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EVALUATION OF THE VHF BAND OF A 140-
600 MC EXPERIMENTAL RADIO DIRECTION
FINDER DEVELOPED BY FTR UNDER NDRC
CONTRACT OEMsr-961

By K. O. Hornberg,

Report R-2998

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WASHINGTON 20, D. C.



Navy Department - Office of Naval Research

NAVAL RESEARCH LABORATORY
Washington, D.C.

RADIO DIVISION II
RADIO COUNTERMEASURES SECTION

15 January 1947

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By K. O. Hornberg

- Report R-2998 -



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* * *

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ABSTRACT

This report covers the evaluation of the general electrical performance of the low frequency (140 to 300 megacycles) band of an experimental radio direction finder (total frequency range from 140 to 600 megacycles) developed by the Federal Telephone and Radio Corporation under NDRC contract OEMsr-961. The purpose of this work was to determine the fundamentals of performance, particularly that of the collector system, and to obtain data for comparison with other types of direction finders in this frequency range.

The results as given in this report bear out the fact that simple Adcock-goniometer type systems are unsatisfactory in this frequency range. The electrical characteristics of the receiver are satisfactory for an experimental equipment.

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INTRODUCTION

1. This report is the second of a series covering the general performance characteristics of radio direction finders in the 150 to 600 megacycle frequency range. The equipment as furnished this Laboratory was not considered a prototype of a complete direction finder. Consequently, only the general electrical characteristics were evaluated.
2. Inasmuch as the higher priority of other work required immediate attention, the technical evaluation of this equipment was halted at the completion of the work on the low frequency band. It was thought advisable to report the results on this low frequency band rather than to with-hold them until the completion of the work on the second band. The evaluation of the second band of this equipment will be covered in a later report.
3. In accordance with the problem assignment, additional reports will be forthcoming as other equipments are tested. A summary report on Problem S1951T-C of particular interest to the Bureau of Ships will follow the completion of the preliminary evaluation reports.

DESCRIPTION OF EQUIPMENT

4. The Federal Telephone and Radio Corporation (FTR), now known as the Federal Telecommunication Laboratories (FTL) developed, under NDRC contract OEMsr-961, a direction finder covering the 140 to 600 megacycle frequency range in two bands. In order to cover this frequency range, two separate collector systems are used, with a common receiver and automatic bearing indicator. Plates 7 and 8 give the block diagrams of the entire equipment and the low frequency band antenna system respectively.
5. The collector system for the 140 to 300 megacycle band consists of a stationary Adcock system as shown in Plates 10 through 12. Four "fat" vertical monopoles (7:1 length to diameter ratio) are mounted on the corners of a square above a ground sheet with a fifth element for sense indication mounted centrally. The diagonal spacing between elements is 0.183 wavelengths at 225 megacycles (the mid frequency). The ground plane is 0.57 wavelengths on a side at the same frequency. The balanced output of each pair of elements is fed into the stators of a variable speed motor-driven capacitive goniometer. The motor which drives this goniometer also drives a Selsyn generator employed in obtaining the synchronized circular trace on the remotely located cathode ray indicator. The output of the goniometer is fed to a balanced to unbalanced transformer (balun) to utilize single coaxial cable. This equipment is supplied with approximately 50 feet of radio frequency transmission line thus permitting the remote location of the collector system.

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6. The receiver is of the tuned line type and is shown in Plates 13 and 14. It has one stage of radio frequency amplification and four intermediate frequency stages. The intermediate frequency (15 megacycles) after detection, drives two separate channels, a video channel through a direct current amplifier for obtaining the bearing indication and an audio channel through an audio frequency amplifier for monitoring. The intermediate frequency has an acceptance bandwidth of approximately 1 megacycle making it suitable for pulse reception. The receiver is tuned by varying the length of the circular transmission lines by means of shorting bars. Motor switching circuits are so arranged that only one antenna system can be used at a time.

7. Bearings in the low frequency band are indicated by the well-known propeller-shaped pattern on a five-inch cathode ray tube. The "no signal" circular trace is obtained from a special rotating linear resistance element from which two sine wave voltages are obtained from two sets of brushes spaced 90 degrees apart. The contractor refers to this assembly as a "B" block. This block is driven in synchronism with the goniometer by the two Selsyn motors energized by the Selsyn generator described in paragraph 5 above. Two Selsyn motors were used apparently because the largest motors available had insufficient power to maintain the desired tracking accuracy. The second motor was presumably added as an "after-thought", as it is belt-connected to the original motor driving the "B" block.

8. Sense indication is provided by means of the sense antenna whose output is fed through a fixed network consisting of baluns and transmission lines so arranged that the output applied to the goniometer rotor, during sense determination, is in the correct phase (relative to the voltage from the directional antennas) over the 140 to 300 megacycle range to give a cardioid response pattern for the collector system. A radio frequency relay is provided in the antenna unit and a power relay in the indicator unit both operating from a switch on the receiver-indicator panel. This switch, when depressed, connects the sense antenna circuit to the directional channel and changes the connection of the oscilloscope plates to cause a 90 degree shift in the pattern, thereby producing a unidirectional or sense pattern.

DESCRIPTION OF FIELD TEST SITE

9. The equipment was tested at Blue Plains which is located about one mile south of this Laboratory. The site used for this problem is free of all underground and overhead wires for a considerable distance. Power for the equipment and target transmitters was furnished by two gasoline-engine-driven generators which had considerable shielding to prevent an undue amount of noise. The

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receiving antenna, secured to a manually rotated turntable, was mounted on the roof of a two-story building approximately 20 feet above the ground. A target transmitter was located at the same height on a telephone pole at a distance of 100 feet. See Plate 9 for a photograph of the test site. A dipole antenna with a flat reflector and driven by a General Radio Type 857-A Oscillator was used as the target transmitter. Several checks indicated that there were no serious disturbances caused by the power cable leading from the power source on the ground to the oscillator. The oscillator was mounted directly behind the reflector to prevent undue radiation from this source.

ANTENNA SYSTEM GAIN

10. The gain of the collector system with respect to an isotropic antenna is given in Table 1. For clarity, it should be stated that the gain of a half wave resonant dipole is 2.14 decibels above an isotropic antenna.

11. The inefficiency of this collector system may be partially attributed to two factors. One factor contributing to this inefficiency is the 6 decibel loss inherent in the monopole system with respect to a dipole. The other factor is the coupling loss in the goniometer which is inherent in the Adcock-goniometer type of direction finder. Experience indicates the probability of rather large losses in this particular type of goniometer. The inadvisability of building rather elaborate test equipment precluded the determination of this coupling loss. It should be stated that the gain is not considered unsatisfactory for an Adcock-goniometer type system.

ANTENNA SYSTEM "EFFECTIVENESS"

12. The antenna "effectiveness" is defined as that quantity which when multiplied by the field intensity yields the voltage across the load impedance. This quantity, which has the dimension of length, is very useful because it enables the determination of the field intensity required for a given receiver sensitivity. Table 2 gives the antenna "effectiveness" for this equipment.

13. The necessary data for determining the antenna gain and antenna "effectiveness" were obtained by stopping the goniometer and orienting the collector system for maximum receiver output. The cable was terminated in its characteristic impedance (50 ohms) in order to have a standard load. A large isolating resistance was placed between the terminating resistance and receiver input to preclude any loading effect that the receiver might have upon the antenna system. The receiver output (below overload) was recorded for constant field intensity. A half wave resonant dipole was then

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substituted for the collector system and the receiver output again recorded. A suitable signal generator (LAF-3) was substituted for the dipole and the attenuator adjusted to give the receiver output readings as obtained from the collector system and dipole measurements. The same cable termination and isolating resistance was used for each measurement. The attenuator readings, together with the receiver linearity correction curve, supplies the required information for the antenna gain and antenna "effectiveness". Inasmuch as the receiver input closely approximated 50 ohms, as indicated by a low standing wave ratio, the antenna "effectiveness" values are valid for computation purposes with this equipment.

OVERALL EQUIPMENT SENSITIVITY

14. The overall equipment sensitivity is shown on Plate 1. These sensitivity figures were computed from the antenna "effectiveness" and the receiver sensitivity inasmuch as it was later determined that the receiver was not functioning properly at the time the overall sensitivity measurements were made in the field. Since it was noted that the electrical length of the 50 foot radio frequency transmission line changed with temperature, a line stretcher was used, in the original measurements, to determine the variation in sensitivity as caused by the resulting change of impedance. This variation increased with frequency and reached approximately 25 per cent at 300 megacycles.

BEARING SENSITIVITY

15. The bearing sensitivity (minimum field intensity required to give 5 degree bearings) is given on Plate 2. Inasmuch as this test was taken in the field with the receiver improperly working, it was necessary to correct the original data. This test was performed with the line stretcher adjusted to give maximum receiver output, increasing the target transmitter output until 5 degree repeatable bearings were observed.

BEARING PATTERNS

16. Plate 16 shows two bearing patterns obtained with this equipment. The bearing pattern taken at 225 megacycles is representative of most patterns up to a frequency of approximately 250 megacycles. Above approximately 250 megacycles, the patterns became distorted, the degree of distortion depending upon the frequency and azimuth. The pattern taken at 260 megacycles shows the extreme distortion observed which made the bearing determination impossible. Above 260 megacycles, the four leafed pattern disappeared.

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17. A four-leaf-clover pattern results from a condition in the collector system that produces four minimums (all of which might not necessarily be "nulls"). There are several causes for this phenomenon. In an antenna system of the type used with the equipment in question it is often caused by a combination of a resonant condition existing in the antenna and goniometer stators together with a tightly coupled goniometer rotor which in combination produce harmonic distortion of what should be a pure sine wave as a result of the goniometer rotation. In an ideal goniometer the two bearing indicating minimums occur at the two points in the sine wave where the voltage is zero, i.e., for each 180° of rotation. If, however strong harmonics exist in the antenna-goniometer system, the voltage induced in the rotor will be (or approach) zero at other angles of rotation. This harmonic distortion will occur when the antenna transmission lines plus the impedance coupled into the two transmission lines from the goniometer rotor approach resonance. A simple example might serve to illustrate the nature of this phenomenon. Imagine a conventional Adecck antenna and tightly coupled capacitive goniometer system with a signal arriving arbitrarily from a bearing of 45°. At bearings of 45° and 225° the voltages in the two goniometer stators to which the rotor is equally coupled are equal and exactly out of phase so that no voltage is passed on to the rotor; these are the positions of true minimums. At 135° and 315° the goniometer rotor is equally coupled to the two stators where the voltages are out of phase and these should be the positions of "maximum". Suppose, however, that at or near a certain critical frequency the antenna transmission lines plus the full capacitance of the rotor and stator of the goniometer become resonant but are non-resonant when the rotor is only 50% coupled to the stators, as at 135° and 315°. In these positions, i.e., at 0, 90, 180 and 270 degrees the highest possible voltage will be induced into the stator. This will produce false maximums at these bearings. This then will produce the following progressive voltages in the receiving system for one rotation of the goniometer rotor:

45° - minimum (true)
90° - maximum (false)
135° - minimum (false)
180° - maximum (false)
225° - minimum (true)
270° - maximum (false)
315° - minimum (false)
360° - maximum (false)

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This progression of voltages will produce on the bearing indicator a four-leaf-cover pattern, similar to that illustrated by Plate 16. As the relative phases of the complex goniometer modulation voltages change with frequency and bearing of the signal, the resulting pattern on the indicator will go through a multiplicity of configurations which will normally hide, displace or blunt the true bearing over a considerable band of frequencies (20 to 30 Mc wide in the equipment under discussion). Reference 4 gives a more complete theoretical explanation of this phenomenon.

18. At frequencies where the four-leaf-clover pattern disappeared, i.e. above 260 Mc INSTRUMENTAL ERRORS of the "Reciprocal Error" type were present. These errors, the magnitude of which varied with the frequency, were as high as 30° and at the higher frequencies the bearing pattern was additionally distorted by having a long and short "blade" on the propeller. RECIPROCAL ERROR is caused by the pick-up of signal voltage by parts of the equipment possessing substantially omnidirectional reception characteristics, which voltages combine with the voltage obtained from the directional antenna system. This type of error is indicated by the two blades of the propeller-shaped pattern not being in line, i.e., not displaced exactly 180° . Several quick checks showed that this undesired signal appeared to enter the equipment only through the power cable. This undesired signal was observed mainly in the vicinity of 300 megacycles.

19. Due to an inadequate repeating system, the bearing patterns were seen to "wander" approximately plus or minus 3 degrees from the bearing.

OPERATIONAL TIME REQUIREMENTS

20. The type of bearing presentation of this equipment and its method of operation are similar to most standard ABI types of direction finders which employ a propeller-shaped type of presentation and require the operation of a switch to obtain sense indication. Accordingly its operational time for indicating the bearing of a transmission to which the receiver is tuned will be the same as for other ABI types of equipment, such as the Models DAU and DBF. The mechanical design of the radio frequency section is such as to make the "tuning in" of the signal at the high frequency end of the receiver very difficult, greatly increasing the operational time requirement.

RECEIVER SELECTIVITY

21. The receiver selectivity is given on Plate 3. It is seen that this receiver has an acceptance bandwidth of 1.35 megacycles at the 6 decibel points, the equivalent rectilinear bandwidth, (3 decibel points) being 1 megacycle, which makes possible the reception of pulsed signals. This selectivity curve is seen to have

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a Shape Factor (bandwidth at 60 db/bandwidth at 6 db) of 2.3. The selectivity was taken at 150 megacycles.

RECEIVER SENSITIVITY

22. The receiver sensitivity over the entire frequency range is shown on Plate 4. In order to obtain these values and to reduce the tuning noise, it was necessary to redesign and install new shorting bars in the radio frequency section, replace the original GL-466 Lighthouse tubes with 2C40 Lighthouse tubes, and completely realign the set. Plate 15 is a photograph showing both the original and redesigned shorting bars. These new shorting bars were designed to have longer and heavier springs and single ball contacts instead of a multiplicity of spring fingers. This not only provided for more uniform pressure but permitted more lateral movement of the springs to better follow "wobble" of the lines when rotated. This practically eliminated the noise during tuning which was excessive with the original contacts, there being four sets of lines, one or more of which usually possessed contact troubles. In addition, the ball type contacts were found decidedly advantageous in eliminating the electrical "torque lash" resulting from the multicontact fingers "rocking" when tuning to a signal and thereby changing the transmission line lengths, when direction of tuning is reversed. The resulting sensitivity values are considered acceptable.

23. This test was performed with the signal generator (IAF-3) feeding the receiver directly. A suitable meter indicated the second detector output. The sensitivity values are given as the voltage in series with 50 ohms required to give a 20 decibel signal plus noise to noise ratio.

24. The noise factor of this receiver which relates its sensitivity to that of the theoretically perfect receiver is given on Plate 5 for comparison purposes with other receivers.

RECEIVER OVERLOAD

25. Plate 6 gives the overload characteristic of this receiver. It is seen that the overload point is sufficiently above the normal operating range as to be satisfactory and that the receiver is linear for inputs under 150 microvolts.

CONCLUSIONS

26. It is concluded:

- (a) That the equipment furnished the Laboratory was not considered as a prototype of a complete direction finder

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- equipment, suitable for service test or duplication, but merely as a model to demonstrate operation of a system and, accordingly, no type tests were conducted to determine mechanical suitability for Naval use.
- (b) That the equipment is not mechanically suitable for Naval use in its present form.
 - (c) That the equipment was mechanically imperfect in so many respects as to obscure or compromise any satisfactory demonstration of the principles of the basic design, i.e., the practicality of employing a fixed Adcock-rotating capacitive goniometer system of direction finder in the frequency range 150 - 300 megacycles.
 - (d) That, inasmuch as the "collection" efficiency of any antenna depends on the area presented to the wave front, any Adcock type of antenna will be increasingly less effective as the frequency increases so that the MAXIMUM RESPONSE SENSITIVITY of an equipment employing such an antenna will be quite low at frequencies in the 150 - 300 Mc range in comparison to that obtainable with lower frequency Adcock equipments, even if all other losses could be eliminated.
 - (e) That, inasmuch as direction finders such as that under discussion must be capable of receiving pulse transmissions, the band-width of the receiver must necessarily be made wide, with a resultant increase in noise and a similar decrease in MAXIMUM RESPONSE SENSITIVITY.
 - (f) That the combination of inherently low antenna efficiency, high goniometer losses and low receiver SENSITIVITY (due to high noise level) all result in the over-all MAXIMUM RESPONSE SENSITIVITY of a 150 - 300 Mc equipment being quite low, particularly in comparison with lower frequency Adcock equipments, 1,000 microvolts per meter for a 20 db S/N ratio being approximately the best that could be hoped for.
 - (g) That accordingly, the MAXIMUM RESPONSE SENSITIVITY of the equipment reported on herein is not considered excessively low with respect to the best that might be expected from an equipment of similar design.
 - (h) That the INSTRUMENTAL ERRORS of the antenna system over the entire frequency range are excessive, it being believed that if the resonant condition at 260 megacycles and

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the sense leakage above 260 megacycles were corrected or reduced the remaining error would still be larger than acceptable for Adcock-goniometer systems.

- (i) That the INSTRUMENTAL ERRORS of the indicator system were excessive and would not be corrected by calibration, being of a "wobble" or "flutter" type resulting from the misapplication of synchro motors for high speed, continuous rotation power service.
- (j) That the electrical characteristics of the receiver (after modification by NRL) were satisfactory considering the tuning range and band-width used.

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TABLE I

ANTENNA SYSTEM GAIN IN DECIBELS WITH RESPECT TO ISOTROPIC ANTENNA

Frequency in Megacycles	Gain in Decibels
150	-13.4
225	-20.7
300	-20.3

The collector system was terminated in 50 ohms.

TABLE II

ANTENNA SYSTEM "EFFECTIVENESS" IN METERS

Frequency in Megacycles	"Effectiveness" in Meters
150	0.0380
225	0.0118
300	0.0089

The antenna system "effectiveness" is defined such that the field intensity when multiplied by the "effectiveness" yields the voltage across the load impedance.

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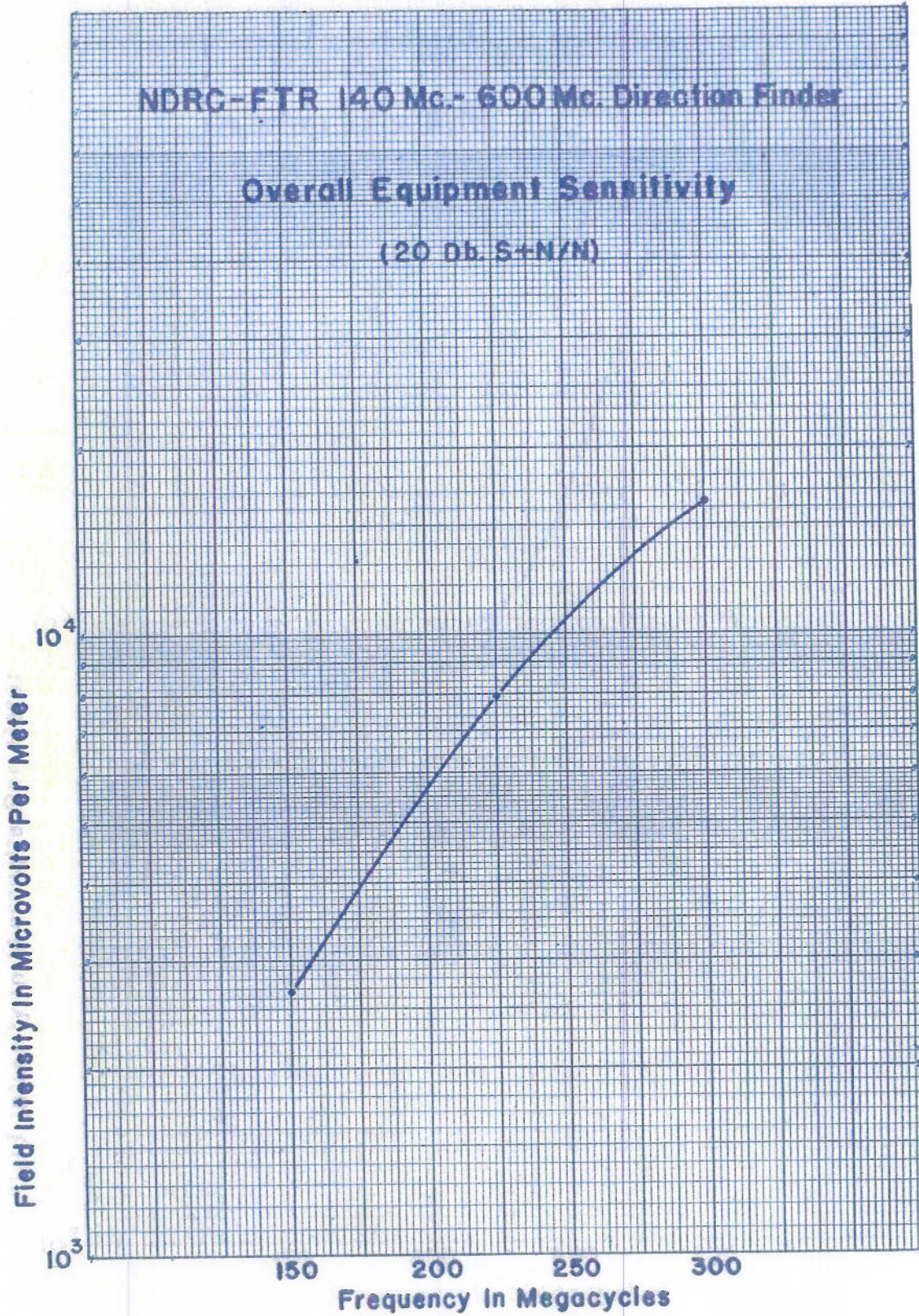
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REFERENCES

1. BuShips Confidential Letter Serial No. 1464 (925D) R & D 25D-130, dated 20 February, 1945 to NRL. Request for assignment of Problem S1051T-C.
2. Federal Telephone and Radio Corporation Pre-preliminary Instruction Book for 140 Mc to 600 Mc Direction Finder, Contract OEMsr-961..
3. NRL Confidential Report R-2742, "Test of RCA UHF Direction Finder Developed Under NDRC Contract OEMsr-1009!"
4. JEIA Report #6908. "The Principles Underlying The Design Of A Radiogoniometer Of The Compound Search Coil Type For Very High Frequencies" by B. G. Pressey, dated October 11, 1944.

Original data recorded in NRL log book 6120.

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NDRG-FTR 140 Mc.- 600 Mc. Direction Finder

Bearing Sensitivity
(5° Repeatability)

Field Intensity In Microvolts Per Meter

10^3

10^2

150

200

250

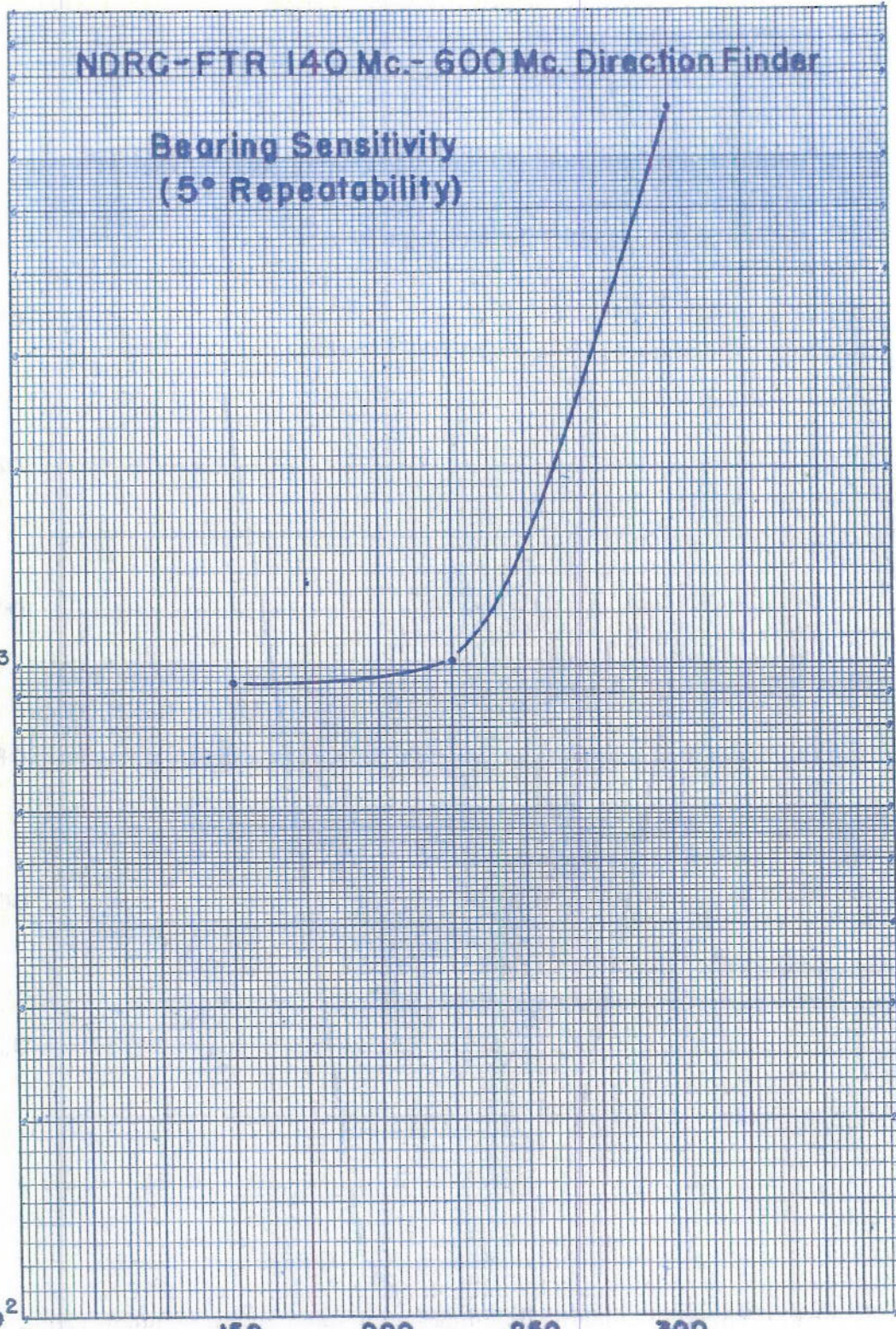
300

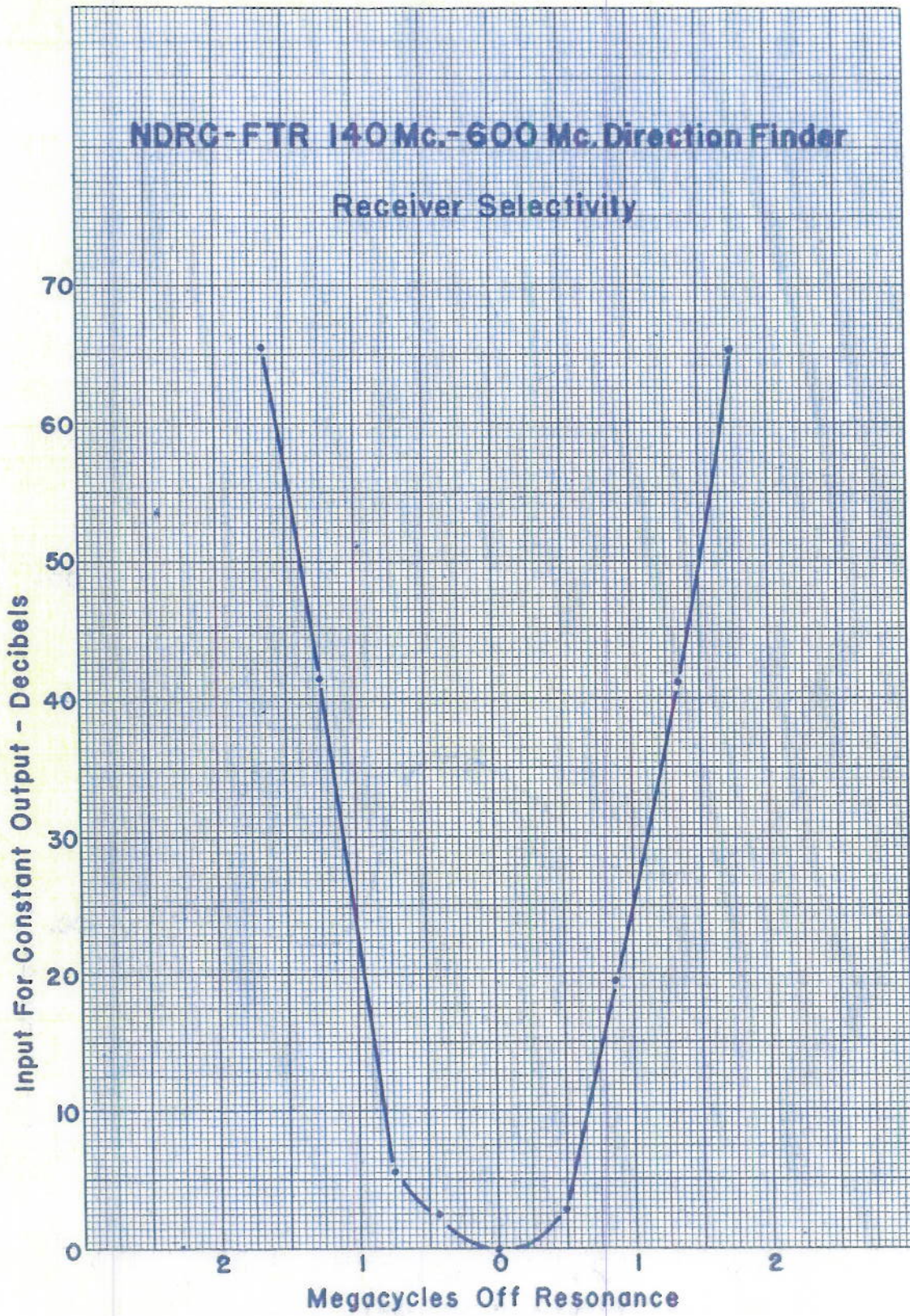
Frequency In Megacycles

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Plate 2





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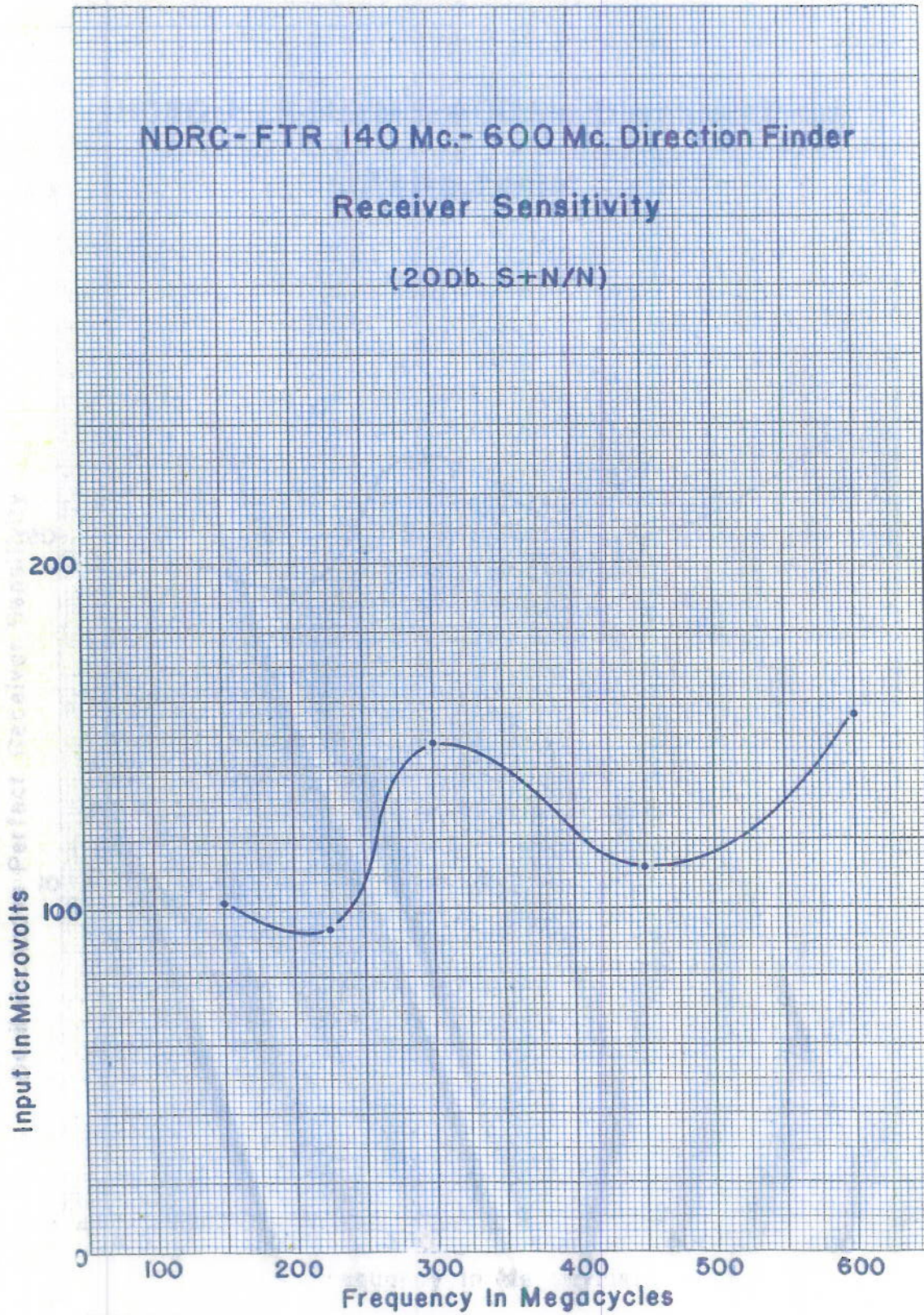
Plate 3

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NDRG-FTR 140 Mc.- 600 Mc. Direction Finder

Receiver Sensitivity

(20Db S+N/N)



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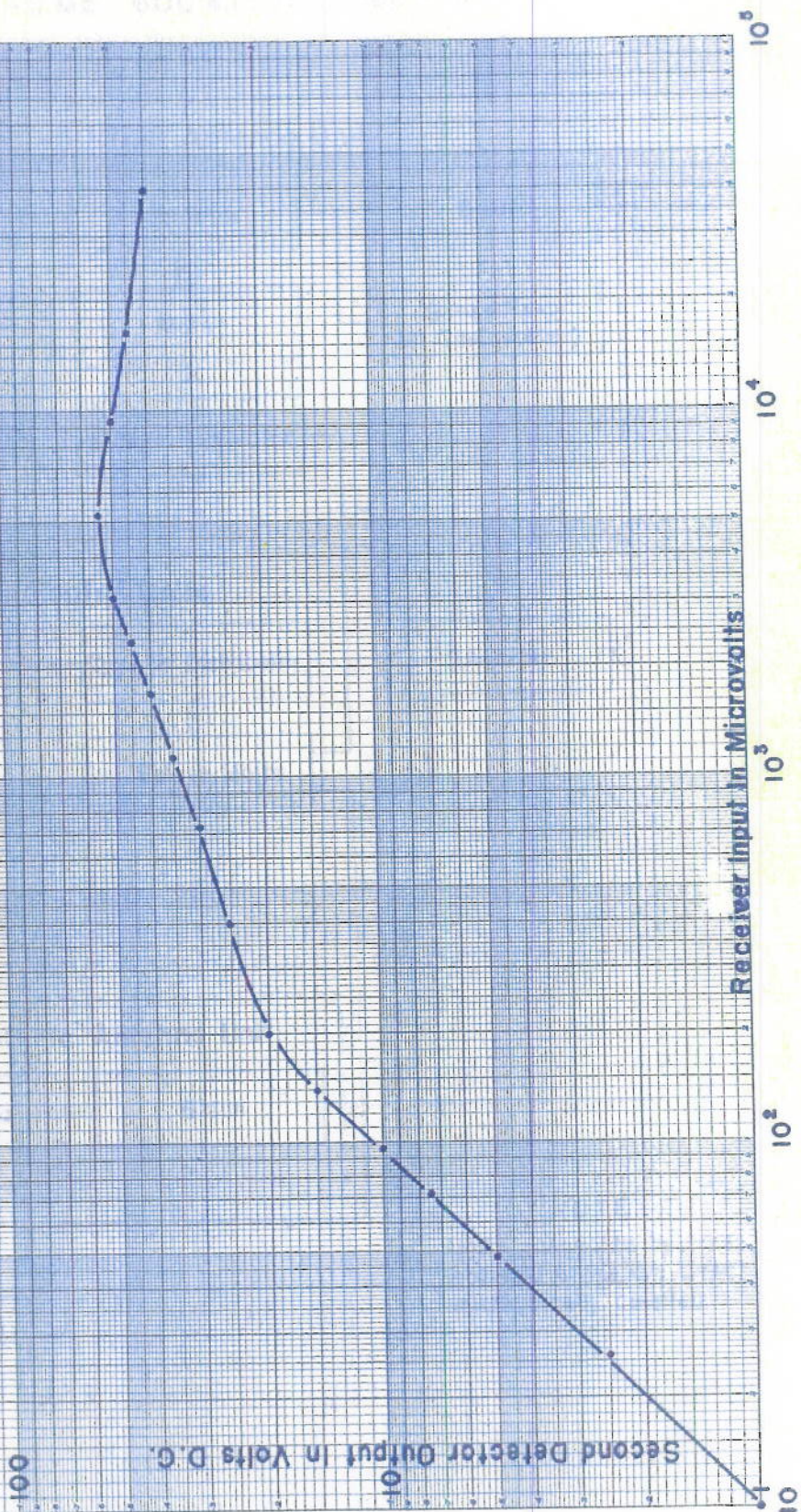
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Plate 4

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NDRG-FTR 140 Mc.-600 Mc. Direction Finder

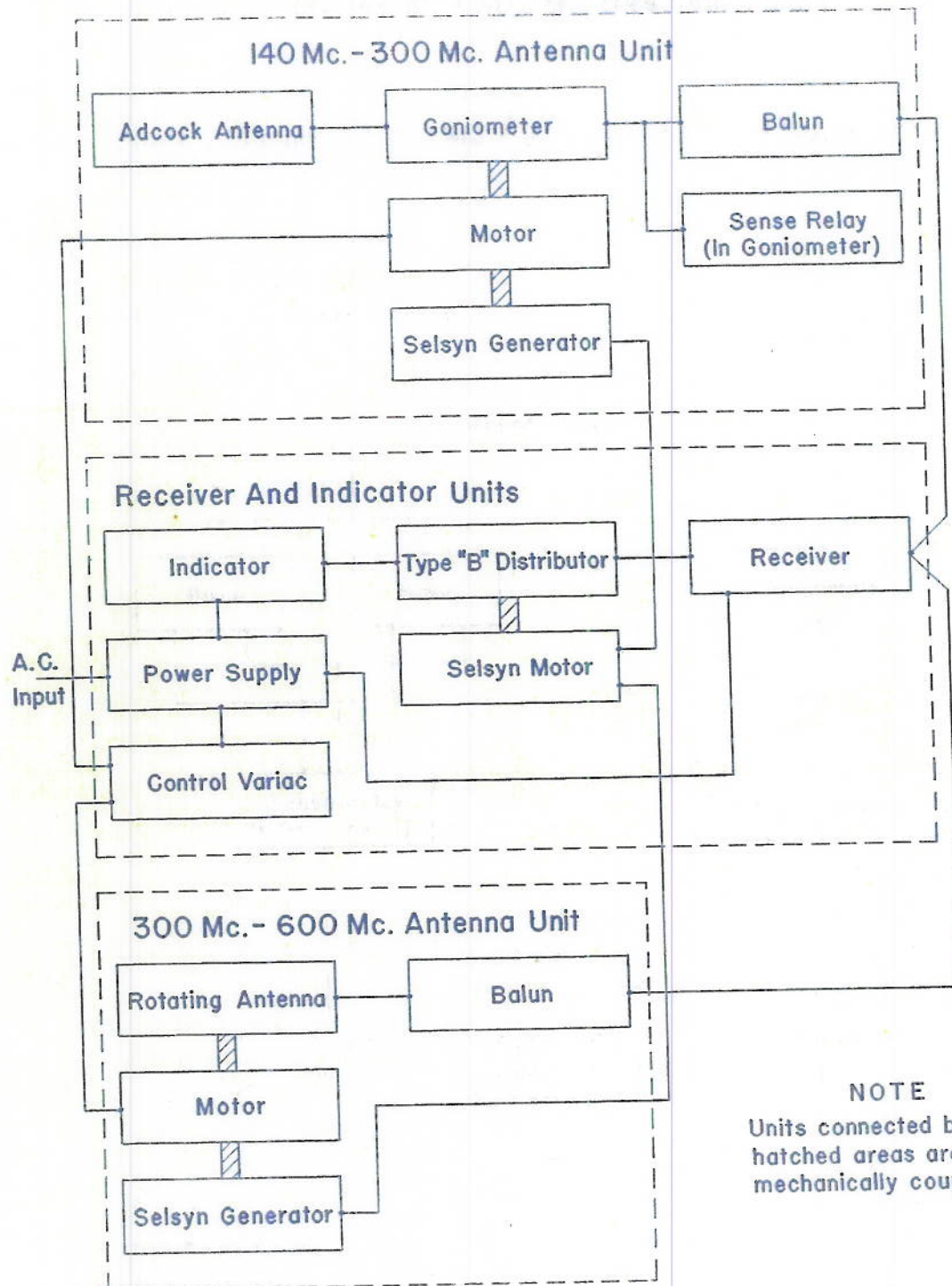
Receiver Overload



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NDRG-FTR 140 Mc. - 600 Mc. Direction Finder

Block Diagram Of Equipment



NOTE
Units connected by cross hatched areas are direct mechanically coupled.

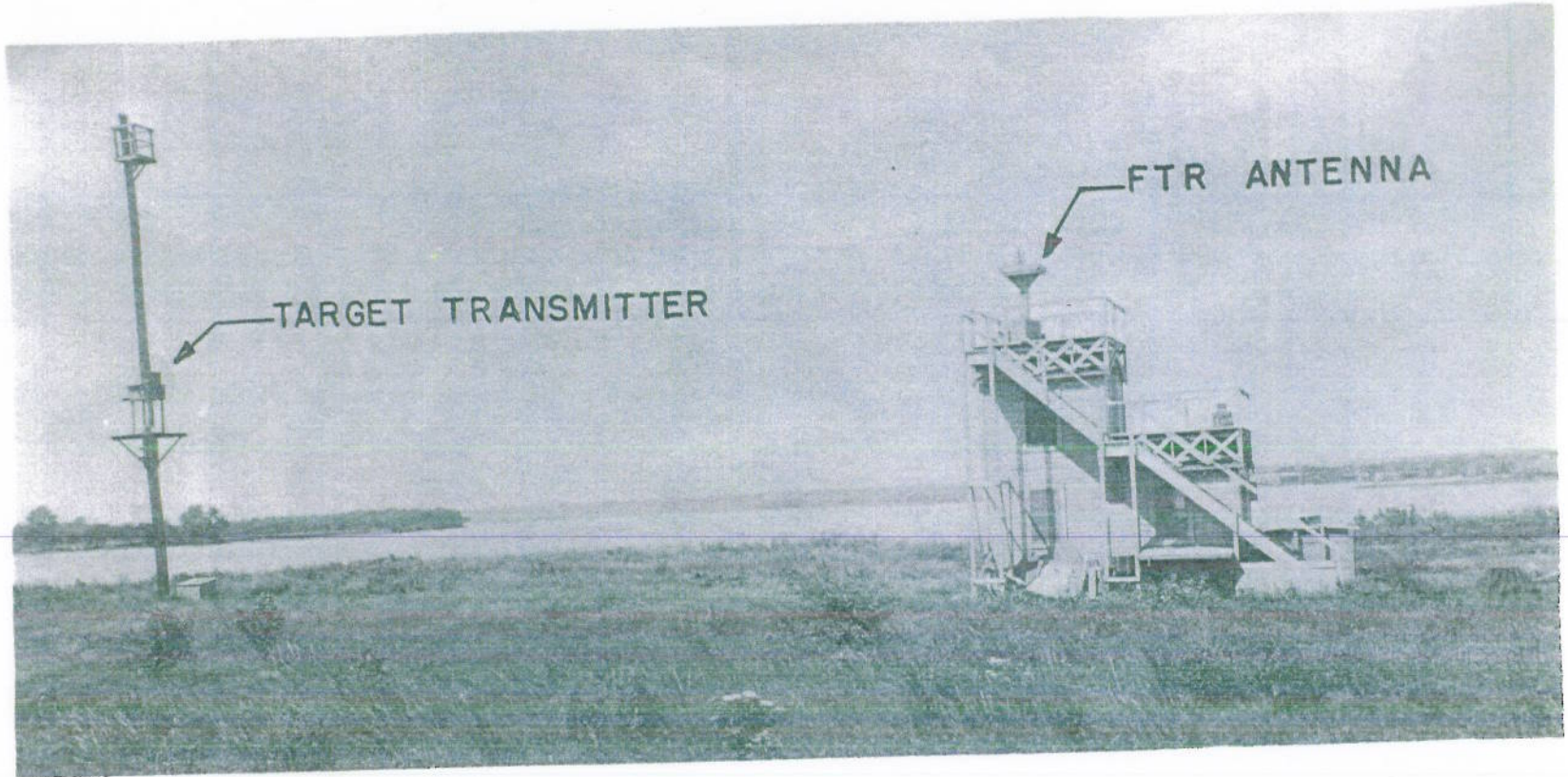
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Plate 7

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NDRC-FTR 140 MC. - 600 MC. DIRECTION FINDER



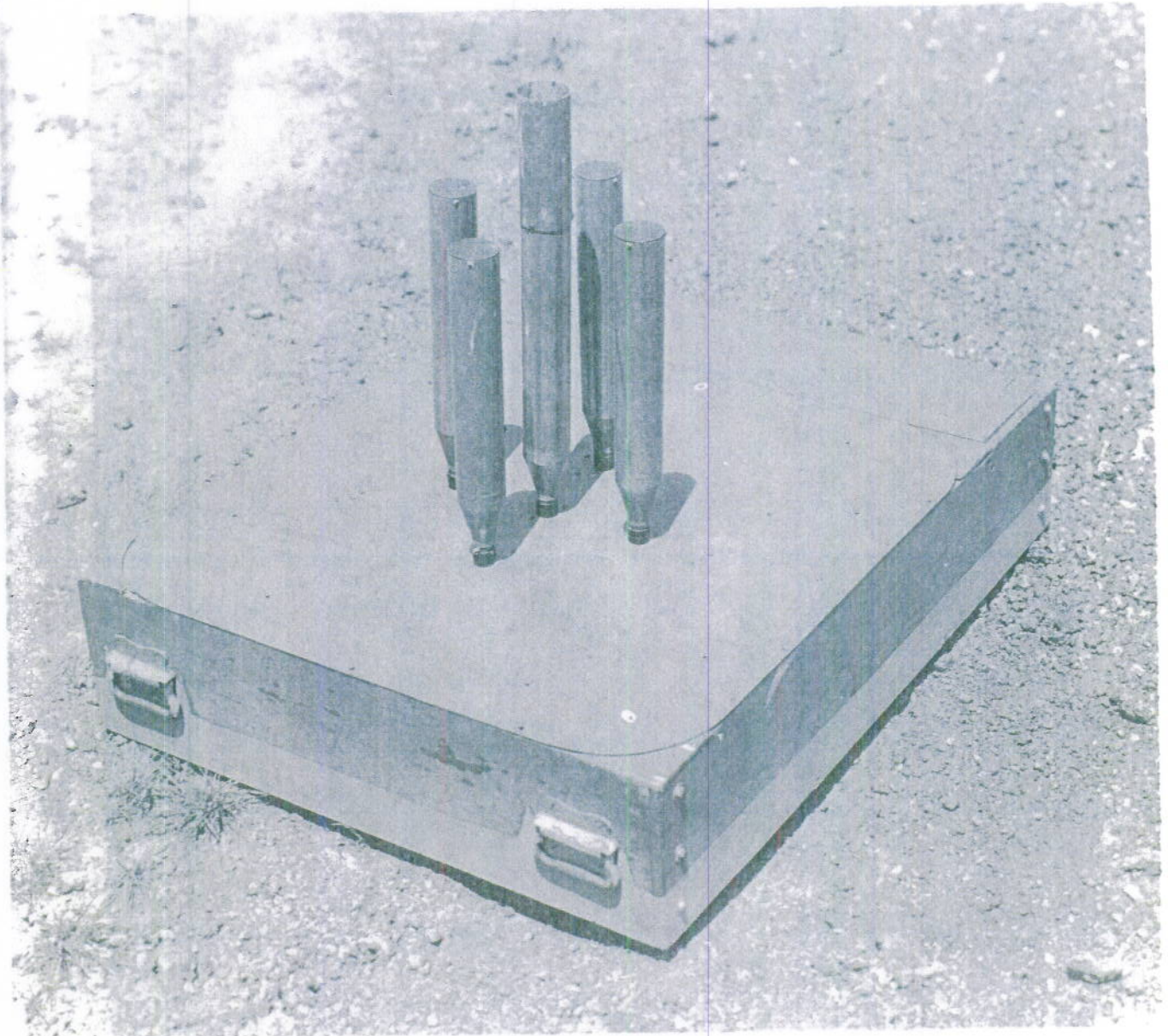
TEST SITE SHOWING LOW FREQUENCY BAND ANTENNA

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NDRC-FTR 140 MC. - 600 MC. DIRECTION FINDER



LOW FREQUENCY BAND ANTENNA

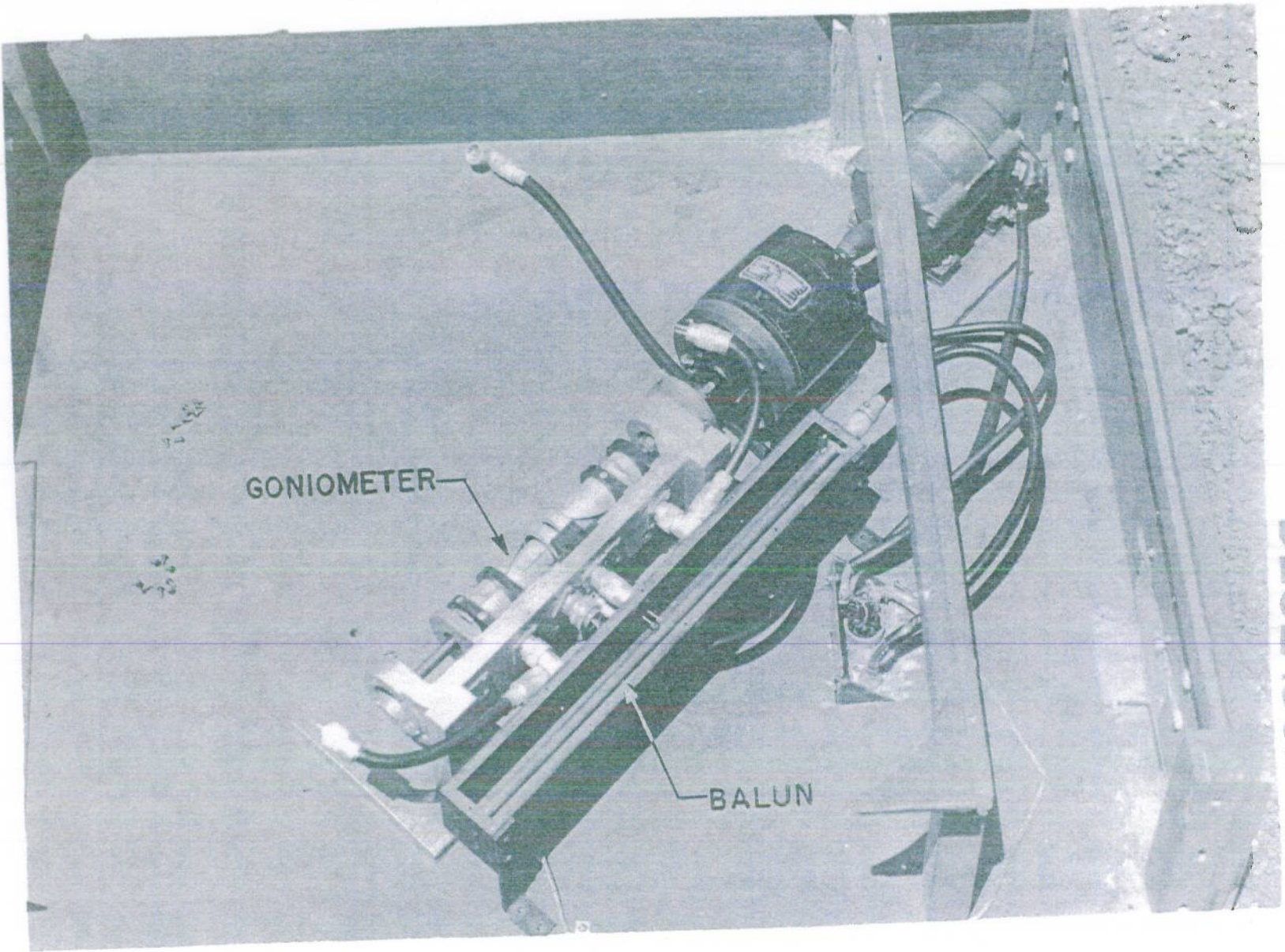
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PLATE 10

NDRC-FTR 140 MC. - 600 MC. DIRECTION FINDER

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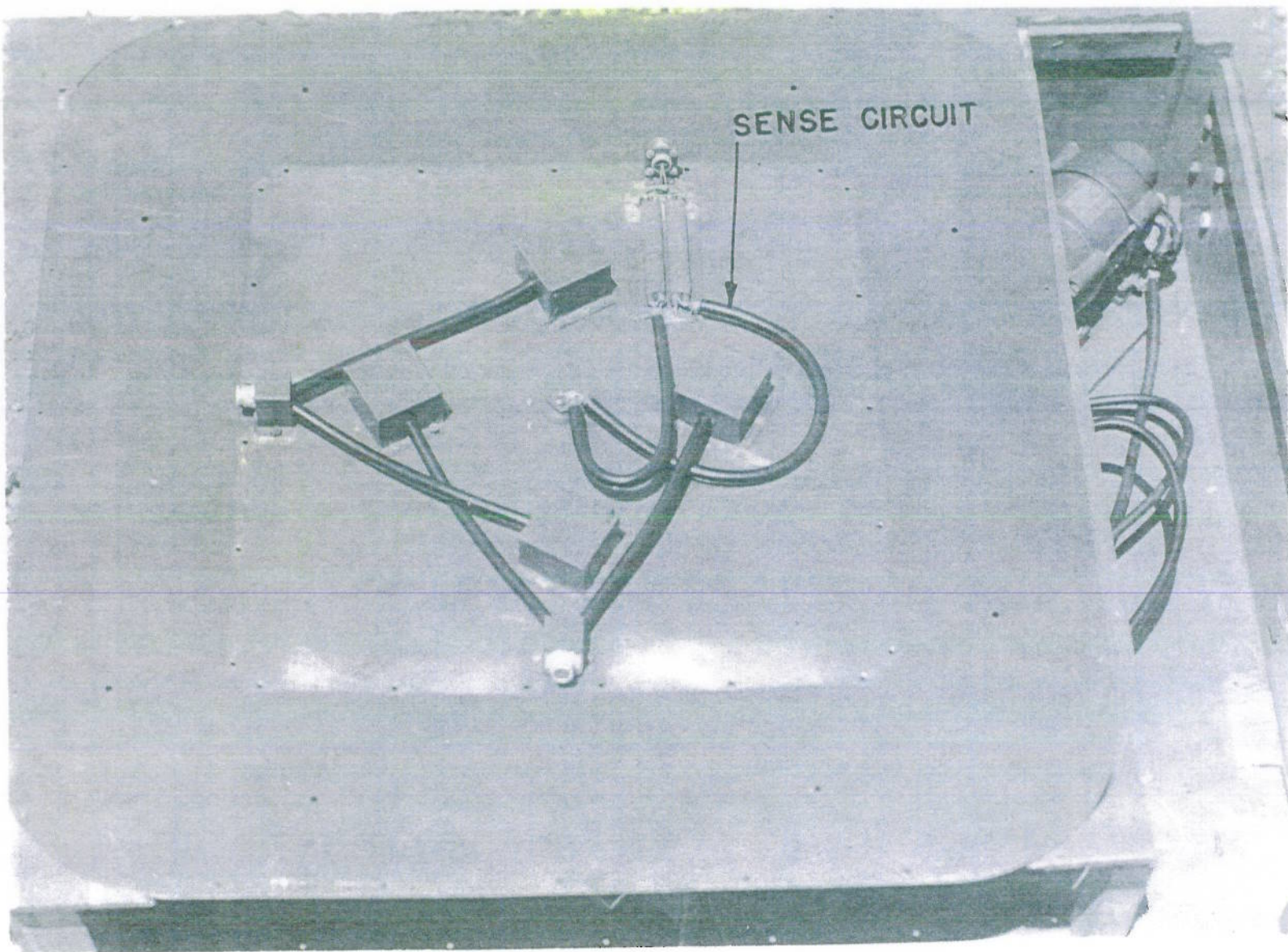
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INSIDE VIEW OF ANTENNA BOX SHOWING GONIOMETER AND BALUN

PLATE 11

NDRC-FTR 140 MC. - 600 MC. DIRECTION FINDER

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SENSE CIRCUIT

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BOTTOM VIEW OF GROUND PLANE SHOWING ANTENNA CONNECTIONS

NDRC-FTR 140 MC. - 600 MC. DIRECTION FINDER

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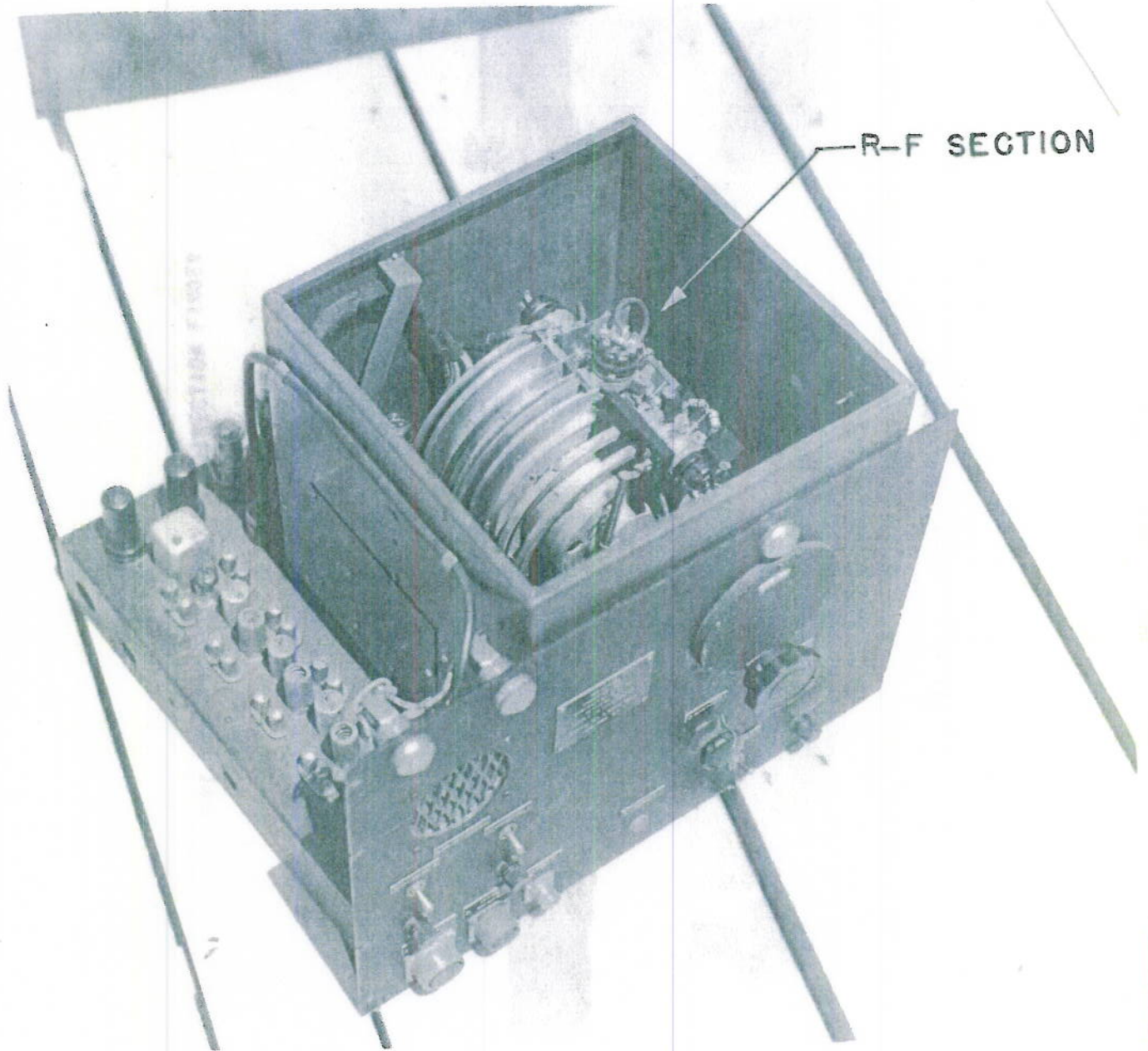
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RECEIVER AND INDICATOR UNITS

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NDRC-FTR 140 MC. - 600 MC. DIRECTION FINDER



VIEW SHOWING RECEIVER R-F SECTION

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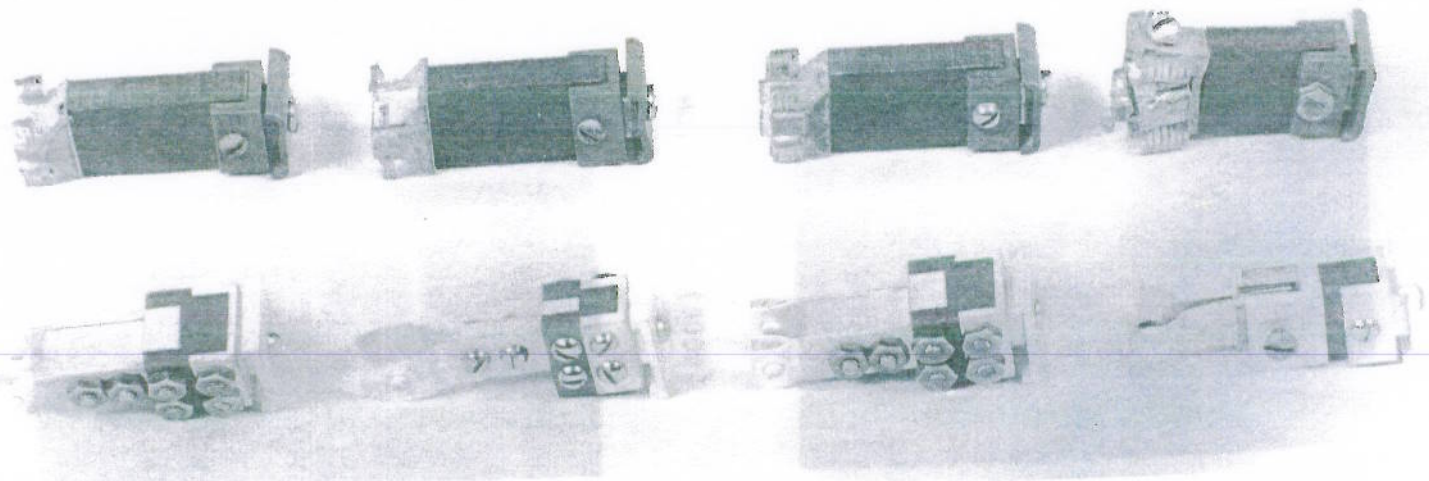
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PLATE 14

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NDRG-FTR 140 MC. - 600 MC. DIRECTION FINDER

ORIGINAL R-F SECTION BARS



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REDESIGNED R-F SECTION SHORTING BARS

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NRRC-FTR 140 MC. - 600 MC. DIRECTION FINDER

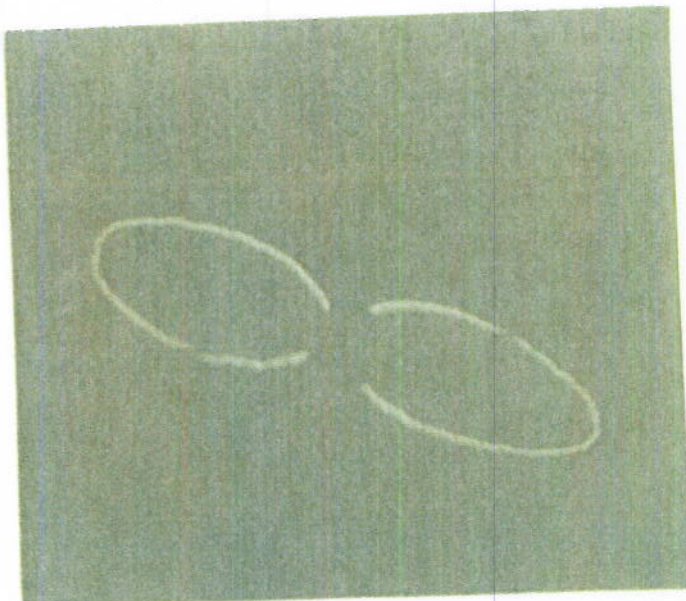


FIG. 1 225 MC. PATTERN (3000)

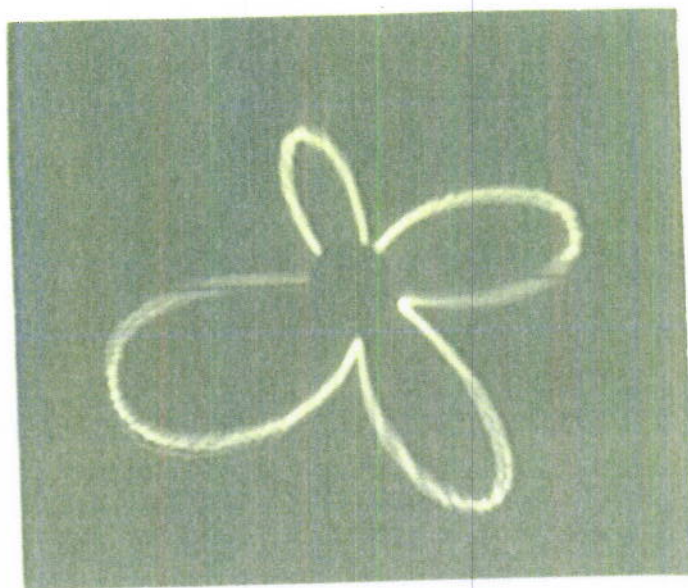


FIG. 2 260 MC. PATTERN (BAD DISTORTION)

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