resulting from variations in standing wave ratios on the lines, which can be equally troublesome.

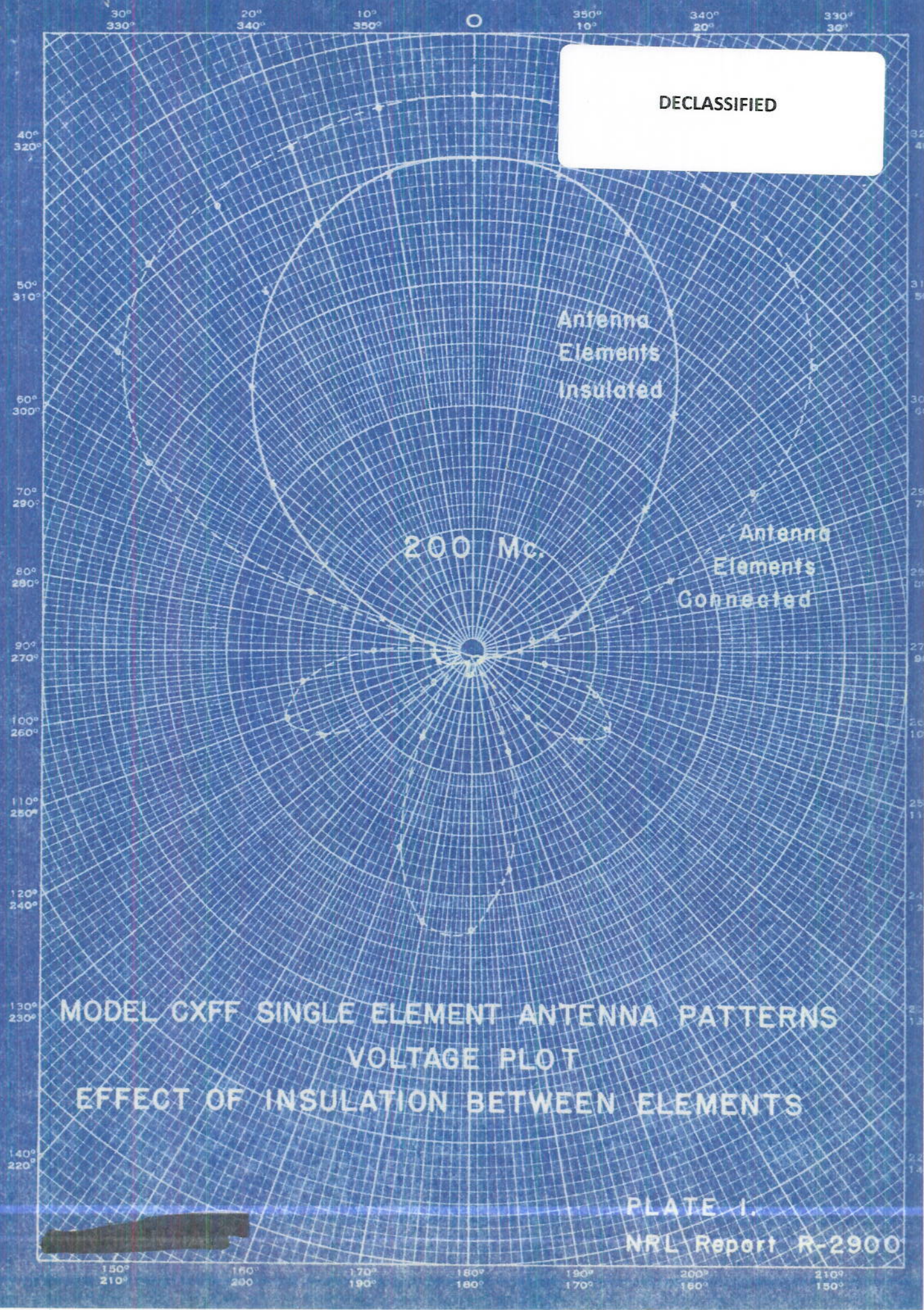
#### REFERENCES

1. BuShips ltr. 1034(925Db) of 3 Nov. 44, to NRL.
2. NRL Ltr. C-S67/69(301B), C342-168/45, 18 Oct. 1945, Radio-Direction Finders, Model CXFF - NRL Problem S926T-C, Interim Report on Test.

Original data recorded in NRL Log Book 5909.

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MODEL CXFF SINGLE ELEMENT ANTENNA PATTERNS  
VOLTAGE PLOT  
EFFECT OF INSULATION BETWEEN ELEMENTS

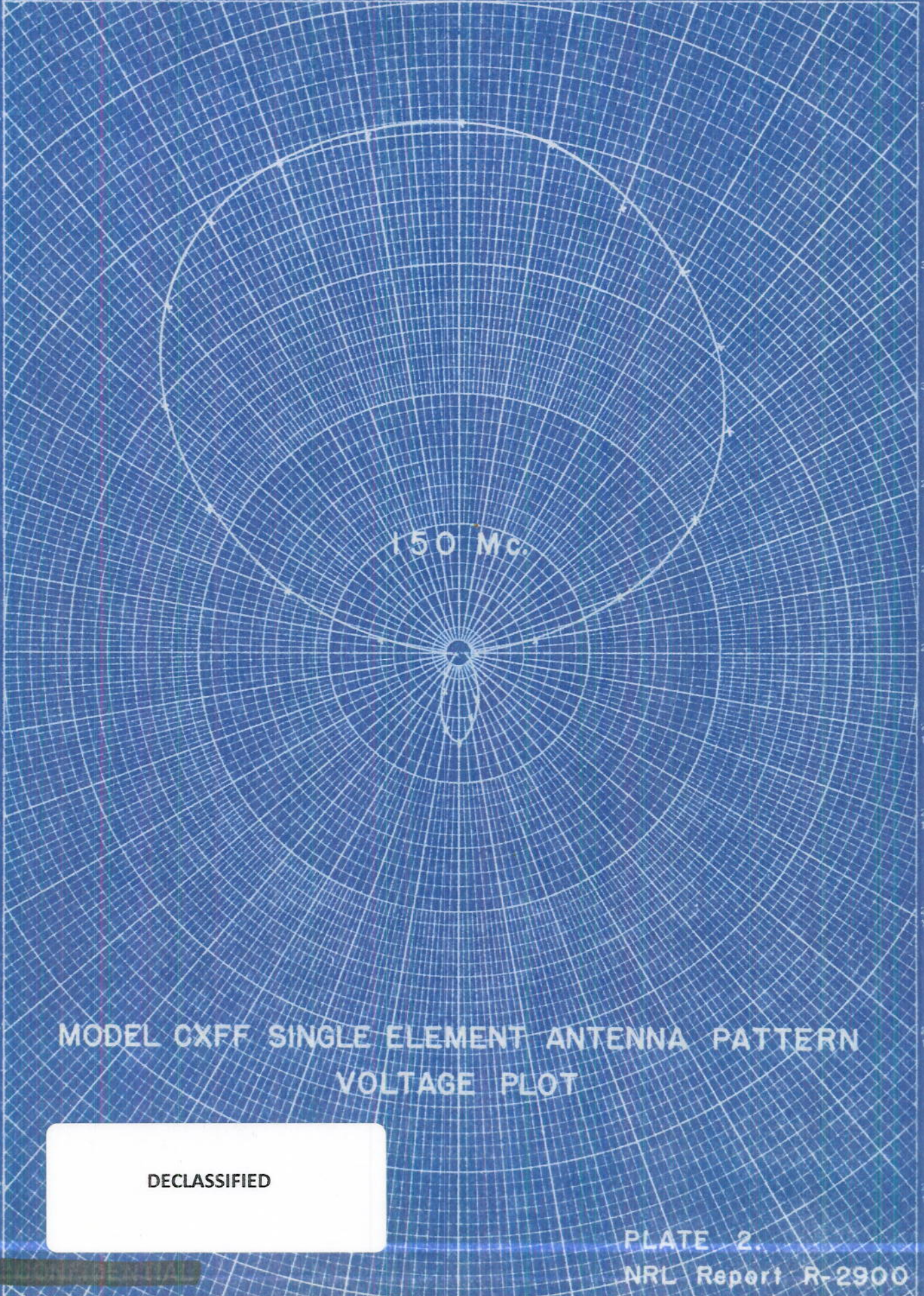
PLATE I.  
NRL Report R-2900



30° 20° 10° 350° 340° 330°  
330° 340° 350° 10° 20° 30°

40° 320°  
50° 310°  
60° 300°  
70° 290°  
80° 280°  
90° 270°  
100° 260°  
110° 250°  
120° 240°  
130° 230°  
140° 220°

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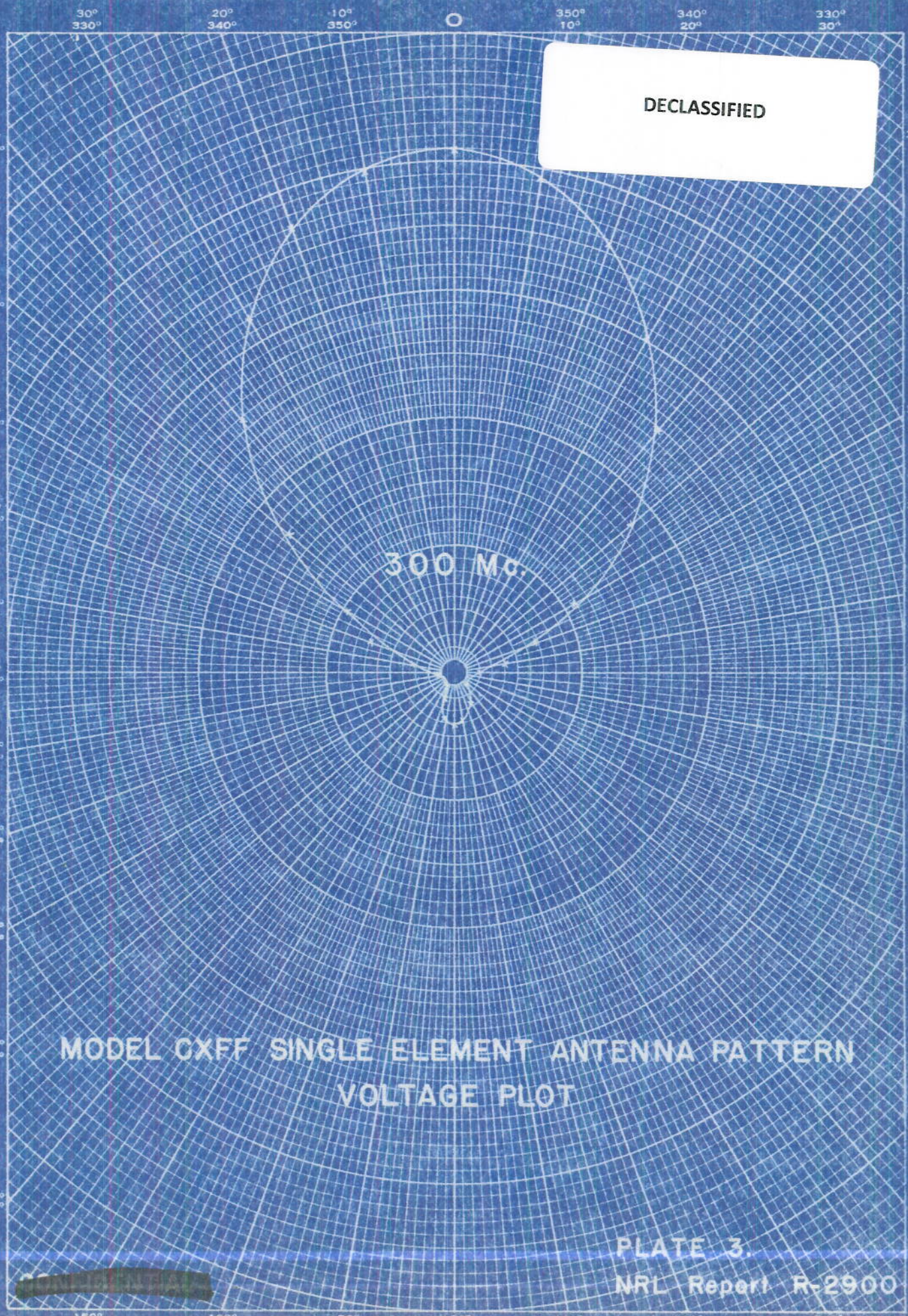


MODEL CXFF SINGLE ELEMENT ANTENNA PATTERN  
VOLTAGE PLOT

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PLATE 2  
NRL Report R-2900

150° 160° 170° 180° 190° 200° 210°  
210° 200° 190° 180° 170° 160° 150°



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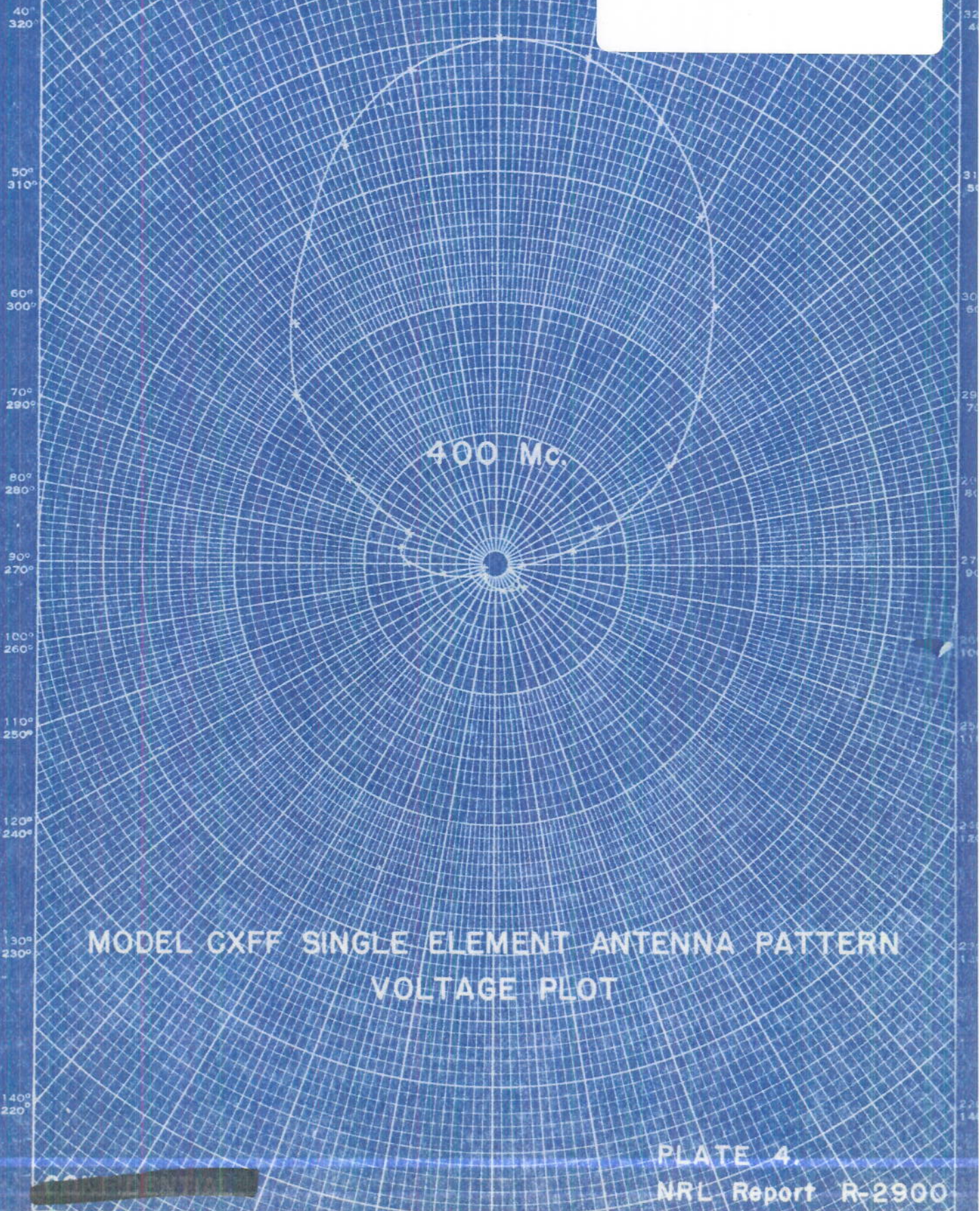
MODEL CXFF SINGLE ELEMENT ANTENNA PATTERN  
VOLTAGE PLOT

PLATE 3.  
NRL Report R-2900



30° 20° 10° 350° 340° 330°  
330° 340° 350° 10° 20° 30°

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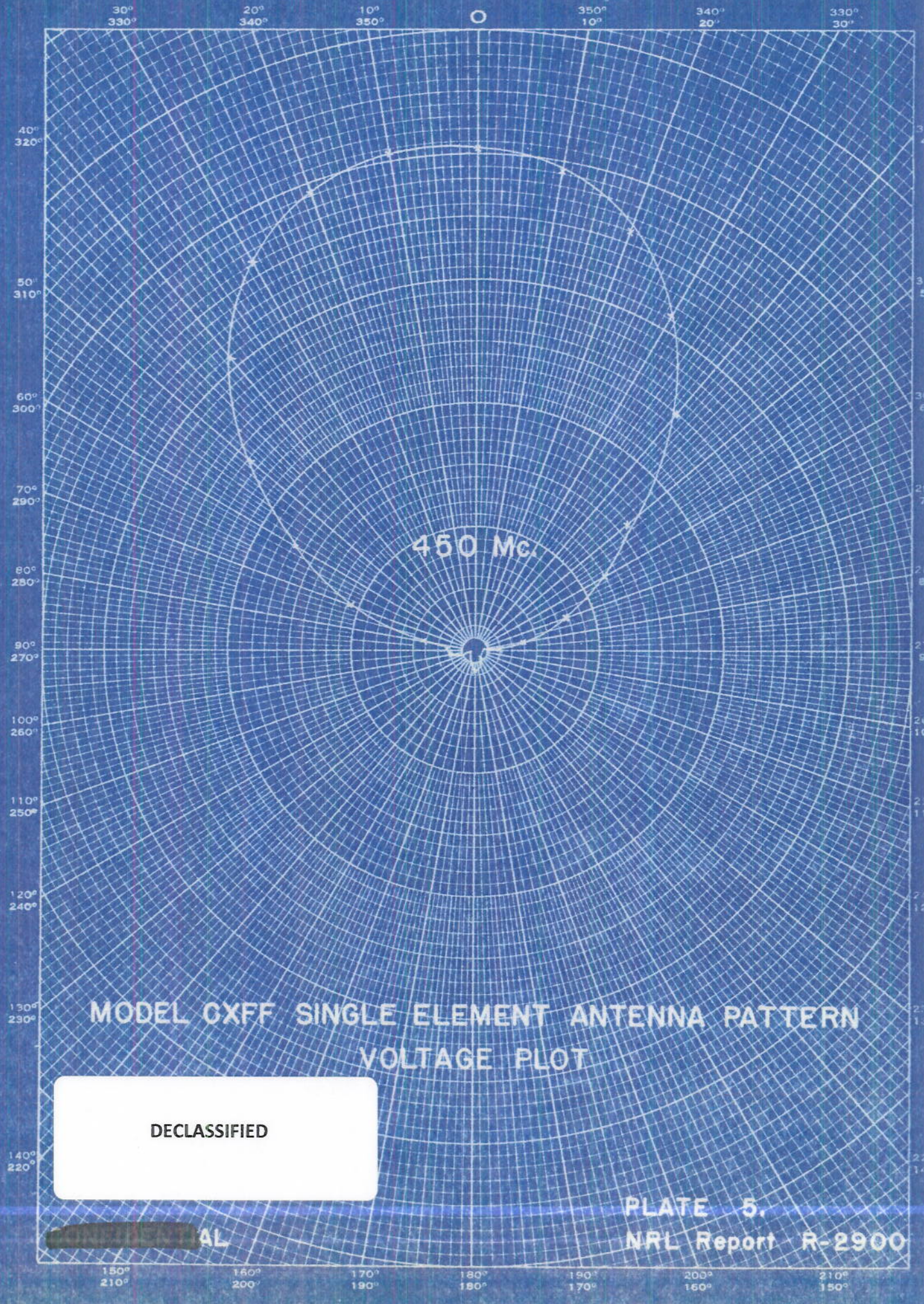
MODEL GXFF SINGLE ELEMENT ANTENNA PATTERN  
VOLTAGE PLOT

PLATE 4.  
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150° 160° 170° 180° 190° 200° 210°  
210° 200° 190° 180° 170° 160° 150°



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MODEL GXFF SINGLE ELEMENT ANTENNA PATTERN  
VOLTAGE PLOT

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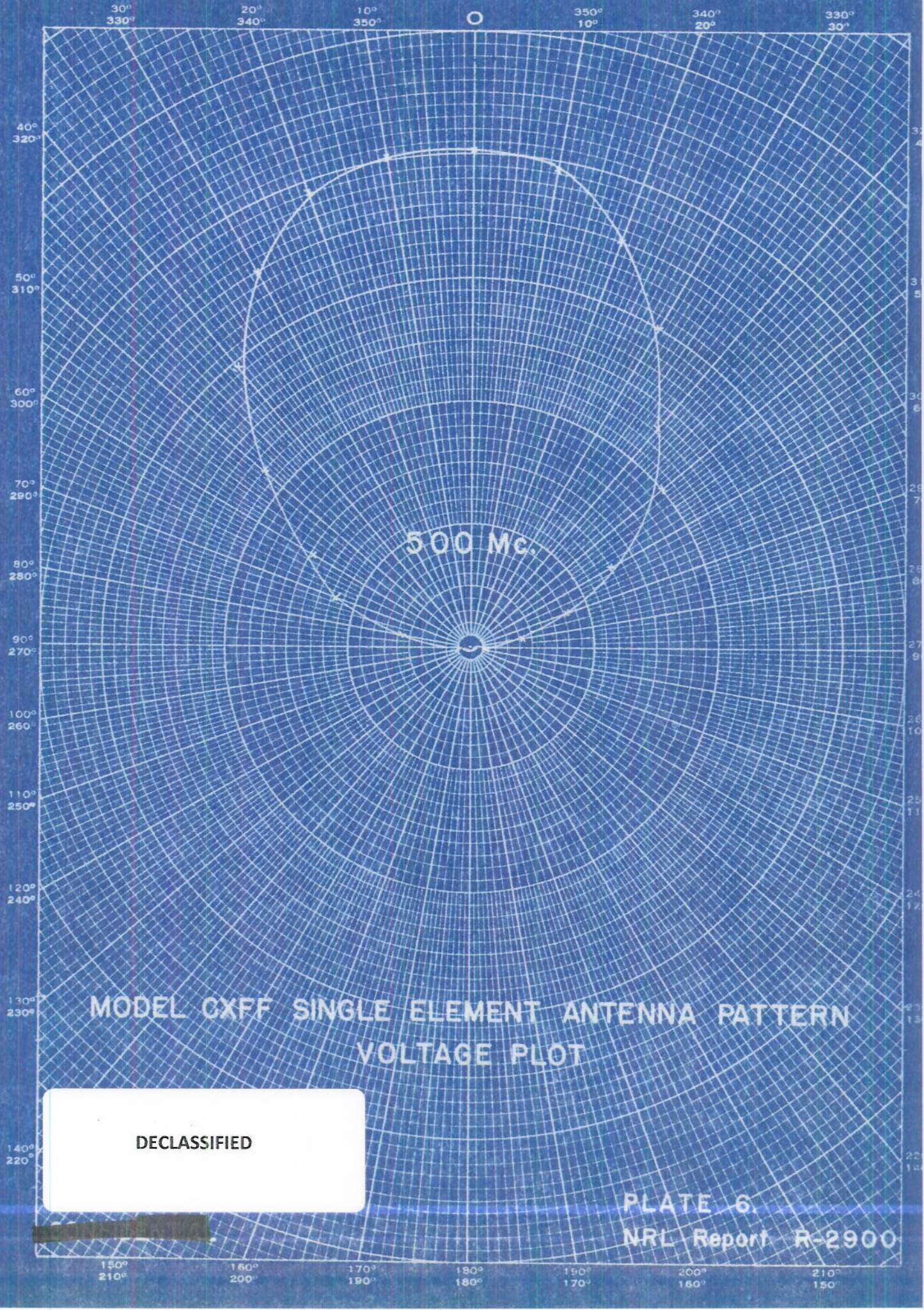
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PLATE 5.  
NRL Report R-2900

150° 210° 160° 200° 170° 190° 180° 190° 170° 200° 160° 210° 150°

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MODEL CXFF SINGLE ELEMENT ANTENNA PATTERN  
VOLTAGE PLOT

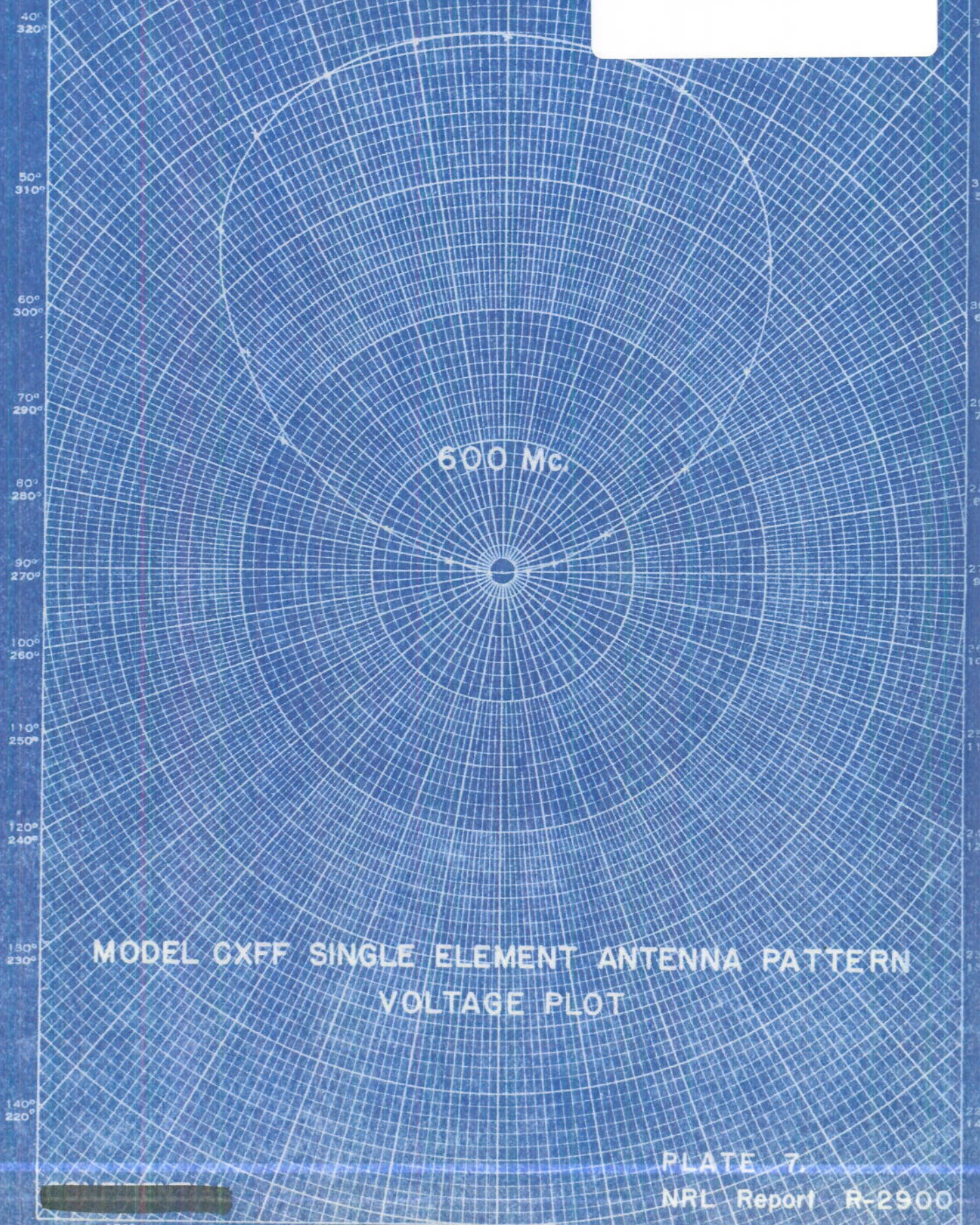
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PLATE 6.  
NRL Report R-2900

150° 210°    160° 200°    170° 190°    180° 180°    190° 170°    200° 160°    210° 150°

30° 20° 10° 350° 340° 330°  
330° 340° 350° 10° 20° 30°

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MODEL CXFF SINGLE ELEMENT ANTENNA PATTERN  
VOLTAGE PLOT

PLATE 7  
NRL Report R-2900

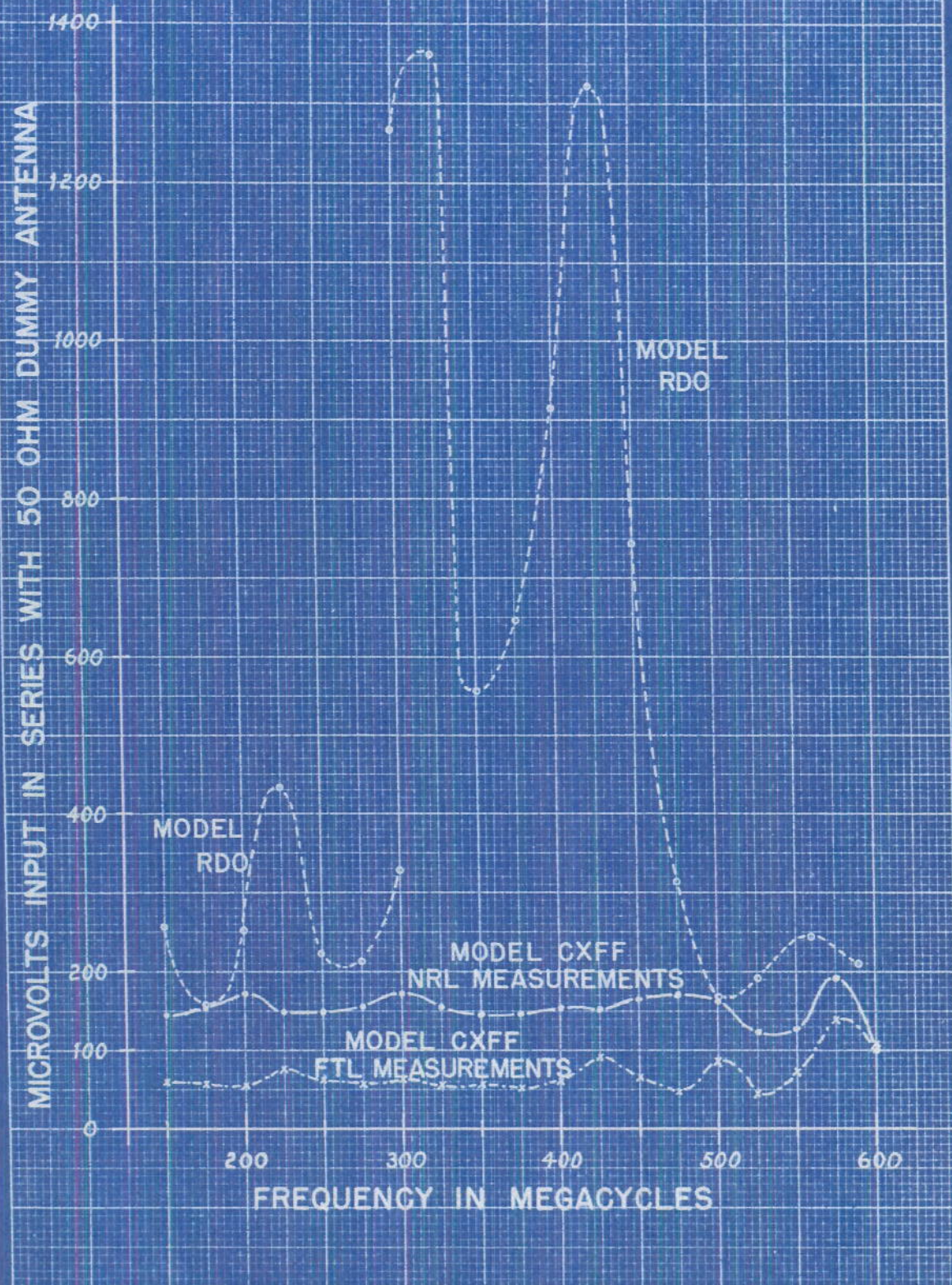
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150° 160° 170° 180° 190° 200° 210°  
210° 200° 190° 180° 170° 160° 150°

# MODELS CXFF AND RDO SENSITIVITY

20 DECIBEL SIGNAL TO NOISE RATIO AT I.F. OUTPUT

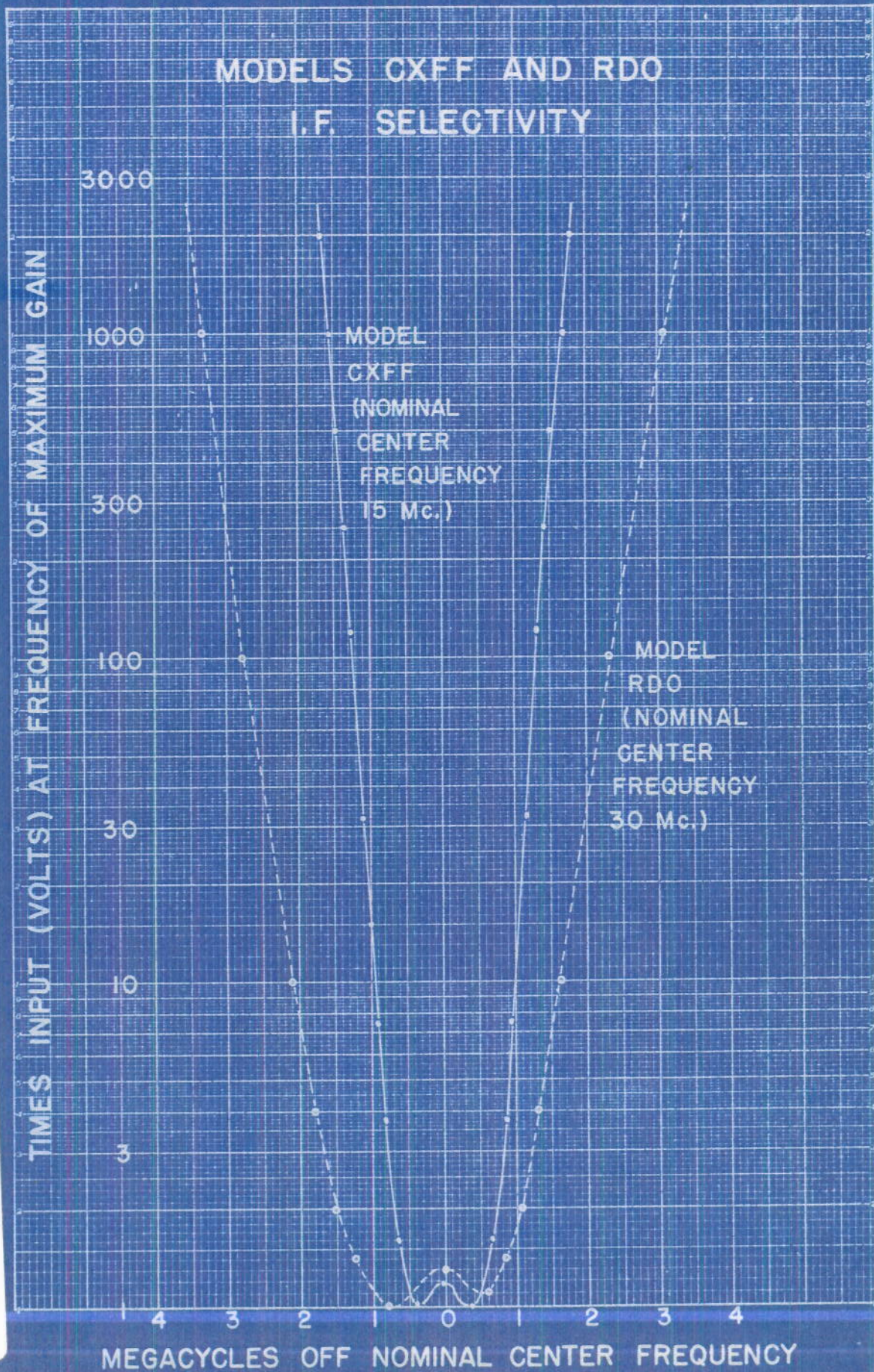


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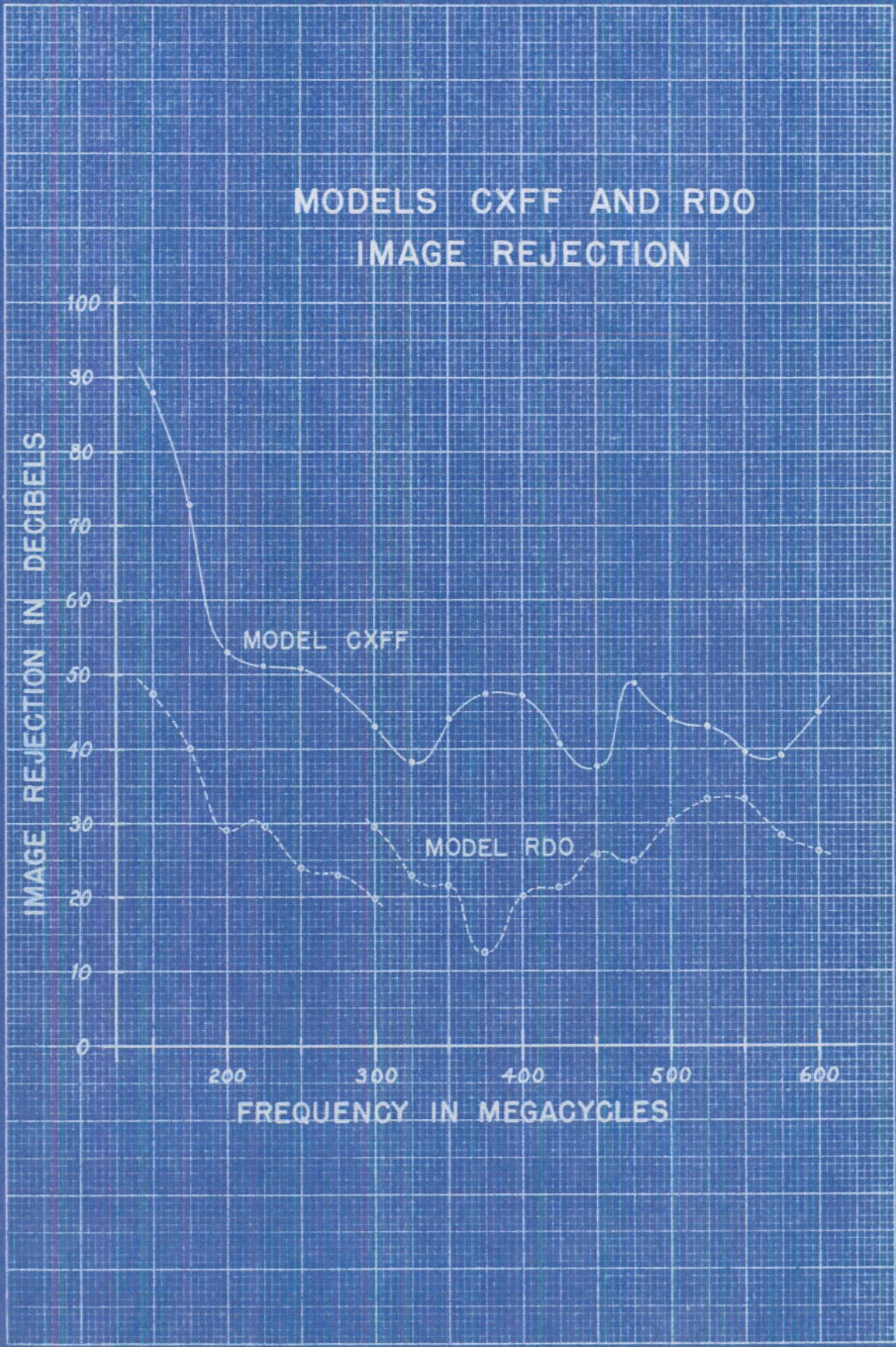
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# MODELS CXFF AND RDO IMAGE REJECTION



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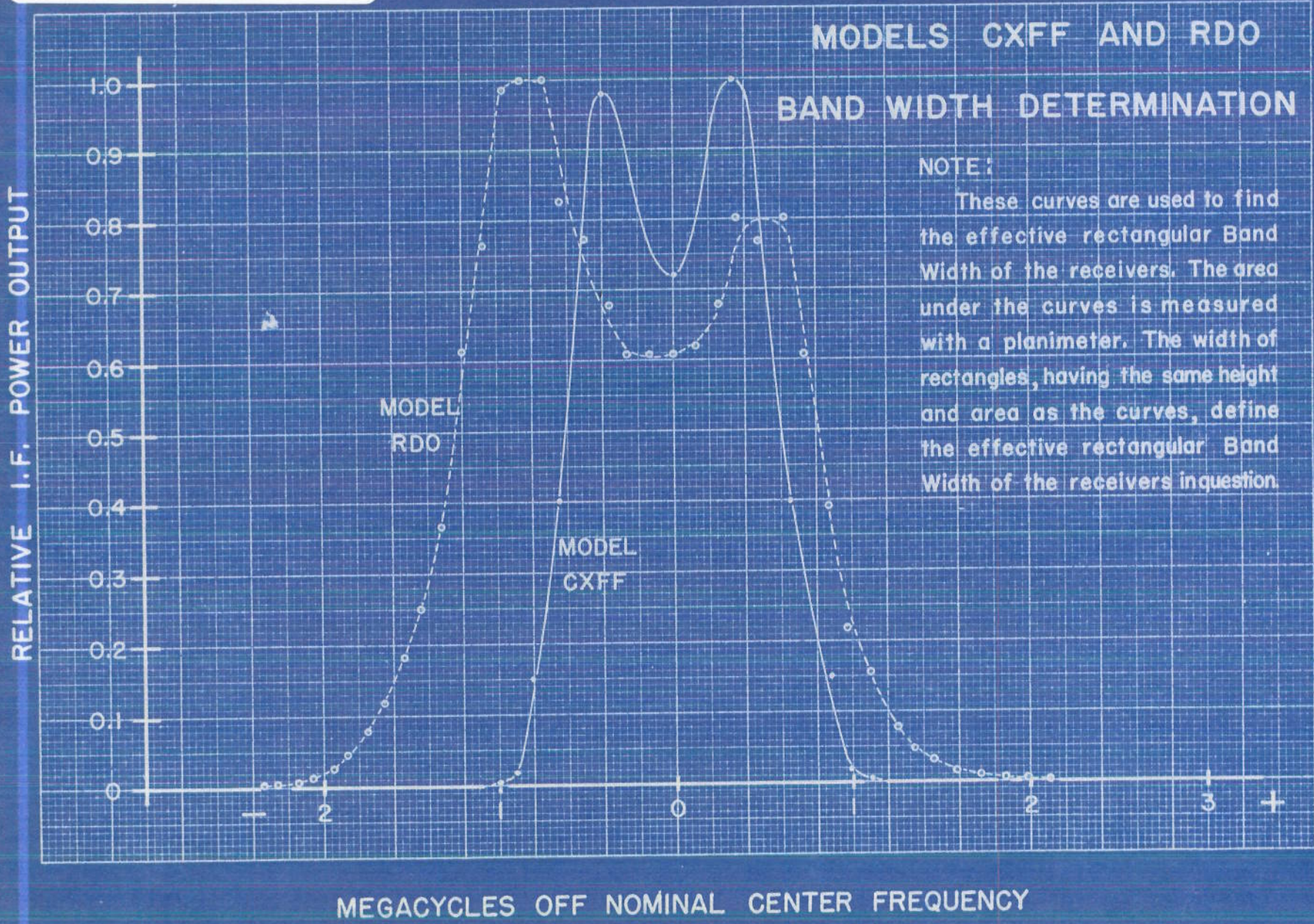


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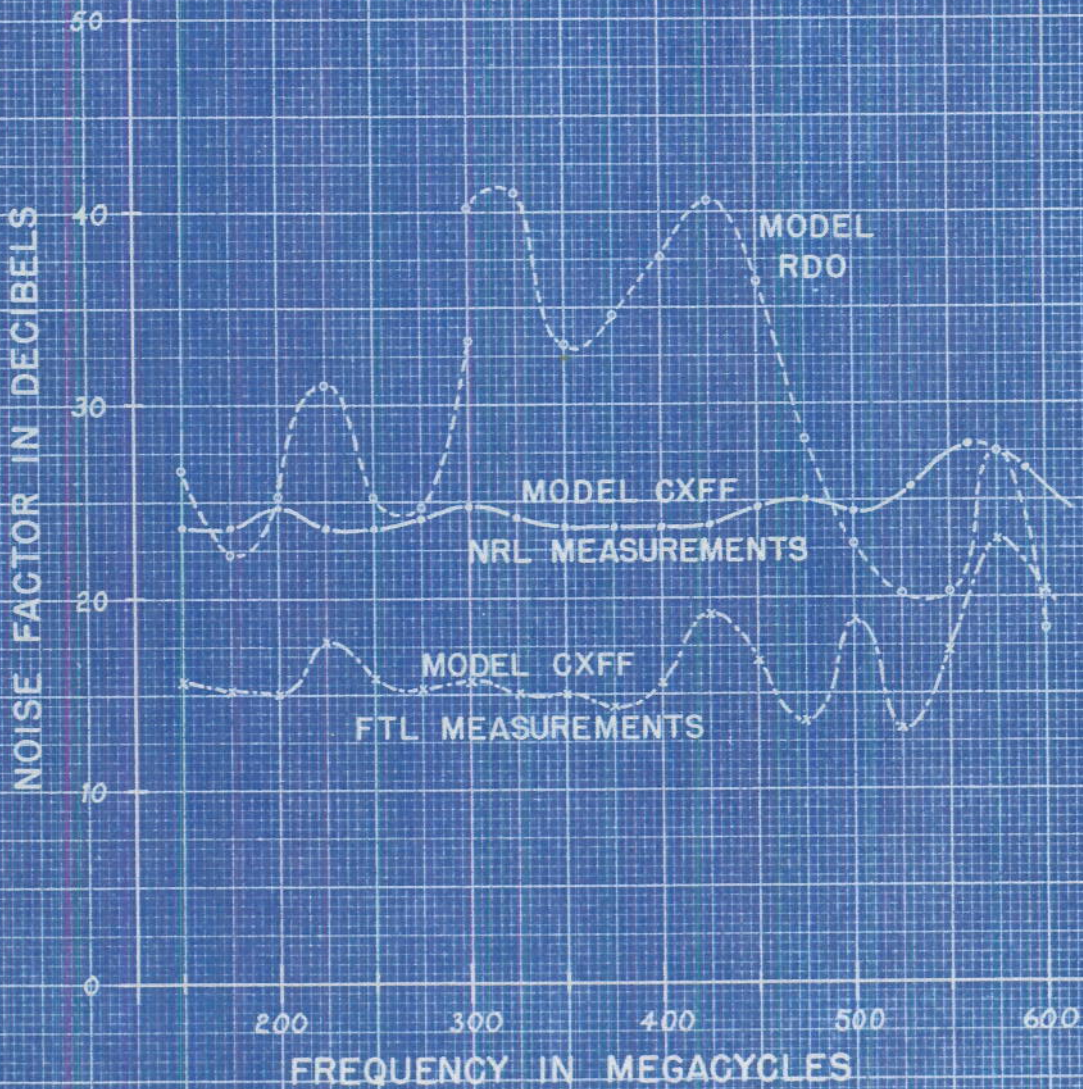
PLATE 11.



MEGACYCLES OFF NOMINAL CENTER FREQUENCY



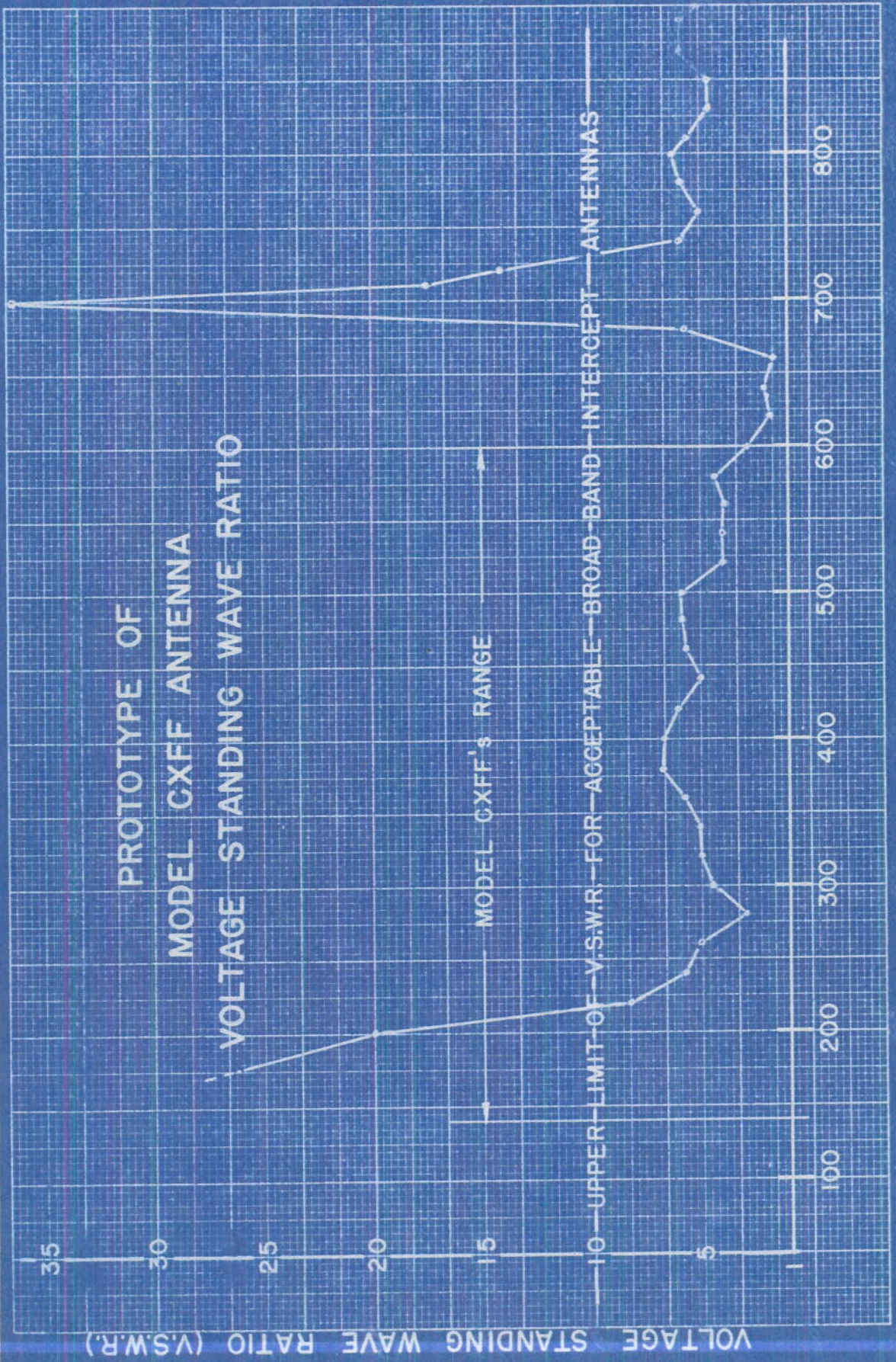
# MODELS CXFF AND RDO NOISE FACTOR IN DECIBELS



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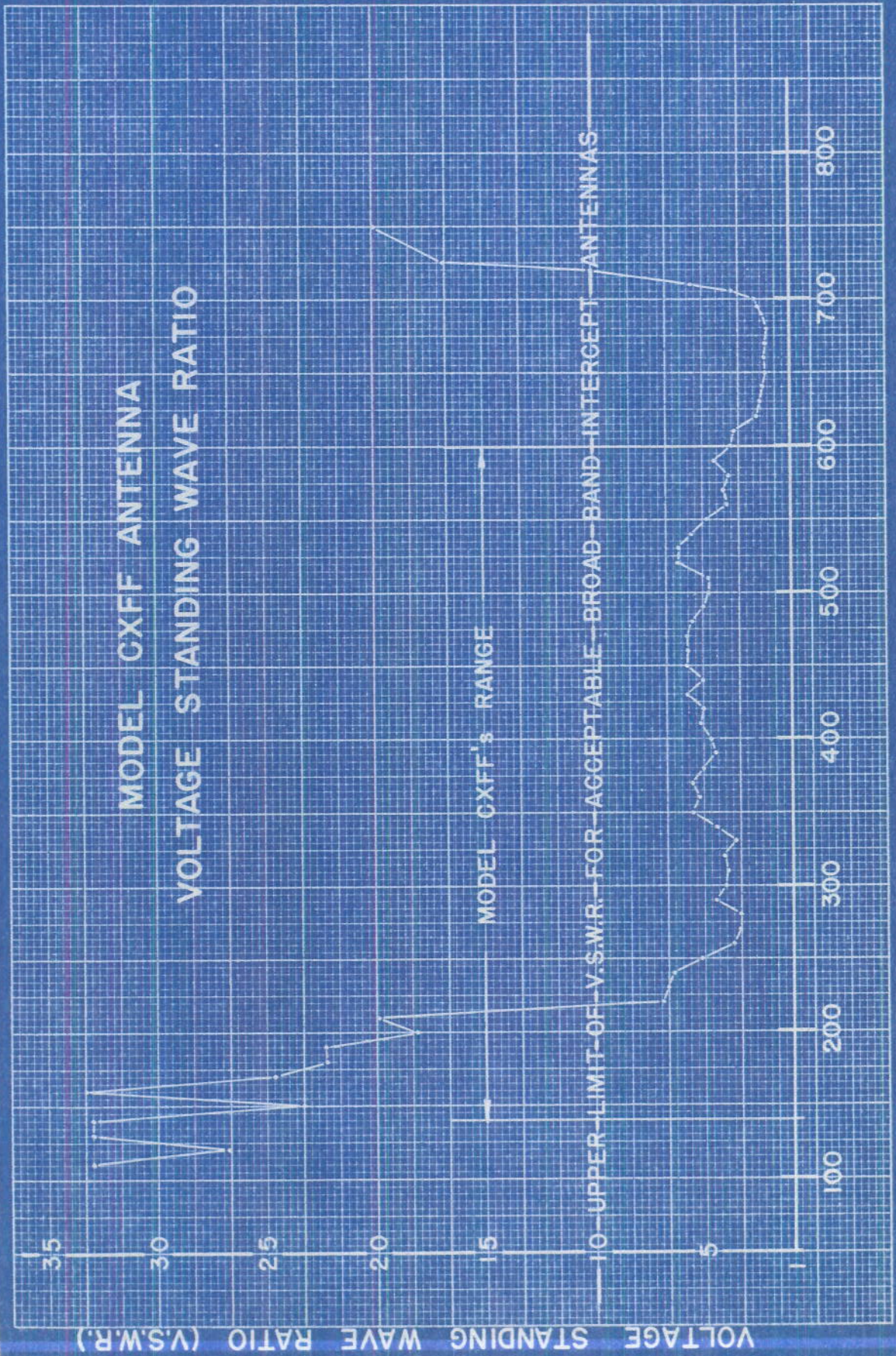
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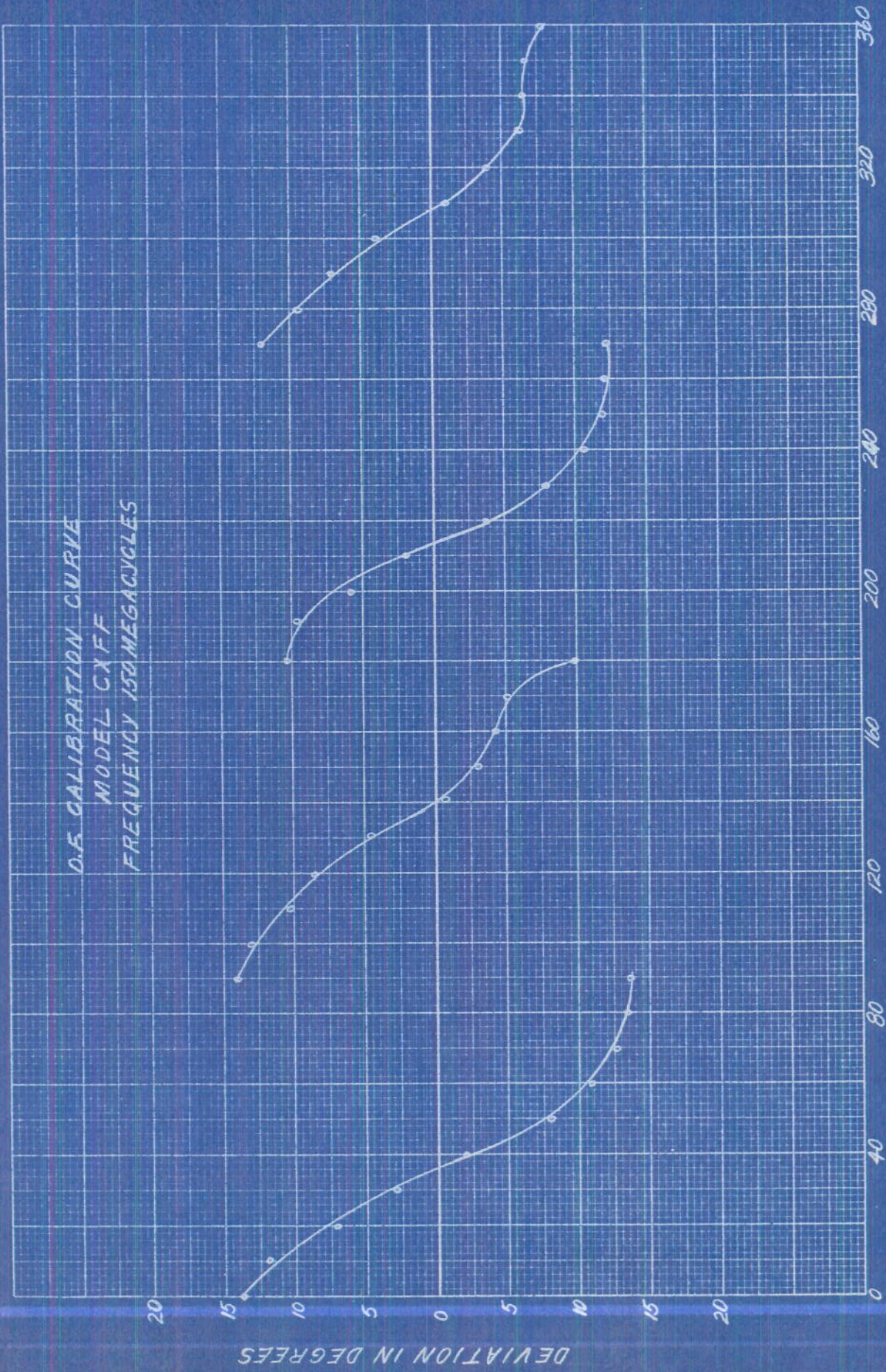
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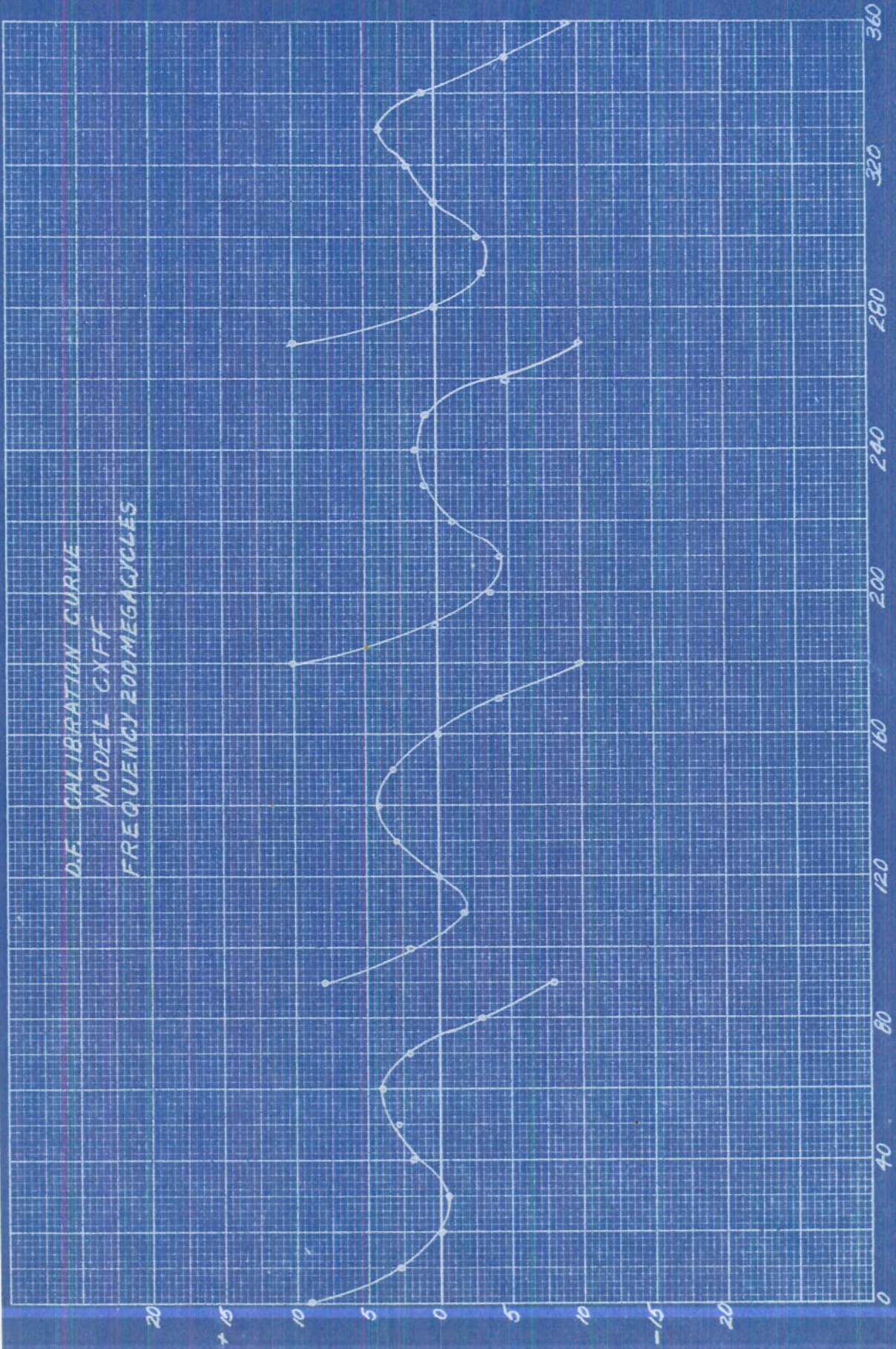
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D.F. BEARING IN DEGREES



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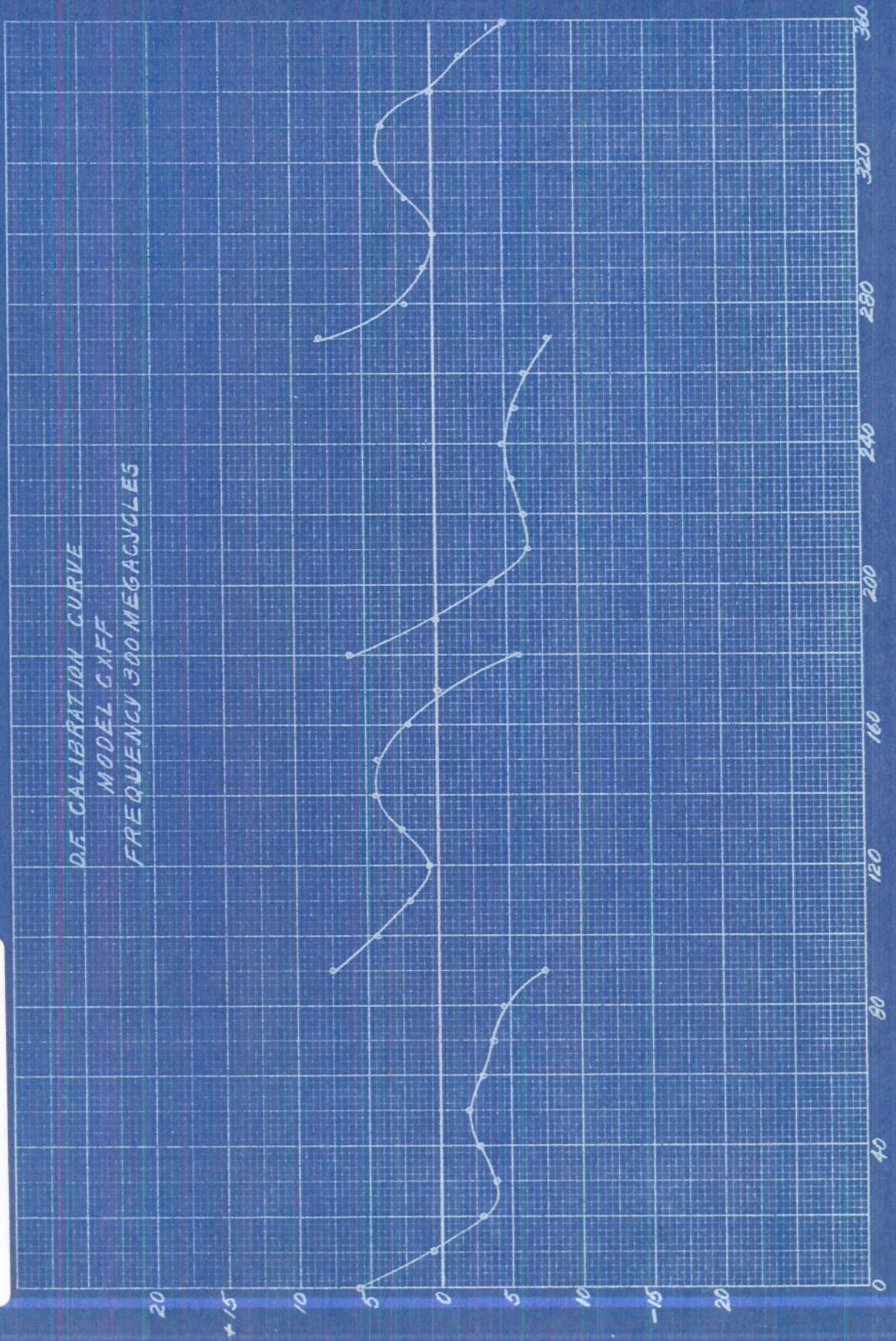
D.F. BEARING IN DEGREES

DEVIATION IN DEGREES

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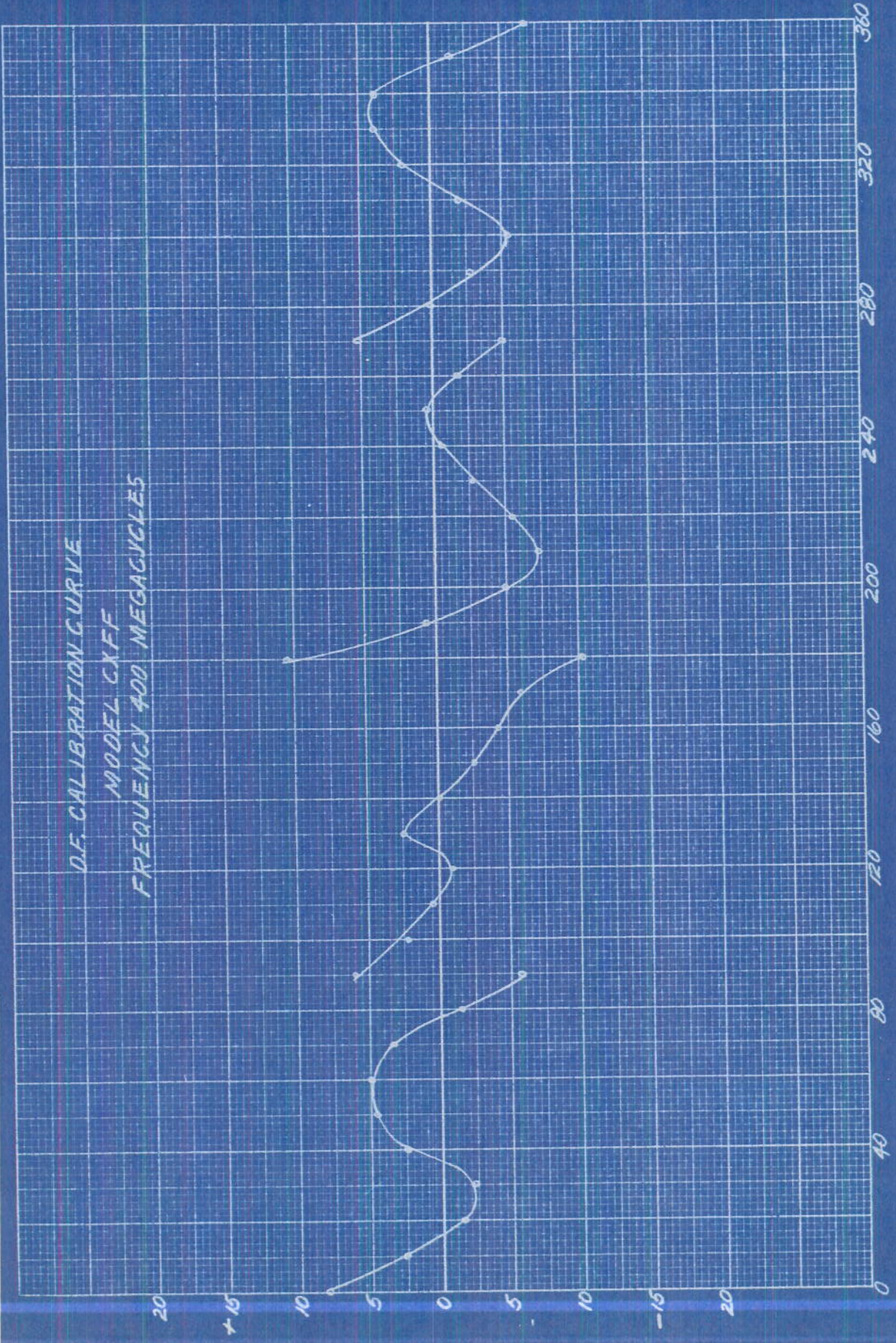
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D.F. CALIBRATION CURVE  
MODEL GAFF  
FREQUENCY 300 MEGACYCLES



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D.F. CALIBRATION CURVE  
MODEL CXFF  
FREQUENCY 400 MEGACYCLES

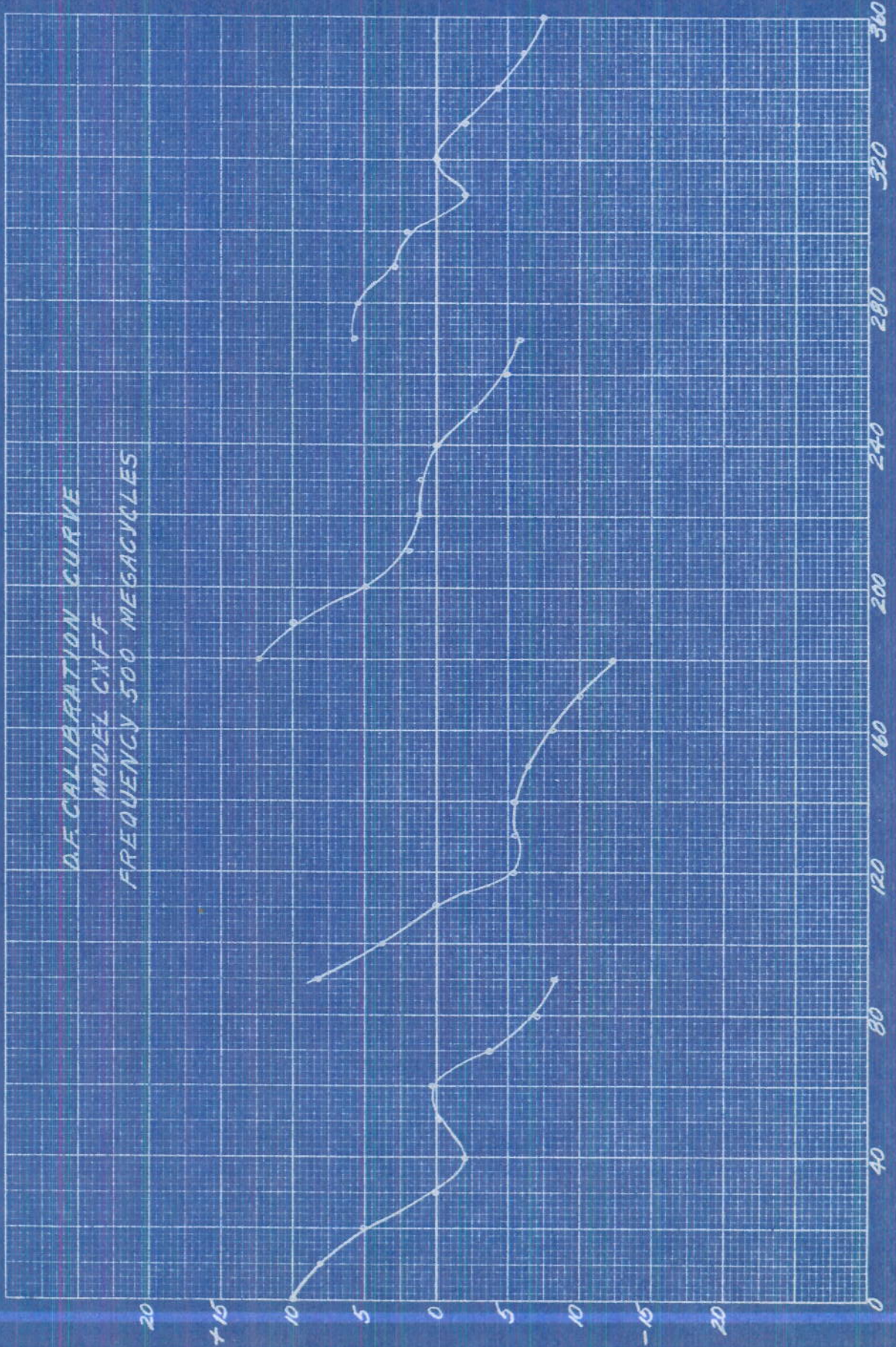


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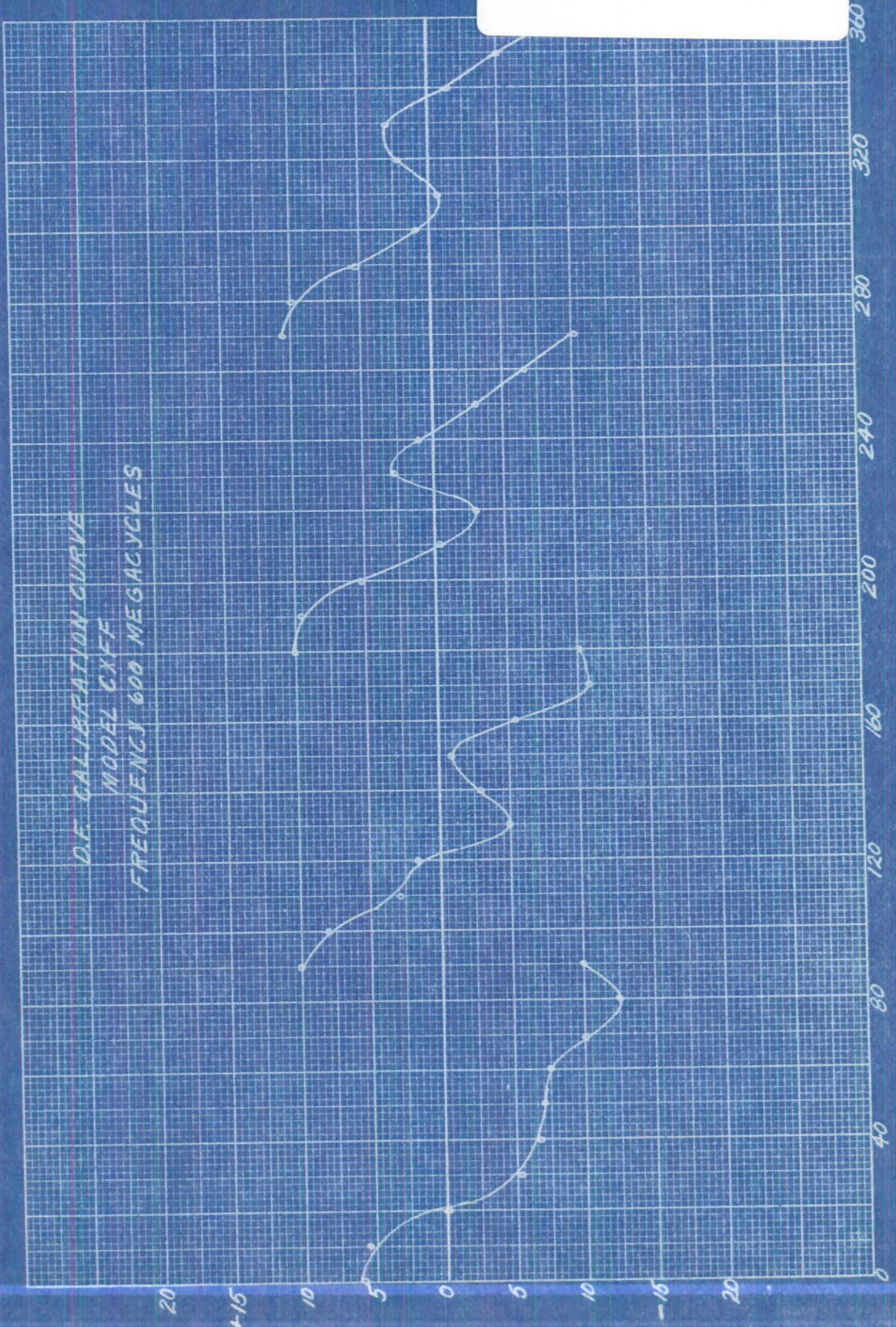




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D.F. BEARING IN DEGREES



D.F. BEARING IN DEGREES

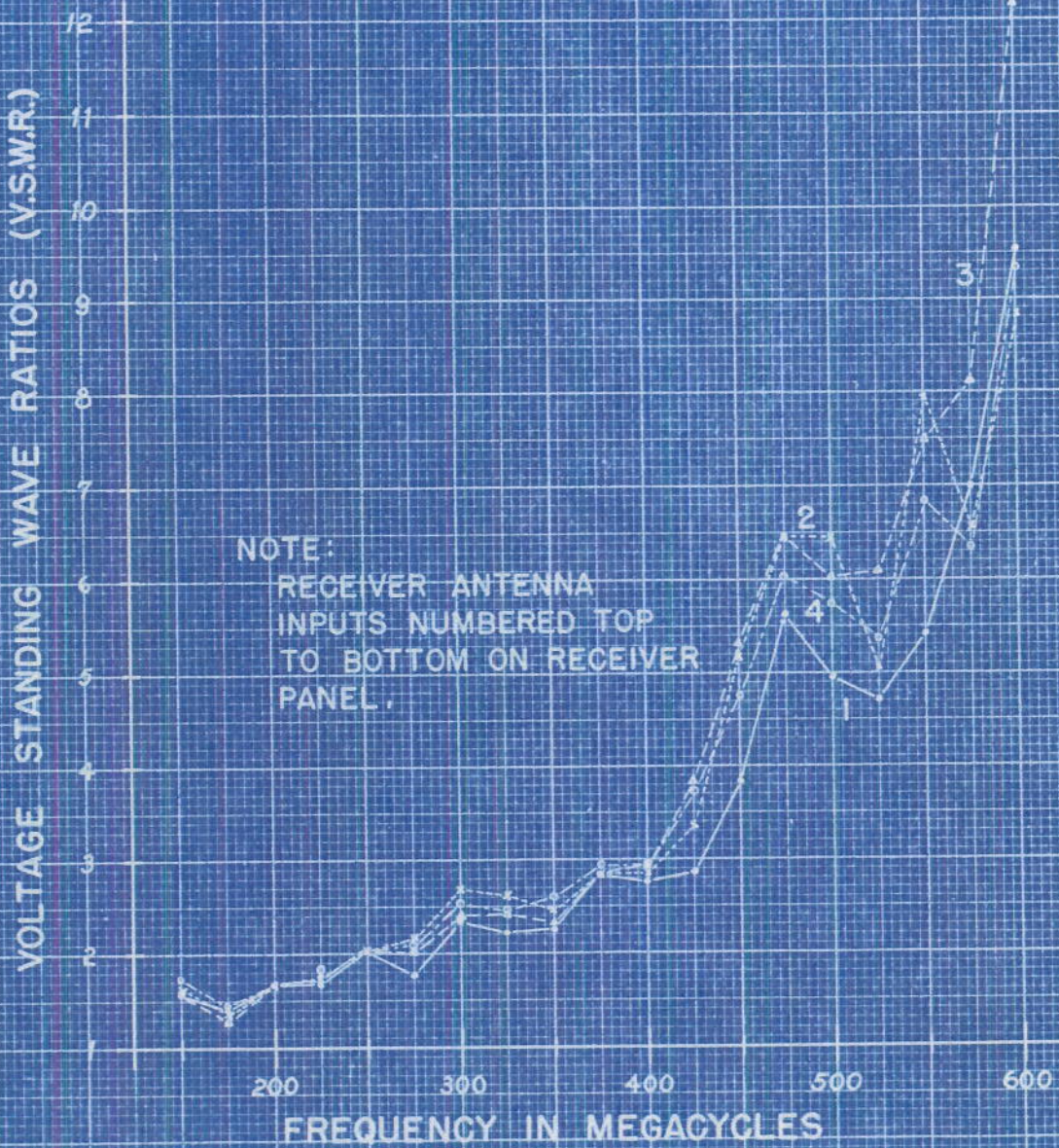
DEVIATION IN DEGREES

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NO. 3110-20 DIVISIONS PER INCH



# MODEL CXFF RECEIVER INPUT VOLTAGE STANDING WAVE RATIOS



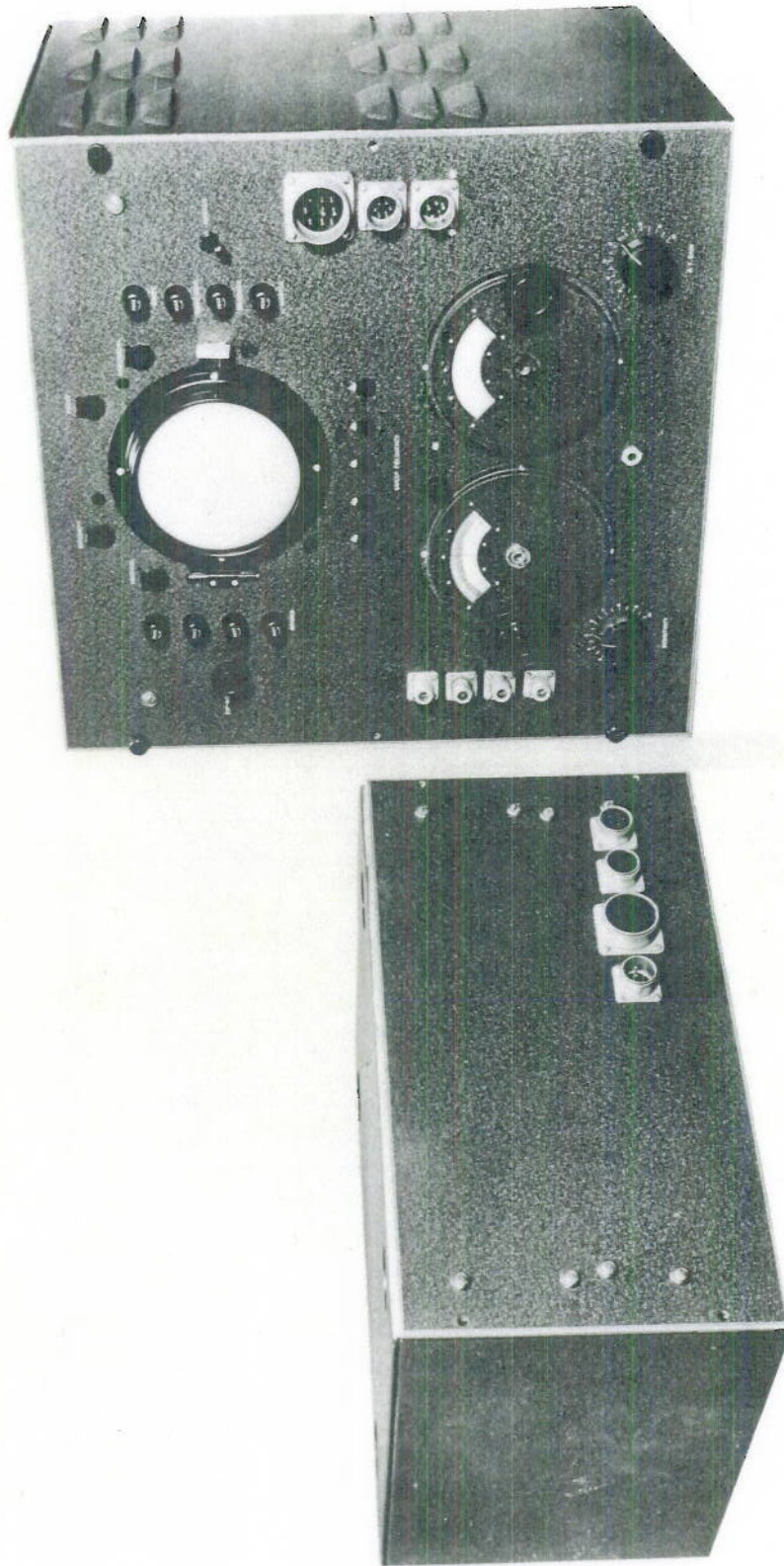
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NO. 3110, 30 DIVISIONS PER INCH BOTH WAYS, 120 BY 180 DIVISIONS.



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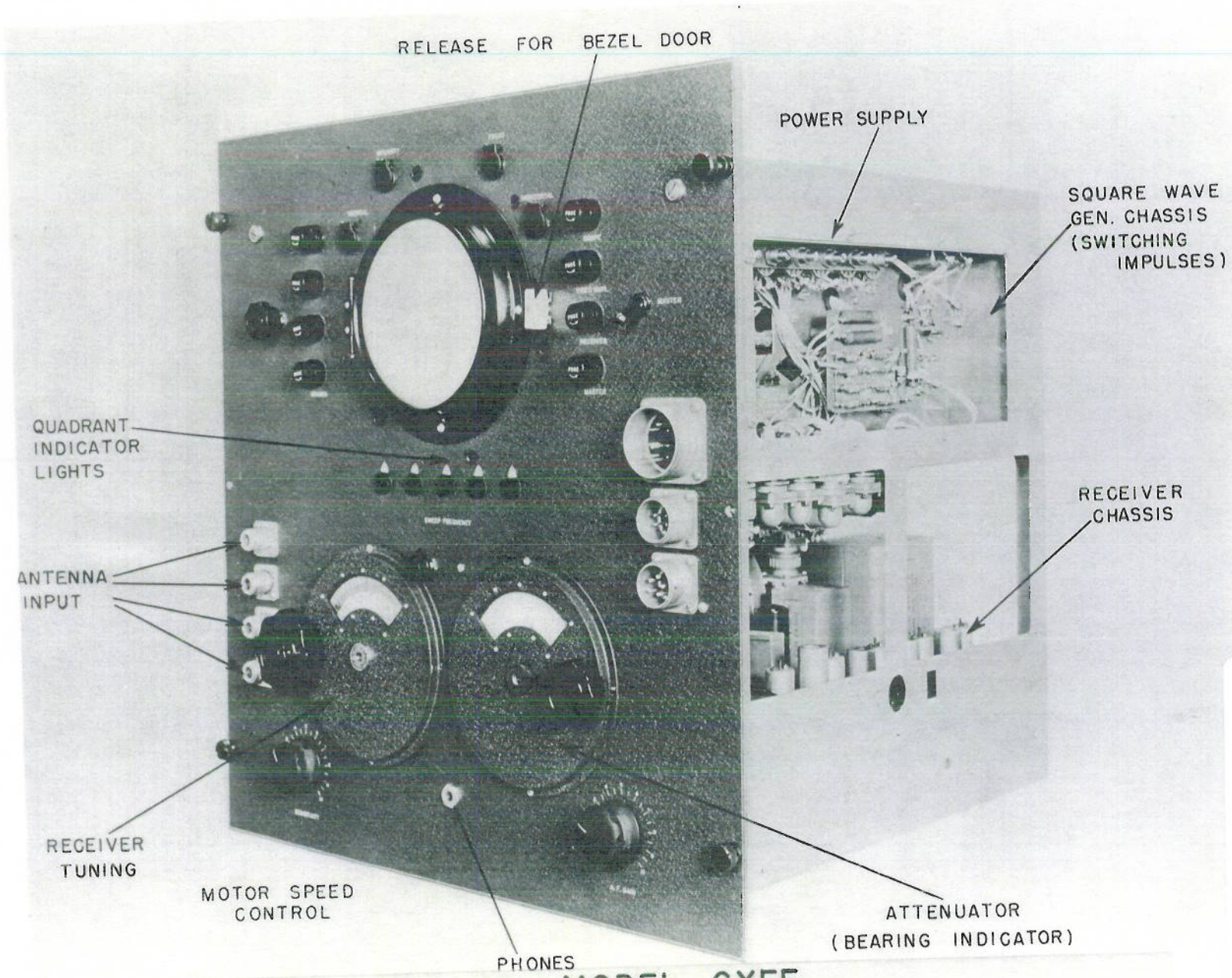
MODEL CXFF RECEIVER-INDICATOR UNIT AND POWER SUPPLY

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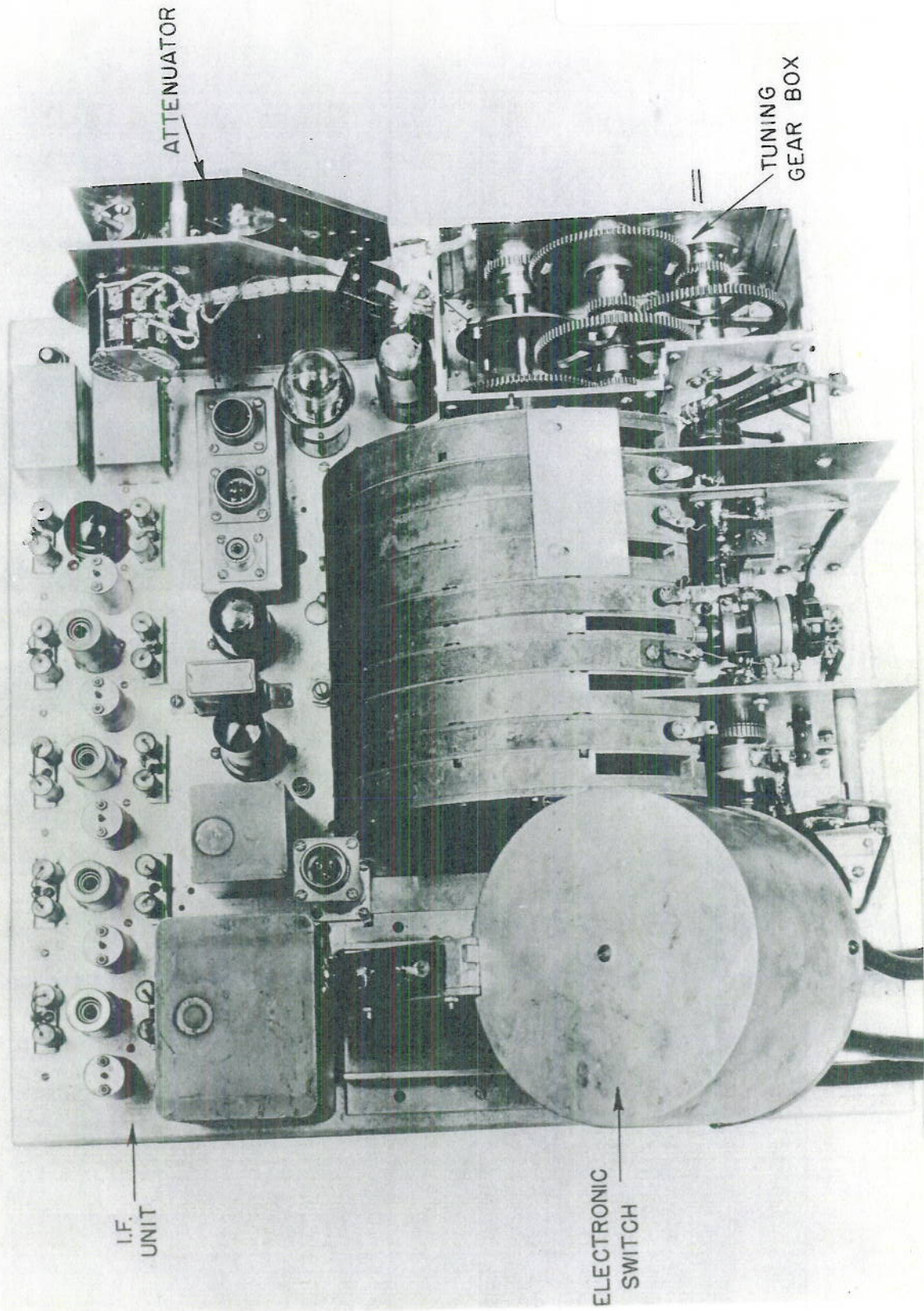
NRL Report R-2900

PLATE 23

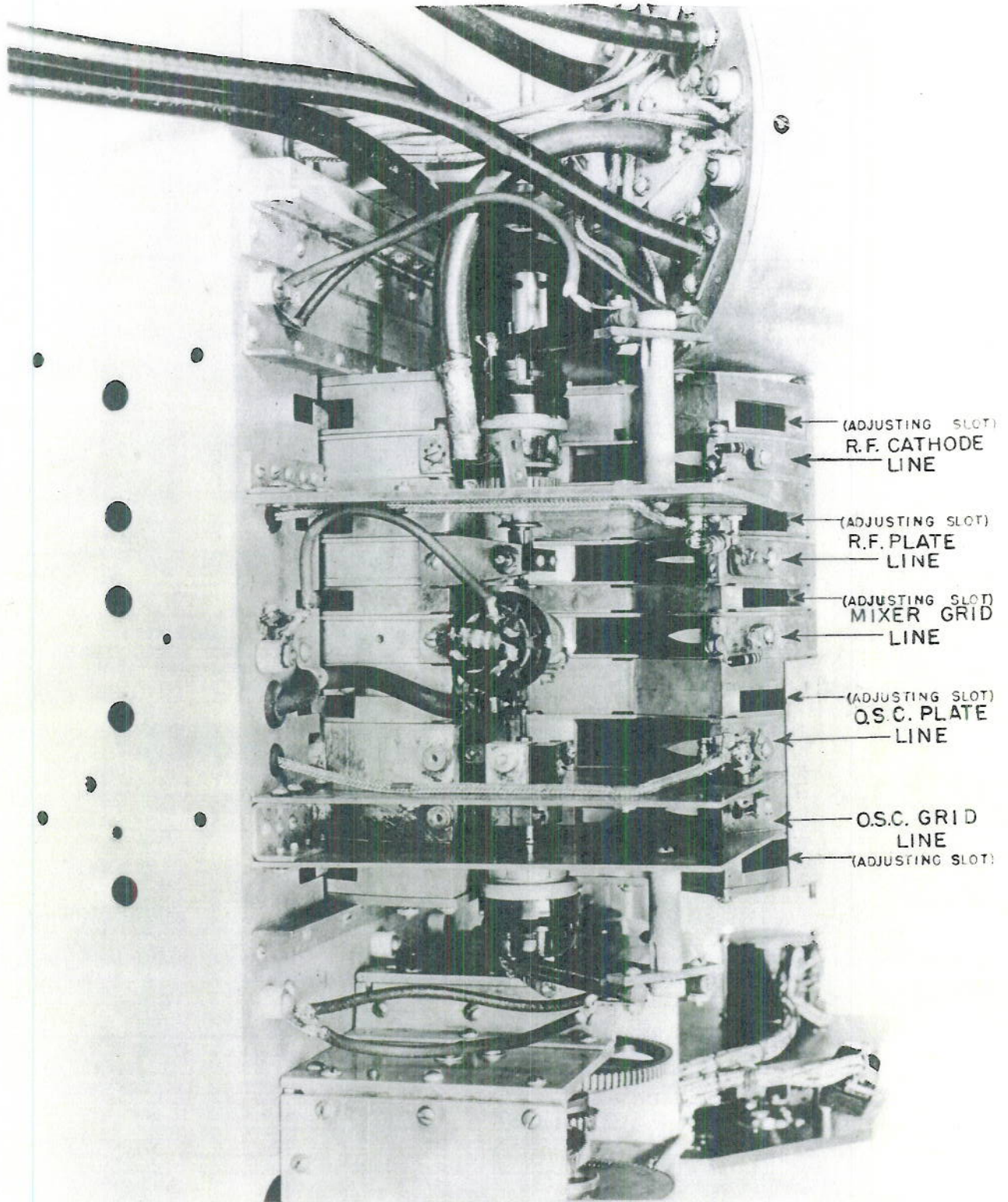


MODEL CXFF  
RECEIVER-INDICATOR UNIT REMOVED FROM CABINET

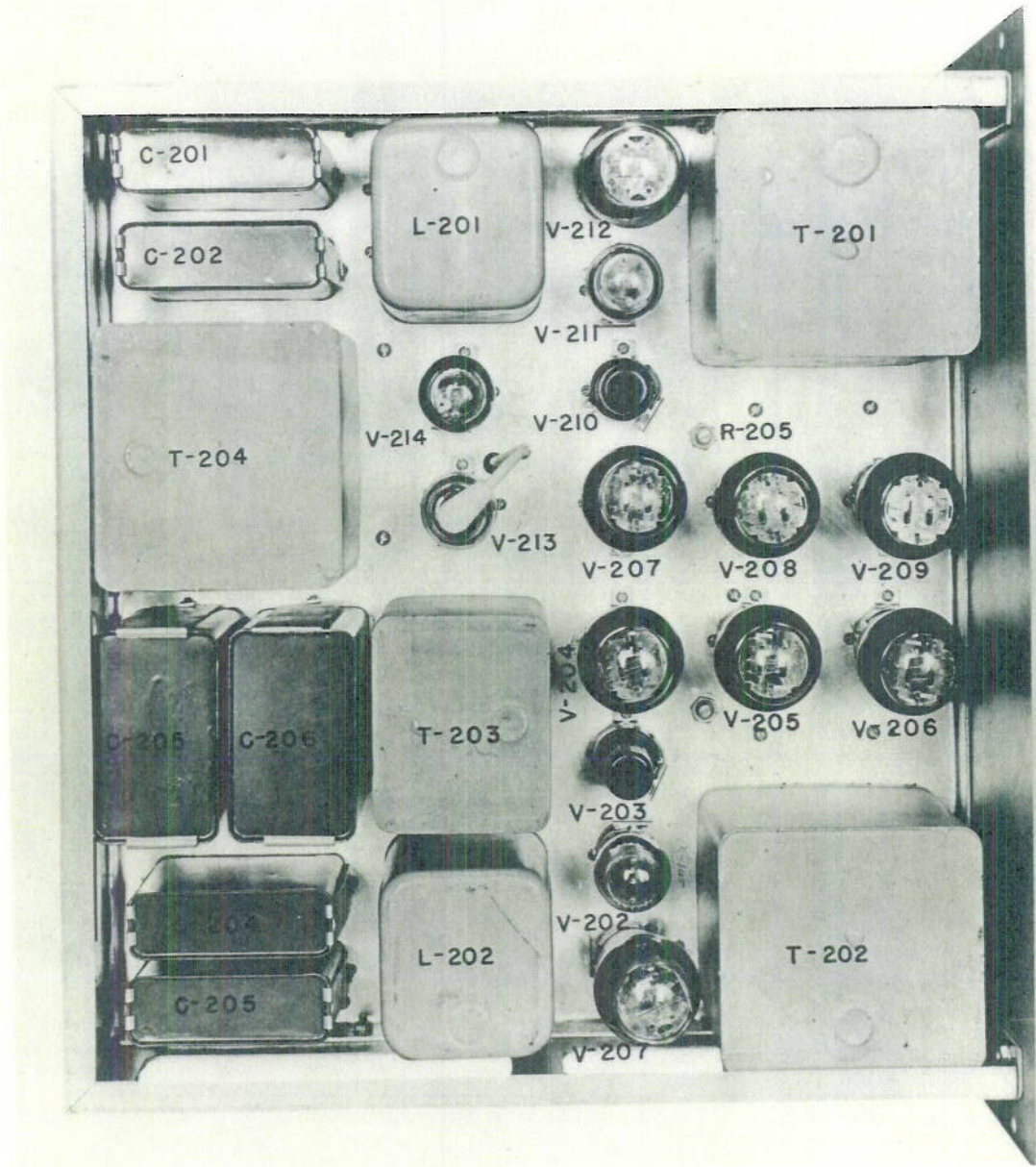
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MODEL CXFF TOP VIEW OF RECEIVER-INDICATOR UNIT



MODEL CXFF  
REAR VIEW OF RECEIVER-INDICATOR UNIT



MODEL GXFF POWER SUPPLY CHASSIS

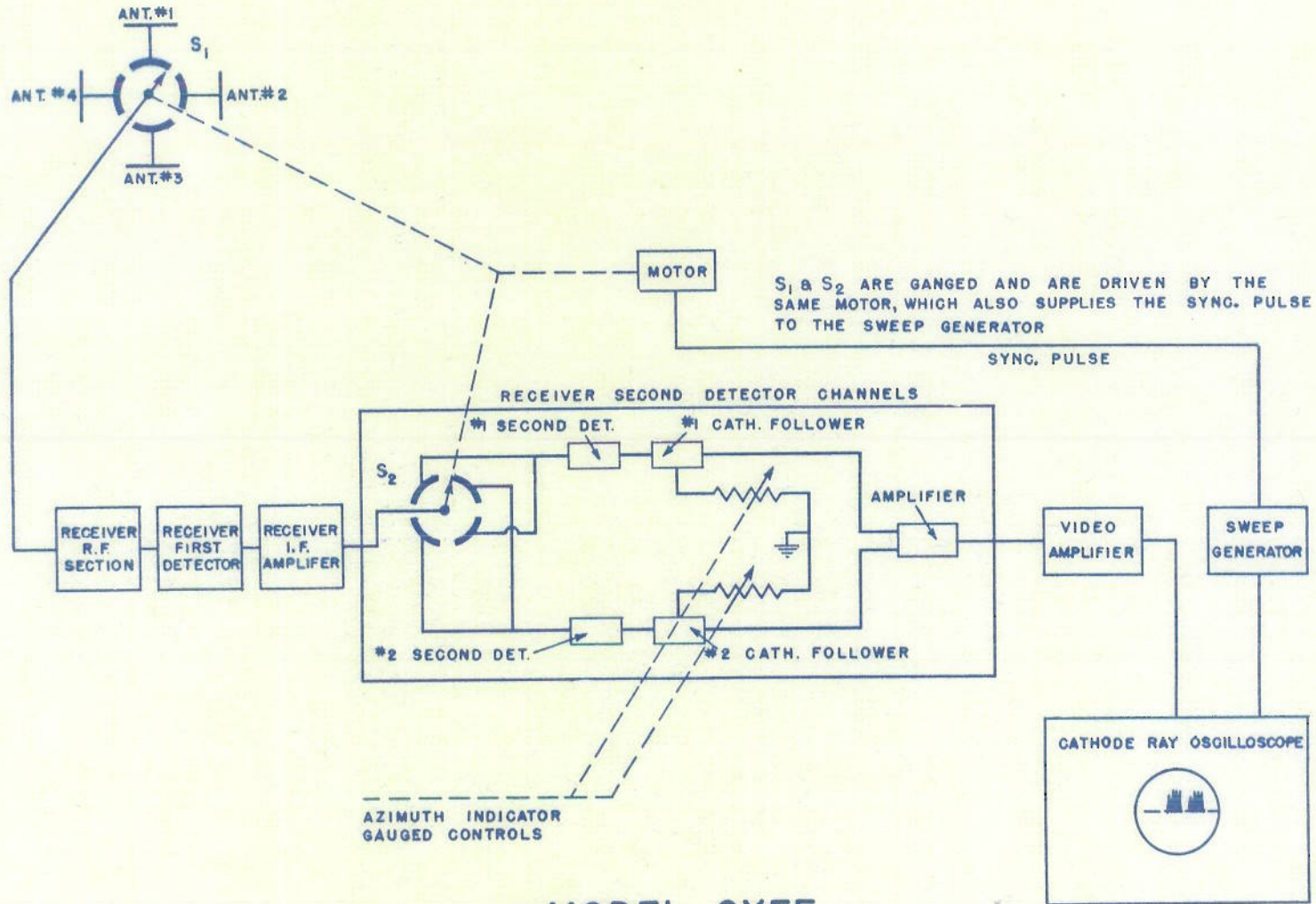
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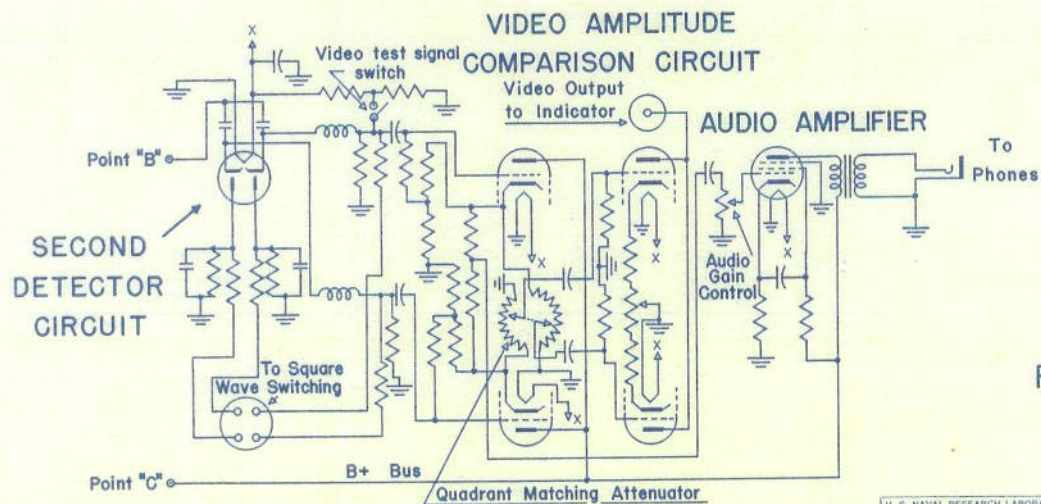
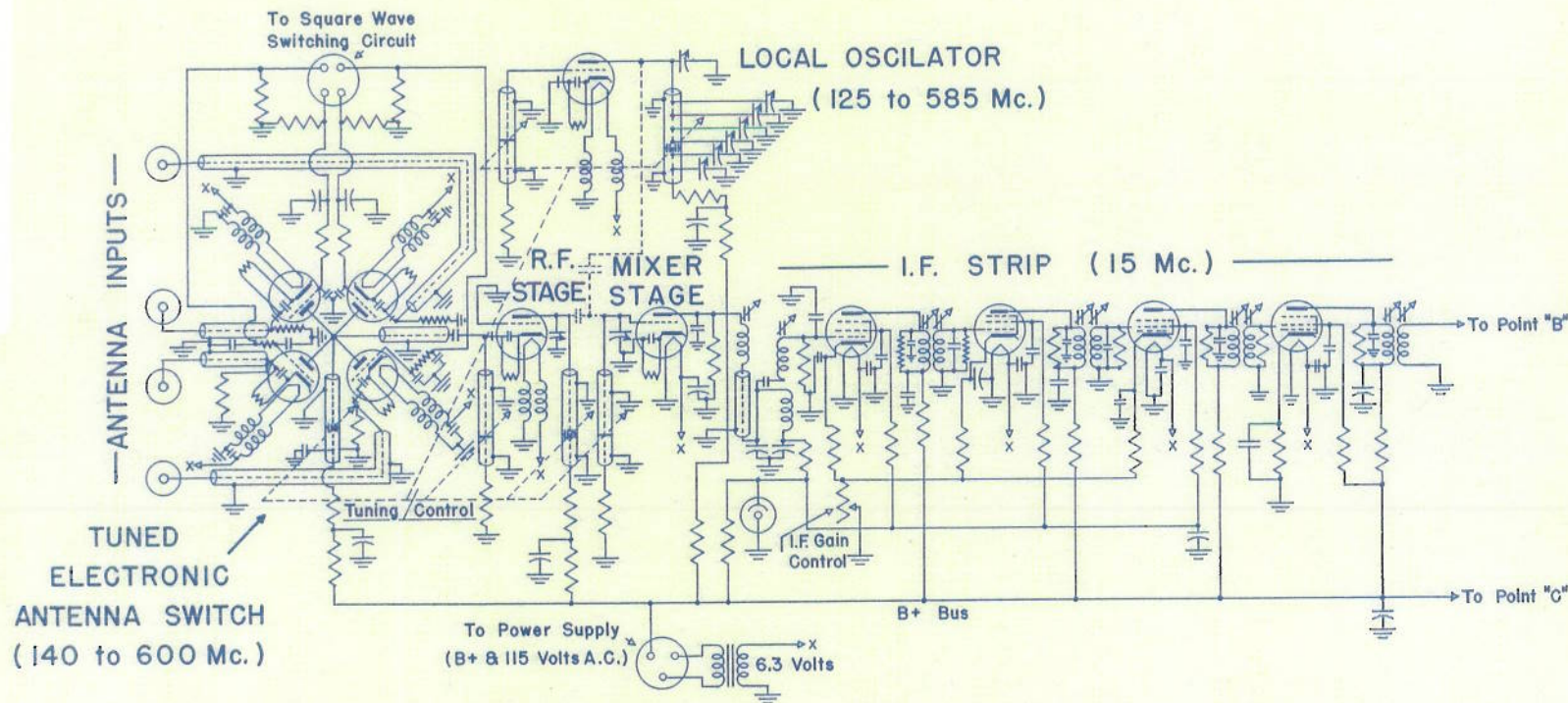
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PLATE 27.



MODEL CXFF  
BLOCK DIAGRAM OF SYSTEM



Note:  
This Circuit Diagram is not complete  
in all details and should not be used  
for maintenance work.

### MODEL CXFF RECEIVER SCHEMATIC

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