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PERFORMANCE STUDY
OF
AN EXPERIMENTAL IRON CORE LOOP

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ABSTRACT

The anti-precipitation static iron-core loop (Experimental No. EX-20916-HU-Serial #3) and its associated adapter unit manufactured by Stewart Warner is designed for airborne radio direction-finding at low and medium frequencies (190 kc/s to 1500 kc/s) when used in conjunction with existing aircraft communication receivers. An investigation and analysis was made of the mechanical and electrical performance and constructional features. The over-all performance of the subject equipment is shown to be unsatisfactory in its present state of design. However, the type of iron core loop and loop housing employed in this equipment show promise and are deserving of further investigation. This suggests that a more thorough and complete study be conducted to ascertain the possible optimum designs of D/F loops for airborne applications including iron-core loops, low drag housings, and anti-precipitation static properties.

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INTRODUCTION

1. In compliance with the request of the Bureau of Aeronautics authorization letter (reference (i)) the performance of an anti-precipitation static iron core loop and its associated adapter was investigated for compliance with specifications given in references (a) and (d). This anti-precipitation static iron core loop and its associated adapter constitute a radio direction-finding equipment designed to operate into a plurality of aircraft communications receivers over a frequency range of 190 to 1500 kcs.

2. This loop includes a streamlined housing whose dimensions can be seen on Plate 17, which has a highly conducting surface to prevent the acquisition of localized charge and subsequent corona discharge, by which means it is intended to reduce radio interference caused by precipitation static. A 12" shaft, for turning the loop, is attached to the loop mounting by means of a coupling at the base of the housing, the other end of the shaft having an azimuthal scale and a knob for manually rotating the shaft. The loop is wound on a cylindrical form 3" in diameter and 3" in length and is surrounded by a Faraday shield to maintain capacity balance of the loop to ground (see Plate 2). The core of the cylindrical form on which the loop is wound is made of granulated iron. At the base of the loop housing is a Selectar cable fitting to provide a means for connecting the transmission line from the adapter unit.

3. The dimensions of the adapter unit are indicated on Plate 18. This adapter permits the loop to operate in conjunction with any one of several aircraft communications receivers and associated vertical antennas. A "sense" switch on the adapter provides the cardioid pattern necessary for resolving the 180 degree ambiguity of the loop's figure of eight pattern.

4. The specifications which the subject equipment is required to meet, are contained in reference (a) in original form, but were amended according to reference (d). The final amended contract specifications to be met by the equipment are shown listed as follows:

- (1) Shall have a range of 190 to 1500 KC.
- (2) Shall be capable of working with any of the following receivers: ARA, RA-10, RAX, RTA-1, AR-10A, and RU.
- (3) Sensitivity shall be in no case less than 100 μ v per meter on MOCW at 4-1 signal-to-noise ratio.
- (4) Directivity shall be secondary to sensitivity.

- (5) Shall use the new loop housing proposed by Stewart-Warner and illustrated by their drawing EX-20817-T (see plate 17). One housing to be externally shielded and one unshielded.
- (6) Shall be continuously rotatable and capable of being locked in any position.
- (7) Shall work into a PT-5 cable of any length up to 15 feet.
- (8) Different transformers for different receivers may be used if necessary and shall be supplied with the loop.
- (9) Adjustment for various receivers in the loop housing shall be permissible.
- (10) Shall be of iron core type, precipitation static shielded and shall weigh not more than 10 pounds, complete with housing and gears.

5. The request of the Bureau of Aeronautics authorization letter (reference (i)) was so worded as to require compliance of the equipment with the unamended specifications. It was deemed advisable, however, to investigate the performance of the equipment for compliance with the amended contract as cited above. The same Bureau of Aeronautics letter, requested that NRL compare performance of the iron core loop (and associated adapter) with the best available loop (and associated adapter) working into an AN/ARC-5 receiver; and that a type test of the anti-precipitation static iron core loop and its associated adapter be conducted in accordance with Standard Navy Type Test Specifications, reference (e).

6. The following procedures were adopted in regard to the prosecution of the assigned problem:

- (a) Only the more pertinent portions of the full standard type testing procedure were followed in order to expedite the investigation with the limited assistance available.
- (b) The anti-precipitation iron-core loop and associated adapter were not checked operationally as requested with the RA-10, RTA-1, and AR-10A communications receivers. These receivers are no longer in common use and were not available.
- (c) An ARA receiver was used instead of an AN/ARC-5 receiver; these receivers being essentially identical.
- (d) Available loops (and their associated adapters) were compared to the anti-precipitation loop (and its adapter) when working into an RU-19 receiver. This was done to reduce to a minimum the time required for making cable connections; the two available loops (and their adapters) being designed to operate in association with an RU type receiver.

- (e) No unshielded housing or facilities were available to determining the comparative effectiveness of the reduction of precipitation static by the shielded housing.

7. Some investigations were made in addition to those requested by BuAer; these investigation being for the purpose of determining more completely the merit of the experimental iron core loop and its adapter. One of these investigations concerned the experimental determination of the effective height of the anti-precipitation loop and two other commonly used loops (RDF-1 and DU-1 types). Also a comparison of the effective height of the anti-precipitation loop was made with an air-core loop of the same dimensions as the iron-core loop, and with an air-core loop approximately 8 inches in diameter; both of the aircore loops having the same inductance as the iron-core loop.. A more fundamental investigation was undertaken for the purpose of comparing the iron-core loop with the optimum air-core loop; the optimum air core loop being defined as that which yields the best signal-to-noise ratio. Other investigations were concerned with the sense circuits and with the response pattern of the iron-core loop.

DISCUSSION OF RESULTS

8. The basic theoretical considerations underlying the use and advantage of iron-core loops are analyzed briefly in Appendix I. A detailed outline of the tests and investigations conducted on the experimental iron-core loop and its adapter is included in Appendix II. The following points of discussion are based on the data taken during these tests and investigations.

Sensitivity

9. As a guide for determining the validity of the experimental techniques used in measuring the sensitivity, a detailed analysis of thermal and shot noise was made on the basis of measured parameters of the loop and antenna coupling networks from which theoretical sensitivities were computed. The results are shown on Table I. In these computations, it was assumed that the bandwidth of the adapter was 3 kc. Also, the cable used in the computations was RG-11/U, which cable has a capacity of only 20 uuf/foot as compared to about 30 uuf/foot which was used in experimental tests for PT-5. The lower capacity cable was chosen because it increased efficiency of the collector system as indicated by the analysis.

10. The first series of sensitivity measurements made a comparison between the performance of the iron-core loop (and associated adapter) and the performances of the RDF-1 and DU-1 loops (and their associated adapter units); an RU-19 receiver being used in all tests. The sensitivities were determined by means of Methode I (see Appendix II) in a shielded room of rather small dimensions (approximately 10 ft. by 10 ft.). Because of the proximity of the equipment to the transmission line, good accuracies were not expected by this method. The results show on Plate 11 that the required field strengths are much higher than the theoretical values of Table I. However, while the absolute values

of field strength are not very accurate, the results do yield information on the comparative sensitivities of the three loops and their associated adapter units.

11. In the second series of sensitivity tests, Method II (see Appendix II) was used in an attempt to obtain increased accuracy. The purpose of the tests was to compare the sensitivities of the loop channel and communication channel of anti-precipitation static loop equipment. The results are shown on Plate 12 for the case of the loop and adapter being operated in association with an ARA receiver. A marked decrease in sensitivity is noted when the loop channel is used in place of the communication channel. Although this loss in sensitivity is very serious, it is partially compensated for by the anti-precipitation static and wind-drag properties of the loop. These results are in good agreement with the theoretical results of Table I. Required values of field strength higher than the theoretical values may be attributed to the R-F noise generated by the receiver dynamotors. Required values of field strength lower than the theoretical may be due to the PT-5 (30 uuf per foot) cable used in the experiments, an incorrectly assumed value for the bandwidth, and possibly the need for further refinement of the experimental technique. However, because of the good agreement between theory and experiment and for reasons of expediency no efforts were made to uncover the cause or causes of the discrepancies.

12. The third series of sensitivity tests compared the performance of the subject iron-core loop and associated adapter on the basis of the types of receivers used. The sensitivities were determined by Method II, and the results for four different receivers (RU, ARA, ARB, and RAX) are shown on Plate 13. The best sensitivities were obtained when the iron-core loop and adapter were operating into an RAX receiver. Since, as theory shows, the sensitivities should be independent of the type of receiver used, the results really constitute a measure of the comparative "quietness" of the four types of receivers. Maximum sensitivity was in all cases in excess of the 100 uv/m limit specified by reference (d). The adapter unit, when operated in close proximity with the RU-19 receiver, gives rise to spurious audio oscillations in the receiver. The effect was eliminated by increasing the spacing between the adapter and RU-19 receiver.

Selectivity

13. The results of the selectivity tests are shown on Plates 14 (a) and (b). As a means of comparison, an air-core loop of the same inductance as the iron-core loop was used with the adapter in the determination of selectivity. This air-core loop consisted of 7 turns of wire on a coil form 8 inches in diameter. The results using the air-core loop are also shown, on Plates 14(a) and (b). The results with the iron-core loop and the air-core loop are almost identical, which indicates that the selectivity is dependent mainly on the circuits of the adapter unit. The Q on the low frequency band shows a lower value than desirable.

"Figure of 8" Radios

14. Table II shows the maximum to minimum ratios in decibels of the "figure of 8" pattern of the loop taken under the two different test conditions. In part A of Table II, are shown the ratios taken on radio range of the ARA receivers. Some AVC action took place for the orientation of maximum signal and the signal-to-noise ratio for the orientation of minimum signal was as low as 1.5 to 1.0 in some cases. However, the ratios obtained are considered satisfactory. Part B of Table II shows the ratios obtained under the calibrated transmission line and were not subject to the limitations inherent in the first method. The values obtained indicate a performance superior to that which could be realized in operation since the field under the transmission line is an idealized field.

"Sense" Circuit

15. The sense circuits of the adapter, when operated with 15 feet of PT-5 cable from the antenna to the adapter and a 5 foot vertical antenna, were found to be entirely inadequate. The cause of this condition was found to be the large capacity loading of the antenna by the cable capacity and the circuit capacity in the adapter unit. Proposed modifications of the sense circuits are shown on Plate 7. In the design, 15 feet of cable of 20 uuf/ft was assumed, the "avy specification number of this cable is RG-11/U. For other cable lengths and other cable capacities, it is necessary to use different circuit parameters. However, reductions in cable capacity or length can easily be compensated by the addition of shunt condensers between the input leads of the resistors and ground.

Loop Effective Height

16. Effective height determinations were made at several points in each band according to the method described in Appendix II. The results are shown on Plate 9. In a like manner, the effective heights of an RDF-1 loop and a DU-1 loop were determined; the results being shown likewise on Plate 9. Both of these loops are 10" in diameter. The deviations of the experimental curves from straight lines are due to the anti-resonant effect of the distributed capacities in the loop windings. The tangent lines to the experimental curves are designated as "true" effective heights, since the data would lie on these straight lines if the anti-resonant effects were not present. To obtain an indication of the experimental accuracy, the effective height of the DU-1 loop was computed from its diameter and number of turns. This calculated value was found to be 10% above the experimentally determined value of effective height; this accuracy was considered satisfactory for the present investigation. The results, as plotted on Plate 9, show the effective height of the iron-core loop to be about 1/2 the effective height of the DU-1 loop and about 1/5 the effective height of the RDF-1 loop.

17. Having compared the effective height of the iron-core loop with the effective heights of two types of existing aircraft loops, it was deemed advisable to make a more fundamental comparison. Assuming a coil form the same size and shape as that of the iron-core loop, an analytical determination was made of the required number of turns of #10 B & S wire to yield an inductance the same as that of the iron-core loop (18.24 μ H). The effective height of this loop was computed for several frequencies and the results plotted on Plate 10a. The effective height of the iron-core loop is also plotted on Plate 10a, and, by comparison, it is seen that the effective height of the iron-core loop is about $5/3$ that of an air-core loop of the same size, shape and inductance. It is recognized that the advantage in effective height of the iron-core loop would be decreased if heavier gauze wire were used on the air-core loop, however #10 B & S wire is the largest convenient size which could be used in practice.

18. Since the loops used with the SCR-269F and SCR-269G equipments are 8" in diameter, it was considered sufficiently important to compare the effective height of the iron-core loop with an 8" air-core loop having an inductance equal to that of the iron-core loop. On Plate 10b is shown the computed effective height of an 8.3" air-core loop of the same inductance as that of the iron-core loop. It was necessary to use 8.3" instead of 8" in order to obtain an integral number of turns. The effective height of the iron-core loop, likewise plotted on Plate 10b for comparison, is shown to be $2/3$ that of the air-core loop.

Comparison of Iron-Core Loop with Optimum Air-Core Loop

19. The preceding paragraph compares the effective height of the anti-precipitation static loop with an air-core loop of the same size and shape, the inductance of the loops being equal. It is recognized that although this constitutes an informative comparison, a more fundamental indication of the merit of the iron-core loop could be determined as follows: For an air-core loop of the same size and shape as that of the iron-core loop, design a loop which yields the optimum signal-to-noise ratio at the grid of the tube in the adapter unit. This signal-to-noise ratio would then be compared with that obtained by the iron-core loop.

20. The signal-to-noise ratio equations utilized under "Sensitivity Test" were examined to determine the effect on the performance of loop effective height and of loop Q. The analysis revealed that the Q of the loop played a secondary role chiefly because of the loose coupling of the coils in the R-F transformers of the adapter unit. On the basis of present design of the R-F circuits, it can be stated that the optimum air-core loop is that loop which yields the maximum effective height; the inductance, size and shape of the air-core loop being assumed the same as that of the anti-precipitation static loop. Time did not permit a careful re-examination of the design of the loop input circuits, but it is evident that such an investigation would be worthwhile.

Temperature and Humidity

21. The results of the temperature and humidity tests are shown on Plates 15 and 16 respectively. The reading obtained indicated that the receiver gain remained unchanged during the temperature test. Variations in output were therefore due only to the effect of the temperature on the iron-core loop and associated adapter unit. The 70% loss in sensitivity on the high frequency band at 50°C is unsatisfactory and may be caused by improper treatment of the R-F coils in the adapter unit. The 20% loss in sensitivity in the low frequency band is also considered objectionable. The 20% loss of sensitivity in both frequency bands during the humidity runs, constitutes an inferior characteristic.

Vibration and Shock

22. The results of the vibration and vibration tests are shown on Table III. No changes in receiver outputs and no "birdies" were noted throughout the range of vibration test, even when mechanical resonance occurred. The shock test procedure was essentially the same as the vibration test. The accelerations used and the results are shown on Table III. The accelerations given are peak accelerations and are not of more than 10 milliseconds duration. This does not simulate aircraft conditions in which the equipment is subjected to accelerations up to 10g for a few seconds. However, the equipment used was the only shock testing apparatus available.

Mechanical Deficiencies

23. In addition to the various electrical and mechanical characteristics of the subject equipment studied and discussed in the preceding paragraphs, the following list of mechanical deficiencies are noted from a careful examination of the equipment.

- a. The adapter unit is not suitably shock-mounted. In fact, it is not shock-mounted at all.
- b. The rotatable mounting and shaft for turning the loop coil is mechanically weak.
- c. No means is provided for remote operation of the sense circuit.
- d. The sense switch should be more sturdily constructed.
- e. The azimuthal scale mechanism should be redesigned to make it more sturdy and rigid.
- f. The power and switch plugs should be of different design from each other in order to avoid possible confusion between them.

- g. The threads on the present coil forms for mounting the tuning slugs become sufficiently worn to allow the slug to fall out.
- h. The band switch relay mechanism should be re-designed to prevent chattering.

SUMMARY OF RESULTS

24. The foregoing discussion of results revealed some detailed points of interest concerning the loop and its adapter which may be summarized in the following list.

Electrical

- 25.
 - a. The sensitivity of the loop and adapter do not meet the specification of 100 microvolts but vary as shown in Plate 11.
 - b. The selectivity of the adapter unit is satisfactory.
 - c. The maximum to minimum ratios of the "figure of 8" pattern of the iron-core loop are considered satisfactory.
 - d. The communication channel of the adapter (with a 5' antenna) is considered satisfactory.
 - e. The use of the loop channel in place of the communication channel introduces a minimum loss of 22 db and a maximum loss of 29 db. This loss must be compensated for by the anti-precipitation static and low wind drag properties of the loop to warrant its adoption.
 - f. The effective height of the iron-core loop is
 - (1) one half ($1/2$) that of the DU-1 loop and about one-fifth ($1/5$) that of the RFD-1 loop.
 - (2) 1.7 times that of an air-core loop of the same size, shape and inductance.
 - (3) Two-thirds ($2/3$) that of an air-core loop approximately 8" in diameter and having the same inductance as the iron-core loop.
 - g. The sense circuits of the loop adapter are unsatisfactory.
 - h. No adjustments of the loop or adapter are necessary when using the equipment with different receivers.
 - i. The presence of the shielded housing does not affect the sensitivity of the loop.

- j. On the basis of an analysis of the factors affecting the signal-to-noise ration, the "Q" of the loop is of secondary importance for reasonable values of Q (Q greater than 20) and that the signal-to-noise ratio varies linearly with the loop effective height.

Mechanical

26. a. The loop is of the iron-core type, precipitation static shielded and weights 7.5 lbs. complete with housing and gears. The combined weight of the loop, adaptor unit, remote band switch, power cables and RF cables is 15 pounds.
- b. The tuning condensers of the adapter may simultaneously be coupled mechanically to the tuning control of two ARA receivers. The "tracking" between the adapter and the ARA receiver tuning control is excellent.
- c. The 2 pound wind drag of the iron-core loop housing compared to the 10 pound wind drag of an SCR-269 G loophousing (present standard "avy loop) at 250 MPH permits the acceptance of some compromise in the sensitivity of the iron-core loop.
- d. The equipment has various mechanical deficiencies which are listed in paragraph 23.

CONCLUSIONS

27. From the tests and investigation conducted on the subject iron-core loops and its associated adapter and reported herein, it is concluded:

- (a) That the overall performance of the subject loop and adapter does not meet either the amended specifications cited in paragraph 4, or the original specifications of reference (a) and are therefore not suitable for Naval aircraft use.
- (b) That the mechanical and electrical characteristics of the iron-core loop and housing offer distinct possibilities for a low-drag, high sensitivity loop.

RECOMMENDATIONS

28. It is recommended:

- (a) That the subject iron-core loop and adapter not be accepted for use on Naval aircraft.
- (b) That further investigations of the use of iron-core loops be carried out, based on the data and results obtained herein.
- (c) That a study be made to determine the relative discrimination of the conducting coating of the loop housing against precipitation static. This detailed study might be conducted along the lines suggested in the preliminary investigation of precipitation static reported in reference (j).

REFERENCES

- a. Stewart-Warner Corporation contract NOa(s)-382.
- b. Confidential letter from W. J. Polydoroff to Bureau of Aeronautics, dated 14 June 1943.
- c. BuAer conf. letter F42-1/64 (Aer E-3168-RVH) to Stewart-Warner Corporation, dated 26 June 1943.
- d. BuAer conf. letter (Aer-PR-251-BJO) to Stewart-Warner Corporation, dated 14 July 1943.
- e. "Type Testing Procedure and Specifications for Airborne Radar and Radio Equipment" A Edition - 30 August 1943, RE-13A-825A.
- f. Confidential letter from W. J. Polydoroff to Bureau of Aeronautics, dated 2 September 1943.
- g. Confidential letter from F. E. Johnston, chief engineer of Stewart-Warner Corporation, to Bureau of Aeronautics, dated 11 November 1943.
- h. Engineer's Data (No. 26719) obtained by R. Bryan, Stewart-Warner Corporation, dated 29 November 1943.
- i. BuAer conf. letter F42-1/66 (Aer-E-3114-DJV) to NRL, dated 11 December 1943 (Problem request).
- j. ARD letter report File No. F42-1/69(312:AB) Ser. No. 310-189/45(emh).

APPENDIX I

Theoretical Consideration of Iron-Core Loops

1. It is of essential interest to consider here some of the factors influencing the effective height of an air-core loop which may be computed from the relation:

$$h_e = \frac{2 \pi N A}{\lambda} \approx KN \quad (1)$$

where h_e is the effective height, N is the number of turns, A is the area, and λ is the wave-length of the received signal. If an iron-core is now placed inside the winding, the new effective height h_e' becomes:

$$h_e' = \frac{2 \pi N A}{\lambda} \cdot \mu_e = KN \mu_e \quad (2)$$

where μ_e is the effective permeability of the loop coil. In other words the field inside the coil is intensified μ_e times thereby increasing the loop effective height proportionately.

2. However due to the presence of the iron core the inductance L of the air-core loop has now been increased to L' . Since it is desirable that the inductance remain unchanged in order to maintain the same tuned circuits the turns of the loop must now be reduced to a new value N' in order that the inductance L be restored. It can easily be shown that:

$$N' = \frac{N}{\sqrt{\mu_e}} \quad (3)$$

And, replacing N by its new value N' in (2), the effective height becomes:

$$h_e'' = KN \sqrt{\mu_e}$$

$$h_e''/h_e = \sqrt{\mu_e}$$

3. This formula is approximate since it does not take into account the effect of reduction of inductance with the greater spacing of turns associated with a decrease of the number of turns for a coil of given length. However, it is the usual practice to make the coil as short as possible in order to reduce weight and reduce the wind-drag.

4. When the number of turns are reduced from N to N' there is, in consequence, an increase in the Q of the loop neglecting losses in the core. If the loop is directly tuned, this increase in Q value results in improved performance. However, in equipments utilizing loop coupling networks, the increased loop Q is often obscured by the Q values of the coils of the transformers, etc.

APPENDIX II

Test Conditions

1. The tests and investigations conducted on the subject loop and adapter and discussed in the body of the report are outlined in detail below.

Sensitivity

2. Method I

- a. The loop and associated equipment was placed under a calibrated transmission line; the transmission line being in a shielded room of normal temperature and humidity. The loop was oriented with respect to the line to the position of maximum signal. A 400 cycle 30% modulated signal was used.
- b. With the standard signal generator (feeding the calibrated transmission line) operating at Modulation Off, the receiver gain control was set to give a 12.5 mW audio noise output. Whenever this noise output was not available, the maximum noise output was used. The standard signal generator was then operated at Modulation On and, by successive adjustments of the output of the standard signal generator and the gain control on the receiver, a 4 to 1 signal-plus-noise to noise ratio ($(S + N)/N$) was obtained and the output of the standard signal generator recorded. From the calibration data of the line, the microvolt per-meter field strength was determined at the center of the loop; this field strength being the measure of the loop sensitivity.

3. Method II

- (a) The loop of the equipment under test was connected in series with a 1 ohm resistor. This was accomplished, in the case of the iron-core loop, by connecting the resistor between the outside of the Selector fitting (at the base of the housing) and the shielding braid of the PT-5 cable. The equipment under test was placed in a shielded room, the temperature and humidity conditions being normal.
- (b) A standard signal generator was connected across the 1 ohm resistor. A 400 cycle 30% modulated signal was used.
- (c) With the standard signal generator operating at Modulation Off, the receiver gain control was set to give a 12.5 mW audio noise output. Whenever this noise output was not available, the maximum noise output was used. The standard signal generator was then operated at Modulation On and,

by successive adjustments of the output of the standard signal generator and the gain control of the receiver, a 4 to 1 signal-plus-noise to noise ratio ($(S+N)/N$) was obtained and the output of the standard signal generator recorded. From a knowledge of the internal impedance of the standard signal generator and the effective height of the loop, the equivalent microvolt-per-meter field strength was determined.

4. When the iron-core loop and associated adapter were operating into the ARA receivers, the adapter and receivers were tuned to approximately the center of each band; the frequencies used being 300 Kc and 1000 Kc. The adapter and receivers were tuned independently and then a flexible tuning shaft was connected between the adapter and receivers. When receivers other than the ARA were used in association with the adapter, this mechanical linkage was not possible and manual tuning of both receiver and adapter unit was necessary at each frequency at which sensitivities were taken.

Selectivity.

- (a) The iron-core loop was placed under a calibrated transmission line; the transmission line being in a shielded room of normal temperature and humidity. The loop was oriented with respect to the line to the position of maximum signal. The loop was connected to the adapter by means of 15 feet of PT-5 cable. The adapter was in turn connected to the input of an ARA receiver.
- (b) An RF signal with 400 cycle 30% modulation was fed into the transmission line. The adapter and receiver were independently turned to the desired frequency (300 K.C. for the low band and 1000 KC for the high band). The adapter was then separately detuned from the signal and the signal strength increased to maintain constant receiver output.
- (c) Measurements were taken of the increase in signal strength at various "off-resonance" frequencies of the adapter unit over the signal strength at the resonant frequency.
- (d) The amount of the change in frequency by which the adapter had been detuned was obtained by altering the frequency of the signal generator to a point of maximum receiver output and noting the change in frequency of the signal generator.

"Figure of 8" Ratios

6. The ratio of the maximum to minimum response of the "figure of 8" pattern of the loop were determined by two different methods.

Method I

- a. The iron-core loop and adapter were operated in association with ARA receiving equipment. The tests were performed in open country, free of metal obstructions.
- b. Local broadcast stations and radio range stations served as signal sources. The control box was switched to CW reception and the receiver was detuned until the beat note giving maximum audio power was reached. This served as the tuning criterion on range and broadcast stations since MCW reception yielded unstable power output meter readings.
- c. Ratios of receiver output in volts corresponding to orientation of loop for maximum and minimum outputs were noted. The receiver gain was adjusted to give a 350 MW signal plus-noise audio power output for the loop oriented for maximum signal pick-up. This audio power level was chosen since above 400 MW the AVC action of the ARA receiver becomes fully active.

Method II

- a. The iron-core loop was placed under a calibrated transmission line into which a 400 cps - 30% modulated signal was fed.
- b. The ratios of standard signal generator voltage were noted which gave equal power outputs with the loop oriented to positions of maximum and minimum signal pick-up. During the test, it was ascertained that the receiver output noise level remained unchanged.

Loop Effective Height

7. In order to determine the effective height of the iron-core loop and various other standard and experimental loops, the following procedures were used. The test set-up is shown in Plate 8.

- a. The tests were conducted in a shielded room with the iron-core loop connected in series with a 1 ohm resistor and then through 10 feet of PT-5 cable to an SX-28 Hallicrafter receiver. A power meter was connected to the audio output of the receiver. A 400 cycle 30% modulated signal was employed. The temperature and humidity conditions of the room were normal.
- b. The loop under test or test loop was placed at a fixed distance, coaxial and coplanar, with an air-core injection loop. The field strength at the test loop was related to the output of the standard signal generator by the following method: The test loop was replaced by an air-core loop of calculated effective height and

connected in series with a 1 ohm resistor. The reading of the power output meter was noted for a given output voltage of the standard signal generator with the generator connected directly across the terminals of the injection loop. The signal generator was then connected across the 1 ohm resistor in series with the air core loop and the output of the standard signal generator varied until the previous reading of the power output meter was obtained. From this generator reading in conjunction with the effective height of the air core loop, the field strength could be computed.

c. In order to determine the effective height of the iron-core loop a voltage was induced in the iron-core loop by means of the injection loop and the reading on the power output meter was noted. The standard signal generator was then connected across the 1 ohm resistor (in series with the iron-core loop) and the output of the standard signal generator adjusted until a like reading on the power output meter was obtained.

8. From a knowledge of the field strength at the iron-core loop and the value of the voltage across the 1 ohm resistor, the effective height of the iron-core loop could be determined.

Temperature

9. a. The loop and adapter were placed in a temperature chamber in a shielded room. The loop and adapter were connected to an ARA receiver located outside the temperature chamber in the shielded room whose temperature and humidity were normal. The iron-core loop was excited by means of an injection loop attached to the housing of the iron-core loop.
- b. The injection loop was fed by a signal generator outside the temperature chamber with a 400 CPS - 30% modulated signal.
- c. The adapter and receivers were tuned to .500 KC and 1475KC. The required injection and receiver input voltages for 50 ^{mV} audio output on the power meter were noted. High signal levels were used.
- d. The temperature was varied between -30°C. and + 50°C, while the relative humidity was maintained approximately constant at 35%.
- e. The ratio of required inputs at the various temperatures to normal temperature were noted for both the receiver and the adapter.

Humidity

10. a. The loop and adapter were placed in a humidity chamber in a shielded room. The loop and adapter were connected to an ARA receiver located outside the humidity chamber in the shielded room whose temperature and humidity were normal. The iron-core loop was excited by means of an injection loop attached to the housing of the iron-core loop.
- b. Same as (b) of temperature test.
- c. Same as (c) of temperature test.
- d. The relative humidity was varied between 35% and 97% while the temperature was held constant at 50°C.
- e. The ratio of required inputs at various humidities to normal humidity were noted for both the receiver and the adapter.

Vibration

11. a. The anti-precipitation static loop and an attached injection loop were securely bolted to a large vibration table, this vibration table being in a room of normal temperature and pressure.
- b. The table was vibrated for about two hours over a frequency range from 0 to approximately 2400 cpm.
- c. The adapter (not mounted on table since no shock mounts were provided) and ARA receivers were tuned to 300 Kc and 1000 Kc. The required injection and receiver input voltages were noted which gave 50 MW readings on the power output meter throughout the vibration runs. High signal levels were used.

Shock

12. a. The iron-core loop and an attached injection loop were securely bolted to a shock table, the shock table being in a room of normal temperature and pressure.
- b. The accelerations used and the results are shown on Table III.
- c. The accelerations given are peak accelerations and are not of more than 10 milliseconds duration. This does not simulate aircraft conditions in which the equipment is subjected to accelerations up to 10G for a few seconds. However, the equipment used was the only shock testing apparatus available.

Performance Study
Experimental Iron-Core Loop

Experimental and Theoretical Sensitivities*

<u>Band</u>	<u>Frequency</u>	<u>Experimental</u>	<u>Theoretical</u>
I	200 Kc.	160 uv/m	171 uv/m
	350	85	107
	500	65	87
II	500	75	69
	1000	45	37.5
	1500	70	25.2

* Iron-core loop and adapter operating in association with ARA receiver. See Appendix for detailed Test Conditions.

TABLE I

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Performance Study
Experimental Iron Core Loop

"Figure of 8" Ratios of Loop*

A. In Open Country, Using Broadcast and Radio Range
Stations as Signal Sources (Method I).

<u>Frequency</u>	<u>Ratio</u>
333 Kc.	31.5 db.
632	25.5
980	32.2
1090	22.4
1340	27.7
1450	23.6
1500	27.1

B. Under Calibrated Transmission Line (Method II)

<u>Frequency</u>	<u>Ratio</u>
200 Kc.	93.1 db.
300	97.1
500	95.2
650	94.5
900	90.9
1475	95.4

* See Appendix II for detailed Test Conditions

TABLE II

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Performance Study
Experimental Iron-Core Loop

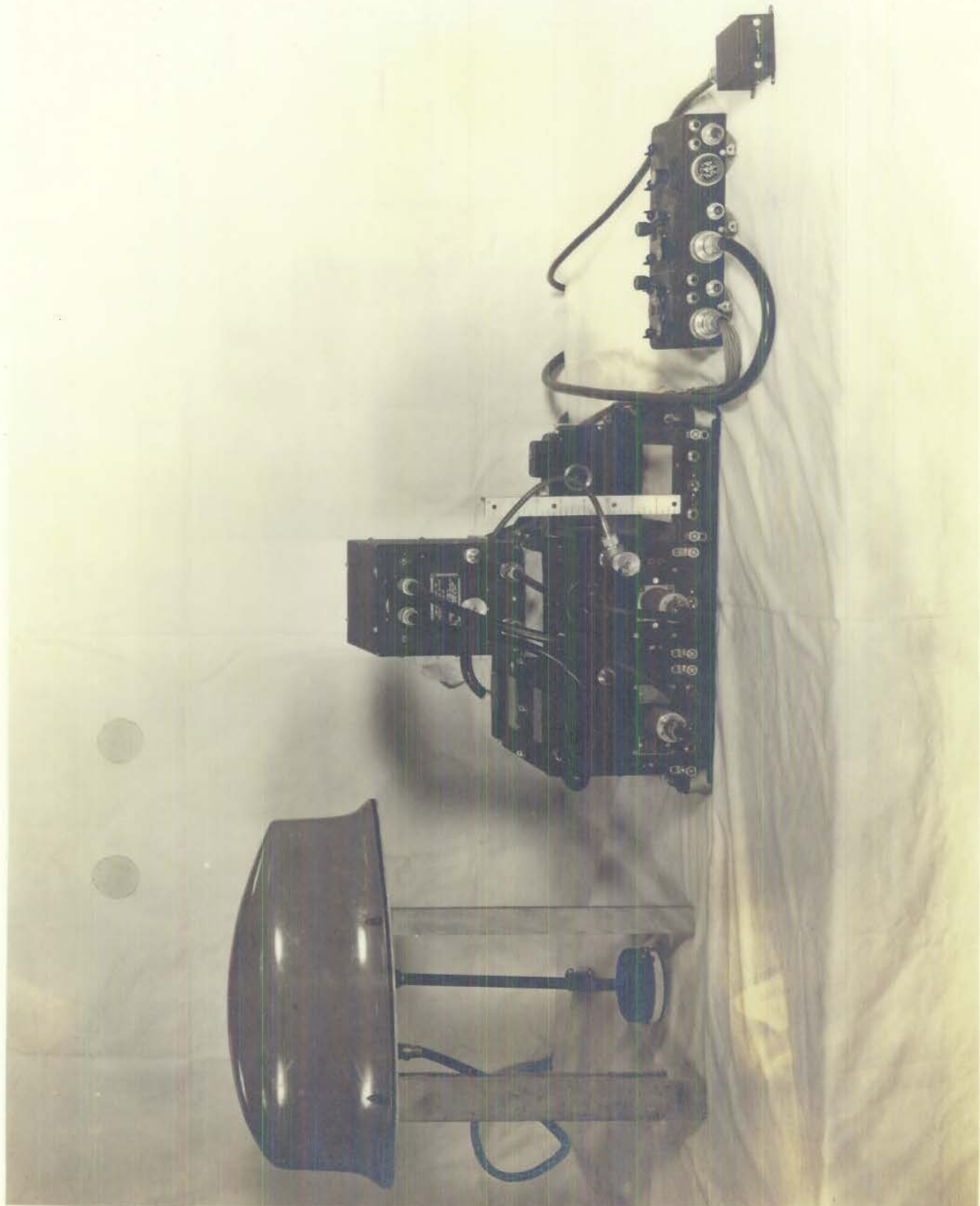
Weight of Loop and Adapter

<u>Loop</u>	<u>*Adapter</u>
7 1/2 lbs.	7 1/2 lbs.

* Includes remote band switch, power cables and RF cables to the receiver.

TABLE IV

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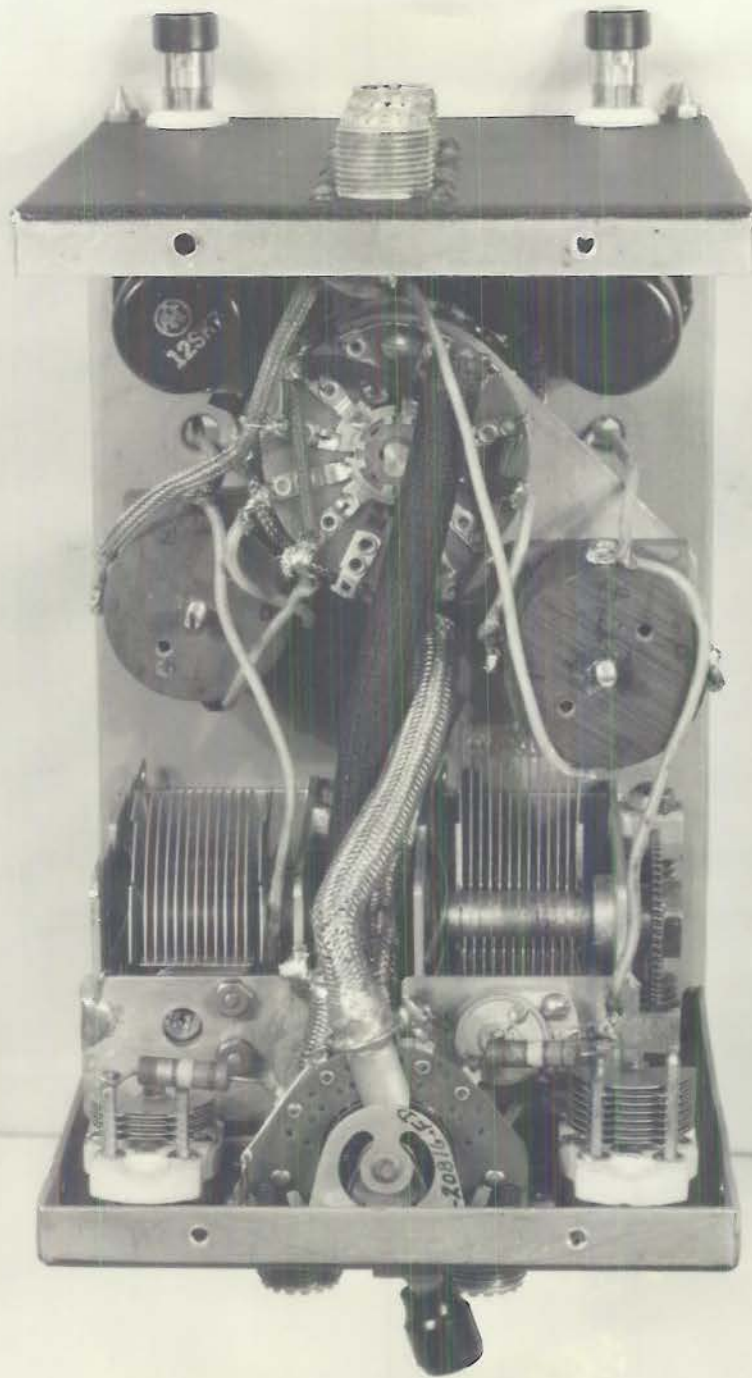
PLATE I



~~CONFIDENTIAL~~

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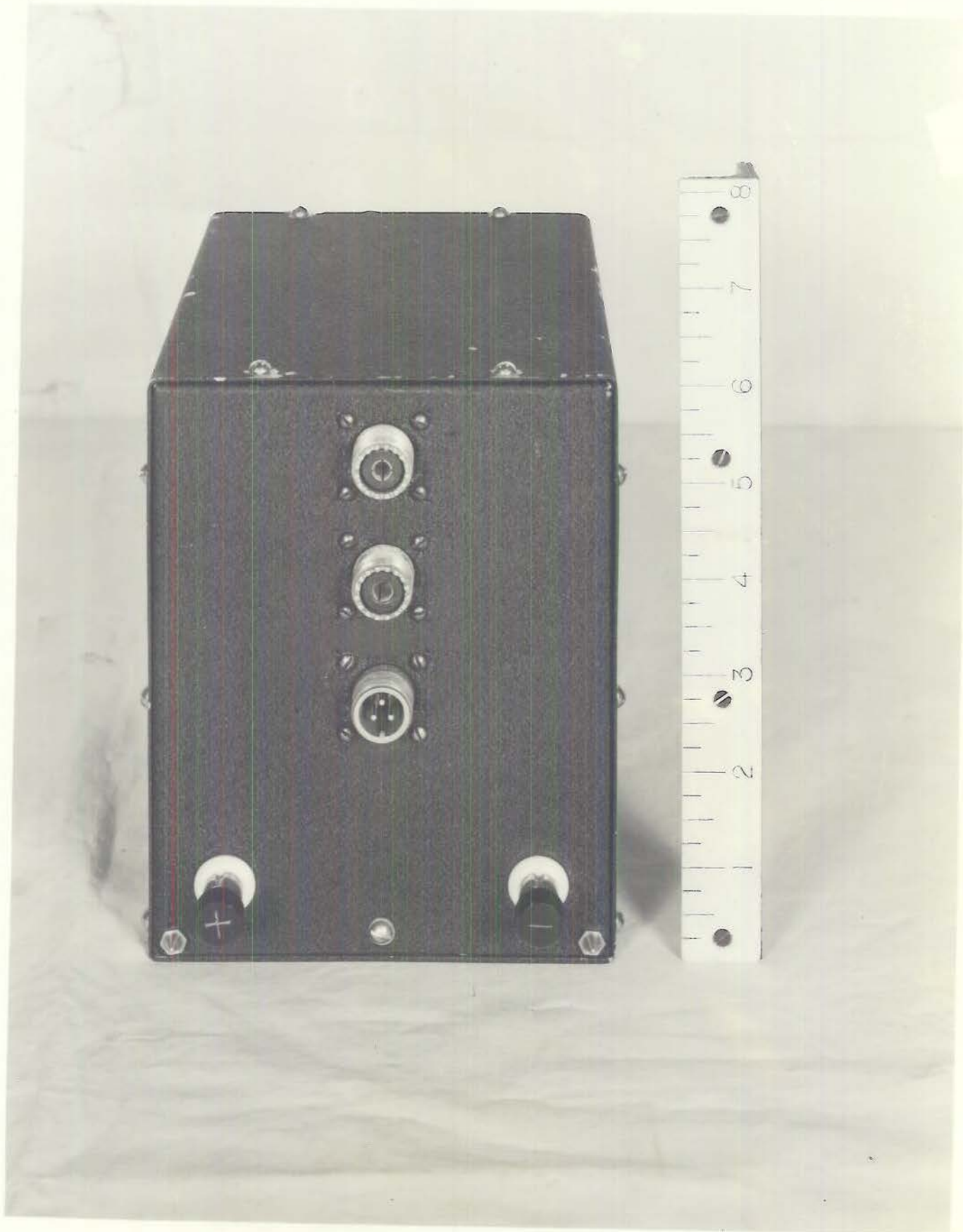
PLATE 2



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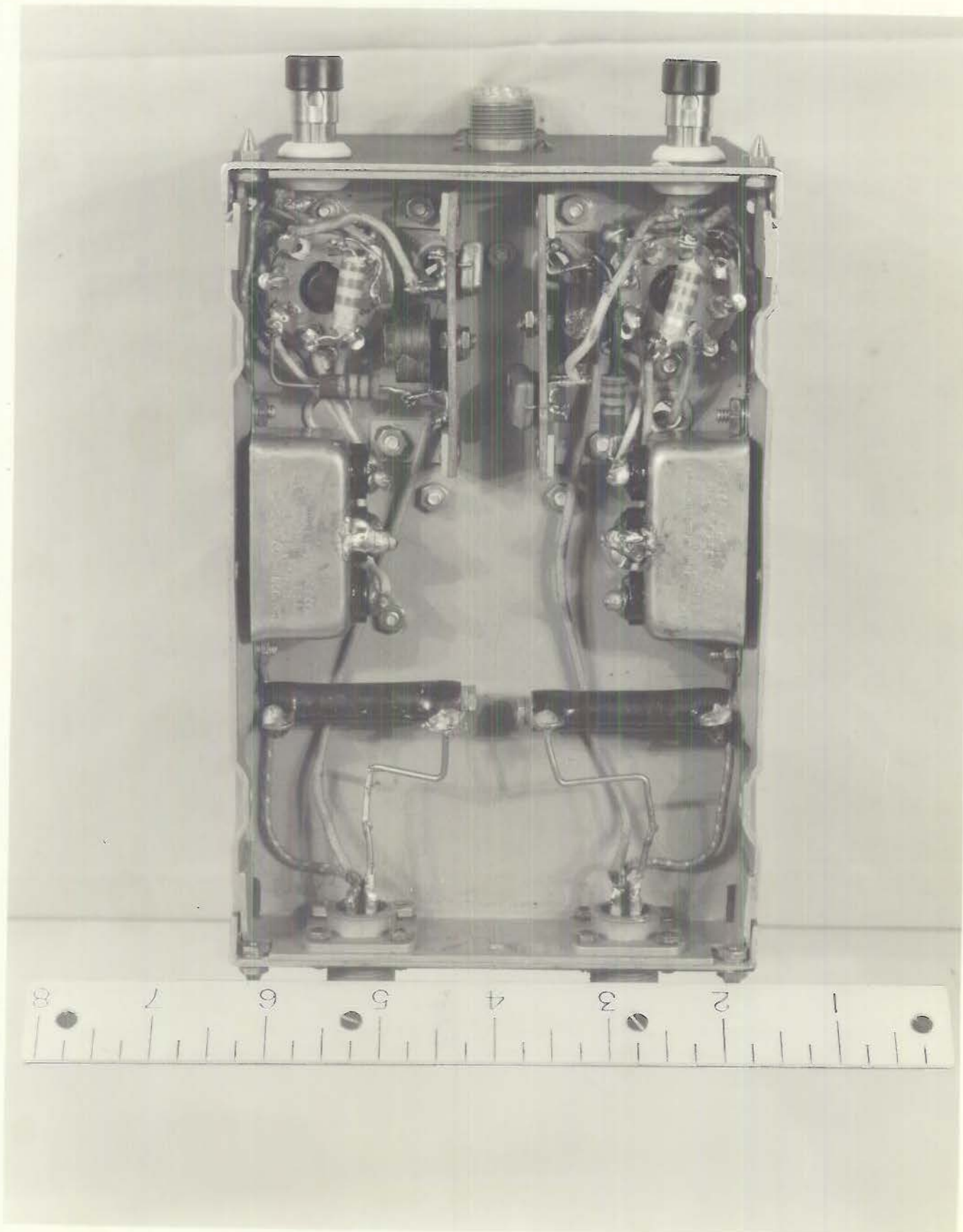
PLATE 3



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PLATE 4



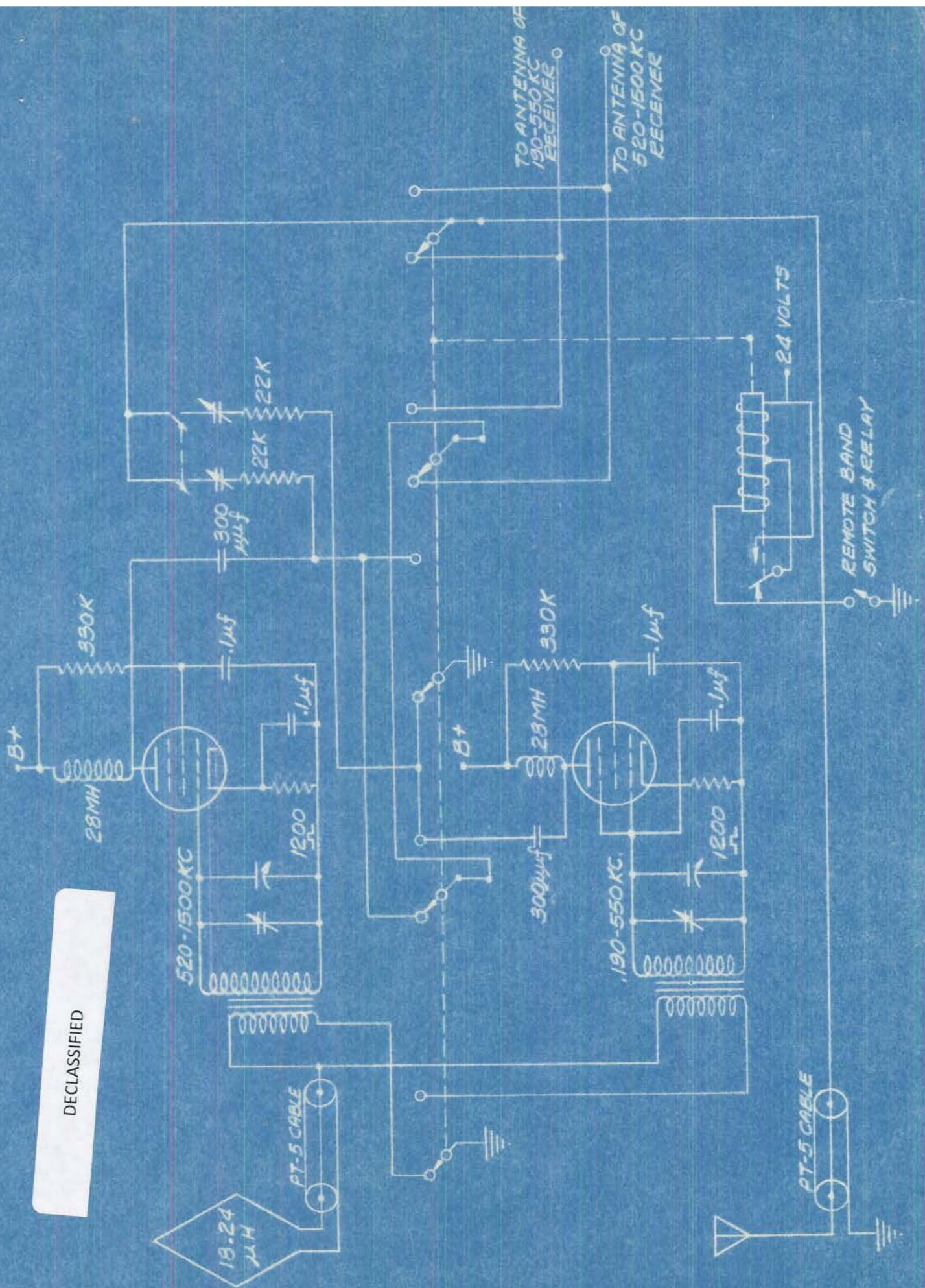
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PLATE 5

~~CONFIDENTIAL~~

SIMPLIFIED SCHEMATIC DIAGRAM

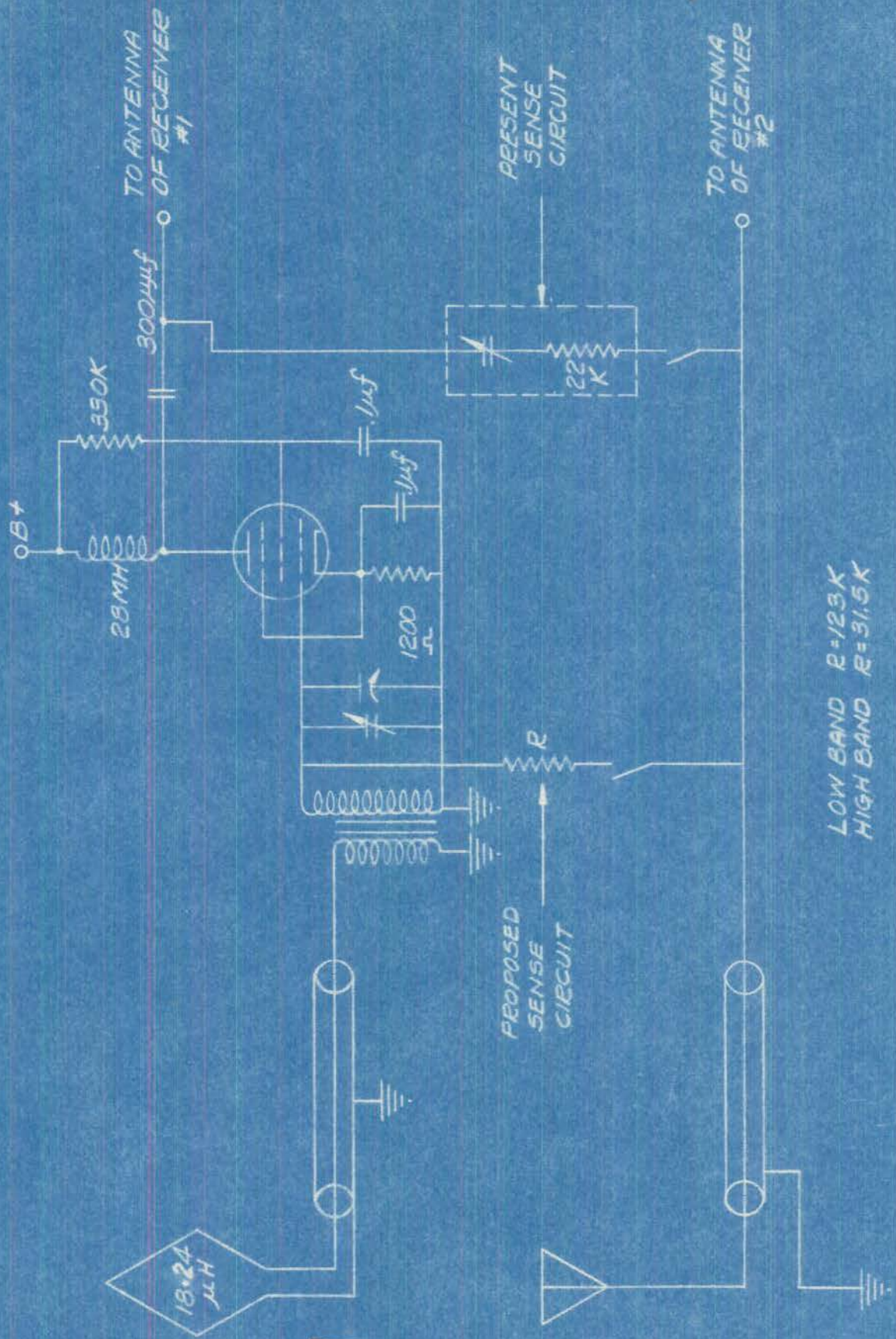
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PLATE 6

PROPOSED MODIFICATION OF SENSE CIRCUITS



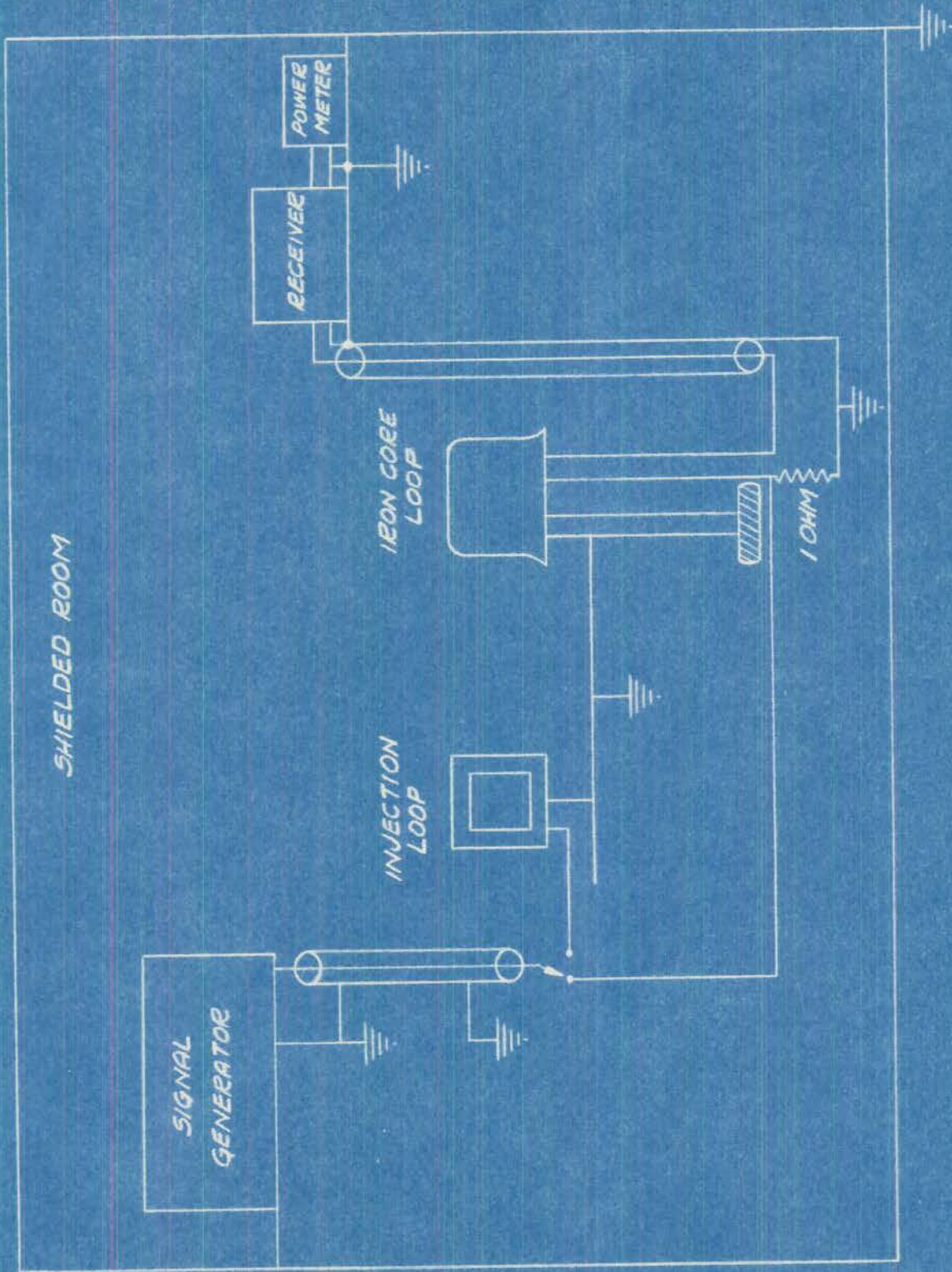
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PLATE - 7

SECRET

EFFECTIVE HEIGHT OF IRON CORE LOOP
EXPERIMENTAL SET-UP



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PLATE 8

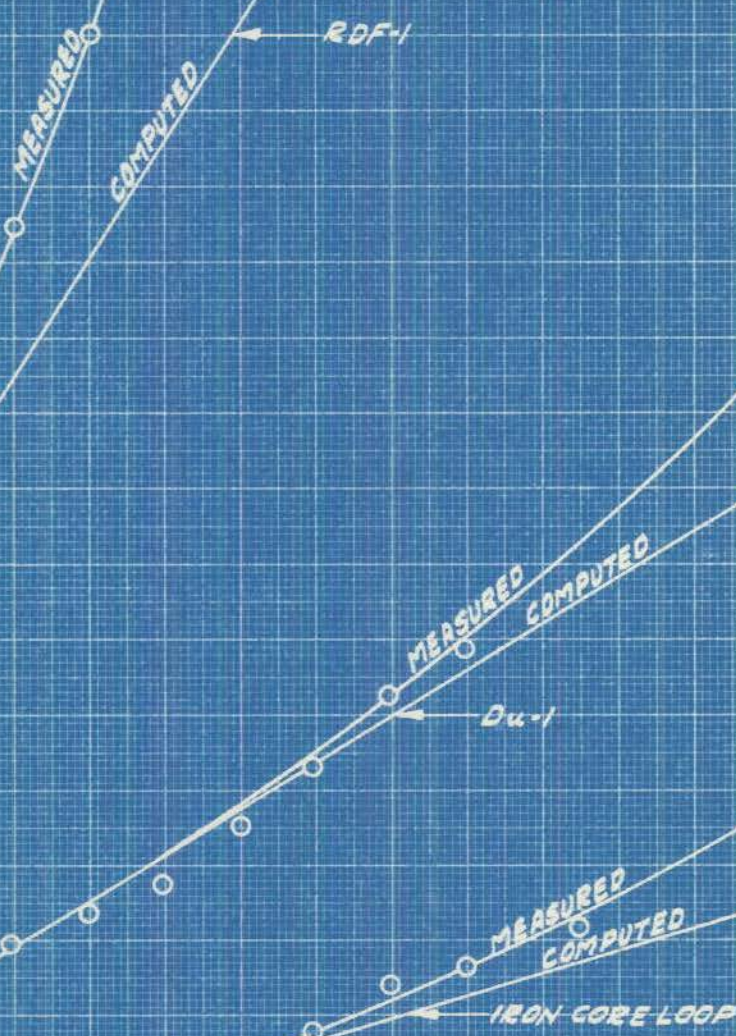
EFFECTIVE HEIGHTS
OF
IRON-CORE LOOP, RDF-1
LOOP AND Du-1 LOOP
(SEE APPENDIX III)

EFFECTIVE HEIGHT IN CENTIMETERS

2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0

0 200 400 600 800 1000 1200 1400 1600

FREQUENCY (KC)



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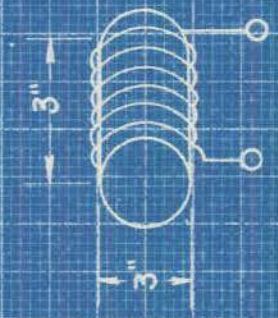
R-2724

PLATE 9

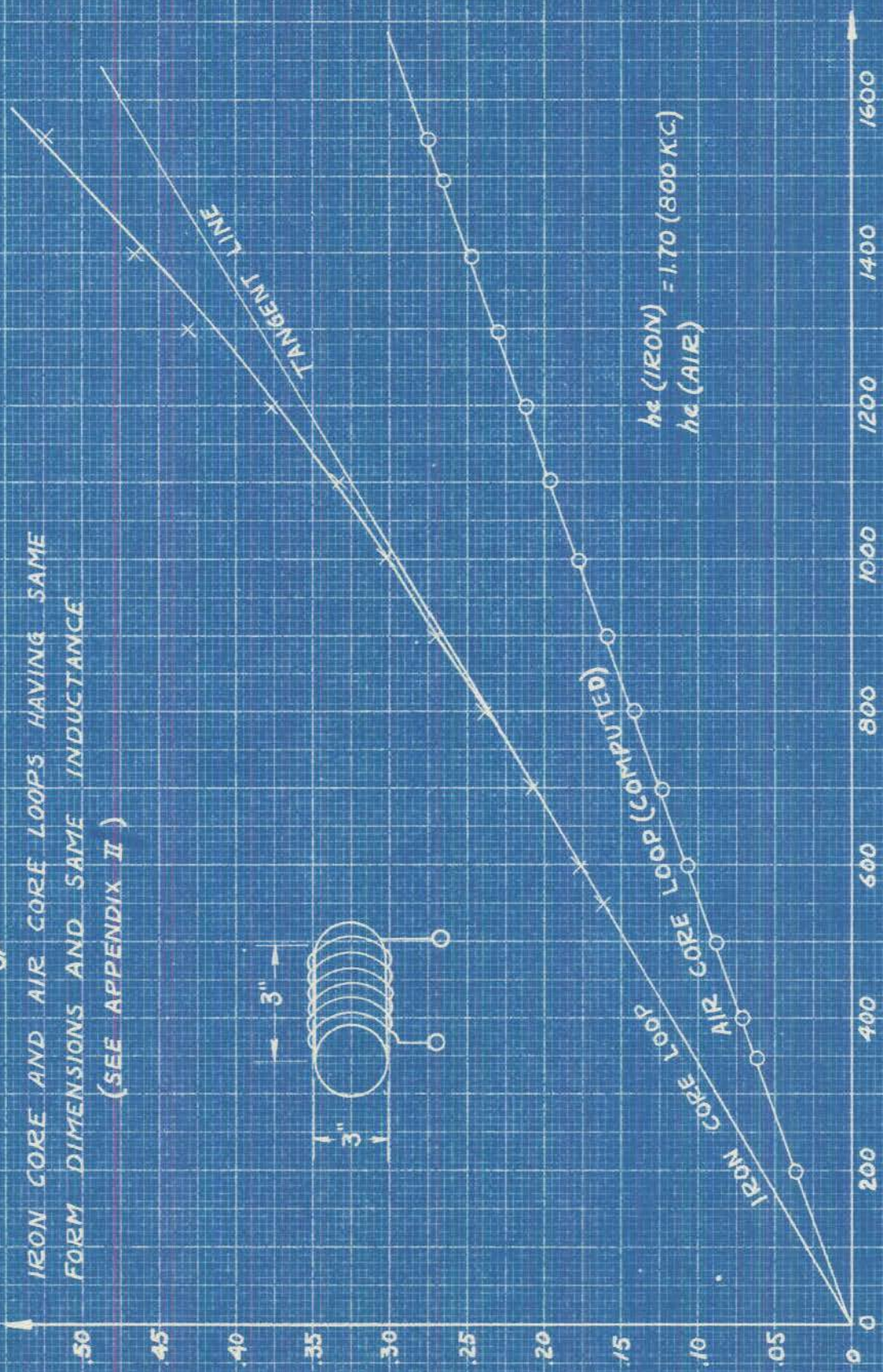
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EFFECTIVE HEIGHT OF

IRON CORE AND AIR CORE LOOPS HAVING SAME FORM DIMENSIONS AND SAME INDUCTANCE (SEE APPENDIX II)



EFFECTIVE HEIGHT IN CENTIMETERS

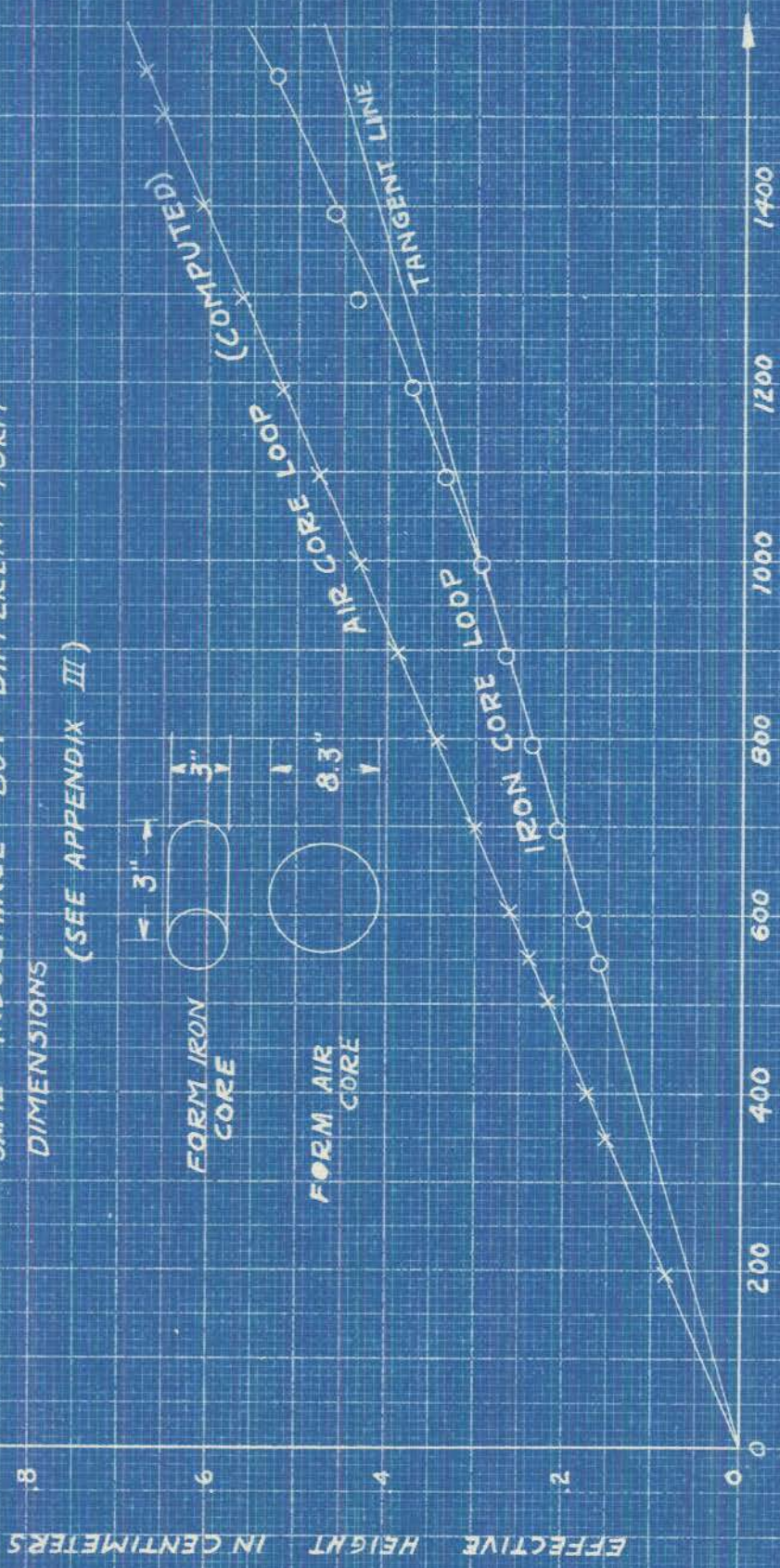
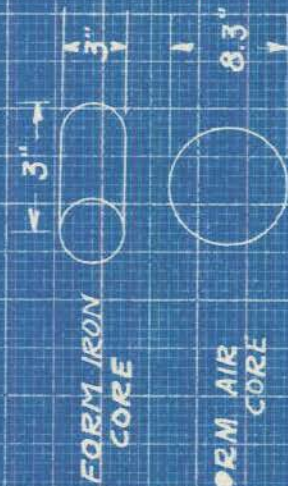


FREQUENCY IN KILOCYCLES

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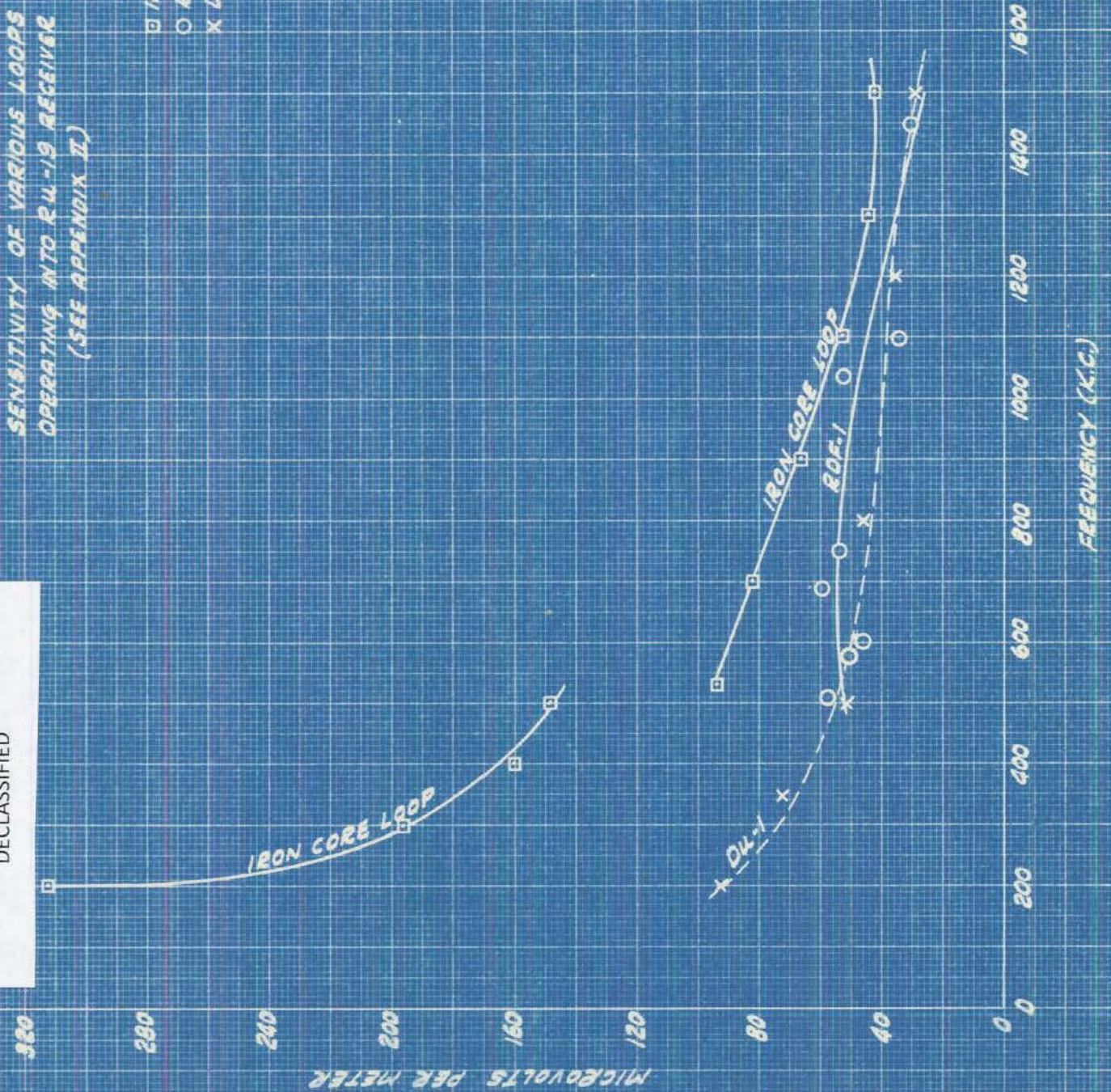
EFFECTIVE HEIGHT
OF
IRON CORE AND AIR CORE LOOPS HAVING
SAME INDUCTANCE BUT DIFFERENT FORM
DIMENSIONS
(SEE APPENDIX III)



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SENSITIVITY OF VARIOUS LOOPS
OPERATING INTO R.U.-19 RECEIVER
(SEE APPENDIX II.)

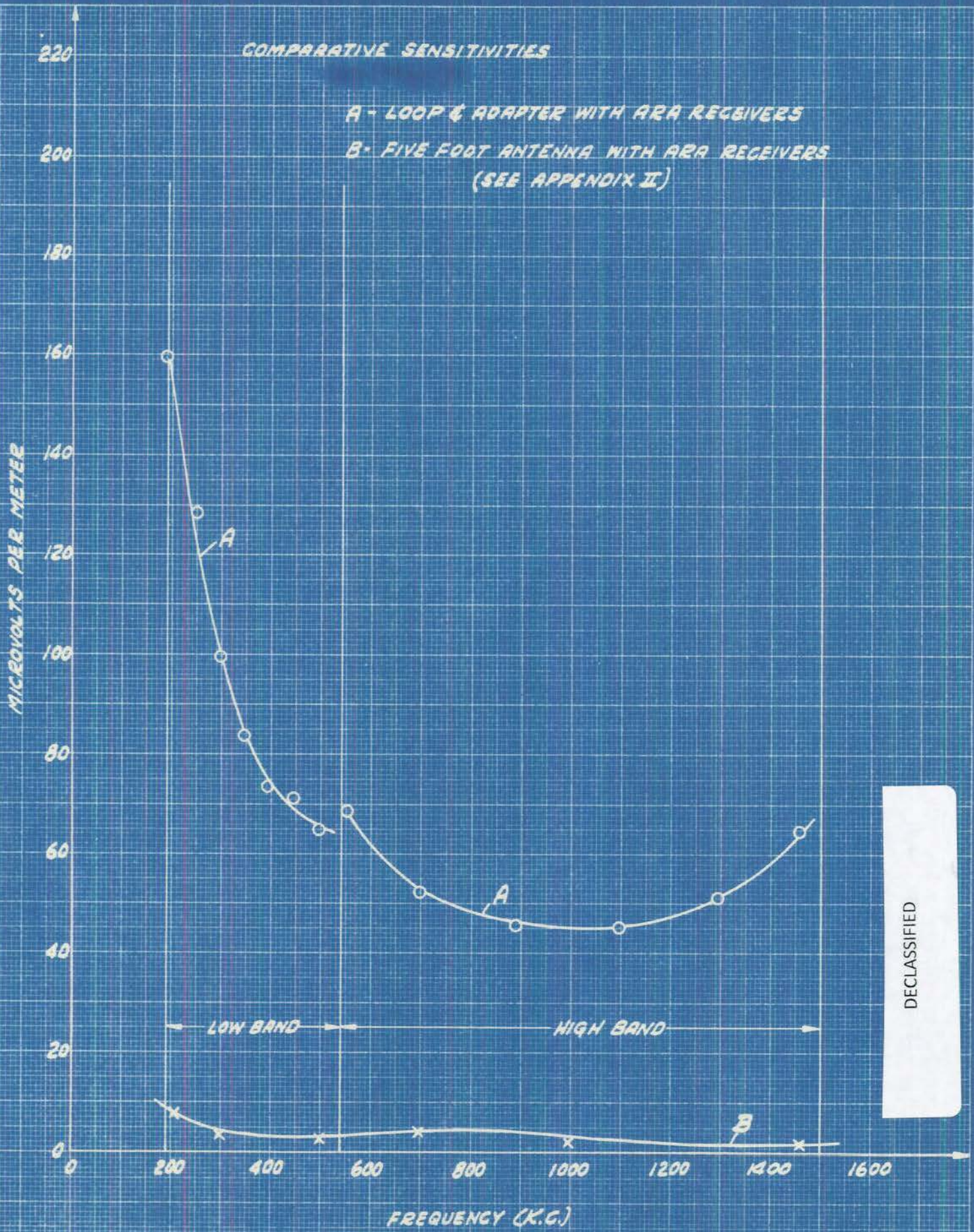
- IRON CORE LOOP
- R.D.F.-1 LOOP
- X D.U.-1 LOOP



COMPARATIVE SENSITIVITIES

A - LOOP & ADAPTER WITH ARA RECEIVERS

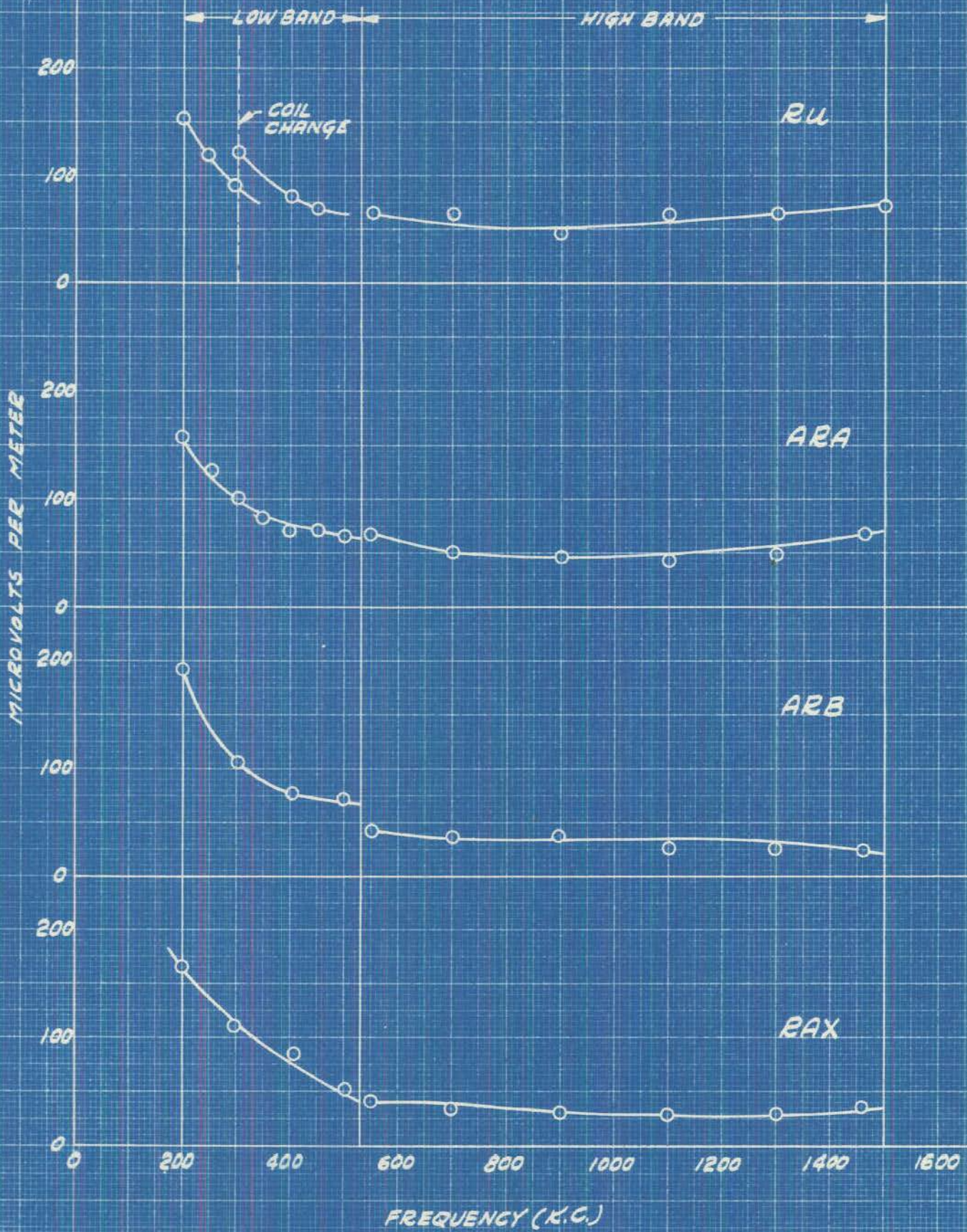
B - FIVE FOOT ANTENNA WITH ARA RECEIVERS
(SEE APPENDIX II)



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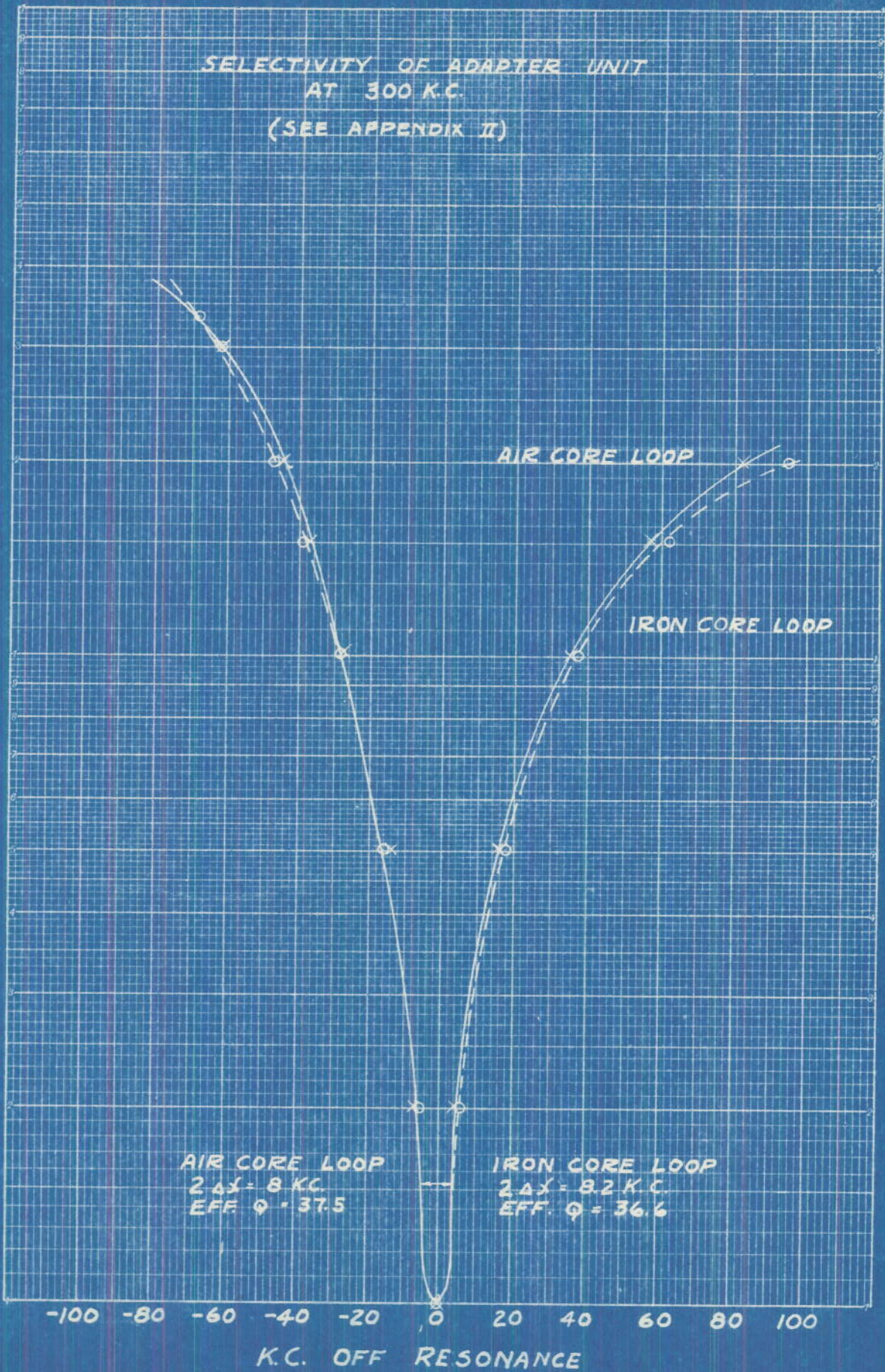
IRON CORE LOOP & ADAPTER SENSITIVITY
WITH VARIOUS RECEIVERS
(SEE APPENDIX II)



SELECTIVITY OF ADAPTER UNIT
AT 300 K.C.

(SEE APPENDIX II)

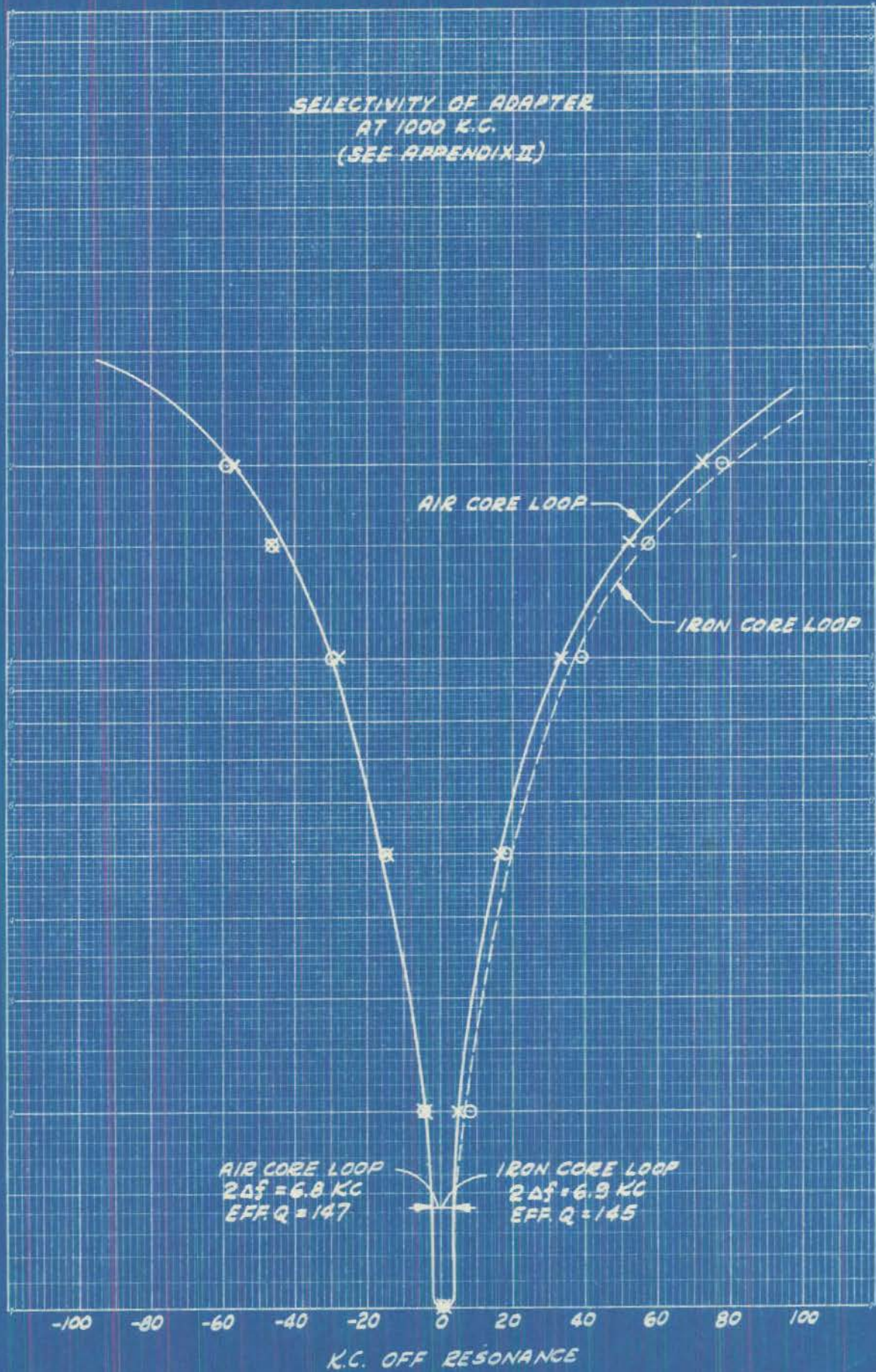
TIMES RESONANT INPUT



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SELECTIVITY OF ADAPTER
AT 1000 K.C.
(SEE APPENDIX II)

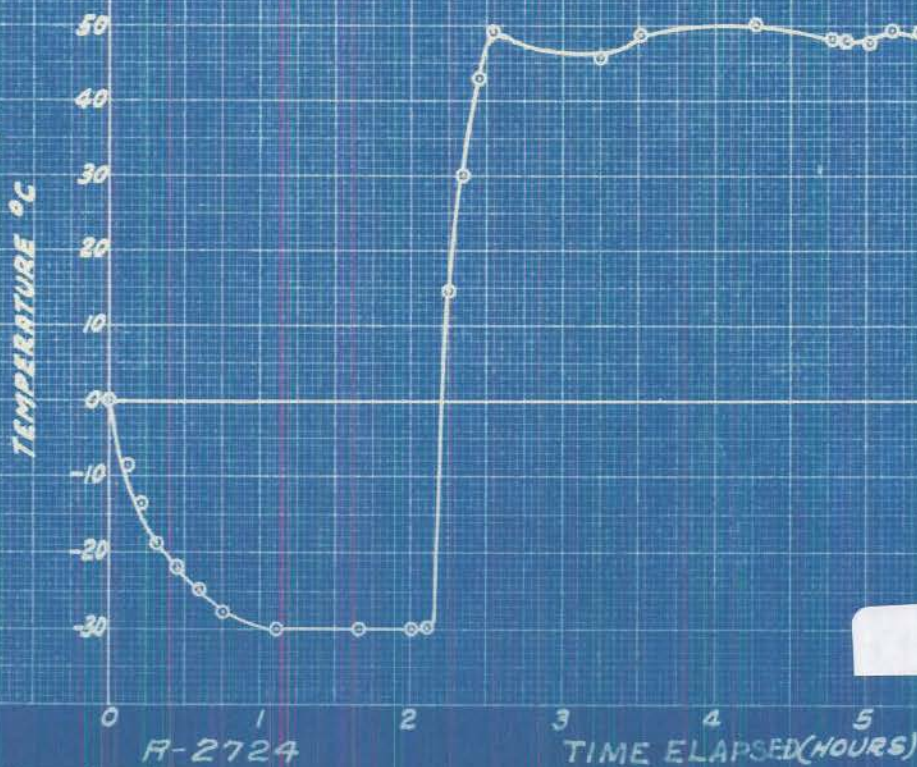
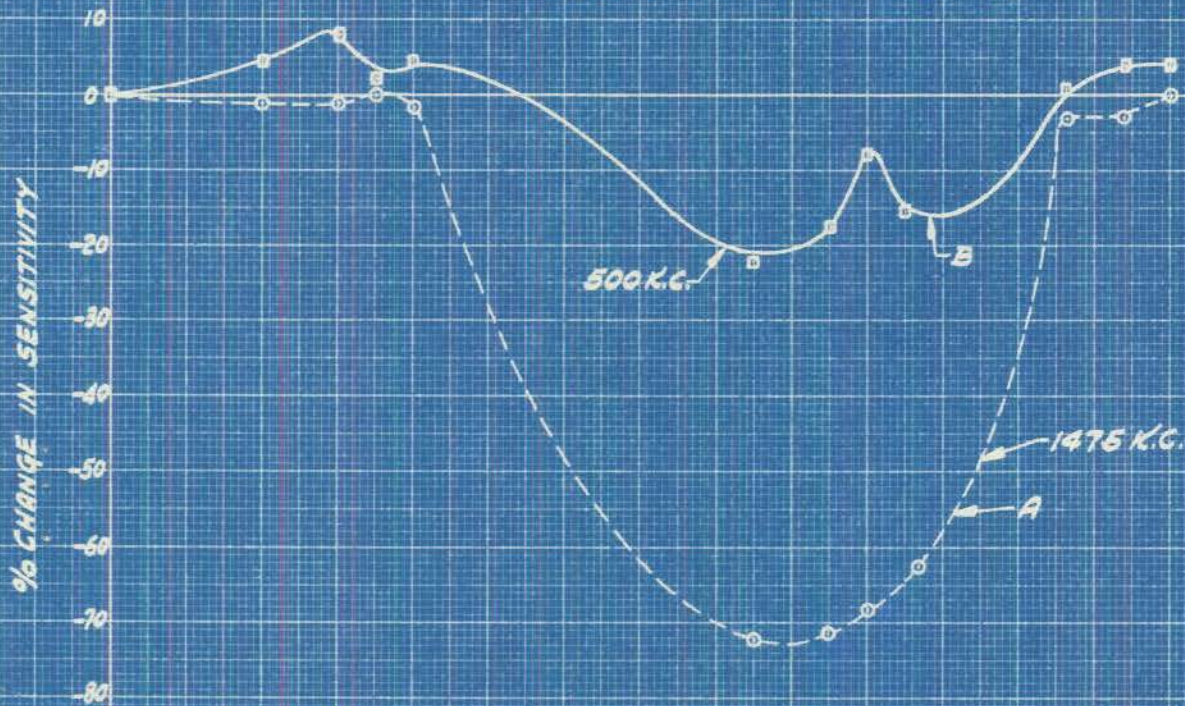
TIMES RESONANT INPUT



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IRON CORE LOOP & ADAPTER
 TEMPERATURE CHARACTERISTIC
 RELATIVE HUMIDITY 35% ALT - SEA LEVEL
 (SEE APPENDIX II)

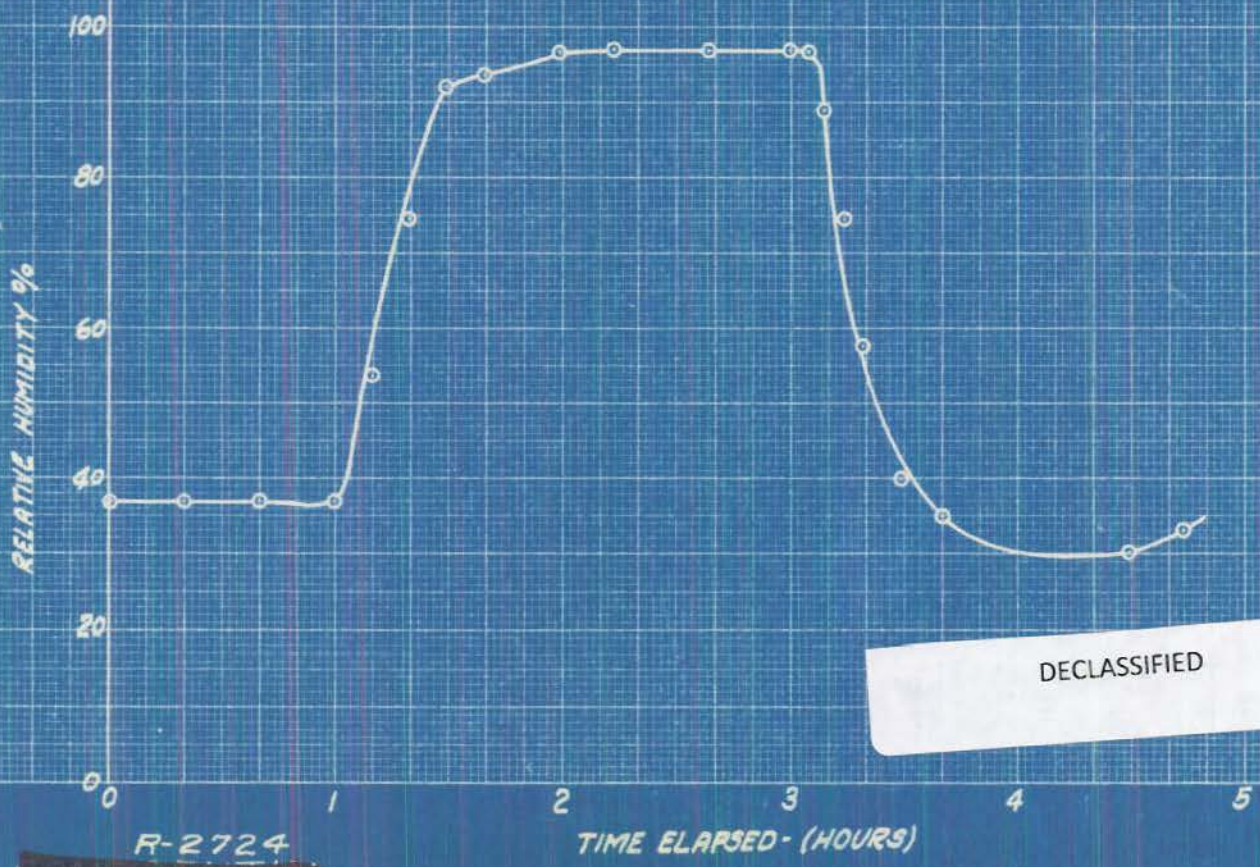
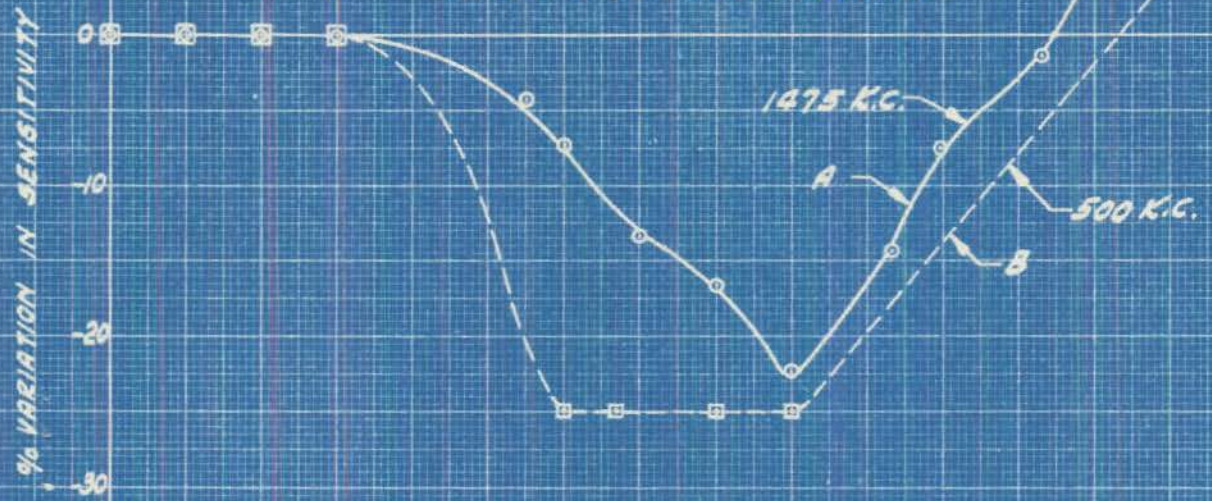
NOTE: - CURVES "A" AND "B" GIVE THE % CHANGE IN
 ADAPTER PLUS LOOP SENSITIVITY



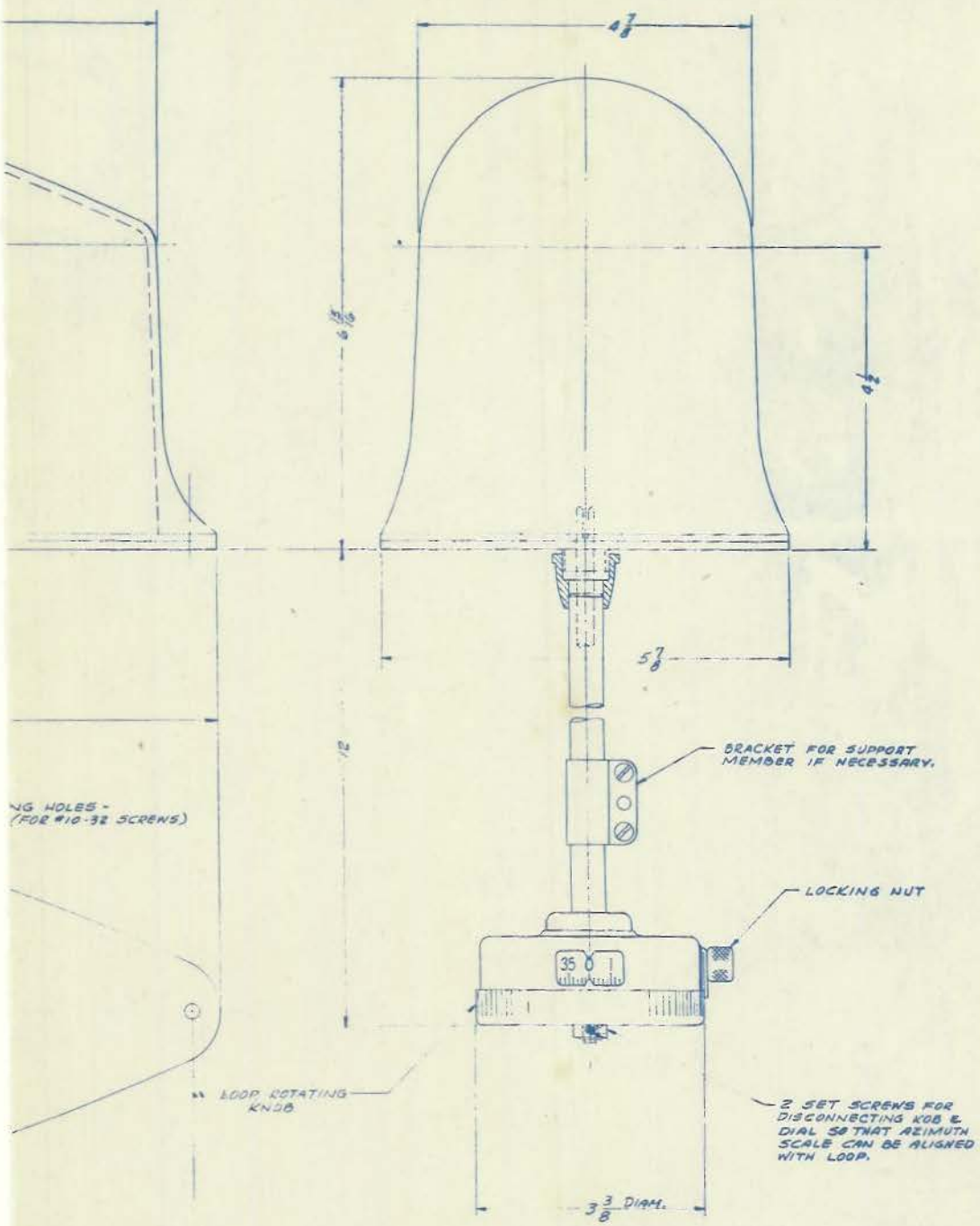
DECLASSIFIED

IRON CORE LOOP & ADAPTER
 HUMIDITY CHARACTERISTIC
 TEMP - 50°C ALT - SEA LEVEL
 (SEE APPENDIX II)

NOTE: - CURVES "A" AND "B" GIVE THE % CHANGE IN
 ADAPTER PLUS LOOP SENSITIVITY



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LOOP WEIGHT ——— 6 LB. 7 OZ.
 CONTROL MECH. WEIGHT ——— 9 OZ.
 TOTAL WEIGHT ——— 7 LBS.

AERODYNAMIC DRAG:
 AT 750 M.P.H. — .75 LBS.
 AT 250 M.P.H. — 2.08 LBS.
 AT 400 M.P.H. — 5.34 LBS.

PURCHASE OR MAKE		MATERIAL		DATE	
FINISH	SIZE AND TOLER.	SCALE	DATE	DRAWN BY	
FINISH	111	11-26-63	EX-20816-HU		
STOCK		WT. PER LB.	CHECKED BY		DATE
STEWART-WARREN CORPORATION, CHICAGO, U. S. A.					

IRON CORE PRECIP.
 STATION STAFF LOOP

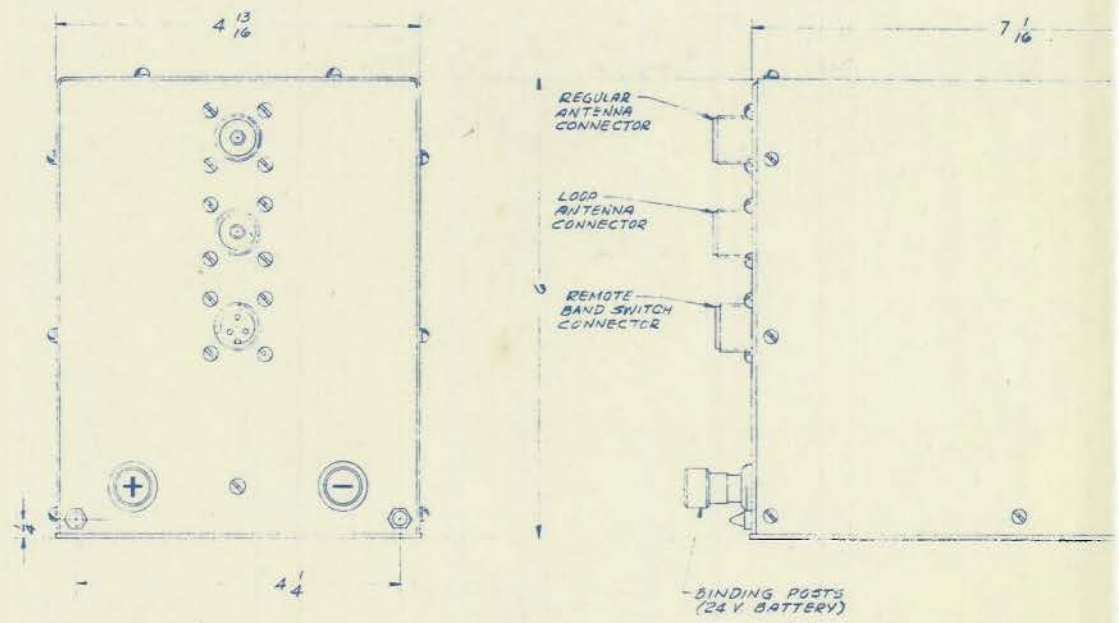
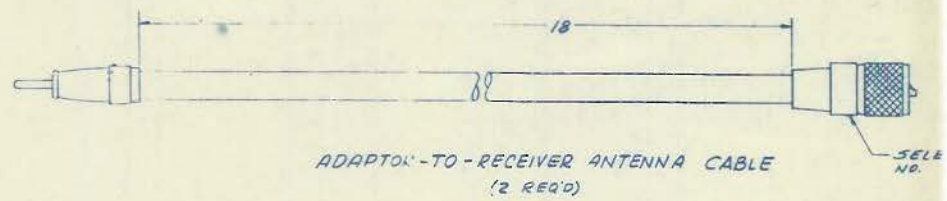
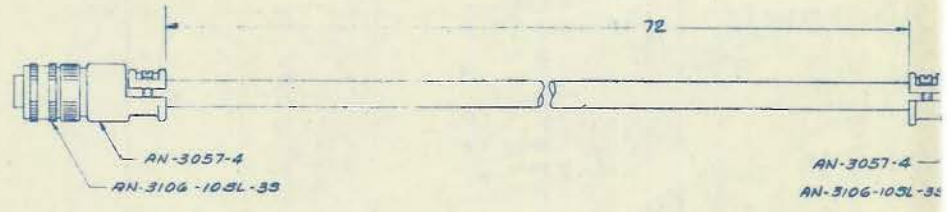
11-26-63

EX-20816-HU

PLATE 17

REVISIONS	DATE	CHANGE NUMBER
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
X		
Y		
Z		

RELEASED FOR PRODUCTION



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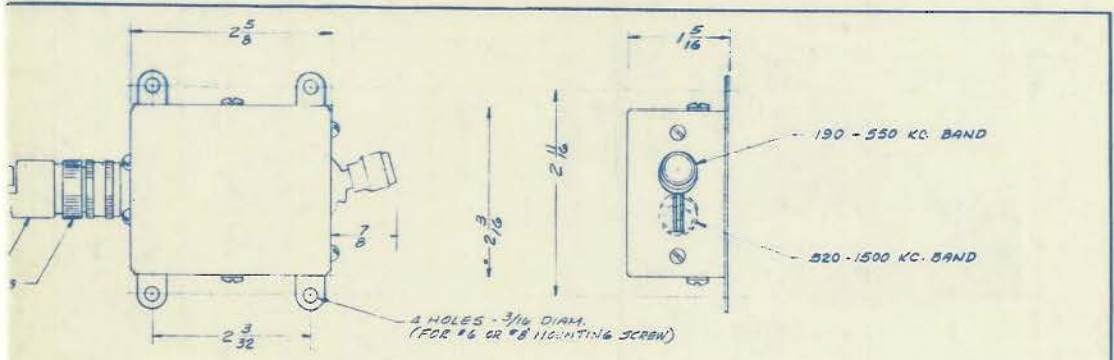
UNLESS SPECIFIED WITH LIMITS DECIMAL DIMENSIONS MAY VARY ± .005 FRACTIONAL DIMENSIONS MAY VARY ± .015 DRILL PUNCH COMMERCIAL SIZES AND MANUFACTURING TOLERANCES ARE NOT INCLUDED IN THE ABOVE

CAUTION
 READ ALL NOTES BEFORE STARTING WORK.
 DO NOT SCALE DRAWING. REFER TO DIMENSIONS.
 ALL DIMENSIONS GIVEN IN INCHES

ANY PATENTS OBTAINED GOVERNMENT CONTRACTORS SHALL BE HELD RESPONSIBLE TO THE GOVERNMENT FOR PROTECTION OF PATENT RIGHTS

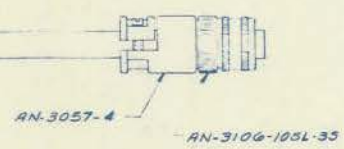
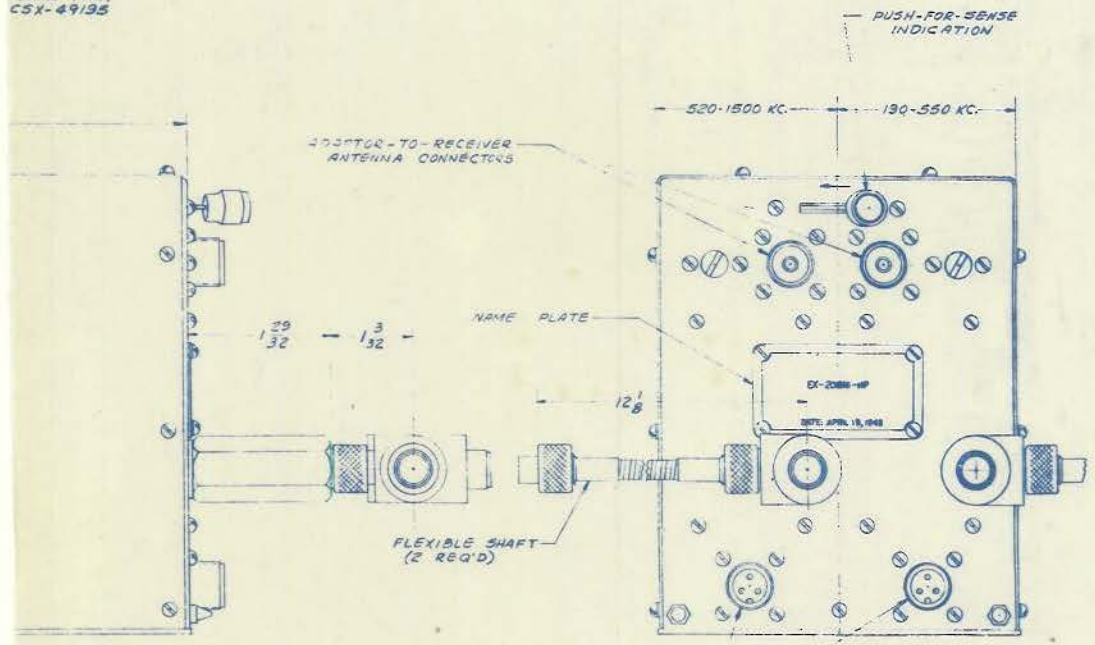
CODE NO. - 77

REV.	NUMBER	NAME



REMOTE BAND SWITCH & CABLE
(1 REQ'D)

FACTORY PART
CSX-49135



CABLE

PURCHASE OR MAKE		FINISH		NAME		USED ON		NO.	
HEAT TREATMENT		KIND AND TEMPER		ADAPTOR UNIT OUTLINE DRAWING		DATE		EXPERIMENTAL NO.	
MATERIAL		FINISH		SCALE		11-24-43		EX-2086-HT	
SIZE		EPOCH		DRAWN BY		CHECKED BY		REV. OF	
STEWART-WARNER CORPORATION, CHICAGO, U. S. A.									

PLATE 13