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Eng. 70-C

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REPORT NO. R-1574

FR-1574

DATE 15 November 1939

DECLASSIFIED by NRL Contract Declassification Team
Date: 12 MAY 2016
Reviewer's name: A. THOMPSON, P. HANNA
Declassification authority: NAVY DECLASS MANUAL, 11 DEC 2012, 03-17, 06 SERIES

SUBJECT

A Study of the Operating Characteristics
of
Shipboard Trunk and Antenna Systems
at Intermediate Frequencies

UNCLASSIFIED
CLASSIFICATION CHANGED TO
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BuEng.Prob. B3-9C

NAVY DEPARTMENT

A Study of the Operating Characteristics of Shipboard Trunk and Antenna Systems at Intermediate Frequencies

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NAVAL RESEARCH LABORATORY
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WASHINGTON, D. C.

Number of Pages: Text - 34 Tables - 9 Plates - 53

Authorization: BuEng let.C-BB55-6/S67(10-7-W2) of 9 Oct. 1937.

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Distribution: BuEng (25)

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Appendices

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AUTHORIZATION

1. The general problem of investigating transmitting antenna systems, particularly as applied to Naval shipboard installations, was originally authorized by reference (a). Subsequent correspondence and conferences indicated the need for certain additional information relative to specific features of the installations.

2. The results of previous investigations and calculations have been submitted in references (b), (c), (d), (e), and (f). Reference (g) is an engineering test report covering the Model TAQ-5 transmitter. Data appearing in this latter report were used in connection with the preparation and conduct of the experimental work herein reported.

Reference:
- (a) BuEng let.C-BB55-6/S67(10-7-W2) of 9 Oct.1937.
- (b) NRL Report No. R-1331 dated 14 December 1936, "Concentrated Capacity and Inductance as Substitute for Horizontal Antennas on Board Ship."
- (c) NRL let.C-S67/66 of 8 March 1938 to BuEng. Subject: Radio - Antenna and Antenna Lead-in System for Battleships 55 and 56."
- (d) NRL Report No. R-1446 of 9 June 1938, "A Mathematical Analysis of the Radiation Characteristics of Partially Shielded Antennas."
- (e) NRL Report No. R-1448 of 13 June 1938, "A Study of the Radiation Characteristics of Shipboard Antenna Systems."
- (f) NRL let.C-S67/66 of 7 October 1938 to BuEng, Subject: Radio - Antenna and Transmission Line System for Battleships 55 and 56 - Transmitting Equipment."
- (g) NRL Report No. R-1553 of 14 August 1939, "Test of Model XTAQ-5 Radio Transmitting Equipment."

INTRODUCTORY

3. Since the tentative design of the transmitting antenna installation for Battleships 55 and 56 is virtually completed, sufficient data have become available to permit further calculations to be made, substantiated by experimental work. Reference to preliminary drawings indicates that the battle condition antenna for use with the Model TAQ-5 transmitter will have the following physical characteristics:

Flat top: 90 feet long (two strands tied together at one end and diverging to 6 ft. spacing at far end).
Vertical element: 68 ft long (slanting)
Trunk: 65 ft long, 12 in. OD, 1/2 in. ID.

Since the TAQ-5 transmitter is the highest power transmitter in the intermediate frequency range carried by the vessels in question, and hence would generate the highest r-f potentials, a transmitter of this type was used in connection with the experimental work which is reported below.

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4. In order to illustrate the effect of antenna height, three different vertical dimensions were employed during the experimental work.

(a) An antenna with a 65 ft. vertical element and a 95 ft. flat top, connected in the form of an inverted "L."

(b) An antenna with a 95 ft. vertical element and a 95 ft. flat top, connected in the form of an inverted "L."

(c) An antenna with a 125 ft. vertical element and a 95 ft. flat top, connected in the form of an inverted "L."

Each antenna was used in connection with a trunk 66 feet in length. The outer diameter of the trunk was 18 inches and the inner conductor was a 3/4 inch diameter copper tube. Thus it will be seen that the antenna system consisting of the 65 foot vertical element with the 95 foot flat top and the 66 foot trunk represents very closely the antenna system which will be employed on Battleships 55 and 56 for use with the TAQ-5 transmitter.

5. At the outset of the experimental work, attempts were made to use a trunk of 12 inch outer diameter and a 3/8 inch inner conductor. This trunk was 68 feet in length. When this trunk was used, voltage breakdowns occurred long before full power output was obtained from the TAQ-5 transmitter. Therefore, an 18 inch diameter trunk with a 3/4 inch inner conductor was constructed. The stand-off insulators which supported the inner conductor were equipped with corona shields after it was discovered that the lack of such shields caused the insulators to be fractured. These features will be discussed in greater detail in the following paragraphs of this report. It is pointed out that the capacity per foot of an 18 inch trunk with a 3/4 inch inner conductor is the same as that of a 12 inch trunk with a 1/2 inch inner conductor.

6. Various locations were investigated in an effort to obtain a scene of operations where the antenna resistance would be comparable with that encountered on board ship. While the resistance characteristics of the location finally selected are undoubtedly somewhat different than will actually be encountered on board ship, it is believed that the agreement will be close enough to permit full use of the experimental results obtained.

7. In order to obtain a fairly comprehensive picture of the factors involved in the investigation of antenna systems of the type under consideration, specific attention must be given to the measurements of antenna constants, the power and voltage considerations encountered and the methods of making field strength determinations. These factors are discussed in detail in the following sections of this report.

MEASUREMENT OF ANTENNA CONSTANTS

8. The measurement of antenna constants for frequencies of 600 kilocycles or less can be made by a number of standard methods. The more common ones are:

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(a) R-F bridge.

(b) R-F bridge, using the bridge as an indicating instrument in the substitution method.

(c) Q meter

(d) Methods based upon tuned tank circuits loosely coupled to a low power oscillator.

(e) Methods based upon a tuned tank circuit loosely coupled to a high power oscillator.

9. The r-f bridge used in connection with these measurements was a General Radio Type 516-C. The bridge can be used as a direct reading instrument for frequencies less than 1000 kilocycles. Capacitance can be determined to $\pm$ 2 micromicrofarads and resistance to about $\pm$ 0.2 ohm. The limit of accuracy with respect to capacitance is determined by the reading of the condenser which is incorporated in the bridge. The accuracy of resistance measurements is governed by the inherent errors in the bridge and by the adjustment of the bridge. The value of $\pm$ 0.2 ohm is given by the manufacturer and agrees with the experience of the Laboratory.

10. The radio frequency bridge can be used to best advantage as an indicating instrument in the substitution method. This method increases the accuracy of measurement of both the capacitance and resistance. The bridge is balanced in the same way as for the direct reading method. The antenna is then disconnected from the "unknown" terminal of the bridge and a variable condenser in series with a variable resistor is connected in its place. The variable condenser and variable resistor are adjusted until the bridge is balanced. When an accurate balance is obtained, the capacitance and resistance readings thus obtained are equal to the antenna capacitance and resistance. By this method, results can be duplicated to an accuracy of approximately 0.02 ohm and a fraction of 1 micromicrofarad. Thus, an extremely high order of accuracy may be obtained in capacity measurements while the accuracy of the resistance measurement is determined by the calibration of the variable resistor and the resistance of the connecting leads. The accuracy of the measurements is probably about $\pm$ 0.05 ohm. A General Radio Type 222 condenser and a General Radio compensated decade resistor were used during the measurements herein described. Care should be exercised to connect the condenser to the high side and the resistor to the ground side of the "unknown" terminals on the r-f bridge. When a measurement has been obtained, the voltage drop across the unknown antenna terminals and the substituted capacitance and resistance must be equal in both magnitude and phase. Since, in antenna measurements, the capacity reactance may be 100 times greater than the resistance, the capacity reactance may have to be balanced 100 times more accurately than the resistance. This necessitates a very careful adjustment of the balancing condenser and at the same time requires that the capacitance of the system remain very constant. Thus, the lower the frequency and the lower the antenna capacitance, the greater is the difficulty of obtaining a good resistance balance. Experience from a large number of antenna measurements has indicated that on a windy day

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the antenna capacitance may vary several micromicrofarads and thus make it impossible to obtain accurate antenna resistance measurements. Local static also interferes with the measurements and at certain times, particularly in the afternoon hours, it was found impossible to obtain satisfactory measurements.

11. The following observations were made during the course of the antenna measurements:

(a) If a trunk is used, the effect of the swinging of the antenna and local static does not interfere to as great an extent as without the trunk. The trunk increases the capacity of the antenna system and thus decreases the capacity reactance. As the capacity reactance decreases, the percentage accuracy of balance for the capacity reactance also decreases, thus permitting greater accuracy in the resistance measurements.

(b) Part of the static that is picked up by the antenna is shunted to ground in the trunk and thus the static interference on the bridge is reduced. This reduction in static increases the accuracy of the measurements.

12. Q meter method of measuring antenna constants. Two different methods may be employed when using the Q meter to measure antenna constants.

(a) In one method the coil or inductor is connected across the coil terminals of the Q meter. The Q meter is set at the desired frequency and the Q of the coil is obtained by adjusting the condenser on the meter to the resonance frequency of the coil and condenser. The Q of the coil and capacity of the condenser are recorded. Next, the antenna is connected to the Q-meter and the condenser is adjusted to resonate the circuit. The Q of the circuit and the capacity of the condenser are recorded. From these readings the capacitance and resistance of the antenna can be calculated.

(b) When the substitution method is used, the coil is connected to the coil terminals of the Q meter and the antenna is connected to the high side of the capacity terminals. The Q meter is adjusted to the desired frequency. The Q meter condenser is adjusted to the resonant frequency of the circuit. The reading of the Q meter is noted. The antenna is disconnected and replaced by a variable condenser and resistor. This condenser is adjusted to resonate the circuit. The resistance is varied to give the same value of Q as for the antenna. The antenna constants are then equal to the capacity of the condenser and the resistance reading of the resistor.

13. The presence of static or an interfering radio signal near the frequency at which the measurements are desired may introduce errors in the measurements. These errors can be mitigated somewhat

by the following method. The antenna is resonated by means of the Q meter condenser. The Q meter is then detuned by changing the frequency of the signal generator. The Q indicator gives a reading greater than zero due to the presence of static or the undesired radio signal. The Q indicator is adjusted, by means of its control, to give a zero reading. The signal generator is then tuned to the resonant frequency of the antenna. The Q of the circuit is noted. The antenna is then replaced by a variable condenser and resistor. The Q indicator is again adjusted to zero after which the condenser and resistor are varied to reproduce the same value of Q on the Q indicator as originally recorded. Then, the condenser and resistor readings correspond to the antenna constants. When antennas of high resistance and/or capacitance are encountered, difficulty is experienced in obtaining accurate measurements, since circuits of this nature have low Q's. It is possible to obviate these difficulties to some extent by inserting a low value fixed condenser in series with the antenna. The measurements are then made in the same manner outlined above, except that the antenna constants have to be calculated.

14. The accuracy of Q meter measurements is restricted by the accuracy to which the value of Q can be reset. The best results are obtained for antenna capacities not over 600 micromicrofarads and for resistance values of 3 to 10 ohms.

15. Methods based upon a tuned tank circuit loosely coupled to a low power oscillator. This method of measuring the antenna constants is the same as that employed in connection with the Q meter, except that the oscillator is electromagnetically coupled to the tank circuit in place of the common resistance coupling. The methods of measurement are the same as for the Q meter. The resistance variation method may be used, but, in general, it is not as accurate as the substitution method. With this method it is not essential to ground the system. Thus measurements can be made between an antenna and counterpoise. Static and interfering radio signals create difficulties in making measurements.

16. Methods based upon tank circuits loosely coupled to a high power oscillator. The general method of measurement is the same as when a low power oscillator is used. It has all the advantages of the low power oscillator method and in addition the effect of static or unwanted r-f signals can generally be overcome due to the use of the high power oscillator. Thus, more accurate measurements can be made in the presence of severe static or when interfering signals exist.

17. Accuracy of measurements. The relative accuracy of the different methods of making antenna measurements is given below. It is assumed that static or other interference is at a moderate level.

(a) R-F bridge (direct method)
Capacitance: ± 2 micromicrofarads
Resistance: ± 0.2 ohm

(b) R-F bridge (substitution method)
Capacitance: ± 0.5 micromicrofarad
Resistance: ± 0.05 ohm

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(c) Q meter method.
In general, less accurate than either bridge method. Degree of accuracy largely dependent upon the values of the antenna constants.

(d) Methods based upon tuned tank circuits coupled to low power oscillators.
Accuracy about the same as for the Q meter method.

(e) Method based upon tuned tank circuits coupled to high power oscillators.
The accuracy is about the same as for the Q meter method except that static and interference do not affect the accuracy of the measurements to as great an extent.

18. The advantages and disadvantages of the various methods of measurement are tabulated, briefly, below:

(a) R-F bridge (direct method)

Advantages:

(1) Accurate measurements even near the quarter wave resonance of the antenna.
(2) The effect of static can be generally made small by using a receiver with a tuned audio amplifier as the detector.
(3) Rapid measurements can be made.

Disadvantages:

(1) Requires that the power factor be balanced for each frequency at which measurements are made.
(2) Requires that measurements be made between antenna and ground, since the measuring equipment is grounded.
(3) High static levels cause difficulties in making resistance measurements.
(4) If the antenna capacity varies slightly (e.g. due to wind), it is difficult to make resistance measurements.
(5) The equipment is rather large and bulky and not easily portable.
(6) The difficulty in making accurate resistance measurements increases as the reactance of the antenna increases.

(b) R-F bridge (substitution method)

Advantages:
The advantages of this method are identical with those listed under R-F bridge (direct method) except that a higher degree of accuracy is obtainable. (See paragraphs 17(a) and 17(b).)

[redacted]

Disadvantages:

The disadvantages are the same as those listed under R-F bridge (direct method) except that in the substitution method it is unnecessary to make a power factor balance.

(c) Q meter method

Advantages:

(1) The equipment is light and compact.
(2) Measurements are readily accomplished.
(3) Small variations in antenna capacitance do not interfere greatly with the measurements.

Disadvantages:

(1) The accuracy of measurement is lower than with the bridge method, especially for low and high resistance antennas.
(2) Static decreases the accuracy of the measurements.
(3) The Q meter is partially grounded through the supply leads so that measurements against counterpoise cannot be made with any degree of accuracy.

(d) Low power oscillator loosely coupled to a tank circuit.

Advantages:

(1) The tank circuit need not be grounded, hence measurements of antenna against counterpoise can be made.
(2) Small variations in antenna capacitance do not interfere greatly with the measurements.

Disadvantages:

(1) The ease of operation is less than the r-f bridge or Q meter methods.
(2) Static interferes with measurements.
(3) Accuracy is not of a high order, especially for low and high resistance antennas.
(4) In general, bulky apparatus is required.

(e) High power oscillator loosely coupled to a tank circuit.

Advantages:

(1) The errors due to static can be reduced or removed by making the signal many times greater than the static level.

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(2) The tank circuit need not be grounded.
(3) Small variations in antenna capacitance do not interfere greatly with the measurements.

Disadvantages:

(1) The equipment is generally bulky and only semi-portable.
(2) Not easy to operate.
(3) Accuracy is not of a high order, especially for low and high resistance antennas.

19. During the course of the investigation herein described, measurements were attempted by the various methods outlined above. In general, however, it was found that the most satisfactory results and the highest order of accuracy was obtained by means of the radio frequency bridge used in the substitution method. The measurements illustrated in the following paragraphs of this report were made by means of the r-f bridge used in the substitution method.

POWER CONSIDERATIONS

20. During the past few years a considerable amount of theoretical and experimental work has been carried on at the Naval Research Laboratory with a view of obtaining a better understanding of the various factors involved in the operation of restricted intermediate frequency antenna systems similar to those employed on Naval vessels. In general, field strengths, radiated power, power input into the antenna system and the power loss in the loading coil were calculated from measured capacitance and resistance values of the antenna, the radiation resistance of the antenna, the measured resistance of the antenna loading coils and curves for the propagation of radio waves. Some experimental tests had been conducted but no thorough investigation as to the validity of all these calculations had been undertaken. In order to substantiate these calculations in a definite manner and at the same time obtain additional information on trunks and specific transmitters, a comprehensive investigation was undertaken.

21. A number of different antenna systems were used in order to show the effect of antenna height and frequency upon the voltages engendered in the antenna system, the radiated power, field strength, the size of trunk required and the safe operating potentials which a Model TAQ-5 transmitter could withstand.

22. In the following paragraphs of this report the terms "antenna system" and "antenna" are defined as follows:

(a) "Antenna System" includes the lead from the antenna terminal of the transmitter to the trunk, the trunk (when a trunk is used), the vertical portion of the antenna and the flat top portion of the antenna.

(b) "Antenna" includes only the vertical element of the antenna and the flat top portion; i.e., vertical radiator and flat top loading.

23. The terms "Antenna System Current" and "Antenna Current" are defined as follows:

(a) "Antenna System Current" - The r-f current as measured at the antenna terminal of the transmitter.

(b) "Antenna Current" - The r-f current as measured at the base of the vertical element of the antenna.

24. At intermediate frequencies the radiation from the flat top portion of the antenna is negligible and is neglected. However, the flat top does have an effect upon the radiation resistance of the vertical element. At the same time the flat top increases the antenna capacitance, which is a very desirable condition as will be shown later. (A more detailed discussion of these factors will be found in reference (e).)

25. As stated above, various antenna systems were studied during the course of this investigation. Essentially, six different antenna systems were used, as follows:

(a) 13 ft. lead-in; 65 ft. vertical; 95 ft. flat top.
(b) 13 ft. lead-in; 95 ft. vertical; 95 ft. flat top.
(c) 13 ft. lead-in; 125 ft. vertical; 95 ft. flat top.
(d) 13 ft. lead-in; 66 ft. trunk; 65 ft. vertical; 95 ft. flat top.
(e) 13 ft. lead-in; 66 ft. trunk; 95 ft. vertical; 95 ft. flat top.
(f) 13 ft. lead-in; 66 ft. trunk; 125 ft. vertical; 95 ft. flat top.

The minimum frequency at which each of the above antenna systems could be resonated by the XTAQ-5 transmitter was determined. These data are tabulated below:

Antenna System	Minimum Frequency kc
1	244
2	232
3	222
4	190
5	182
6	176

26. The location at which these experiments were performed is illustrated in Plate 46 and a photographic view of the transmitting location is shown in Plate 48. The trunk used in the experiments was 66 feet long and was constructed of 26 gauge galvanized iron, 18 inches in diameter. The inner conductor consisted of a 3/4 inch diameter copper tube. General views of the trunk installation are shown in Plates 48 and 49. The small circular openings along the trunk were provided to permit visual observation of the interior in order to determine whether visual corona or arcing existed and to permit cleaning of the insulators. The inner conductor was supported by means of isolantite insulators eight inches long and of one inch square cross section. The fittings by means of which the conductor was secured to

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the insulators were cast aluminum caps designed in the form of corona shields. Precautions were observed to provide smooth surfaces, free from burrs and filings and all edges were rounded. Plate 53 illustrates the form of construction used. The antenna conductors consisted of 5/16" diameter bronze cable and special fittings were devised so that the length of the vertical element could be changed from 65 feet to 95 feet and 125 feet. Special care was taken in the construction of the antenna to prevent corona from occurring. The antenna was supported by means of a messenger cable between two 200 foot steel towers, the bases of the towers being grounded. Manila lines were used to suspend the antenna from the messenger cable and 18 inch isolantite insulators were used between the antenna conductor and the suspension lines. The base of the antenna terminated 8 feet above the ground approximately 2 feet distant from the building which housed the transmitter. (See Plates 48 and 49.) The base of the antenna could be connected either to the trunk or by means of the 13 foot lead-in, to the antenna terminal of the TAQ-5 transmitter. This lead-in terminated at the wall of the building in a large pyrex entrance insulator provided with corona shields. When the trunk was used, the 13 foot lead-in was brought out of an open window and connected to the input terminal of the trunk. The lower 22 feet of the vertical section of the antenna was shielded by the transmitter building, which is a reinforced concrete structure. A large quantity of heavy copper strips, securely bonded together, are imbedded in the walls and under the footings of the transmitter building. The average spacing of the antenna from the building was about 4 feet. The block diagram shown in Plate 47 illustrates further the arrangement of the equipment used.

27. General test procedure. The general purpose of the experiments was to determine the following:

(a) Determine the voltage breakdown of the trunk system.

(b) Determine the safe operating characteristics of the Model XTAQ-5 transmitter when operating into antennas of the dimensions outlined above.

(c) Determine the agreement between calculated and measured values of field strength.

(d) Determine the distribution of the r-f power generated in the transmitter; i.e., the magnitude of the losses dissipated in the various portions of the circuit and the useful power radiated.

The transmitter was carefully adjusted for operation in connection with a certain antenna. The power amplifier plate current and the plate voltage were set at definite values and these values were maintained the same when working into the various antenna systems. The settings of the various tuning controls on the transmitter were recorded and the transmitter antenna current and the current at the base of the antenna were noted and recorded when possible. Field strength determinations were made at the location indicated in Plate 46 (at No. 1 Compass House). The transmitter was then shut down and the constants of the transmitting antenna were measured. This procedure was repeated

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at a number of frequencies for the six different antenna systems.

28. The resistance and capacitance of the antenna systems were measured by means of the radio frequency bridge used in the substitution method. The measurements were made at the transmitter end of the lead-in and care was exercised to keep the leads used as short as possible. The antenna constants were measured immediately before or immediately after a series of transmissions. Since it is possible for the antenna constants to vary from day to day, due to weather and atmospheric conditions, this procedure was adopted in order to reduce errors to an experimental minimum. The resistance and capacitance of the six different antenna systems, as a function of frequency, are plotted in the curves shown in Plates 1, 2, 3, 5, 6, and 7. The antenna systems may be divided into two classes, one when the 66 foot trunk is used and the other when the trunk is not used. In either case a 13 foot lead connects the antenna terminal of the transmitter to either the trunk or to the base of the vertical element of the antenna.

29. For the three antenna systems where no trunk is employed, the antenna resistance increases with frequency, starting at a value of about 1.7 ohms at 250 kilocycles. See Plates 1, 2, and 3. The antenna resistance increases only slightly with antenna height at 250 kilocycles. The larger increase in antenna resistance noted at 565 kilocycles, as the antenna height is increased, is primarily due to an increase in radiation resistance. For the three antenna systems where the 66 foot trunk is used, an antenna resistance of about 0.9 ohm is obtained at 200 kilocycles and the resistance increases with an increase in frequency. It will be observed that at 200 kilocycles, the resistance is about the same for the three antenna heights, but at 565 kilocycles, the antenna resistance shows a considerable increase in value due to the increase in radiation resistance.

30. The radiation resistance of the three different height antennas, without trunk, is shown in Plates 1, 2, and 3 as a function of frequency. The radiation resistance is calculated at the base of the vertical element and the partial shielding of the antennas by the transmitter building is taken into account in performing these calculations. This partial shielding of the antenna by the building is important and will be discussed in detail later in this report. The gain in radiation resistance with antenna height is shown clearly in Plate 9. This increase in radiation resistance, both with frequency and antenna height, is also emphasized in Plates 23, 24, 25, and 26, which show the radiated power in watts. From Plates 1, 2, and 3 it is seen that the radiation resistance is a small fraction of the total antenna resistance. The radiation efficiency of the antenna is:

$$\frac{\text{Radiation resistance x 100}}{\text{Antenna resistance}} \%$$

This gives the percentage of the power into the antenna that is actually radiated. From the curves in Plates 1, 2, and 3 it is evident that the antenna efficiency increases rapidly with both antenna height and frequency. The antenna efficiency for a number of frequencies is tabulated below:

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Antenna System (*)	Frequency kc	Radiation Efficiency of Antenna System
1	250	7%
1	400	16
1	565	21
2	250	17
2	400	36
2	565	39
3	250	29
3	400	55
3	565	60

(*) See paragraph 25 above for description of antenna systems referred to.

31. The antenna efficiencies in the above table were computed from the radiation resistance as calculated at the base of the antenna and the antenna resistance as measured at the end of the 13 foot lead-in. The antenna resistance should have been measured at the base of the antenna to provide the greatest degree of accuracy. (This was not done due to physical difficulties.) The antenna resistance measured at the base of the antenna would be slightly higher than the values used and thus the actual antenna efficiency is slightly less than the values given.

32. The following procedure was followed in determining the resistance of the antenna loading coil. After all the field strength measurements were completed, the coupling lead between the antenna loading coil and the power amplifier circuit was disconnected. The antenna terminal of the transmitter and the r-f ground end of the antenna loading coil were then connected to the coil terminals on the Q meter. The antenna tuning controls on the XTAQ-5 transmitter were set to the positions which had been recorded for a particular antenna and frequency. The Q meter was set to the same frequency and the Q of the antenna loading coil measured. From the Q and capacity readings, the r-f resistance of the antenna loading coil was computed. Thus, from a series of Q meter measurements, the antenna loading coil resistance was calculated for all the antenna systems and for all the frequencies used during the tests. The loading coil resistance is plotted as a function of the frequency for the six antenna systems in Plates 1, 2, 3, 5, 6, and 7 as curve No. 3. The antenna loading coil resistance decreases as the frequency increases. The minimum frequency to which the transmitter would resonate the 65 foot vertical antenna (no trunk) was 244 kilocycles. At this frequency the antenna loading coil resistance is greater than at 250 kilocycles. If lower frequencies were to be used, the inductance of the antenna loading coil would have to be increased and this would increase the resistance of the loading coil at all frequencies. The same statements apply, within limits, to the other five antenna systems.

33. Since the antenna loading coil is effectively in series with the antenna system, the same current flows in both the antenna loading coil and the antenna system. This current is measured at the antenna terminal of the transmitter and is called the antenna

system current. Thus, if the antenna system current were known, the power fed into the antenna system and the power lost in the antenna loading coil could be computed.

34. The percentage of the power amplifier tank power that is fed into the antenna system is:

$$\frac{R_A \times 100}{R_A + R_L} \% \qquad (1)$$

The percentage of the total power lost in the antenna loading coil is:

$$\frac{R_L \times 100}{R_A + R_L} \% \qquad (2)$$

Where R_A is the resistance of the antenna system and R_L is the resistance of the antenna loading coil.

35. Thus to limit the power loss in the antenna loading coil the antenna loading coil resistance must be low compared to the antenna system resistance. When the two resistances are equal, one-half of the power amplifier tank power is dissipated in the antenna loading coil. A study of curves No. 1 and 3 in Plates 1, 2, 3, 5, 6, and 7 shows that the antenna loading coil losses are greater than the antenna system power for the low frequencies and that the antenna loading coil losses are less than the antenna system power for the high frequencies. The frequencies at which the antenna system power is equal to the power dissipated in the antenna loading coil is tabulated below for the six different antenna systems used during the investigation.

Antenna System *	Frequency at which antenna system power equals antenna loading coil power loss	See Plate
1	470 kilocycles	1
2	380	2
3	330	3
4	450	5
5	420	6
6	340	7

36. At 250 kilocycles the percentage of the power amplifier tank power lost in the antenna loading coil is given in the following table for the six antenna systems investigated.

Antenna System*	Percentage of P.A. tank power lost in antenna loading coil at 250 kc
1	69%
2	63%
3	61%
4	72%
5	66%
6	63%

* See paragraph 25 above.

[redacted]

37. The percentage of the power amplifier tank power lost in the antenna loading coil can be computed from Equation (2) for any of the six antenna systems (Curves No. 1 and 3 in Plates 1, 2, 3, 5, 6, and 7). Thus, if the resistance of the antenna system and the resistance of the antenna loading coil are known, considerable information is easily computed. The antenna system power and the antenna loading coil power loss are discussed in paragraphs 40 and 41.

38. In Plate 4 the capacitance of the three antenna systems where no trunk is used is given as a function of the frequency. There is a marked gain in antenna system capacity with antenna height. This increase in antenna capacity with antenna height decreases the amount of antenna loading inductance required to resonate the antenna. The less the antenna loading inductance the less the resistance of the loading coil which in turn will decrease the power lost in the antenna loading inductance.

39. In Plate 8 the capacity of the antenna system is given as a function of the frequency for the three antenna heights when using the 66 foot trunk. The capacity of the antenna alone is also given as a function of the antenna height. Both sets of curves show the increase in capacity with increased antenna height. Curves No. 4, 5, and 6 in Plate 8 show that the capacity per foot of antenna is 2.1 micromicrofarads. This, of course, refers to the low frequencies where the static capacity is about equal to the r-f capacity. Thus for short antennas in the clear, the figure 2.1 micromicrofarads per foot can be used as a rule of thumb method for obtaining the antenna capacity, if the antenna wire is about 5/16 inch in diameter (e.g., the above value should not be used for a 2 foot diameter cage). For short antennas near the ground, the antenna capacity may be as high as 2.5 micromicrofarads per foot for a 5/16 inch cable.

40. As pointed out in paragraph 33 above, the antenna loading coil is in series with the antenna system and the same current flows through both. The power lost in the antenna loading coil is equal to

$$I^2R_L \tag{3}$$

The power supplied to the antenna system is

$$I^2R_A \tag{4}$$

The power delivered by the power amplifier tank is equal to the sum of the power lost in the antenna loading coil and the power supplied to the antenna system, and is

$$P = I^2\ (R_L + R_A) \tag{5}$$

where P is the power amplifier tank power and I is the antenna system current. R_L is the resistance of the antenna loading coil and R_A is the resistance of the antenna system.

41. The power amplifier tank power P is greater than the nominal power rating of the transmitter because the power lost in the antenna loading coil is not included in this rating. The antenna

system power may be divided into a number of parts. Part of the antenna system power is dissipated in the lead-in; part in the trunk (if a trunk is used); part in the ground and dielectric losses and a part is radiated. If three of the quantities in Equation (5) are known, then the fourth can be computed. For example, if P, R_L and R_A are known, then the antenna system current can be calculated.

42. In Plates 10 to 15 inclusive, the power lost in the antenna loading coil and the antenna system power are given as a function of the frequency for the six different antenna systems. The points were calculated from the antenna system resistance, loading coil resistance and the antenna system current by Equations (3) and (4). The antenna system current or the current at the antenna terminal of the transmitter was not measured directly because no commercial r-f ammeters were available which would measure r-f currents of 40 amperes at r-f potentials as great as 40,000 volts. The transmitter antenna current was measured; this is the current in the ground side of the antenna loading coil. A study of the acceptance test data of the XTAQ-5, as contained in reference (g), indicated that the antenna system current is about 86% of the current as read on the transmitter antenna r-f ammeter.

43. The curves in Plates 10 to 15 inclusive were calculated from the power amplifier tank power, the antenna system resistance and the antenna loading coil resistance by Equation (5). The power amplifier tank power was taken as the average value of the 35 sets of measurements shown in Plates 10 to 15. The points do not fall upon a smooth curve. The plotted points may be in error due to the following causes:

(a) The transmitter could be tuned and adjusted with a high degree of care and accuracy, but a check sometime later would indicate that a falling off in tank power had occurred. This would result in a lower average value of tank power. Differences of this nature would have but small influence upon practical communications, but would introduce a source of error in the precise measurements which were being attempted during the course of this investigation.

(b) Errors in measuring the antenna system resistance.

(c) Errors in measuring the antenna loading coil resistance.

(d) Errors in measuring the antenna system current.

The last three sources of error will average out over a series of measurements.

44. Certain fundamental facts can be observed from Plates 10 to 15, inclusive.

(a) For a given antenna system and transmitter, the frequency at which the power lost in the antenna loading coil equals the antenna system power, decreases as the antenna height increases.

(b) For the same antenna, the power supplied to the antenna system is less when the trunk is used; i.e., the antenna loading coil power losses increase with the increase in length of the trunk. (Compare Plates 10 and 13; 11 and 14; and 12 and 15.)

(c) The higher the antenna the more power that is supplied to the antenna system.

(d) The antenna loading coil losses always decrease with frequency for any antenna system.

(e) The power supplied to the antenna system increases with frequency.

45. As previously pointed out, the power amplifier tank power is equal to the sum of the power lost in the antenna loading system and the power supplied to the antenna system. The power amplifier tank power is given in line 31 of Tables 2, 3, 4, 5, 6, and 7, or can be obtained by adding the antenna system power and the power lost in the antenna loading coil as presented in Plates 10 to 15, inclusive. In Plate 16, the power amplifier tank power is plotted as a function of the test number (from 1 to 35) from the data appearing in line 1 of Tables 2, 3, 4, 5, 6, and 7. The average value of the power amplifier tank power as computed from the 35 measurements is 1770 watts. During these tests the transmitter was operated at 62% of full power to avoid potential breakdowns. The average deviation from 1770 watts is less than 10%. The power amplifier tank power as computed from the acceptance test data of reference (g) for full power operation is 3100 watts. The input power to the power amplifier tank under full power conditions, E_p 2250 and I_p 2 amperes, is 4500 watts. The power amplifier tank power as calculated from the average value of line 31 in Table 8 is 3090 watts. Here the transmitter was operated at full power input of 4500 watts to the power amplifier. Thus it will be seen that there is excellent agreement between the power amplifier tank power as calculated from the acceptance test data and the data obtained during this experimental investigation. During the acceptance tests of the transmitter, dummy antennas were used and the resistance of these dummy antennas was generally several times the resistance of the loading coil; hence the losses in the loading coil did not reach excessive values. The resistance of a dummy antenna can be measured with a higher degree of accuracy than the resistance of an actual antenna and thus the power amplifier tank power could be determined with a high degree of accuracy.

46. The conversion efficiency of the power amplifier, as determined from the acceptance test data, is

$$\frac{3100 \times 100}{4500} = 68.9\%$$

when operating at full power. The actual conversion efficiency is slightly greater than this value due to small power losses in the power amplifier tank circuit.

47. From Plate 16 it was determined that the average power amplifier tank power during these tests was 1770 watts. The input to the power amplifier was 2800 watts, or 62% of full power. The conversion efficiency under these conditions is

$$\frac{1770 \times 100}{2800} = 63.2\%$$

As discussed later in paragraph 66 and as shown in Plate 29, the power amplifier conversion efficiency at 2800 watts input to the power amplifier is the same, within experimental limits of error, as when operating at 4500 watts power amplifier input. Thus the power amplifier tank power for an input of 2800 watts should be approximately 68.9% of 2800 or 1920 watts. Therefore, it will be seen that the average measured power amplifier tank power of 1770 watts is about 8% low. This disagreement is largely due to the reason discussed in paragraph 43(a) above. However, this difference of 8% is not considered excessive when the possibility of errors from a large number of sources is taken into account. In general, the degree of accuracy obtainable in r-f power measurements, when made under controlled laboratory conditions, is considered to be approximately 5%.

48. Thus it can be concluded that the power amplifier tank power of the Model XTAQ-5 transmitter is about constant for all frequencies within the range of operation and for all antenna systems if the input power is kept constant. Thus, if the resistance of the antenna system and the resistance of the antenna loading coil are known, it is possible to calculate the antenna system current by Equation (5) as accurately as it can be measured. The resistance of the antenna loading coil can be measured at all frequencies for all values of inductance and thus, if the antenna capacity is known, the resistance of the antenna loading coil can be determined from a set of curves. Therefore, only the antenna resistance and capacitance are necessary in order to calculate the antenna current at the output terminal of the transmitter.

49. <u>Power supplied to the antenna system</u>. The power supplied to the antenna system is either lost in some point of the antenna system or it is radiated. A comparison of the curves for the power supplied to the antenna system, Plates 10 to 15 inclusive, and the power radiated, Plates 23 to 26 inclusive, shows that the radiation efficiency of the antenna systems may be very low, particularly when short antennas are used at the lower frequencies. Power may be lost in the lead-in, in the trunk (if a trunk is used) and in the loss resistance of the antenna.

50. <u>Power loss in lead-in</u>. The power lost in the lead-in is due to conductor loss and dielectric loss in the dielectric adjacent to or surrounding the conductor. It was determined that the conductor loss in the 13 foot lead-in used in these experiments varied between approximately 10 and 20 watts when the XTAQ-5 transmitter was operating at 62% of full power into the different antenna systems at various frequencies. There is indirect evidence to show that the dielectric

loss in the lead-in was many times the conductor loss. The lead-in carried high current, was at very high r-f potentials and was within 15 to 20 inches of a re-inforced concrete wall. A large volume of dielectric in a strong electric field may produce relatively high power losses. However, the dielectric loss in the lead-in is only a small portion of the total power amplifier tank power and in actual shipboard installations where the majority of the surrounding objects are of high conducting metal, dielectric losses will be practically negligible .

51. Power loss in trunks. Power losses in trunks may be produced by the following factors:

(a) Conductor losses.
(b) Dielectric losses.
(c) Losses due to corona.
(d) Indirect losses due to trunk.

These separate losses are discussed in some detail below.

52. Conductor losses in trunks. The expression presented as Equation (5) on page 6 of reference (f) gives the conductor power loss in trunks at intermediate frequencies and may be applied if the trunk is less than 500 feet long and the antenna is not over one-eighth wave length. From Equation (15) of the appended mathematical note, the following simplified formula for the conductor loss in a trunk is derived:

$$P = rL/3\ (I^2 + I\ I_1 + I_1^2) \qquad (6)$$

where

I is the current at the transmitter end of the trunk.
P is the power in watts.
r is the resistance per foot of trunk.
L is the length of the trunk in feet.
I_1 is the current in amperes at the base of the antenna.

The above formula is not as accurate as Equation (5) of reference (f), but for trunks that are not over 100 feet long it is sufficiently accurate for practical purposes. Conductor losses in the trunk used during these experiments were calculated by both of the above methods and good agreement was obtained. It was found that the conductor loss in the 66 foot trunk used with the various antennas and at the various frequencies employed in these experiments, varied between 15 and 40 watts when the XTAQ-5 transmitter was operating at 62% of full power.

53. Dielectric losses in trunks. It has been determined that the dielectric loss per cubic centimeter of isolantite is proportional to the frequency and the electric field. At 200 kilocycles, the power

[redacted]

loss in isolantite at 1000 volts per centimeter was found to be 1.7×10^{-3} watts per cubic centimeter. The general formula for the power loss in a stand-off insulator in a trunk is derived in Equation (18) of the appended mathematical note. The power loss in such an insulator is

$$P = A\,E_p \text{ watts} \tag{7}$$

where

- P is the power loss
- A is the cross-sectional area of the insulator in square centimeters.
- E is the r-f potential in RMS kilovolts across the insulator.
- p is the power loss in watts per cubic centimeter of isolantite for an electric field of 1000 RMS volts per centimeter.

For the 65 foot vertical antenna with the 95 foot flat top at 200 kilocycles, the potential E is 26,600 RMS volts (see Table 3). The area A of the insulators was 6.45 square centimeters. The power lost per insulator is 0.3 watt. Since there were 23 insulators used in the trunk, the total dielectric loss from this source was about 7 watts. This was the maximum dielectric loss in the trunk for the various antennas used during the tests.

54. Losses due to corona. In the foregoing calculations, it is assumed that there was neither corona nor arcing within the trunk. If corona does exist within the trunk, the losses will be very high, as illustrated in Table 9 attached hereto. As previously stated, the power amplifier tank power of the Model XTAQ-5 transmitter is approximately 3100 watts at full power operation. The calculated power amplifier tank power shown in line 31 of Table 9 is of a much lower value. The difference between 3100 watts and the values shown in Table 9 is approximately equal to the power loss occasioned by corona. Therefore, the losses due to corona were as high as 700 to 900 watts under these particular conditions. Attention is invited to the fact that this corona existed without actual breakdown or arcing occurring in the trunk.

55. Indirect losses due to trunk. It was not practicable to make antenna resistance measurements at the time of the field strength measurements. (The antenna resistance refers to the resistance at the base of the vertical radiator.) This antenna resistance could be calculated indirectly from other measurements. Thus, although the antenna current is known, the antenna power cannot be calculated directly in this case. However, the major part of the antenna system power must be supplied to the antenna if corona does not exist in the trunk. Thus, for safe operation of the transmitter, the losses in the trunk are very small and the lead-in losses can be made very small if the lead-in is short and if the volume of bad dielectric near the lead-in is small. Although the power lost in the trunk may be vanishingly small, it cannot be concluded that the radiated power with and without the trunk is the same.

[redacted]

The trunk and lead-in shunt part of the antenna system current to ground. Thus the current in the antenna loading coil is greater than the antenna current. Therefore the antenna loading coil losses are greater with the trunk and the power supplied to the antenna is less. This is shown in Plates 10 to 15 inclusive.

56. Calculation of current at the base of the antenna. When no trunk was used, only the transmitter antenna current was measured for the reasons given in paragraph 42 above. Thus the current at the base of the antenna had to be calculated. From the measurements which were made, it was possible to calculate the antenna current by three different methods.

Method I. The current at the base of the antenna may be computed by the following formula:

$$I_2 = \frac{C_a}{C_A} I \tag{8}$$

where
- I is the antenna system current
- I_2 is the antenna current
- C_a is the antenna capacity (given in curves 4, 5, and 6 of Plate 8)
- C_A is the antenna system capacity (given in Plate 4)

Method II. At 28% of full power, both the transmitter antenna current I_6 and the antenna current I_7 were measured. Then the antenna current at 62% of full power is:

$$I_3 = \frac{I_7}{I_6} I_8 \tag{9}$$

where

I_8 is the transmitter antenna current at 62% of full power.

Method III. When using the trunk, both the antenna current I_1 and the field strength S_1 were measured. When using the same height antenna, without trunk, the field strength S_2 was measured. Therefore, the antenna current, when no trunk is used is:

$$I_4 = \frac{S_2}{S_1} I_1 \tag{10}$$

57. Comparison of results by Methods I, II, and III. The curves in Plates 17, 18, and 19 give the antenna current as computed by the three methods as a function of the frequency for the three antenna heights. The agreement among the values arrived at by the three different methods is as good as can be expected when consideration is given to the accuracy with which some of the measurements could be made. Since the accuracy of the three methods is about the same, the antenna current I_9 is:

$$I_9 = 1/3\ (I_2 + I_3 + I_4) \tag{11}$$

[redacted]

When the trunk was used, the antenna current I_1 was measured. The antenna current can be computed from the following formula:

$$I_5 = \frac{C_a}{C_A} I \qquad (12)$$

where
- I_5 is the computed antenna current
- C_a is the antenna capacity (curves 4, 5, and 6 of Plate 8)
- C_A is the antenna system capacity (curves 1, 2, and 3 in Plate 8)
- I is the antenna system current.

The measured current and the current computed by Equation (12) are plotted as a function of the frequency for the three antenna heights in Plates 20, 21, and 22. It will be noted that good agreement exists between the measured and computed antenna currents, indicating that the current may be calculated with about the same degree of accuracy as it is possible to measure this value.

58. Determination of radiated power. The radiation resistance R of the partially shielded antennas is given as a function of frequency in Plate 9. The radiation resistance is referred to the base of the antenna. The radiated power, in watts, is:

I_9^2R when the trunk is not used

and

I_1^2R when the trunk is used.

In Plate 23, with the transmitter operating at 62% of full power, the radiated power is plotted as a function of the frequency for the three different antenna heights when no trunk was used. The average gain in radiated power, in the frequency band of 250 to 565 kilocycles, obtained by increasing the antenna height from 65 feet to 95 feet is 123%. A gain of 349% is obtained by increasing the antenna height from 65 feet to 125 feet. Thus by increasing the antenna height by 30 feet, or about 50%, the radiated power is more than doubled and by approximately doubling the antenna height, the radiated power is more than quadrupled.

59. Radiated power as a function of antenna height at frequencies of 250 and 400 kilocycles is plotted in Plate 24, when the trunk was not used. For purposes of comparison, data in connection with a 180 foot vertical antenna carrying a 200 foot flat top are included. The curves show that the radiated power increases with antenna height at a rapid rate up to antenna heights of 180 feet. The power radiated by the 180 foot vertical with the 200 foot flat top is 18.6 times the power radiated by the 65 vertical antenna with the 95 foot flat top.

60. In Plate 25 the radiated power is plotted as a function of the frequency for three antenna heights when using the 66 foot trunk. The transmitter was operated at 62% of full power. The increase in

radiated power with frequency is clearly illustrated by these curves. For example, the power radiated by the 65 foot vertical antenna at 565 kilocycles is 8.5 times the power radiated at 200 kilocycles. The average gain in radiated power over the frequency band of 200 to 565 kilocycles by increasing the antenna height from 65 feet to 95 feet is 232% and the gain obtained by increasing the antenna height from 65 feet to 125 feet is 568%.

61. In Plate 26 the radiated power is plotted as a function of the antenna height for a number of frequencies when the 66 foot trunk is used. The rapid decrease of radiated power with decrease in antenna height at all frequencies is vividly illustrated. From the curves it appears that the radiated power would be nearly zero for antenna heights of 40 feet.

62. As previously stated, during these tests the transmitter was operated at 62% of full power, which was the maximum power at which voltage breakdowns would not occur in the transmitter when operating with the 65 foot antenna. Under these conditions the power amplifier tank power was at least 1770 watts. The difference between the power amplifier tank power and the radiated power is the r-f power which is dissipated in the antenna loading coil and in the antenna system. The results of this investigation reveal that the radiated power may be as low as one-half of one percent (0.5%) of the power amplifier tank power. This extremely low efficiency is encountered when operating into short antennas at the low end of the frequency band, and under such conditions as much as 99.5% of the power amplifier tank power is lost.

63. The above data on radiated power have been calculated from the radiation resistance and the antenna current. In paragraph 83 below the agreement between the measured field strength and the field strength calculated from the radiated power is discussed. The agreement between the calculated and measured field strengths is such as to convince one that the calculated radiated power must be fairly accurate.

VOLTAGE CONSIDERATIONS

64. In addition to the power considerations which have been discussed in the previous paragraphs of this report, the antenna voltage, the trunk voltage and the potentials existing in the transmitter unit are factors of the utmost importance. Proper precautions must be observed to avoid damage due to destructive arcing or serious losses due to corona. For example, it was found that a No. 8 wire could not be used for the antenna as corona occurred at various points along the wire, due to the small diameter. The power loss due to visual corona may assume serious proportions, as pointed out in paragraph 54 above. Therefore, precautions must be exercised to insure that the transmitter, the trunk and the antenna are designed to withstand the maximum potentials which are likely to be encountered. When the length of the antenna system is a small fraction of a wave length, as is the case for shipboard antennas in the region of 200 kilocycles, the potential at all points along the antenna system is about the same. This is illustrated in the following table, which was compiled from data obtained with the Model XTAQ-5 transmitter operating at 62% of full power.

(1)	(2)	(3)
Antenna* System	Peak Voltage at Transmitter	Peak Voltage at Antenna End of Trunk
4	37,500	39,000
5	34,100	36,200
6	30,600	31,400

(*) See paragraph 25 above for description of antenna systems.

The potentials at the end of the antenna are slightly higher than the values listed under column (3) of the above table. During the course of the tests it was observed that the corona did not show any distinct preference for the antenna end of the trunk, indicating that the potentials at various points along the trunk did not vary appreciably. The difference in potentials as listed in columns (2) and (3) above may be partially due to experimental errors.

65. The potential at the antenna terminal of the transmitter was calculated from the antenna system current, the antenna system capacity and the frequency. In Plates 27 and 28 the antenna system voltage, trunk voltage or antenna voltage, is plotted as a function of the frequency for the three antenna heights, with and without the 66 foot trunk. During these tests the transmitter was operated at 62% of full power. The antenna system voltage increases as the height of the antenna is decreased, for a given frequency. This is true whether a trunk is or is not used. Reference to the curves reveals that the transmitter can be resonated to a lower frequency with a trunk than without a trunk, when a given antenna is used. The antenna system voltage, however, is approximately of the same value in both instances; however, the frequency is lower in the case where the 66 foot trunk was used. At the same frequency, the antenna system voltage will be much lower when the trunk is used.

66. In line 38 of Table 8 the peak antenna voltage was calculated from the antenna system capacity, the antenna system current and the frequency while the Model XTAQ-5 transmitter was operating at full power into the 125 foot antenna system with 95 foot flat top and without the trunk. If one assumes that the power amplifier conversion efficiency is the same at 62% of full power, then the full power antenna system peak voltage can be computed from the 62% measurements. This computation was performed by multiplying the 62% values of antenna system peak voltage, appearing in line 37 of Table 6 by the square root of 100/62 to give the antenna system peak voltage at full power. Line 38 of Tables 2, 3, 4, 5, 6, and 7 were calculated by this method. In Plate 29 the antenna system peak voltage is plotted as a function of frequency for antenna system No. 3. One set of points was computed from the full power measurements, line 38 of Table 8, and the other set of points from the 62% measurements of line 38 of Table 6. Both sets of points fall on the same curve; hence it may be assumed that the conversion efficiency of the power amplifier is approximately the same at 62% of full power as at full power. This agreement appears to justify the translation of the 62% values to full power values.

67. In Plates 30 and 31 the antenna system peak voltage for full power operation of the XTAQ-5 transmitter is plotted as a function of the frequency for the six antenna systems used during the tests. For the 65 foot vertical antenna, the antenna system peak voltage may be as high as 47,600 volts, with or without the trunk. It should be noted, however, that this peak voltage does not occur at the same frequency with and without the trunk.

68. During the acceptance tests of the Model XTAQ-5 transmitter it was demonstrated that the equipment was capable of producing the required power when operating into the antenna constants prescribed by the governing specifications. The maximum peak voltage encountered during these tests, as computed from the data contained in reference (g), was 36,200 volts, which occurred at 175 kilocycles when the antenna constants were 1.0 ohm resistance and 1179 micromicrofarads capacitance. The peak antenna voltage encountered during the tests wherein the transmitter was operated at 62% of full power into the 65 foot antenna system, with or without the trunk, was 37,500 volts. These voltages occurred at 200 kilocycles when the trunk was used and at 250 kilocycles when no trunk was employed. Thus it will be seen that the transmitter was actually subjected to over voltage even though the power was reduced to 62% of the full power rating. When the 125 foot vertical antenna and trunk were used, the transmitter could have been operated at about 70% of full power and still remain within the specification limits of antenna voltage. An antenna system on board ship will usually have somewhat lower resistance than a comparable antenna on shore, due to the decreased "ground" resistance. This will result in somewhat increased antenna current and increased antenna potentials. It is believed, however, that this increase will be of no great magnitude due to the limiting action of the antenna loading coil, which results from the fact that at the lower frequencies the resistance of the loading coil is likely to be several times greater than the resistance of the antenna system. (See Plates 5, 6, and 7.)

69. Shortly after starting the experiments, voltage breakdowns occurred within the transmitter unit while operating into the 95 foot vertical, 95 foot flat top antenna system. The trunk was being used at the time. In general, the damage consisted of a burned litz conductor near the top of the loading coil, a blistering of the bakelite form on which the loading coil is wound and arc-overs from the antenna conductor within the transmitter. While operating into the 125 foot antenna, with and without the trunk, several arc-overs were noted within the transmitter, but no permanent damage was observed at the time, although these arcs may have contributed to the failure which occurred later. These troubles were encountered while attempting to operate at the lower end of the frequency range in the vicinity of 200 kilocycles. It should be pointed out that while operating under these conditions, the transmitter was actually subjected to potentials in excess of the voltages which would be encountered if antenna constants in accordance with the specifications under which the XTAQ-5 was constructed had been adhered to.

70. During the course of the measurements the following general observations were made:

(1) Corona would occur at a lower trunk voltage on days of high humidity.

(2) Arcing or voltage breakdown in the trunk started at a lower antenna system voltage on days of high humidity.

(3) Visual corona on the inner conductor of the trunk could exist for several minutes without voltage breakdown occurring.

(4) There seemed to be no preferred points or region at which visual corona would start in the trunk.

(5) Generally, the visual corona would start on the inner trunk conductor between insulators and travel along the inner conductor.

(6) There were times when visual corona started near a corona shield. The corona shields, insulator and inner conductor construction are shown in Plate 53 appended hereto.

(7) No sharp point or rough area was ever found at or near the point where visual corona started.

(8) Visual corona produces ozone.

(9) The presence of corona is indicated by a hissing noise.

(10) Visual corona generally occurs before voltage breakdown.

(11) The presence of visual corona is sometimes indicated by unsteady or fluctuating antenna current.

(12) No voltage breakdown was observed in the trunk after corona shields were applied to all insulators.

(13) The trunk was capable of withstanding higher potentials than the transmitter, but voltages which produced breakdown in the transmitter were capable of causing corona in the trunk.

(14) The potential necessary for corona decreases with an increase in frequency.

71. In Plate 32, the potential gradient at the surface of the inner conductor of the trunk is plotted as a function of the diameter of the trunk for various diameters of inner conductors. The potential

difference between the inner and outer conductor is 1000 volts. For a trunk of 18 inch outer diameter with a 3/4 inch inner conductor, the potential gradient at the inner conductor is 335 volts per centimeter per 1000 volts. During the tests it was observed that visual corona would start at 37,500 volts. This corresponds to a potential gradient at the inner conductor of 12,600 volts per centimeter. Thus, if the potential gradient were in excess of 12,600 volts per centimeter in a trunk with a 3/4 inch inner conductor, visual corona may exist. While every effort was made to provide a smooth surface on the inner conductor of the trunk used during these tests, slightly rough areas may have existed which may have been instrumental in reducing the potential gradient necessary for corona as compared to the gradient which would have to exist on a perfectly smooth and polished conductor. It is believed, however, that the trunk used in these tests had an inner conductor which would compare favorably with the general run of trunk installations on board ship. Hence, from a practical viewpoint a potential gradient of 12,600 peak volts per centimeter at the surface of the inner conductor may be considered an average value at which visual corona will start in trunks with 3/4 inch inner conductors.

72. In Plate 33 the potential gradient necessary for visual corona at 60 cycles, is plotted as a function of the diameter of the inner conductor. Investigations have proven experimentally that the potential gradient necessary for visual corona decreases with an increase in frequency. From this curve the potential gradient necessary for visual corona for a 3/4 inch inner conductor is 40,700 peak volts per centimeter. If moisture were condensed upon the inner conductor the potential necessary for visual corona is reduced to about 12,000 peak volts per centimeter. At 60 cycles the potential gradient necessary for visual corona is not a function of the humidity if the dew point is not reached. (See "Dielectric Phenomena in High Voltage Engineering" by F. W. Peek.) Since, during the observations made, the inner conductor was dry, then 40,700 divided by 12,600 equals 3.25, which is the factor by which the potential gradient at 60 cycles is decreased at 175 kilocycles for average trunks. Applying this factor to a 12 inch trunk with a 3/8 inch inner conductor, it will be seen that 13,800 peak volts per centimeter is the potential gradient necessary for visual corona at 175 kilocycles for an average trunk. From Plate 32, the potential gradient at the inner conductor per 1,000 volts applied to the 12 inch x 3/8 inch trunk is 610 peak volts per centimeter. 13,800 divided by 610 equals 22,600 peak volts, or the maximum corona free voltage that can be applied to a 12 inch trunk with a 3/8 inch inner conductor at 175 kilocycles. During the course of these tests, evidence was noted which indicated that high humidities did have an effect upon the potential gradient necessary to produce corona. Hence, it appears that if the humidity was high or the inner conductor was wet, the maximum corona free voltage would be less than 22,600 peak volts.

73. The maximum corona free voltage at 175 kilocycles for a number of trunks is given in the table below. It is assumed that the humidity is not excessive:

Outside Diameter of Trunk	Inside Diameter of Trunk	Maximum Corona Free Peak Voltage	Capacity per ft. micromicrofarads
18"	1"	45,900	5.83
18"	3/4"	37,500	5.3
18"	1/2"	29,300	4.73
18"	3/8"	25,100	4.37
12"	1"	38,800	6.8
12"	3/4"	33,000	6.1
12"	1/2"	26,400	5.3
12"	3/8"	22,600	4.9
9"	1"	34,000	7.35
9"	3/4"	29,700	6.8
9"	1/2"	25,000	5.83
9"	3/8"	21,000	5.3
9"	1/4"	16,200	4.73

74. It is realized that the data from which the above table was computed are limited and are not based on sound experimental or theoretical considerations of proven value. Hence, the above table should be used with care, especially for design purposes until more data of proven worth are accumulated. However, it is believed that the above method of obtaining the maximum corona free voltage is a step forward and may be used to advantage until more accurate information is available.

75. It is apparent from the above table that the maximum corona free voltage across the trunk depends primarily upon the diameter of the inner conductor; e.g., a 12 inch trunk with a 1 inch inner conductor will withstand a higher potential than an 18 inch trunk with a 3/4 inch inner conductor. The capacity of 66 feet of the 18 inch trunk is 350 micromicrofarads, while the capacity of the same length of 12 inch trunk is 450 micromicrofarads. Thus while the 12 inch trunk is capable of withstanding higher potentials, the increased capacity of the trunk will decrease the radiated power, especially for short antennas.

76. As shown in paragraph 64 above, the antenna system and antenna voltage are about the same. Therefore, the transmitter, the lead-in, the trunk and the antenna itself must all be designed to withstand the same maximum peak potentials. The data obtained during the acceptance tests of the Model XTAQ-5 transmitter and during the course of this investigation, indicate that about 36,000 volts is the maximum peak voltage which this transmitter will withstand without voltage breakdown. If transmitters of this type are to be used with short antennas and trunks for which the antenna system capacity is less than 900 micromicrofarads at 175 kilocycles, the inductance of the antenna loading coil will have to be increased and the insulation of the antenna loading coil and other elements within the transmitter will have to be materially improved. For example, the 65 foot vertical antenna with 95 feet of flat top, operating in conjunction with a 66 foot trunk, has a capacity of 775 micromicrofarads at 175 kilocycles. Thus the inductance of the loading coil would have to

be increased 16% to resonate the antenna at 175 kilocycles. At the same time the insulation of the transmitter and the antenna system would have to be sufficient to withstand at least 50,000 peak volts instead of 36,000 peak volts as at present. Reference to Plate 52, which is a rear view of the Model XTAQ-5 transmitter with shields removed, shows that at present the antenna circuits occupy about 50% of the entire volume of the transmitter. Plate 50 shows the precautions which must be exercised to keep the antenna lead well in the clear and Plate 51, showing a close-up of the antenna load coil, indicates the precautions which must be taken to prevent arcing from connectors, switch parts, etc., by enclosing such parts in corona shields. To increase the inductance of the antenna loading coil 16% and at the same time require the insulation to withstand a 50% increase in voltage, would result in a very decided increase in the space required for the antenna loading coil circuit. Similar precautions would be necessary to insure that sufficient voltage clearances and reasonable potential gradients existed in the entire antenna system.

FIELD STRENGTH CONSIDERATIONS

77. The field strength at any short distance can be calculated from the radiated power for short antennas. If this theoretical value of field strength agrees with the experimentally measured values, then the validity of the theoretical calculations of field strength and radiated power as computed from the antenna constants and the type of transmitter employed, have been substantiated.

78. Plate 46 is a sketch of the area in which the experiments were conducted. As indicated in this sketch, the field strength measurements were made at No. 1 Compass House location which is 505 meters (1650 feet) distant from the transmitting antenna. The majority of field strength measurements were made in connection with the six antenna systems energized by means of the Model XTAQ-5 transmitter operating at 62% of full power. For comparison purposes, however, some measurements were made at 28% of full power and at full power.

79. Field strength measurements were made with a receiver equipped with an electron-ray tube. The receiver was so adjusted that the signal under observation caused the shadow angle to reduce to exactly zero. A Standard Signal Generator was then connected to the input of the receiver and the output of the signal generator was adjusted to again reduce the shadow angle of the electron-ray tube to zero. This method gives only the relative field strength; hence it was necessary to calibrate the equipment in order to obtain the field strength in millivolts per meter. This was accomplished by taking simultaneous measurements by the above described method and by means of standard field strength measuring equipment. All measurements were made at the same location and for all frequencies used during the experiments. Thus the Electron-Ray Tube/Standard Signal Generator equipment was calibrated at one value of field strength for all necessary frequencies. If the field strength is directly proportional to the reading obtained with the standard field strength measuring equipment, it is only necessary to calibrate the Electron-Ray Tube/Standard Signal Generator equipment at one field strength for each frequency.

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80. The antenna current is directly proportional to the field strength, if the antenna is not changed. In Plate 34 the relative field strength is directly proportional to the antenna current or actual field strength. Therefore, the field strength measuring apparatus used for these tests had to be calibrated only as a function of the frequency and not as a function of the field strength.

81. It is also possible to compute the field strength from the radiated power. The radiated power is equal to the square of the antenna current times the radiation resistance. The method of computing the radiation resistance of shielded and unshielded antennas is given in reference (e). The antenna current can be measured directly or may be computed by the methods outlined in paragraphs 40, 56 and 57 above. During this investigation the measured value of antenna current was used in the computations for the antenna systems when a trunk was employed. The antenna current was calculated from Equation (11) of paragraph 57, when the trunk was not used.

82. In Plate 35 the field strength is plotted as a function of the distance for a radiated power of 1 watt. The square root of the radiated power, in watts, times the field strength as read from Plate 35, may be used to calculate the field strength for any given level of radiated power. The field strength can also be computed from the dimensions of the antenna, the dimensions of the shield, if shielding is present, and the antenna current. The two methods are fundamentally the same.

83. During the course of this investigation, the field strengths at No. 1 Compass House were calculated for the two following cases:

(1) The partial shielding of the antenna by the transmitter building was neglected; that is, the antenna was assumed to be in the clear.

(2) The partial shielding of the antenna by the transmitter building was taken into account in the computations.

In Plates 36, 37, 38, 39, 40, and 41 the field strength is plotted as a function of frequency for the six antenna systems. A careful study of the curves in these plates reveals the following facts:

(1) For the 65 foot antennas, with and without the trunk (Plates 36 and 39) the calculated field strength for a partially shielded antenna agrees very well with the measured field strength.

(2) The field strengths as computed from the formulas, neglecting partial shielding of the antenna, are definitely too high for all antenna systems. (Plates 36 to 41)

(3) The computed field strength for partially shielded antennas is about 20% higher than the measured field strength for the 95 foot antennas, with and without the trunk. (Plates 37 and 40)

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(4) The calculated field strength for partially shielded antennas is about 35% higher than the measured field strengths for the 125 foot antennas. (Plates 38 and 41)

It is emphasized that the absolute value (not relative values) of measured and calculated field strengths were plotted in Plates 36 to 41 inclusive.

84. In Plates 42 to 45 inclusive the field strength is plotted as a function of the antenna height for various frequencies. Here again it is clearly evident that the measured and calculated field strength curves diverge as the antenna height is increased. Only the calculated field strengths for partially shielded antennas are shown in these plates because the field strengths that were computed for antennas in the clear were definitely in error. (See Plates 36 to 41 inclusive.)

85. The divergence of the computed and measured field strengths with antenna height, in Plates 42 to 45 inclusive, is believed to be due to neglecting the effect of a non-symmetrical ground system and neglecting the effect of the antenna towers and the messenger cable (steel) between the towers from which the various antennas were suspended. It was assumed in the computations that the earth is a perfect conductor. This assumption is justified for these frequencies if the earth has a finite conductivity and the conductivity is the same in all directions.

86. During the preliminary work in connection with this investigation, it was found that the antenna resistance of a 100 foot vertical antenna operating in conjunction with a metallic stake driven into the ground, was 25 ohms or more at 250 kilocycles. By increasing the conductivity of the ground near the base of the antenna many fold, the ground resistance was reduced to less than 2 ohms at 250 kilocycles. Thus, by decreasing the ground resistance near the antenna, the antenna current and ground currents were increased although the same radiator and the same transmitter were used. The field strength at any point is proportional to the antenna current and therefore the field strength increases as the ground resistance near the antenna is decreased.

87. The low resistance ground area, which was finally selected as the scene of the transmitting experiments, was not symmetrical about the antenna. Thus within a radius R the ground resistance is the same in all directions, but outside a circle of radius R, the ground resistance is still low in some directions but high in others. The shorter the antenna the more rapidly the ground current decreases with the distance from the antenna. Thus, the effect of the non-symmetrical ground was the greatest for the 125 foot antenna, which was the highest antenna consistently used during these experiments.

88. It is shown in Equation (27) of the appended "Mathematical Note" that the field strength is proportional to the ground current. Since there was a smaller area of low resistance ground on the side of the antenna in the direction of the field strength measuring location than on the opposite side of the antenna, the ground current,

and hence the field strength, will be less than the average value at the field strength measuring location, and conversely will be greater than the average value in the opposite direction. As indicated above, the effect of a non-symmetrical ground increases with antenna height and therefore it is to be expected that the measured and computed field strength curves in Plates 42 to 45 inclusive will diverge. The vertical radiators and the 95 foot flat top employed in these tests were supported by a steel messenger cable between the 200 foot towers. As the antenna height increased, the distance between the flat top and the ground messenger cable decreased. Thus the coupling between the flat top and the messenger cable increased with antenna height. This coupling had the tendency to decrease the radiation resistance of the antenna and again one would expect the measured and computed field strengths to diverge with antenna height.

89. If the tests had been carried out under more ideal conditions, or if the corrections indicated in the above paragraphs were carried out quantitatively, it is reasonable to assume that the agreement between the experimental and theoretical curves in Plates 36 to 45 inclusive would be better. In view of the number of possible sources of error in the measurements and possible errors due to the non-symmetrical ground system, and surrounding objects, the degree of agreement which was obtained is considered good.

90. This leads to the important conclusion that if the antenna constants are known, the following quantities can be calculated accurately for any given intermediate frequency transmitter:

(1) Field strength at short distances from the transmitting antenna.
(2) The maximum and minimum expected field strengths at any distance from the transmitter.
(3) The radiation resistance of antennas in the clear.
(4) The radiation resistance of partially shielded antennas.
(5) Potentials existing in the trunk system.
(6) Potentials existing in the antenna system.
(7) Power supplied to the antenna system.
(8) Power lost in the antenna loading coil.
(9) The current flowing into the antenna system.
(10) The current at the base of the radiating portion of the antenna.

Information of this nature should be helpful in estimating the results which will be obtained from contemplated antenna systems as well as from existing transmitting installations.

FACTORS RELEVANT TO PROPOSED TRANSMITTING INSTALLATIONS ON BATTLESHIPS 55 and 56.

91. Many of the results obtained from the foregoing investigation are applicable to the problems which will be encountered in connection with the proposed transmitter and antenna system installations on Battleships 55 and 56. It will be noted that there is close agreement between the dimensions of one of the antenna systems used during

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the above tests and the antenna system proposed for use with Model TAQ transmitters on Battleships 55 and 56.

	Battleship Conditions	Test Conditions
Transmitters:	TAQ-5	XTAQ-5
Length of trunk:	65 ft.	66 ft.
Diameter of trunk:	12 in.	18 in.
Diameter of inner trunk conductor:	1/2 in.	3/4 in.
Capacity of trunk:	345 uuf	350 uuf
Length of vertical antenna:	68 ft.	65 ft.
Length of flat top:	90 ft.	95 ft.
Antenna system capacity:	Approx. same for both conditions.	

92. The battleship antenna referred to above is No. T-7 used in the battle condition; that is, with the after section removed. The addition of this after section will result in some increased efficiency, lower antenna system potentials and lower antenna loading coil losses. However, according to the opinion expressed in paragraph 4 of the Bureau of Ordnance 1st endorsement BB55&56/S1-1(2/112)(T11) of 22 December 1938, it is likely that the transmitter would be required to operate without the assistance of the after section for long periods of time.

93. As pointed out in the above discussion under VOLTAGE CONSIDERATIONS, the Model XTAQ-5 transmitter was capable of withstanding potentials of approximately 36,000 volts. Based on available information, the data indicate that a 12 inch trunk with a 1/2 inch inner conductor will be limited to a potential of approximately 26,400 volts. Hence the contemplated trunk will be incapable of withstanding the voltages generated by the transmitter. Experimental evidence indicates that the trunk in question should be approximately 18 inches in diameter with a 3/4 inch inner conductor. It is realized that trunks of this dimension are objectionable from several viewpoints. Such trunks detract from the armor and gas protection integrity of the vessel and occupy a large volume of valuable space. However, with the restricted antenna dimensions permissible, high r-f voltages will be encountered which cannot be handled by small trunks. It is further noted that the plans of Battleships 55 and 56 indicate that where trunks pass through armor, the diameter of the trunk is made smaller. This restricted area will be the limiting factor as far as voltage breakdown is concerned. Thus, if a 12 inch trunk is arbitrarily reduced to a 9 inch diameter at armor locations, the voltage capability will be reduced from approximately 26,400 volts to 25,000 volts. If any discontinuities in the form of sharp projections, etc., occur at this point, the voltage capabilities will be still further reduced. It appears likely that some method of overcoming these difficulties is feasible. If the inner conductor is increased in diameter, say to 1 inch, at the armor locations where a 9 inch outer diameter is used, the trunk would withstand a potential of approximately 34,000 volts. The transition from one inner conductor diameter to another should be made gradually and smoothly to avoid sharp discontinuities. Furthermore, as pointed out in paragraph 74 above, insufficient data are available at the present time to calculate exact voltages. Further investigation is needed along these lines.

94. As pointed out under POWER CONSIDERATIONS, and particularly as summarized in paragraph 62 above, antennas possessing characteristics similar to those of No. T-7 used under "battle conditions," may possess a radiation efficiency at the lower end of the frequency range of the order of one-half of one per cent (Radiated Power/Power Amplifier Tank Power x 100). At the same time the high potentials encountered prevent operation of the transmitter at full power input and the power must be further reduced to prevent arcing in the trunk system. All these factors cooperate to reduce the radiated power and the consequent field strengths produced to vanishingly small magnitudes.

95. For purposes of information and comparison, the following data are tabulated with respect to the cubical areas necessary for the accommodation of a transmitting installation similar to a Model TAQ-5:

TAQ-5 transmitter unit, complete:	70 cu.ft.
Antenna unit of TAQ-5 transmitter:	35 cu.ft.
Trunk, 65 ft. long, 12 inch OD:	51 cu.ft.
Trunk, 65 ft. long, 18 inch OD:	115 cu.ft.
Motor gener ator and starter:	30 cu.ft.

96. In the proposed plans for Battleships 55 and 56, antenna A-11 is intended for use with a Model TAJ-7 transmitter which is rated at 500 watts in the frequency range 175 to 600 kilocycles. For a part of the distance the lead from this antenna is carried in a section of submarine loop cable. The constants of this antenna were calculated and a dummy antenna simulating these constants was connected to a Model TAJ transmitter through a short section of submarine loop cable. The transmitter was operated at 180 kilocycles. With the transmitter operating at 1/4 of full power antenna voltages in the neighborhood of 10,000 volts were produced. This voltage was sufficient to cause corona on the surface of the submarine cable when a grounded metallic object was placed in contact with the cable. When the transmitter was operated at full power, corona would appear when the metallic object was brought to within one inch of the surface of the cable and arcs three or four inches in length would persist as the metallic object was gradually withdrawn from the vicinity of the submarine cable. Thus it is seen that an unprotected cable of this nature would constitute a distinct hazard if located in areas where personnel could come in contact with it. Additionally, practically all power would be dissipated if any foreign object were permitted to come in contact with the cable.

SUMMARY

97. The results of the investigation herein reported have substantiated to a large degree the validity of the theoretical and empirical work which has been previously submitted in references (b), (c), (d), (e), and (f). In addition to this corroborative data, certain additional data and information have been derived from the tests which present a clearer and more detailed concept of the conditions surrounding the operation of intermediate frequency transmitting installations on board Naval vessels.

98. If the physical and electrical properties of the antenna system are known, then the following quantities can be computed for any given transmitter at intermediate frequencies:

(1) Field strength near the transmitter.

(2) The maximum and minimum expected field strength at any distance from the transmitter.

(3) Radiated power in watts.

(4) Radiation resistance of antennas in the clear.

(5) Radiation resistance of partially shielded antennas.

(6) Voltage at the antenna terminal of the transmitter and in the antenna system, since these voltages are practically the same under the conditions herein considered.

(7) Power lost in the antenna loading coil.

(8) Power supplied to the antenna system.

(9) The antenna system current.

(10) The current at the base of the radiating portion of the antenna.

The methods for calculating the above quantities are discussed in detail.

99. The direct power loss in trunks is negligible, but the use of trunks increases the power losses in other parts of the circuits, such as the antenna loading coil, to a serious degree and thus decreases the radiated power.

100. The capacity of the trunk is more important than the length of the trunk in determining the losses due to trunks; i.e., the radiation efficiency decreases more rapidly with the capacity of the trunk than with the length of the trunk.

101. Factors to be considered in the design and construction of trunks are discussed. It is pointed out that certain additional empirical data must be accumulated in order to clarify all aspects of this problem.

102. When trunks are used, the radiated power increases as the cube of the antenna height. This fact is independent of frequency in the range under consideration (175 to 600 kilocycles).

103. The restricted dimensions of existing and contemplated shipboard antennas possess characteristics of such a nature that transmitters designed in accordance with current specifications may exceed their safe maximum potential limits, if the transmitters are operated at full power. In some instances, safe operating potentials will be exceeded if the transmitter is operated at about 60% of full power.

104. The radiation efficiency at frequencies below 300 kilocycles may be less than 1 per cent; that is, more than 99 per cent of the power amplifier tank power may be lost.

105. The use of short antennas requires the use of larger trunks to withstand the increased r-f potentials. This may give rise to conditions where the cubical area appropriated by the trunk may be twice the cubical area consumed by the transmitter itself. The large diameter of such trunks may seriously affect the integrity of the vessel.

106. The r-f trunk and antenna potential is approximately inversely proportional to the frequency. At 350 kilocycles the trunk voltage is about half the voltage encountered at 175 kilocycles.

107. A general discussion on the methods of measuring antenna constants is included. The advantages and disadvantages of several methods are briefly enumerated, together with the degree of accuracy which may be expected when using the various methods.

108. Certain items, relevant to the proposed transmitting installations of Battleships 55 and 56 are discussed in some detail. Certain aspects of the installations which may require modification in order to avoid difficulties are pointed out.

109. Sufficient data of a varied nature are submitted which will permit conclusions to be drawn and comparisons to be made of the many factors which are inherent in the intermediate frequency transmitting systems encountered on board Naval vessels.

110. In general, the investigation reveals, and substantiates previous data of this nature, that the use of frequencies below 300 kilocycles is subject to such serious limitations with respect to voltage, power, and physical size of the equipment used, that extreme inefficiency of operation must be expected when employing short, partially shielded antennas and high capacity trunks.

The conductor power loss in trunks.

If the trunk is not too long, the current shunted to ground per foot of trunk is approximately the same at all points along the trunk. The current at the transmitter end of the trunk is I and the current at the antenna end is I_1. The trunk is of length L. The current I_x at any distance x from the transmitter end of the trunk is given by the equation. (See Fig. 1)

$$I_x = \frac{(I_1 - I)}{L} x + I \tag{13}$$

The conductor power loss in the trunk is

$$P = \int_0^L I_x^2 \, r \, dx \tag{14}$$

where r is the resistance per foot of trunk.

Substituting Equation (13) in Equation (14) one obtains after integration.

$$P = \frac{rL}{3} (I^2 + I I_1 + I_1^2) \tag{15}$$

The dielectric loss in a trunk insulator.

The dielectric loss in an isolantite insulator at radio frequencies is directly proportional to the electric field and the frequency. If p is the dielectric loss in watts per cc per 1,000 volts per centimeter; then the dielectric loss in watts in an isolantite trunk insulator of area A and of length $(R - r)$ is (see Fig. 2)

$$P = \int_r^R \frac{A p E}{x \log_e (R/r)} \, dx \tag{16}$$

where $\frac{E}{x \log_e R/r}$ is the potential gradient at a radius x in kilovolts per centimeter and E is the potential across the trunk in kilovolts.

Equation (16) can be integrated to give

$$P = \frac{A p E}{\log_e R/r} \log x \Big|_r^R \tag{17}$$

Substituting in the limits of integration, one obtains

$$P = A\,p\,E \tag{18}$$

where P is the power loss in watts in the insulator

A is the area of the insulator in square centimeters.

E is the r-m-s potential across the insulator in kilovolts.

p is the dielectric loss in watts per cc per kilovolt per cm. p is 1.5×10^{-3} watts per cc per kilovolt per cm at 175 kilocycles.

<u>The effect of an unsymmetrical ground resistance upon the directivity of a vertical antenna.</u>

It is assumed that the antenna is of height h above a perfectly conducting ground. The current at the base of the antenna is I. Thus the current I flows into the ground at the base of the antenna.

From Maxwell's Equations one has

$$\frac{1}{c}\frac{\partial \vec{D}}{\partial t} + 4\pi\frac{\vec{J}}{c} = \text{curl}\,\vec{H} \tag{19}$$

Equation (19) can be transformed to the integral form to give

$$\iint_S (\text{curl}\,\vec{H})_n\,dS = \iint_S \left(\frac{1}{c}\frac{\partial \vec{D}}{\partial t} + \frac{4\pi}{c}\vec{J}\right)_n dS \tag{20}$$

If one applies Stokes' Theorem to Equation (20), one obtains

$$\int_s H_s\,ds = \frac{4\pi}{c}\iint_S \frac{1}{4\pi}\frac{\partial \vec{D}_n}{\partial t}\,dS + \frac{4\pi}{c}\iint_S J_n\,dS \tag{21}$$

where S is the area and s is the perimeter of the surface (ground) shown in Fig. 3.

The second integral on the right hand side of Equation (21) gives the antenna ground current I. Thus in the ground lead J is equal to I. The first term on the right hand side of Equation (21) gives the total displacement current between the area S and the antenna. The ground current that flows through the perimeter s of the area S plus the displacement current in the area S is equal to the antenna ground current. As the area S increases, the displacement current decreases and in the limit the displacement

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current is equal to the antenna ground current. If I is the antenna ground current and I' is the displacement current in the area S (see Fig.3), then the ground current at the perimeter of the area S is given by

$$I'' = I - I' \tag{22}$$

Substituting I and I' in Equation (21) one has

$$\int_S Hs\, ds = -\frac{4\pi}{c}\, I' + \frac{4\pi}{c}\, I = \frac{4\pi}{c}\, I'' \tag{23}$$

Equation (23) gives a definite relationship between the ground current and the magnetic field just above the ground due to the antenna. Hs is at right angles to the radius vector and parallel to the surface of the earth.

If the area S is a circle of radius r with its center at the base of the antenna, then

$$I'' = \int_0^{2\pi} i''\,(\theta\,,\, r)\, r\, d\theta \tag{24}$$

where $i''\,(\ \ ,\, r)$ is the ground current at a radius r per unit length of arc of the circle.

For a circle of radius r

$$\int_S Hs\, ds = \int_0^{2\pi} H\,(\theta\,,\, r)\, r\, d\theta \tag{25}$$

From Equation (23), (24), and (25) one obtains

$$\int_0^{2\pi} H\,(\theta\,,\, r)\, r\, d\theta = \frac{4\pi}{c} \int_0^{2\pi} i''\,(\theta\,,\, r)\, r\, d\theta \tag{26}$$

Since Equation (26) is valid for a circle of radius r or any area S , the integrands are equal

$$H\,(r, \theta) = \frac{4\pi}{c}\, i''\,(\theta\,,\, r) \tag{27}$$

[redacted]

Therefore, the magnetic field at the surface of the ground is directly proportional to the ground current. The magnitudes of the electric and magnetic fields are equal. Thus the electric field is the greatest in the direction having the greatest ground current.

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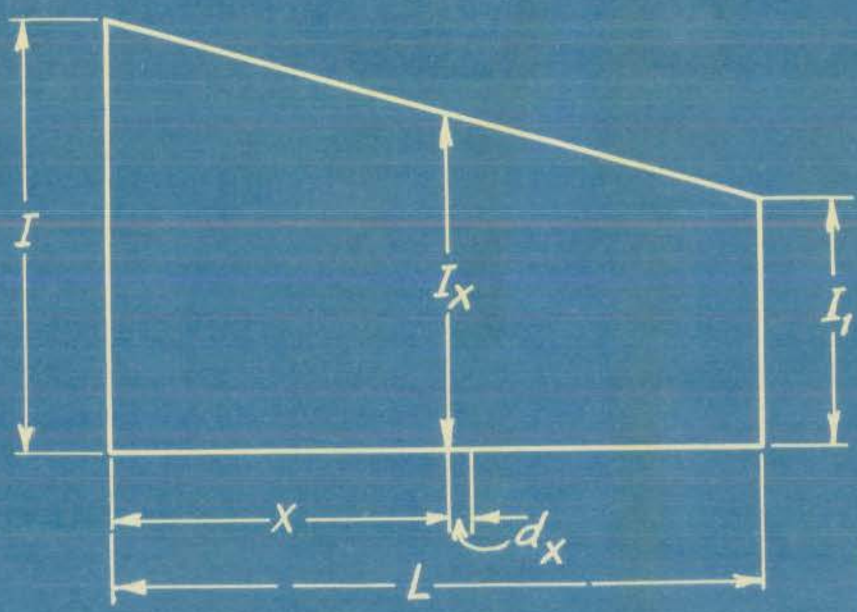

FIG. 1

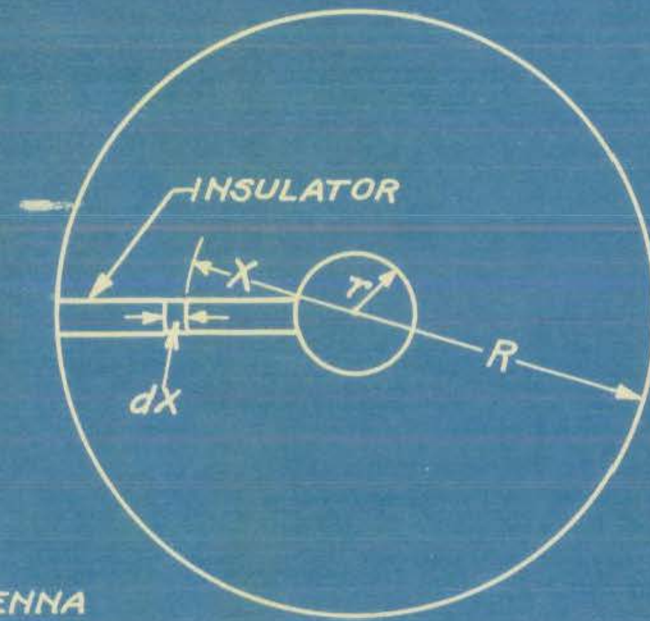

FIG. 2

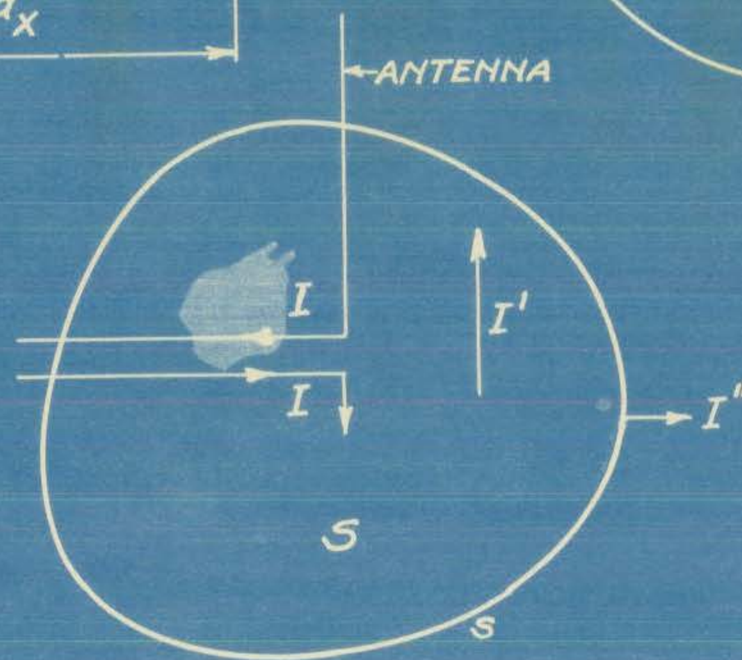

FIG. 3

Table 1

Definition of Symbols
appearing in Tables 2 to 9 inclusive.

A is the master oscillator band change switch on the XTAQ-5 transmitter.

B is the master oscillator tuning control.

C is the intermediate power amplifier band change switch.

D is the intermediate power amplifier tuning control.

E is the power amplifier band change switch.

F is the power amplifier tuning control.

G is the antenna coupling switch.

H is the antenna tuning control.

I is the antenna band change switch.

PA E_p is the power amplifier plate voltage in volts.

PA I_p is the power amplifier plate current in milliamperes.

IPA I_p is the intermediate power amplifier plate current in milliamperes.

MO E_p is the master oscillator plate voltage in volts.

MO I_p is the master oscillator plate current in milliamperes.

E_g is the bias voltage in volts.

R_A is the resistance of the antenna system in ohms.

C_A is the capacity of the antenna in micromicrofarads.

R_L is the resistance of the antenna loading coil in ohms.

I_8 is the transmitter antenna current in amperes as measured in the ground side of the antenna loading coil.

I is the antenna system current in amperes.

I_1 is the measured antenna current in amperes when using the trunk.

I_2 is the antenna current calculated by method I (no trunk).

I_3 is the antenna current calculated by method II (no trunk).

I_4 is the antenna current calculated by method III (no trunk).

I_5 is the antenna current computed by Equation (12) when using the trunk.

I_9 is the average calculated antenna current (no trunk).

I^2R_L is the power lost in antenna loading coil in watts.

I^2R_A is the power supplied to the antenna system in watts.

$I^2(R_A + R_L)$ is the computed PA tank power in watts.

R_1 is the radiation resistance of the antenna in the clear.

R is the radiation resistance of a partially shielded antenna.

$I_9^2 R_1$ or $I_1^2 R_1$ is the radiated power in watts (neglecting shielding of the antenna).

$I_9^2 R$ or $I_1^2 R$ is the radiated power in watts for a partially shielded antenna.

[redacted]

E_{62} rms is the rms antenna system voltage when operating the XTAQ-5 transmitter at 62% of full power.

E_{62} peak is the peak antenna system voltage when operating the XTAQ-5 transmitter at 62% of full power.

E_{100} peak is the peak antenna system voltage when operating the XTAQ-5 transmitter at full power.

Fd.Str.M is the measured field strength in millivolts per meter.

Fd.Str. C_1 is the computed field strength in millivolts per meter if the antenna were in the clear.

Fd.Str. C is the computed field strength in millivolts per meter for the partially shielded antenna.

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Table 2

Field Strength and Power Measurement Data
on XTAQ-5 Transmitter
operating at 62% of full power

13 ft.lead-in, 65 ft. vertical, and 95 ft.flat top antenna system

Line No.	Freq.kc	250	300	400	460	565
1	Test No.	1	2	3	4	5
2	A	3	4	5	6	7
3	B	206	162	565	385	485
4	C	3	4	5	6	7
5	D	21	17	56	38	43
6	E	5	6	6	7	7
7	F	47	24	56	32	67
8	G	2	2	2	2	2
9	H	55	68	35	37	34
10	I	1	6	11	12	13
11	PA E_p	1750	1750	1750	1750	1750
12	PA I_p	1600	1600	1600	1600	1600
13	IPA I_p	65	70	75	85	90
14	MO E_p	740	735	735	740	735
15	MO I_p	34	32	32	31	32
16	E_b	110	110	112	111	112
17	R_A	1.5	1.65	1.7	1.95	2.6
18	C_A	442	446	459	470	494
19	C_a	344	349	358	367	386
20	R_L	3.27	2.73	2.25	2.12	1.53
21	I_8	21.6	24.8	26.8	27.0	24.0
22	I	18.5	21.3	23.0	23.1	20.6
24	I_2	14.4	16.6	17.9	18.0	16.1
25	I_3	14.8	14.5	15.6	15.7	14.7
26	I_4	12.2	13.8	15.0	15.4	15.1
28	I_9	13.8	15.0	16.2	16.3	15.3
29	$I^2 R_L$	1120	1240	1190	1130	650
30	$I^2 R_A$	510	750	900	1040	1100
31	$I^2 (R_A + R_L)$	1630	1990	2090	2170	1750
32	R_1	.28	.40	.71	.94	1.42
33	R	.11	.16	.28	.37	.56
34	$I_9^2 R_1$	53	90	186	250	330
35	$I_9^2 R$	21	36	73	98	130
36	E_{62} rms	26600	25300	19900	17000	11700
37	E_{62} peak	37500	35700	28100	24000	16500
38	E_{100} peak	47600	45300	35600	30400	20900
39	Fd.Str.M	77	105	150	175	200
40	Fd.Str.C_1	137	180	257	300	340
41	Fd.Str.C	87	113	160	187	215

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Table 3

Field Strength and Power Measurement Data
on XTAQ-5 Transmitter
operating at 62% of full power

13 ft. lead-in, 66 ft. trunk, 65 ft. vertical, and 95 ft. flat top antenna system.

Line No.	Freq.kc	200	250	300	400	460	565
1	Test No.	6	7	8	9	10	11
2	A *	1	3	4	5	6	7
3	B	700	206	162	565	385	485
4	C	1	3	4	5	6	7
5	D	71	21	17	56	39	43
6	E	3	5	6	6	7	7
7	F	49	31	13	64	25	63
8	G	2	2	2	2	2	2
9	H	35	40	54	59	41	28
10	I	3	8	10	12	13	14
11	PA E_p	1750	1750	1750	1750	1750	1750
12	PA I_p	1600	1600	1600	1600	1600	1600
13	IPA I_p	54	58	70	80	85	56
14	MO E_p	750	750	750	750	750	750
15	MO I_p	36	36	34	32	32	32
16	E_g	115	112	112	115	115	111
17	R_A	0.8	0.65	0.9	0.9	1.1	1.4
18	C_A	775	785	796	830	856	920
19	C_a	342	344	349	358	367	386
20	R_L	2.25	1.69	1.44	1.30	1.00	.89
21	I_8	30.2	31.8	31.5	32.8	28.8	32.1
22	I	25.9	27.3	27.0	28.2	24.7	27.5
23	I_1	11.9	11.1	11.0	11.0	10.2	12.2
27	I_5	11.5	12.0	11.8	12.1	10.6	11.6
29	I^2R_L	1510	1260	1050	1030	610	670
30	I^2R_A	540	490	660	720	670	1060
31	$I^2(R_A + R_L)$	2050	1750	1710	1750	1280	1730
32	R_1	0.18	0.28	0.40	0.71	0.94	1.42
33	R	0.07	0.11	0.16	0.28	0.37	0.56
34	$I_1^2 R_1$	25	34	48	86	98	211
35	$I_1^2 R$	9.8	13.4	19	34	39	83
36	E_{62} rms	26600	22100	18000	13500	10000	8400
37	E_{62} peak	37500	31200	25400	19000	14100	11800
38	E_{100} peak	47600	39600	32200	24100	17900	15000
39	Fd.Str. M	55	70	84	110	116	162
40	Fd.Str. C_1	94	110	131	175	187	274
41	Fd.Str. C	60	69	83	110	118	172

*See Table 1 for definition of symbols.

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Table 4

Field Strength and Power Measurement Data
on XTAQ-5 Transmitter
operating at 62% of full power

13 ft. lead-in, 95 ft. vertical, and 95 ft. flat top antenna system.

Line No.	Freq. kc.	250	300	400	460	565
1	Test No.	12	13	14	15	16
2	A *	3	4	5	6	7
3	B	206	162	565	385	485
4	C	3	4	5	6	7
5	D	21	17	56	38	43
6	E	5	6	6	7	7
7	F	47	24	68	90	68
8	G	2	2	2	2	2
9	H	56	84	57	54	47
10	I	3	7	11	12	13
11	PA E_p	1750	1750	1750	1750	1750
12	PA I_p	1600	1600	1600	1600	1600
13	IPA $^{P}I_p$	68	75	83	90	94
14	MO E_p	750	750	740	735	735
15	MO I_p	35	34	32	32	32
16	E_g	114	114	113	112	112
17	R_A	1.65	1.85	2.00	2.30	3.65
18	C_A	505	511	533	553	593
19	C_a	407	413	429	445	475
20	R_1	2.84	2.33	1.92	1.84	1.52
21	I_8	23.2	24.7	25.0	24.6	20.1
22	I	19.9	21.2	21.4	21.1	17.2
24	I_2	16.0	17.1	17.2	16.9	13.8
25	I_3	15.3	16.2	15.3	14.7	12.2
26	I_4	16.3	18.2	15.5	14.3	11.4
28	I_9	15.9	17.2	16.0	15.3	12.5
29	$I^2 R_L$	1130	1050	880	830	390
30	$I^2 R_A$	650	830	920	1040	1080
31	$I^2 (R_A + R_L)$	1780	1880	1800	1870	1470
32	R_1	0.51	0.73	1.30	1.71	2.60
33	R	0.28	0.40	0.72	0.95	1.44
34	$I_9^2 R_1$	88	216	330	400	405
35	$I_9^2 R$	48	118	184	222	225
36	E_{62} rms	25100	22000	16000	13200	8200
37	E_{62} peak	35400	31000	22600	18600	11600
38	E_{100} peak	44900	39300	28700	23600	14700
39	Fd.Str. M	135	175	207	230	225
40	Fd.Str. C_1	177	277	344	378	380
41	Fd.Str. C	131	205	255	280	283

*See Table 1 for definition of symbols.

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Table 5

Field Strength and Power Measurement Data
on XTAQ-5 Transmitter
operating on 62% of full power

13 ft. lead-in, 66 ft. trunk, 95 ft. vertical and 96 ft. flat top antenna system.

Line No.	Freq. kc.	182	200	250	300	400	460	565
1	Test No.	17	18	19	20	21	22	23
2	A *	1	1	3	4	5	6	7
3	B	350	700	206	162	585	385	485
4	C	1	1	3	4	5	6	7
5	D	44	71	21	17	56	38	43
6	E	2	3	5	6	6	7	7
7	F	54	51	36	16	64	23	67
8	G	2	2	2	2	2	2	2
9	H	9	64	57	67	66	48	36
10	I	1	3	8	10	12	13	14
11	PA E_p	1750	1750	1750	1750	1750	1750	1750
12	PA I_p	1600	1600	1600	1600	1600	1600	1600
13	IPA I_p	60	55	65	72	82	80	80
14	MO E_p	740	740	745	745	745	749	730
15	MO I_p	36	34	34	33	32	32	32
16	E_g	113	112	114	113	113	113	112
17	R_A	0.80	0.95	0.80	0.95	1.00	1.25	2.35
18	C_A	840	843	855	877	925	970	1064
19	C_a	395	396	407	413	429	445	475
20	R_L	2.39	2.13	1.55	1.37	1.22	0.94	0.82
21	I_g	28.0	29.9	30.2	30.3	30.0	30.6	30.8
22	I	24.0	25.6	25.9	26.0	25.7	26.2	26.4
23	I_1	12.0	12.8	12.7	12.5	12.0	13.1	13.2
27	I_5	11.3	12.0	12.3	12.3	11.9	12.0	11.8
29	$I^2 R_L$	1380	1400	1040	930	810	640	450
30	$I^2 R_A$	460	620	540	640	660	860	1640
31	$I^2 (R_A + R_L)$	1840	2020	1580	1570	1470	1500	2090
32	R_1	0.27	0.32	0.51	0.73	1.30	1.71	2.60
33	R_2	0.15	0.18	0.28	0.40	0.72	0.95	1.44
34	$I_1^2 R_1$	39	52	82	114	187	290	450
35	$I_1^2 R_2$	22	29	46	64	105	163	250
36	E_{62} rms	25000	24200	19300	15700	11100	9300	7000
37	E_{62} peak	35200	34100	27200	22100	15600	13100	9900
38	E_{100} peak	44600	43200	34500	28000	19800	16600	12600
39	Fd.Str. M	70	81	105	120	160	210	260
40	Fd.Str. C_1	118	136	171	200	260	320	400
41	Fd.Str. C	89	101	128	150	190	240	300

* See Table 1 for definition of symbols.

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Table 6

Field Strength and Power Measurement Data
on XTAQ-5 Transmitter
operating at 62% of full power

13 ft. lead-in, 125 ft. vertical and 95 ft. flat top antenna system.

Line No.	Freq. kc	250	300	400	460	565
1	Test No.	24	25	26	27	28
2	A *	3	4	5	6	7
3	B	206	162	565	385	485
4	C	3	4	5	6	7
5	D	21	17	56	38	43
6	E	5	6	6	7	7
7	F	46	24	66	31	69
8	G	2	2	2	2	2
9	H	75	63	20	66	58
10	I	4	8	12	12	13
11	PA E_p	1750	1750	1750	1750	1750
12	PA I_p	1600	1600	1600	1600	1600
13	IPA I_p	67	70	75	85	90
14	MO E_p	740	730	750	740	745
15	MO I_p	34	33	32	32	32
16	E_g	112	113	114	114	114
17	R_A	1.65	1.95	2.25	2.40	4.20
18	C_A	574	582	613	646	712
19	C_a	476	487	514	543	593
20	R_L	2.53	2.04	1.76	1.64	1.17
21	I_8	24.1	24.2	26.4	25.1	21.0
22	I	20.7	20.8	22.6	21.5	28.0
24	I_2	17.2	17.4	18.9	18.0	15.0
25	I_3	16.4	16.6	16.0	14.8	11.9
26	I_4	17.5	18.3	17.3	15.5	13.7
28	I_9	17.0	17.4	17.4	16.1	13.5
29	$I^2 R_L$	1090	830	900	760	380
30	$I^2 R_A$	700	840	1150	1110	1360
31	$I^2 (R_A + R_L)$	1790	1730	2050	1870	1740
32	R_1	0.78	1.12	2.00	2.60	4.00
33	R	0.48	0.70	1.24	1.64	2.50
34	$I_8^2 R_1$	225	340	606	673	728
35	$I_9^2 R$	139	212	376	425	455
36	E_{62} rms	23000	19000	14700	11500	7100
37	E_{62} peak	32400	26800	20700	16200	10000
38	E_{100} peak	41100	34000	26200	20500	12700
39	Fd. Str. M	175	205	260	280	290
40	Fd. Str. C_1	283	347	464	490	510
41	Fd. Str. C	223	275	366	390	400

* See Table 1 for definition of symbols.

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Table 7

Field Strength and Power Measurement Data
on XTAQ-5 Transmitter
operating at 62% of full power

13 ft. lead-in, 66 ft. trunk, 125 ft. vertical and 95 ft. flat top antenna system.

Line No.	Freq.kc	176	200	250	300	400	460	565
1	Test No.	29	30	31	32	33	34	35
2	A *	1	1	3	4	5	6	7
3	B	206	700	206	162	565	385	485
4	C	1	1	3	4	5	6	7
5	D	34	71	21	17	56	38	43
6	E	2	3	5	6	6	7	7
7	F	65	53	40	12	65	25	64
8	G	2	2	2	2	2	2	2
9	H	0	65	38	37	78	55	45
10	I	1	4	9	11	12	13	14
11	PA E_p	1750	1750	1750	1750	1750	1750	1750
12	PA I_p	1600	1600	1600	1600	1600	1600	1600
13	IPA I_p	54	52	54	72	80	82	95
14	MO E_p	750	750	750	750	745	745	740
15	MO I_p	38	36	36	34	32	32	32
16	E_g	114	114	114	114	114	114	113
17	R_A	0.80	1.05	0.85	1.10	1.30	1.65	3.10
18	C_A	908	913	931	955	1023	1084	1237
19	C_a	463	469	476	487	514	543	593
20	R_L	2.39	1.98	1.43	1.23	1.14	0.86	0.71
21	I_g	25.5	29.0	32.1	32.0	30.0	29.0	27.5
22	I	21.9	24.9	27.5	27.4	25.7	24.9	23.6
23	I_1	12.2	13.7	14.5	14.3	13.6	13.8	13.4
27	I_5	11.2	12.8	14.1	14.0	12.9	12.5	11.3
29	$I^2 R_L$	1150	1230	1080	920	710	530	400
30	$I^2 R_A$	380	650	640	830	760	1030	1720
31	$I^2 (R_A + R_L)$	1530	1880	1720	1750	1470	1560	2120
32	R_1	0.39	0.50	0.78	1.12	2.00	2.60	4.0
33	R	0.24	0.31	0.48	0.70	1.24	1.64	2.5
34	$I_1^2 R_1$	58	94	164	230	370	495	720
35	$I_1^2 R$	36	58	102	143	230	307	446
36	E_{62} rms	22100	21700	18800	15200	10000	8000	5400
37	E_{62} peak	31200	30600	26500	21400	14100	11300	7600
38	E_{100} peak	39600	38800	33600	27100	17900	14300	9600
39	Fd. Str. M	84	106	145	160	205	250	285
40	Fd. Str. C_1	144	183	240	285	360	420	506
41	Fd. Str. C	113	144	190	224	285	330	400

* See Table 1 for definition of symbols.

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Table 8

Field Strength and Power Measurement Data
on XTAQ-5 Transmitter
operating at full power

13 ft. lead-in, 125 ft. vertical and 95' flat top antenna system.

Line No.	Freq. kc	250	300	400	460	565
1	Test No.	36	37	38	39	40
2	A *	3	4	5	6	7
3	B	206	162	565	384	485
4	C	3	4	5	6	7
5	D	21	17	56	38	43
6	E	5	6	6	7	7
7	F	43	22	67	30	68
8	G	2	2	2	2	2
9	H	89	69	80	67	60
10	I	4	8	11	12	13
11	PA E_p	2250	2250	2250	2250	2250
12	PA I_p	2000	2000	2000	2000	2000
13	IPA I_p	90	100	105	110	95
14	MO E_p	750	750	750	750	750
15	MO I_p	34	34	34	34	32
16	E_g	115	115	115	115	115
17	R_A	1.73	2.05	2.25	2.50	5.30
18	C_A	574	587	618	646	712
19	C_a	476	487	514	543	593
20	R_L	2.40	2.20	1.72	1.55	1.13
21	I_8	30.0	32.8	34.4	32.0	25.1
22	I	25.7	28.1	29.5	27.4	21.5
29	I^2R_L	1590	1740	1500	1160	520
30	I^2R_A	1140	1620	1850	1880	2450
31	$I^2 (R_A + R_L)$	2730	3360	3350	3040	2970
38	E_{100} peak	40300	35800	26800	20700	12000

* See Table 1 for definition of symbols.

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Table 9

Power Measurement Data on XTAQ-5 Transmitter operating at full power.

13 ft. lead-in, 66 ft. trunk, 125 ft. vertical and 95 ft. flat top antenna system.

Line No.	Freq. kc.	176	200	250	300
1	Test No.	41	42	43	44
2	A *	1	1	3	4
3	B	206	700	206	162
4	C	1	1	3	4
5	D	34	72	23	17
6	E	2	3	5	6
7	F	53	56	54	34
8	G	2	2	1	1
9	H	18	67	42	40
10	I	1	4	9	11
11	PA E_p	2250	2250	2250	2250
12	PA I_p	2000	2000	2000	2000
13	IPA I_p	60	60	70	100
14	MO E_p	750	750	750	750
15	MO I_p	38	38	32	32
16	E_g	115	115	115	115
17	R_A	1.15	1.15	1.00	1.10
18	C_A	903	904	930	942
20	R_L	2.16	1.83	1.41	1.33
21	I_8	31.0	31.5	35.3	40.2
22	I	26.6	27.0	30.3	34.5
23	I_1	14.3#	14.4#	16.2#	17.2
29	$I^2 R_L$	1530	1340	1300	1580
30	$I^2 R_A$	810	840	920	1310
31	$I^2 (R_A + R_L)$	2340	2180	2220	2890

*See Table 1 for definition of symbols.

#Visual corona in trunk.

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Variation of the following quantities with frequency for a 13' lead-in, 65' vertical and 95' flat top antenna system.

1. Antenna system resistance.
2. Antenna system capacitance.
3. Transmitter XTAQ-5 antenna loading coil resistance.
4. Antenna radiation resistance.

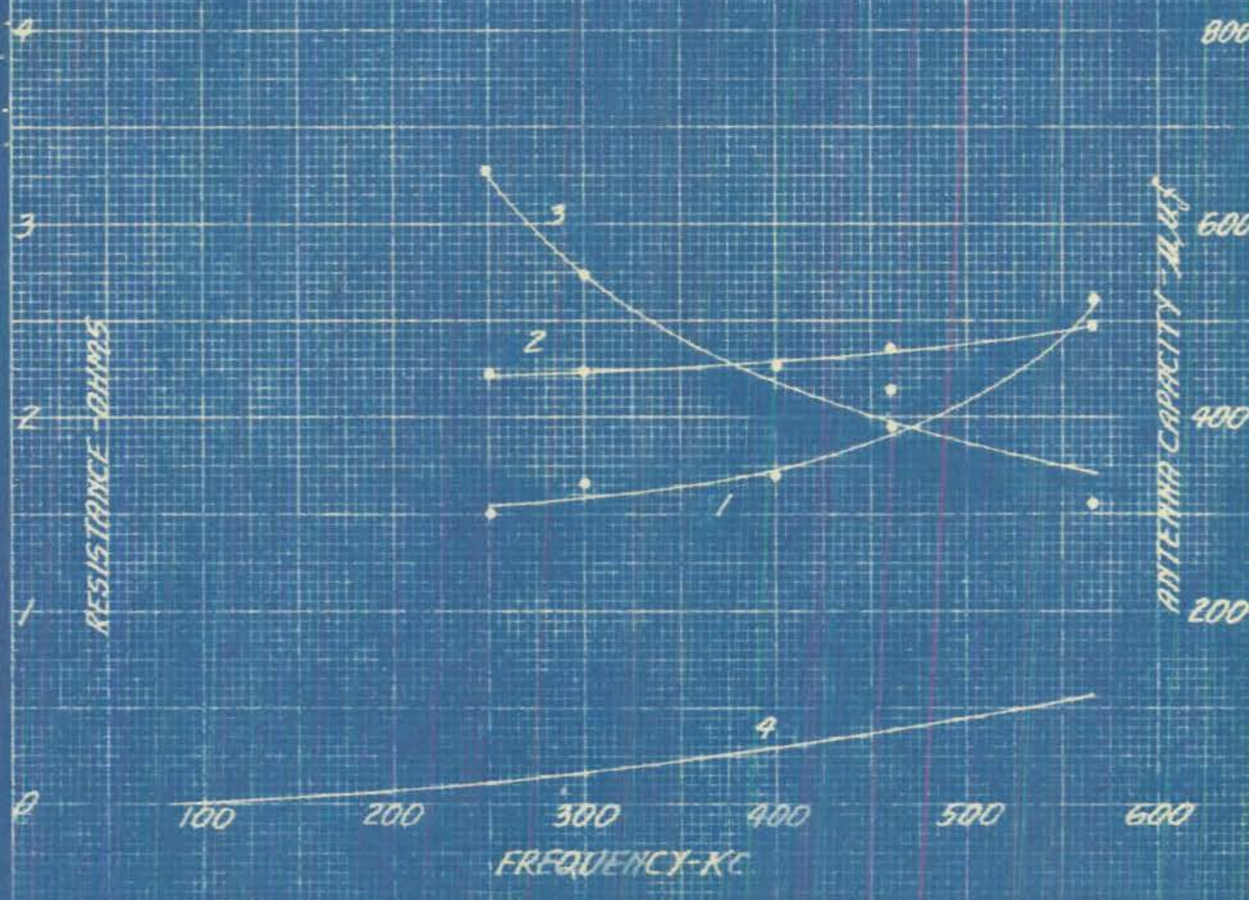
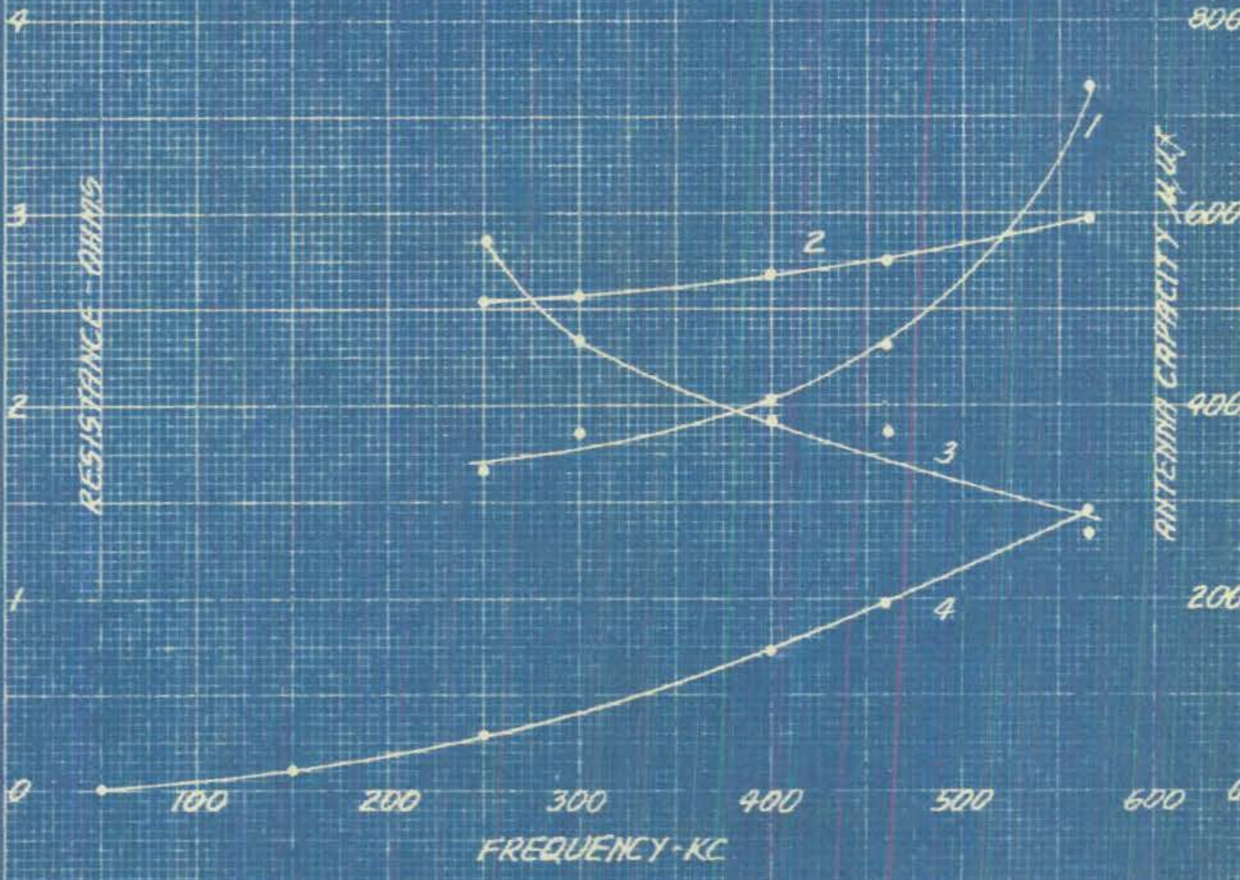


PLATE I

Variation of the following quantities with frequency for a 13' lead-in, 95' vertical and 95' flat top antenna system.

1. Antenna system resistance.
2. Antenna system capacitance.
3. Transmitter XTAQ-5 antenna loading coil resistance.
4. Antenna radiation resistance.



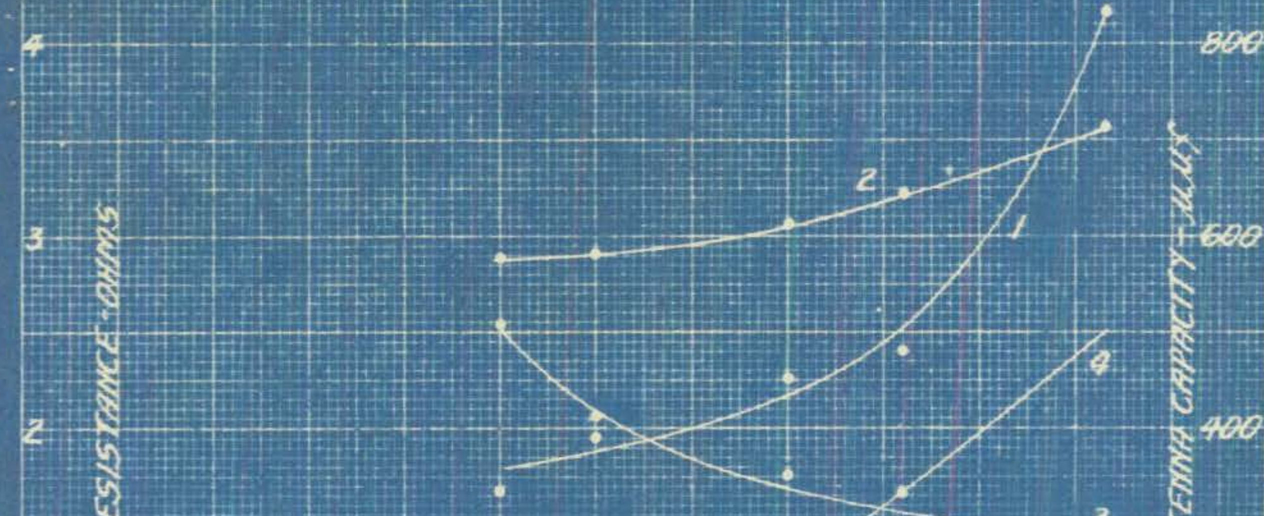
Variation of the following quantities with frequency for a 13' lead-in, 125' vertical and 95' flat top antenna system.

1. Antenna system resistance.

2. Antenna system capacitance.

3. Transmitter XTAQ-5 antenna loading coil resistance.

4. Antenna radiation resistance.

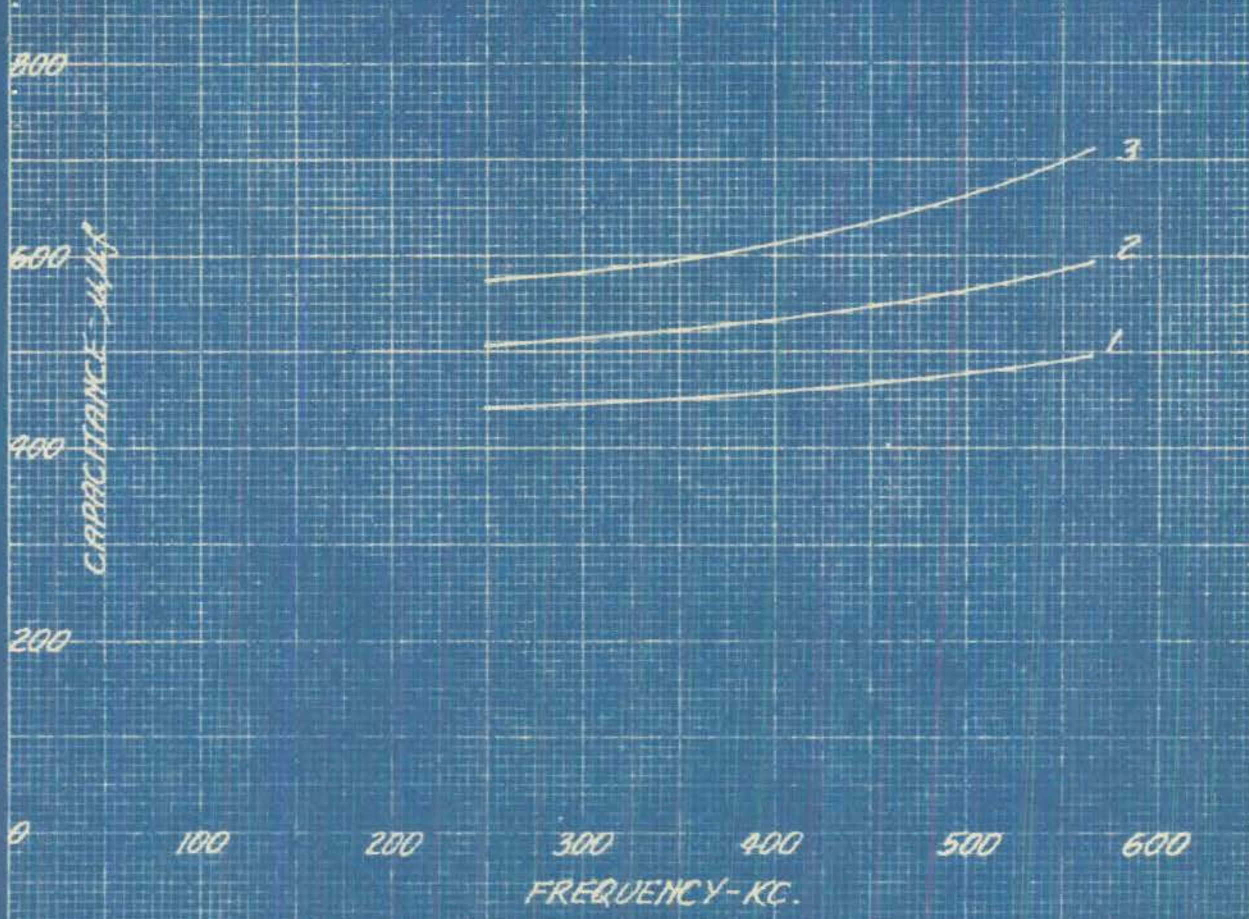


Antenna system capacitance as a function of frequency for the following antenna systems.

1. 13' lead-in, 65' vertical and 95' flat top.

2. 13' lead-in, 95' vertical and 95' flat top.

3. 13' lead-in, 125' vertical and 95' flat top.



Variation of the following quantities with frequency for a 13' lead-in, 68' trunk, 65' vertical and 95' flat top antenna system.

1. Antenna system resistance.
2. Antenna system capacitance.
3. Transmitter XTAQ-5 antenna loading coil resistance.

(Trunk 18" OD; 3/4" ID)

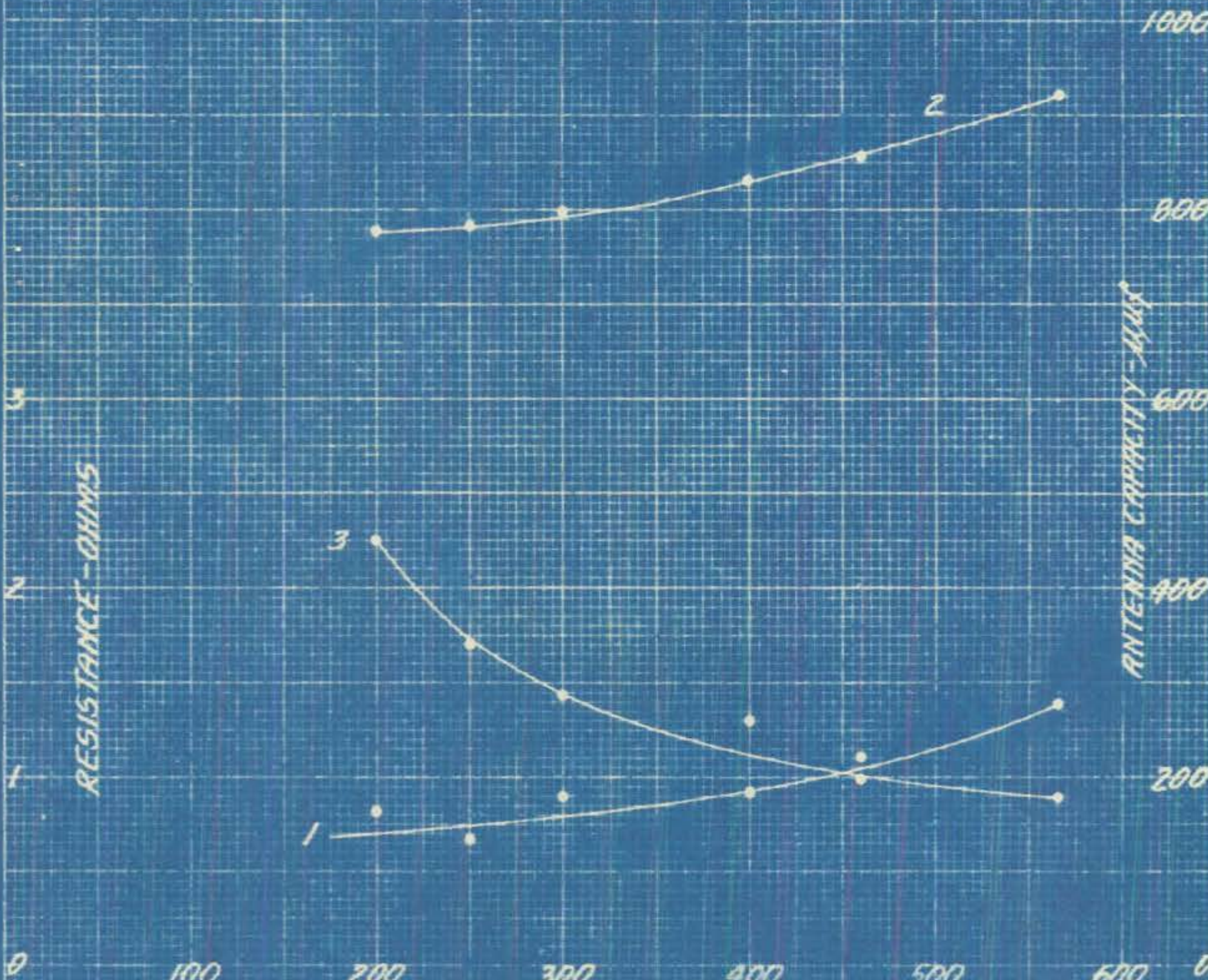


PLATE 5

Variation of the following quantities with frequency for a 13' lead-in, 66' trunk, 95' vertical and 95' flat top antenna system.

1. Antenna system resistance.
2. Antenna system capacitance.
3. Transmitter XTAQ-5 antenna loading coil resistance. (Trunk 18" O.D.; 3/4" I.D.)

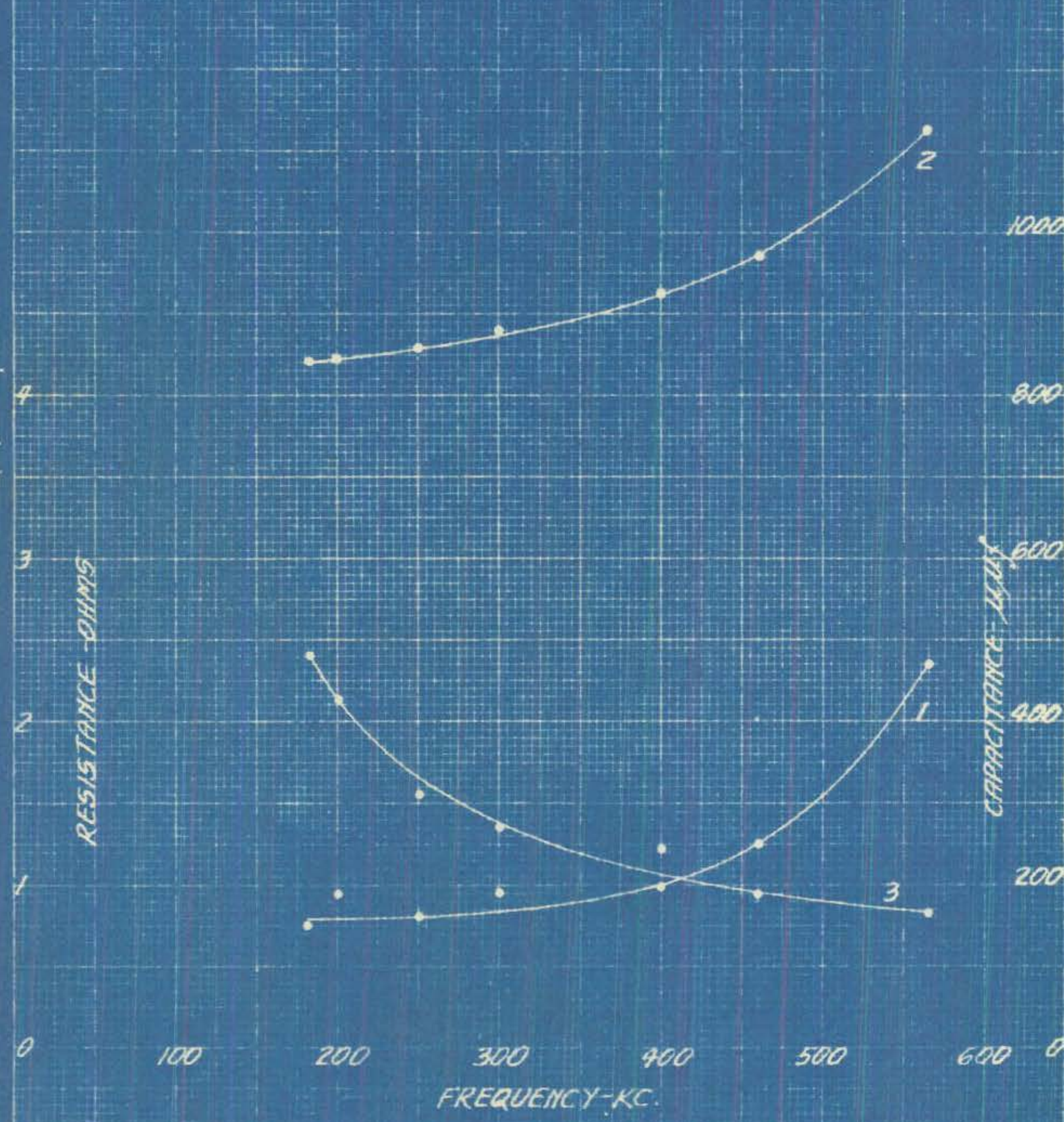


PLATE 6

Variation of the following quantities, with frequency for a 13' lead-in, 66' trunk, 125' vertical and 95' flat top antenna system.

1. Antenna system resistance.

2. Antenna system capacitance.

3. Transmitter XTAQ-5 Antenna loading coil resistance.

(Trunk 18" O.D.; 3/4" I.D.)

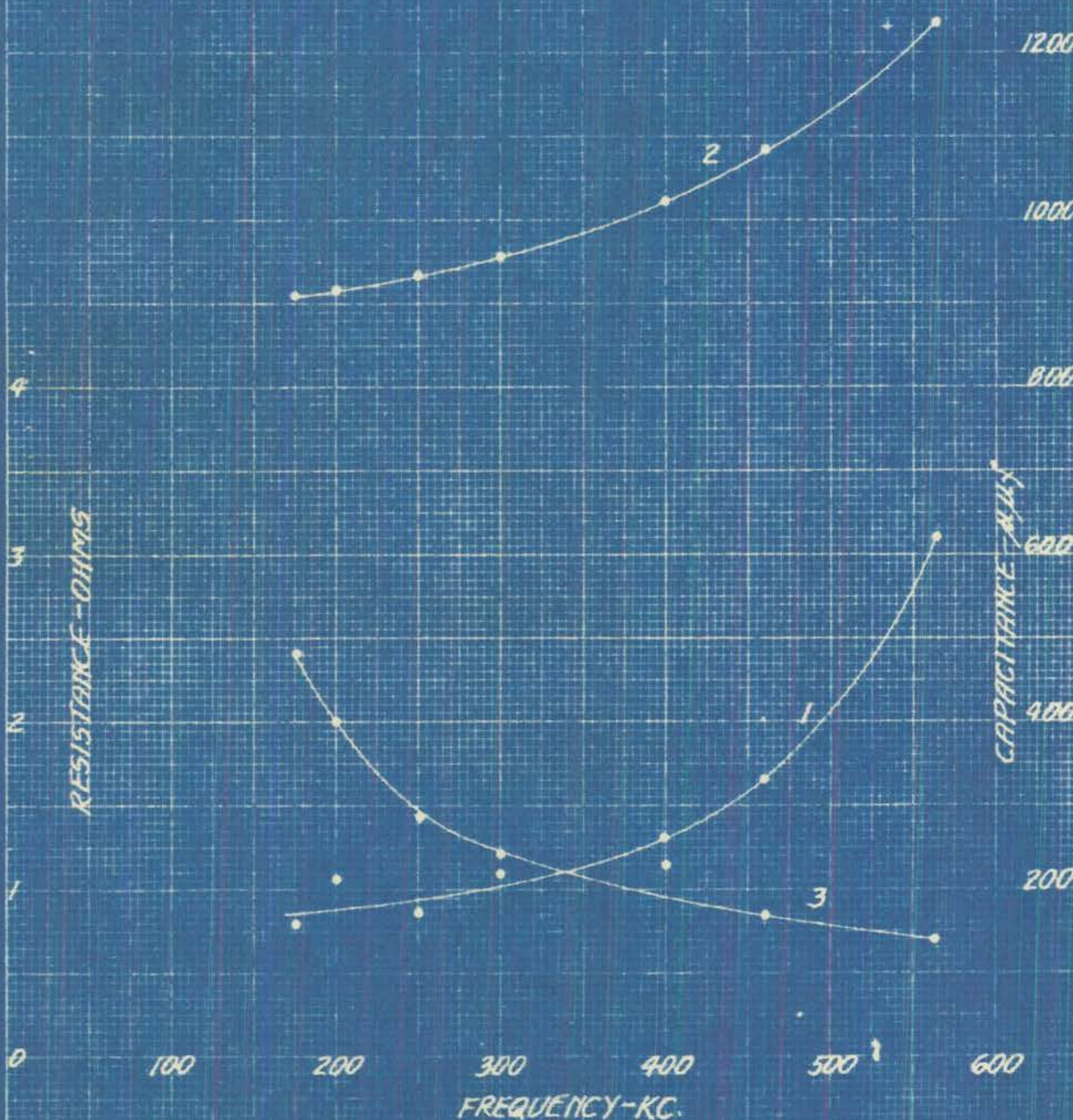


PLATE 7

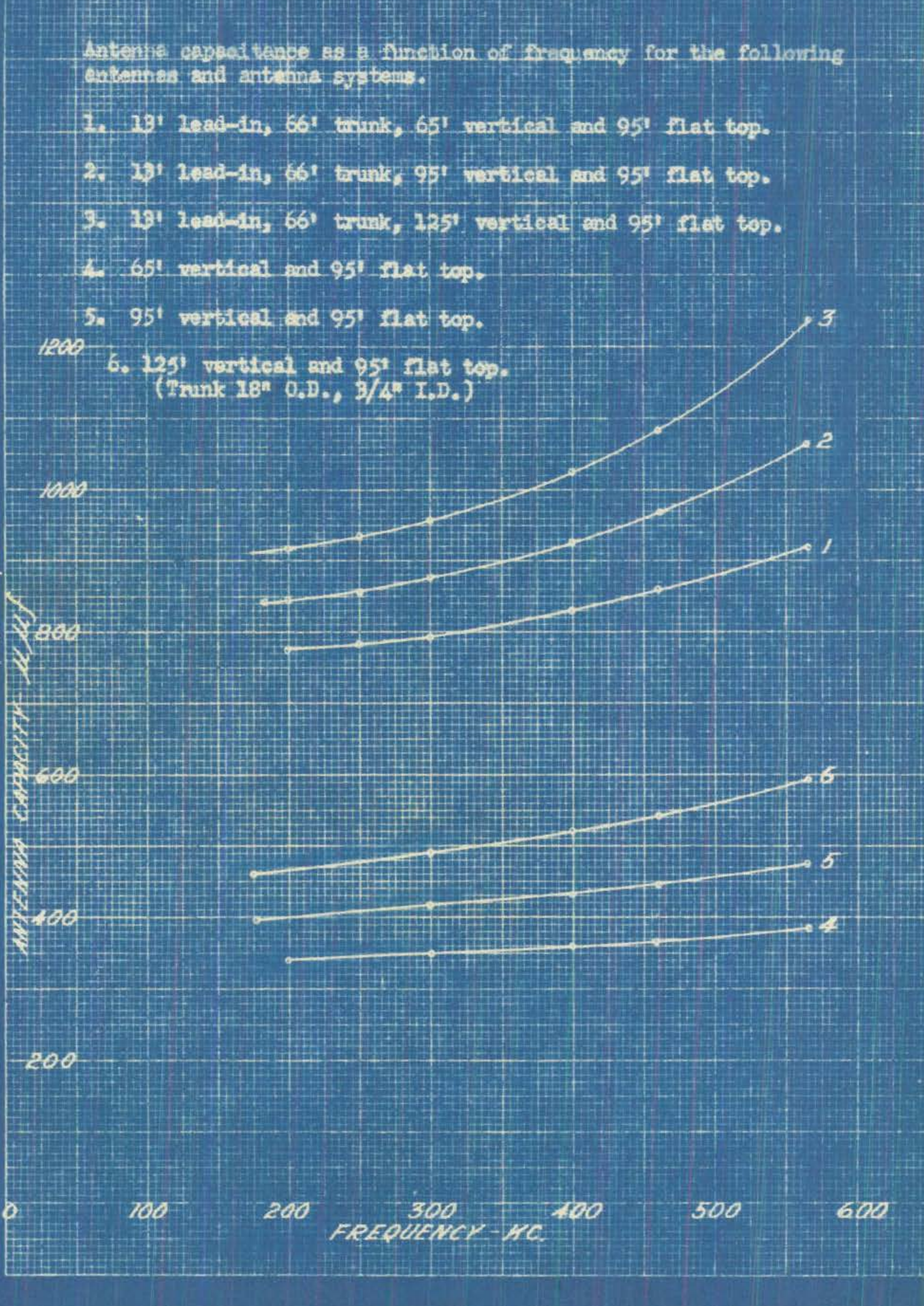

Antenna capacitance as a function of frequency for the following antennas and antenna systems.
1. 13' lead-in, 66' trunk, 65' vertical and 95' flat top.
2. 13' lead-in, 66' trunk, 95' vertical and 95' flat top.
3. 13' lead-in, 66' trunk, 125' vertical and 95' flat top.
4. 65' vertical and 95' flat top.
5. 95' vertical and 95' flat top.
6. 125' vertical and 95' flat top.
(Trunk 18" O.D., 3/4" I.D.)
1200
1000
800
600
400
200
0
100
200
300
400
500
600
FREQUENCY - KC.
3
2
1
6
5
4

PLATE 8

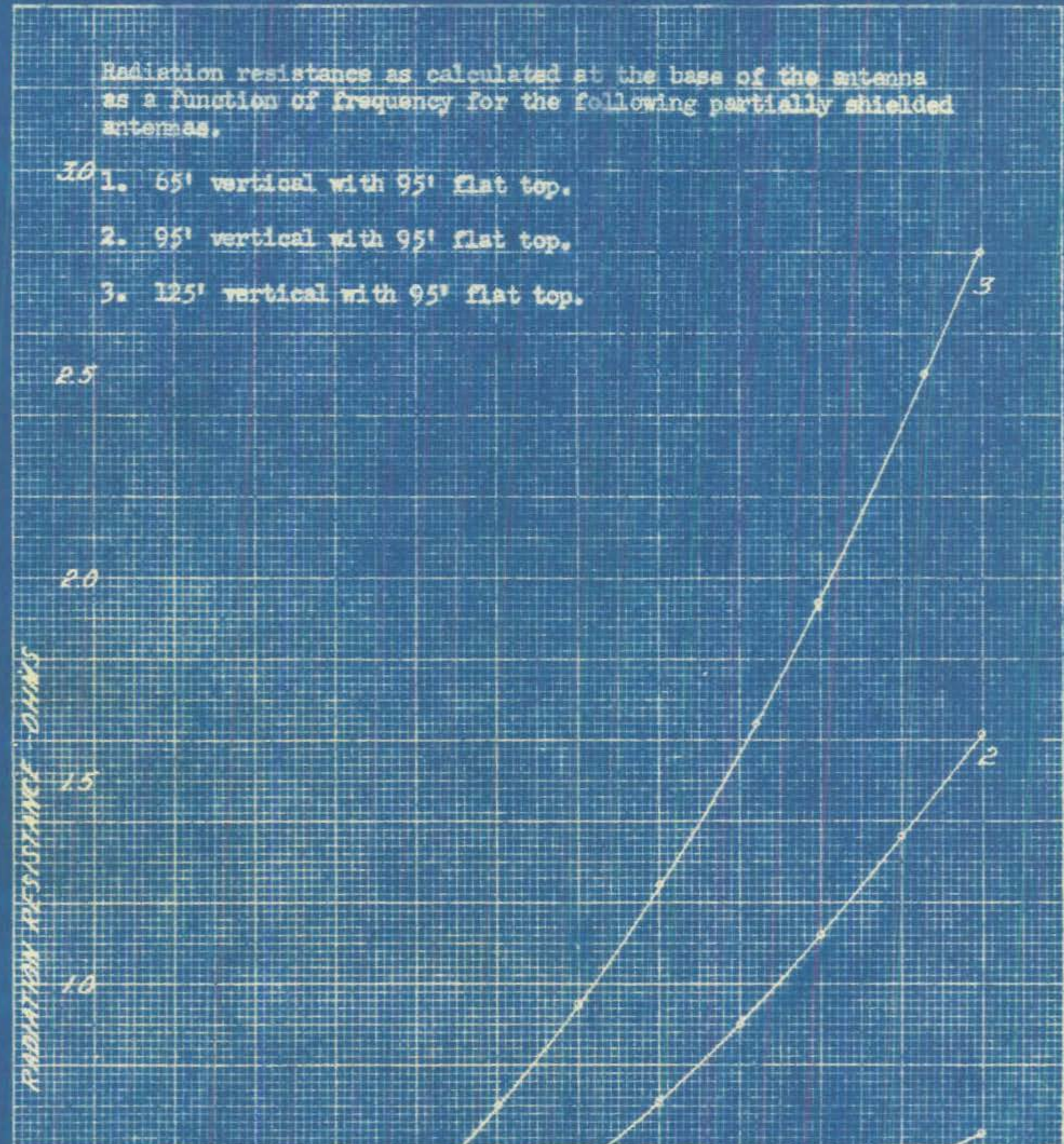

Radiation resistance as calculated at the base of the antenna as a function of frequency for the following partially shielded antennas.
1. 65' vertical with 95' flat top.
2. 95' vertical with 95' flat top.
3. 125' vertical with 95' flat top.
3.0
2.5
2.0
1.5
1.0
.5
0
100
200
300
400
500
600
FREQUENCY- MC.
RADIATION RESISTANCE - OHMS
1
2
3

PLATE 9

RF Power as a Function of Frequency

Model XTAQ-5 Transmitter Operating at 62% of Full Power into a 13' Lead-In, 65' Vertical and 95' Flat Top Antenna System.

(1) RF Power Loss in Antenna Loading Coil
(2) RF Power Supplied to the Antenna System

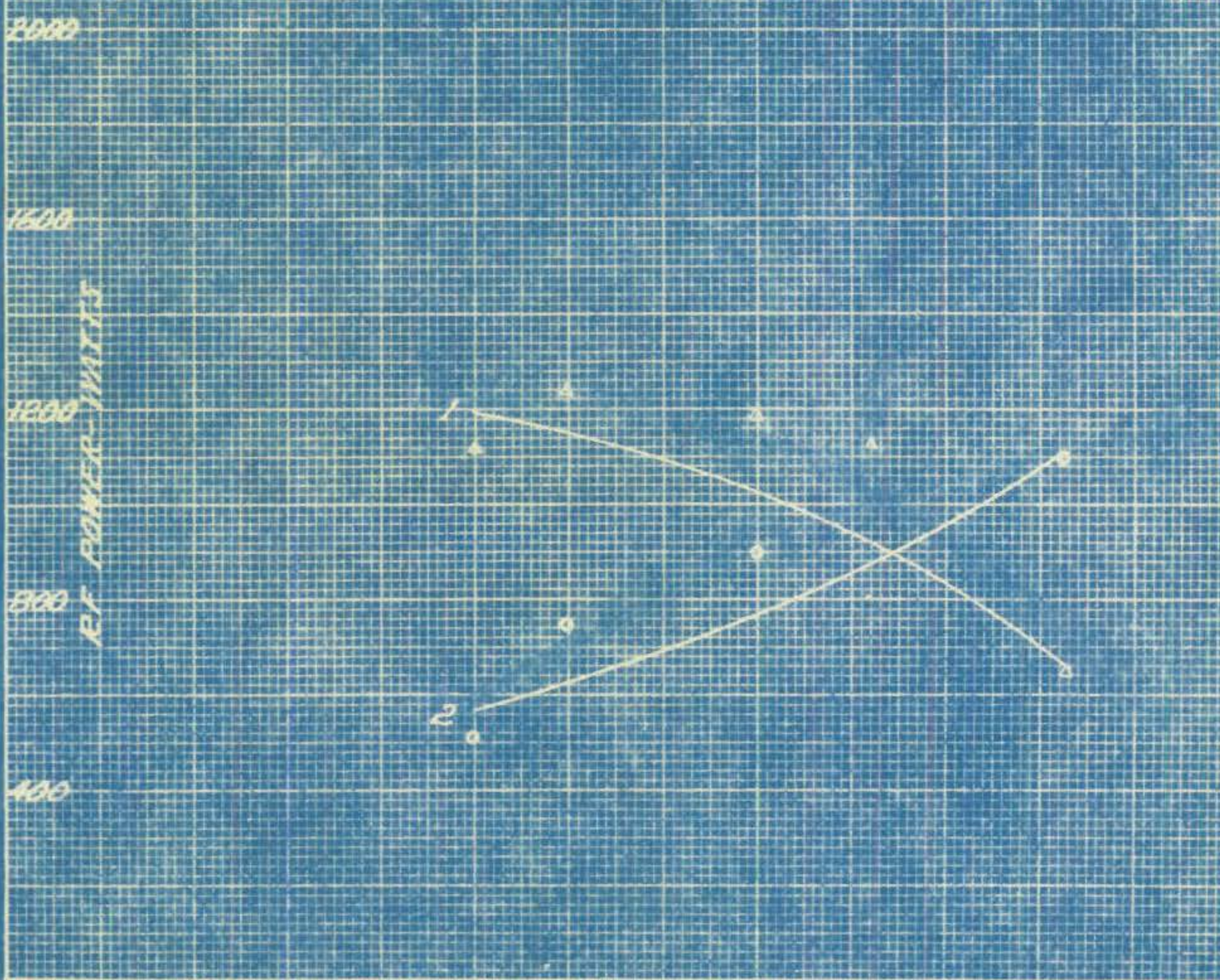


PLATE 10

RF Power as a Function of Frequency.

Model XTAQ-5 Transmitter Operating at 62% of full power into a 13' Lead-In, 95' vertical, 95' Flat Top Antenna System.

(1) RF Power Loss in Antenna Loading Coil
(2) RF Power Supplied to the Antenna System

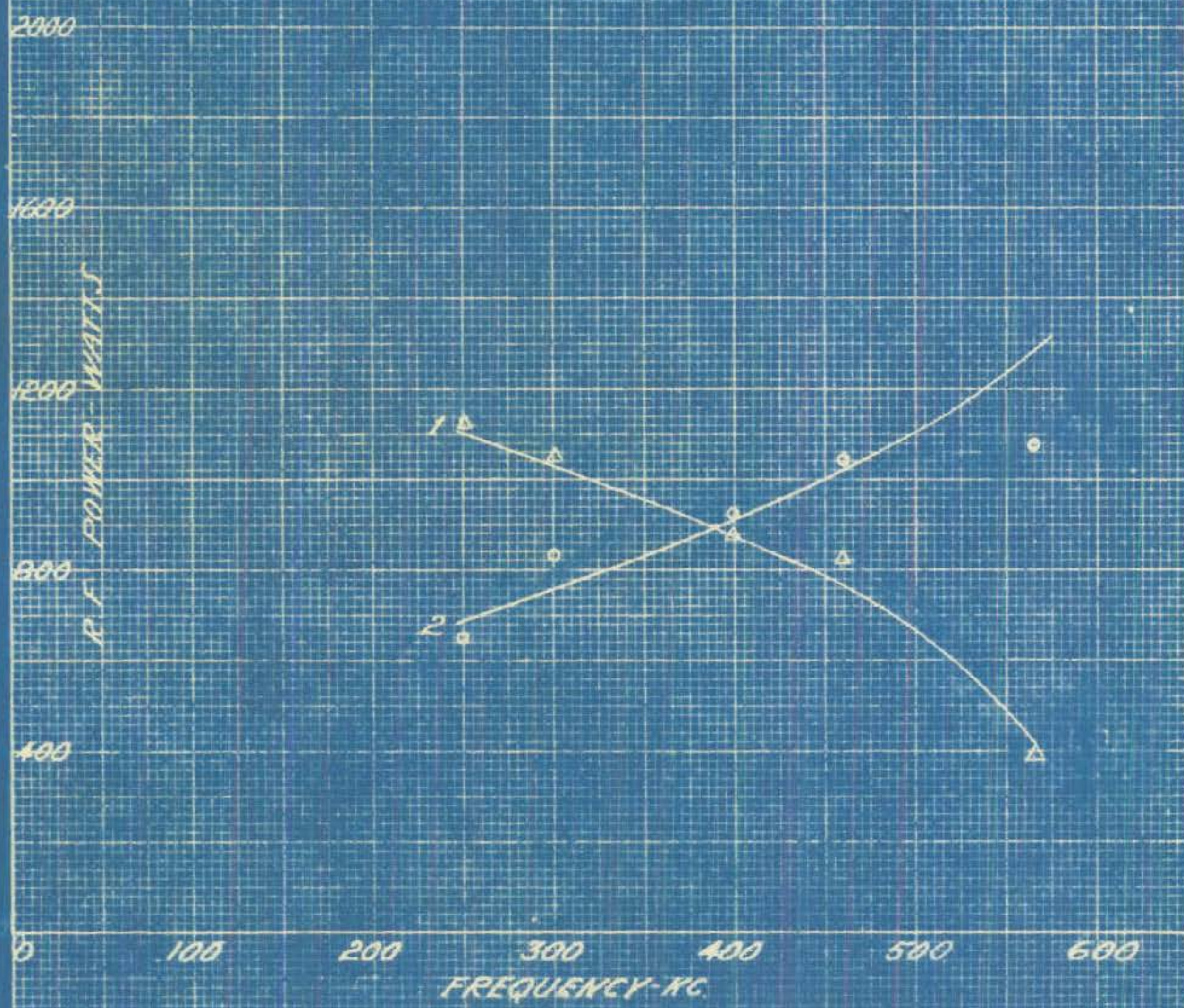
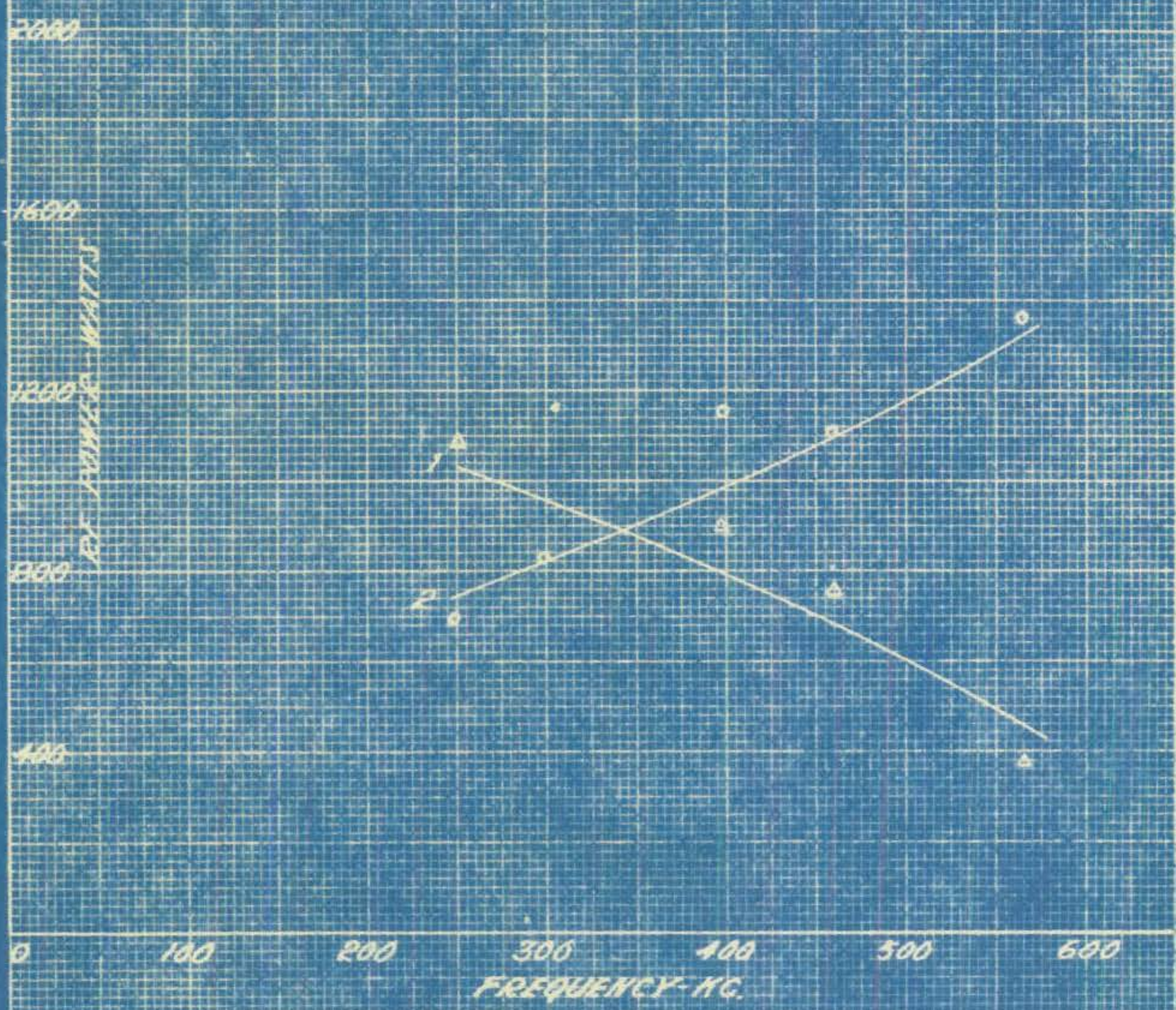


PLATE 11

RF Power as a Function of Frequency

Model XTAQ-5 Transmitter Operating at 62% of Full Power into a 13' Lead-In, 125' Vertical and 95' Flat Top Antenna System.

(1) RF Power Loss in Antenna Loading Coil
(2) RF Power Supplied to the Antenna System



RF Power as a Function of Frequency

Model XTAQ-5 Transmitter Operating at 62% of Full Power into a 13' Lead-In, 66' Trunk, 65' Vertical and 95' Flat Top Antenna System.

(1) RF Power Loss in Antenna Loading Coil
(2) RF Power Supplied to the Antenna System

(Trunk 18" OD; 3/4" ID)

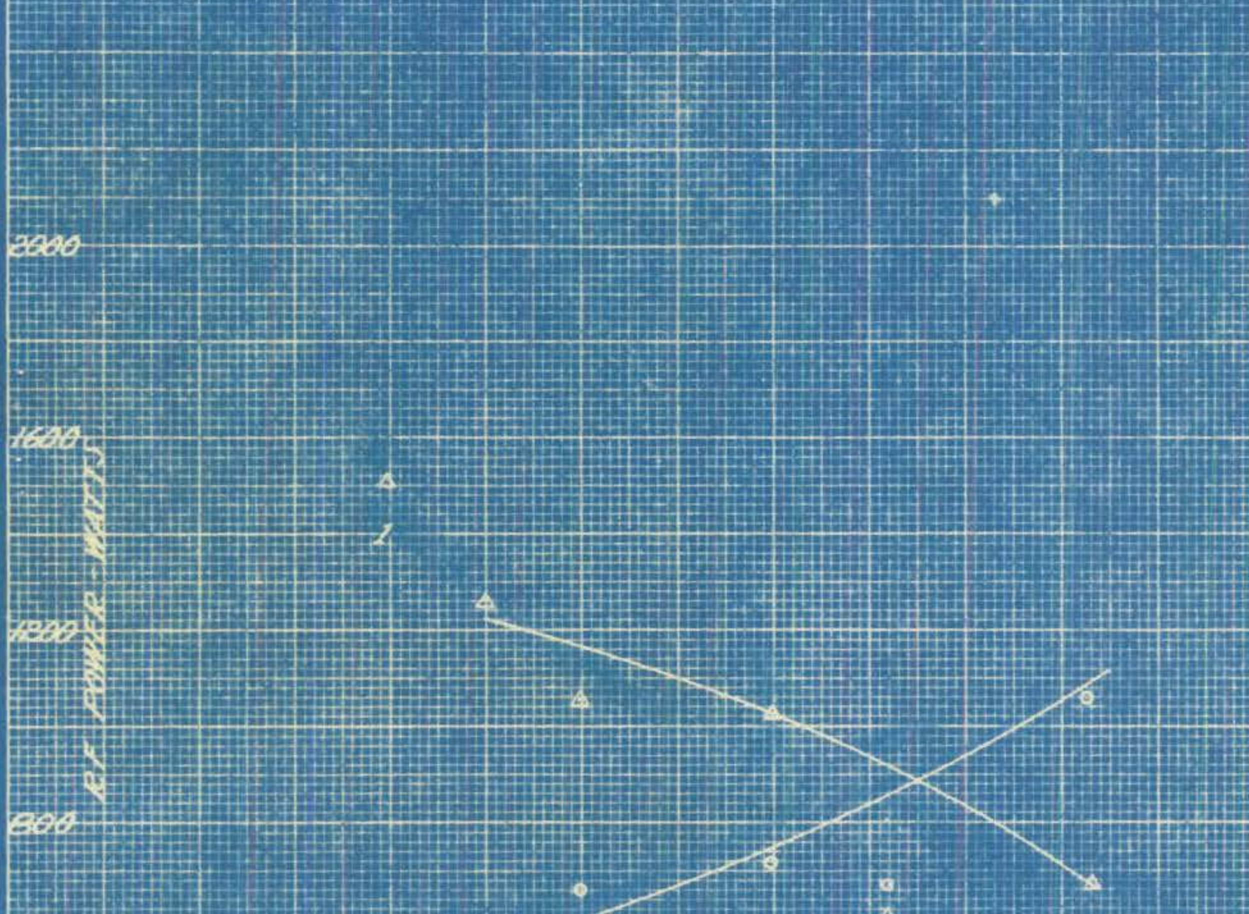


PLATE 13

RF Power as a Function of Frequency

Model XTAQ-5 Transmitter Operating at 62% of Full Power into a 13' Lead-In, 66' Trunk, 95' vertical and 95' Flat Top Antenna System.

(1) RF Power Loss in Antenna Loading Coil
(2) RF Power Supplied to the Antenna System

(Trunk 18" OD; 3/4" ID)

PLATE 14

RF Power as a Function of Frequency

Model XTAQ-5 Transmitter Operating at 62% of Full Power into a 13' Lead-In, 66' Trunk, 125' Vertical and 95' Flat Top Antenna System.

(1) RF Power Loss in Antenna Loading Coil
(2) RF Power Supplied to the Antenna System

(Trunk 18" OD; 3/4" ID)

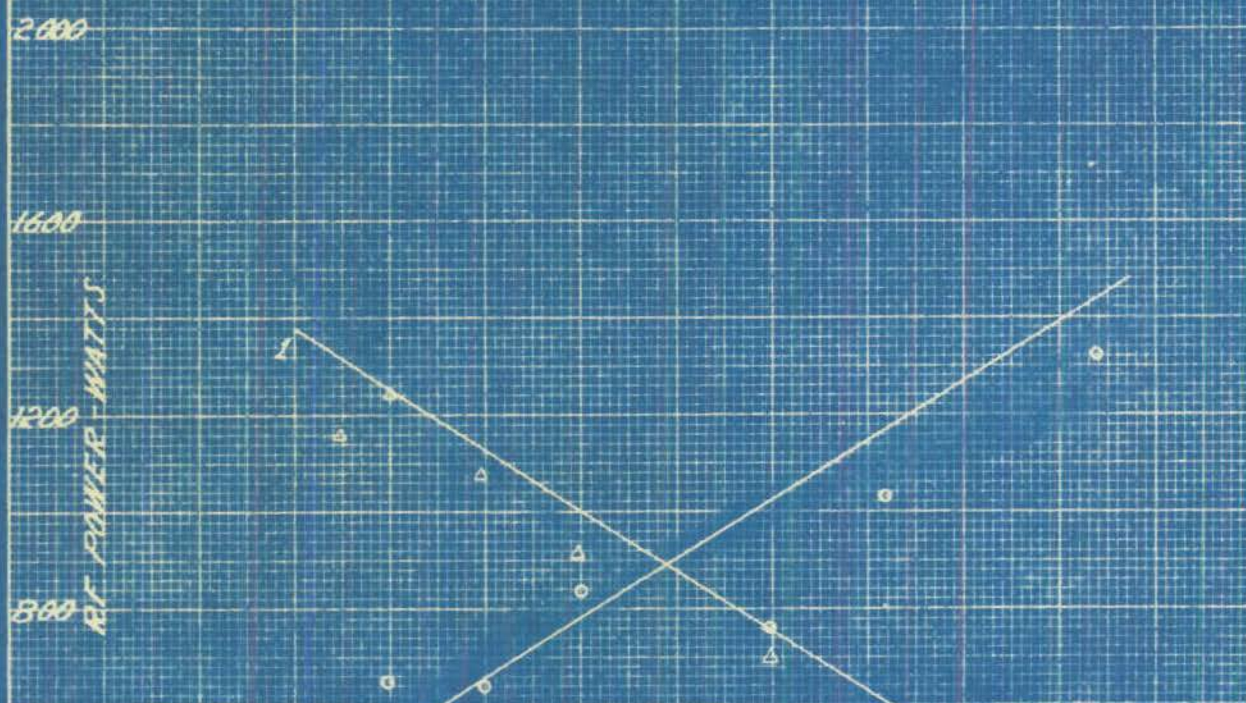


PLATE 15

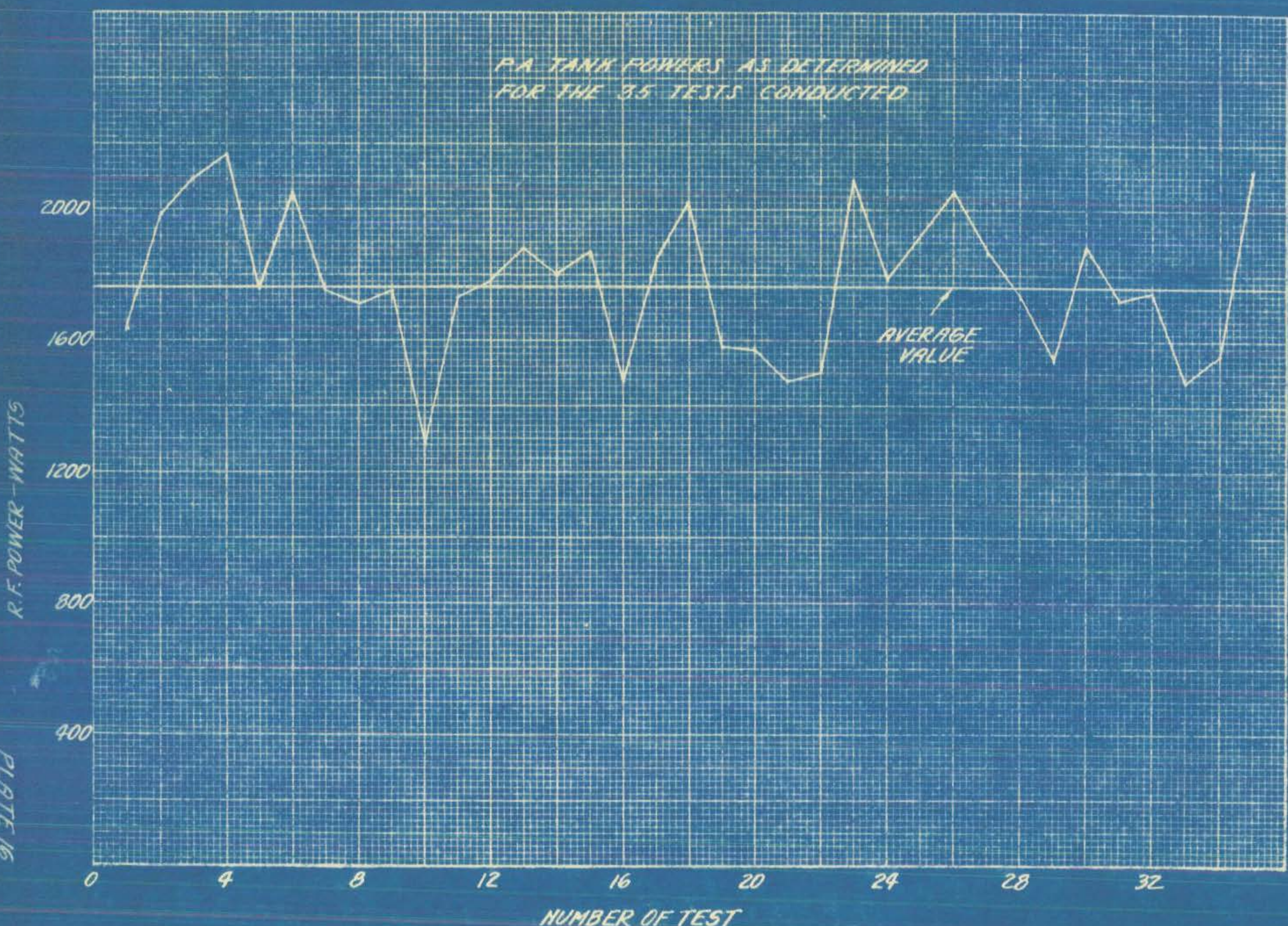

P.A. TANK POWERS AS DETERMINED
FOR THE 35 TESTS CONDUCTED
AVERAGE
VALUE
R.F. POWER-WATTS
2000
1600
1200
800
400
0
4
8
12
16
20
24
28
32
NUMBER OF TEST

PLATE 16

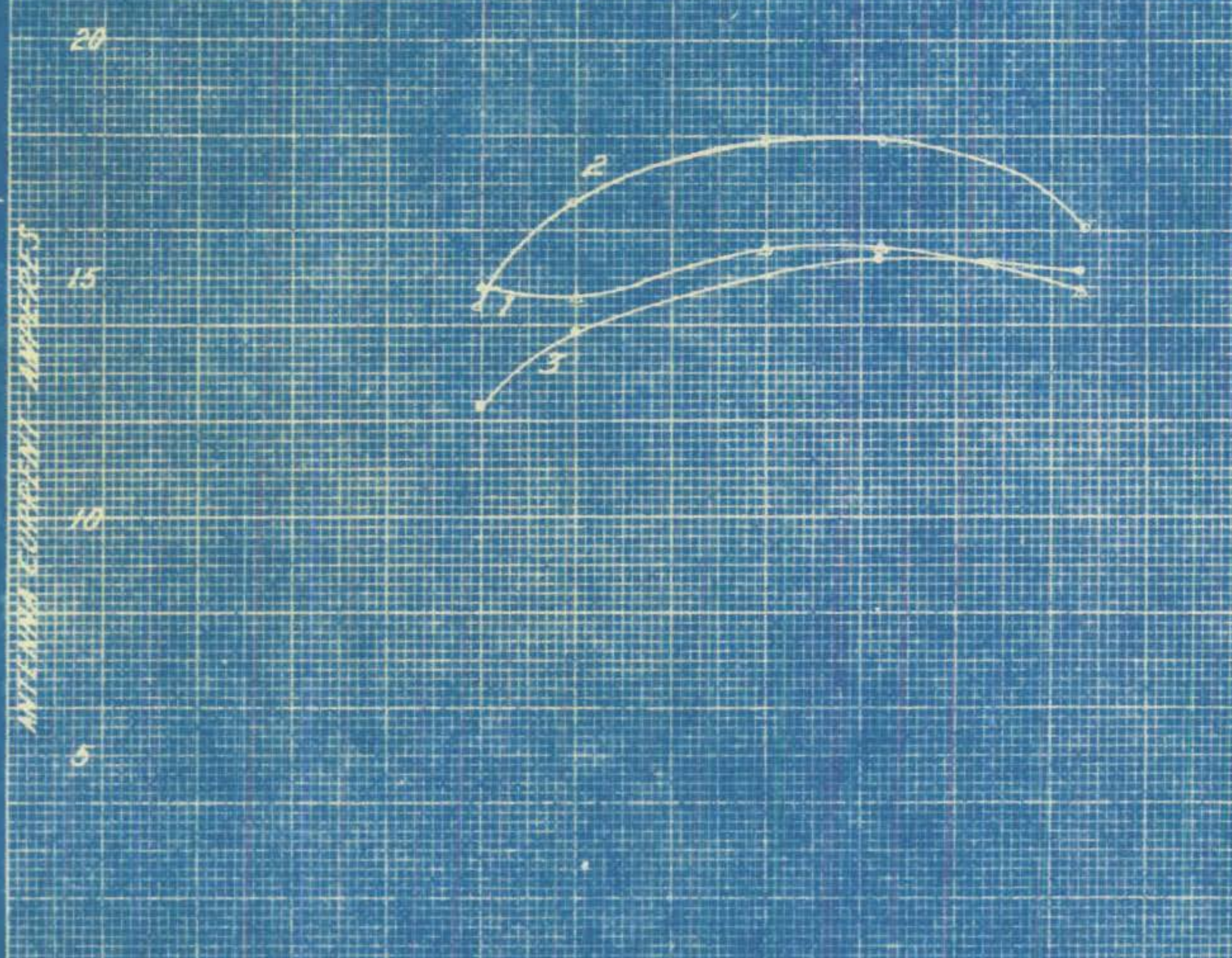
Antenna Current at the base of the vertical element as a function of frequency for a 13' lead-in, 65' vertical and 95' flat top antenna system.
Model XTAG-5 Transmitter operating at 62% of full power.

1. Calculated by Method 1.*

2. Calculated by Method 2.

3. Calculated by Method 3.

* (See Paragraph 56 for methods of calculation.)



Antenna Current at the base of the vertical element as a function of frequency for 13' lead-in, 95' vertical and 95' flat top antenna system.
Model XTAQ-5 Transmitter operating at 62% of full power.

1. Calculated by Method 1*.

2. Calculated by Method 2.

3. Calculated by Method 3.

* (See Paragraph 56 for methods of calculation.)

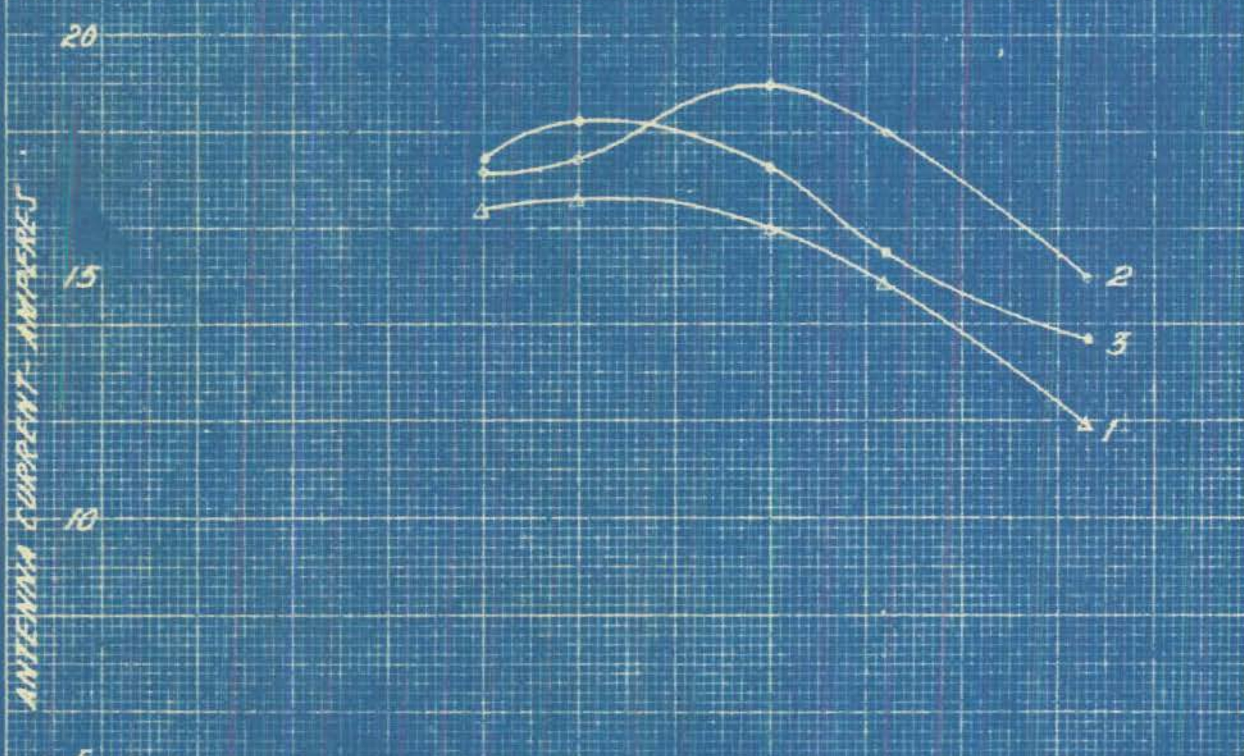
Antenna current at the base of the vertical element as a function of frequency for a 13' lead-in, 125' vertical and 95' flat top antenna system.
Model XTAQ-5 Transmitter operating at 62% of full power.

1. Calculated by Method 1. *

2. Calculated by Method 2.

3. Calculated by Method 3.

* (See Paragraph 56 for methods of calculation.)



Antenna current at the base of the vertical element as a function of frequency for a 13' lead-in, 66' trunk, 65' vertical and 95' flat top antenna system. Model XTAQ-5 transmitter operating at 62% of full power.

(Trunk 18" OD; 3/4" ID)

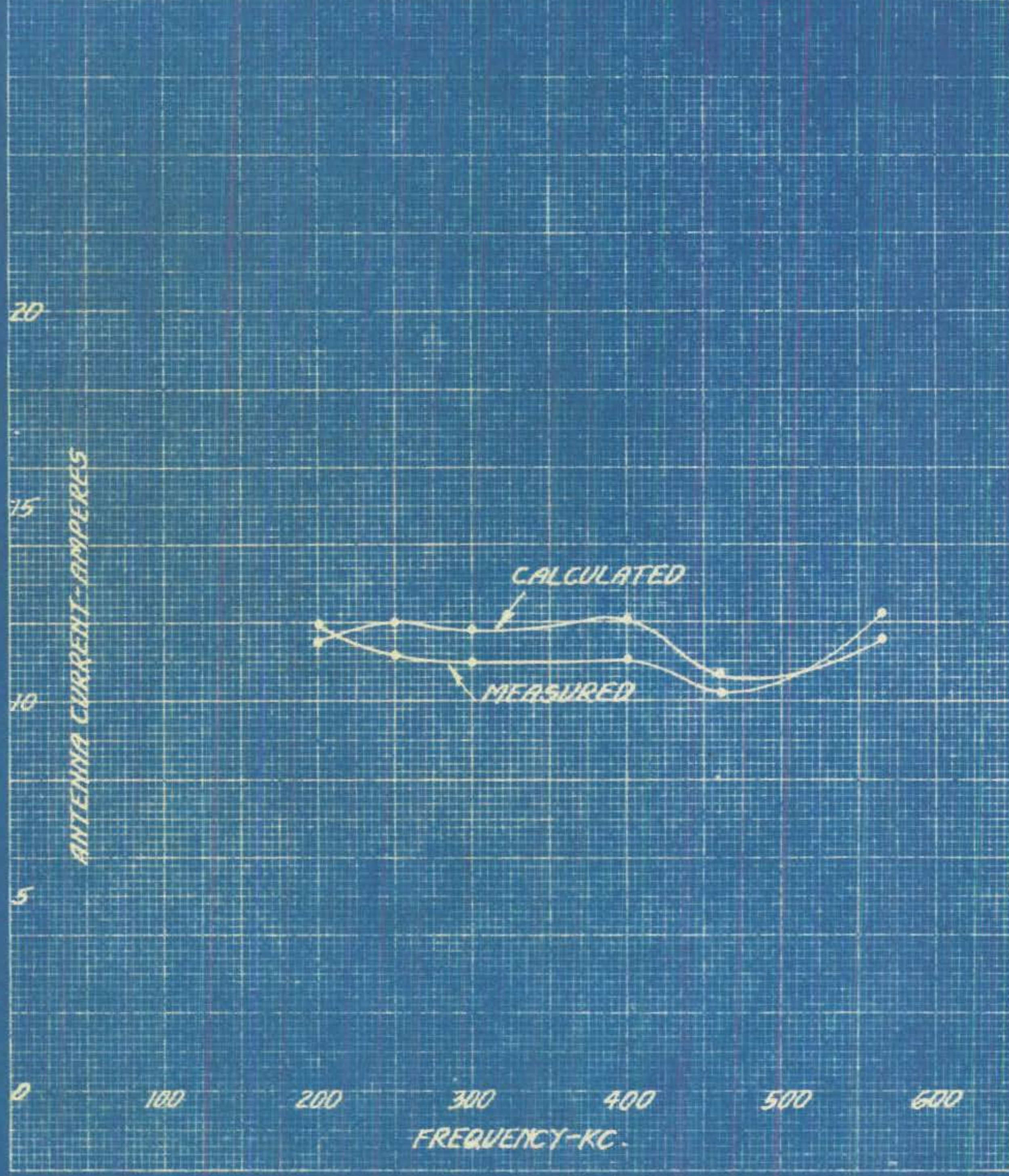


PLATE 20

Antenna current at the base of the vertical element as a function of the frequency for a 13' lead-in, 66' trunk, 95' vertical and 95' flat top. Model XTAC-5 transmitter operating at 62% of full power.

(Trunk 18" OD; 3/4" ID)

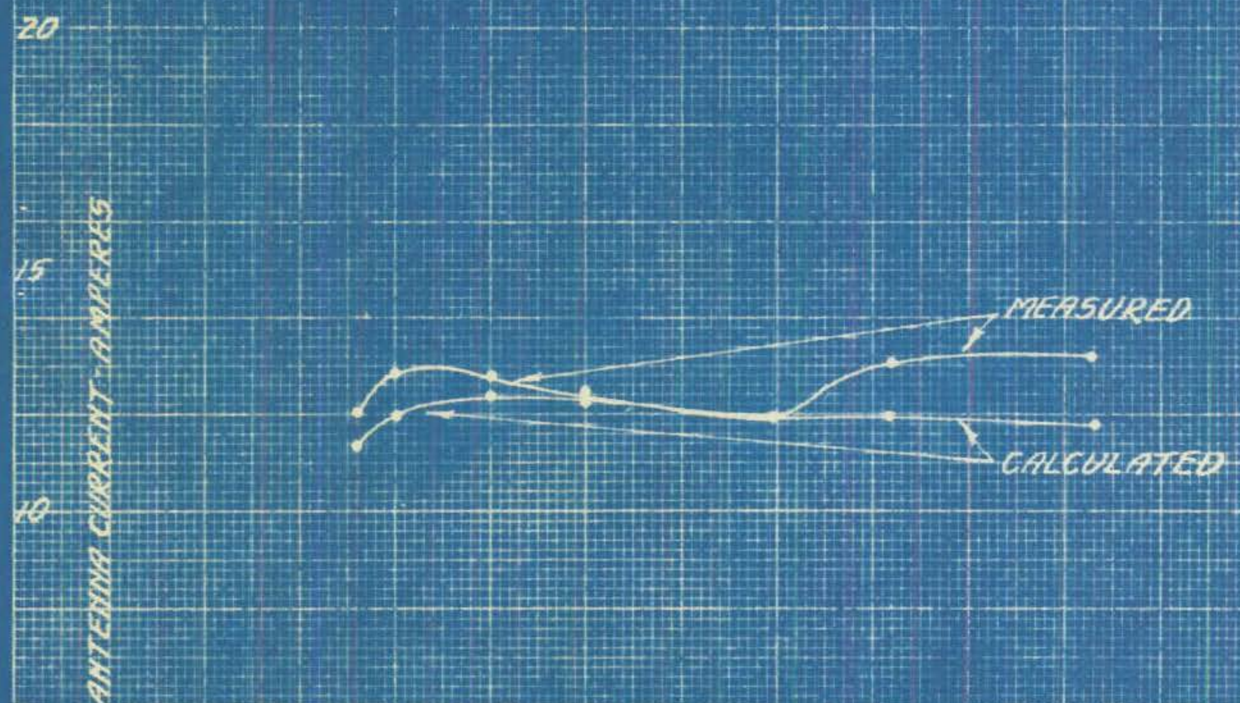


PLATE 21

Antenna current at the base of the vertical element as a function of the frequency for a 13' lead-in, 66' trunk, 125' vertical and 95' flat top antenna system. Model XTAQ-5 transmitter operating at 62% of full power.

(Trunk 18" OD; 3/4" ID)

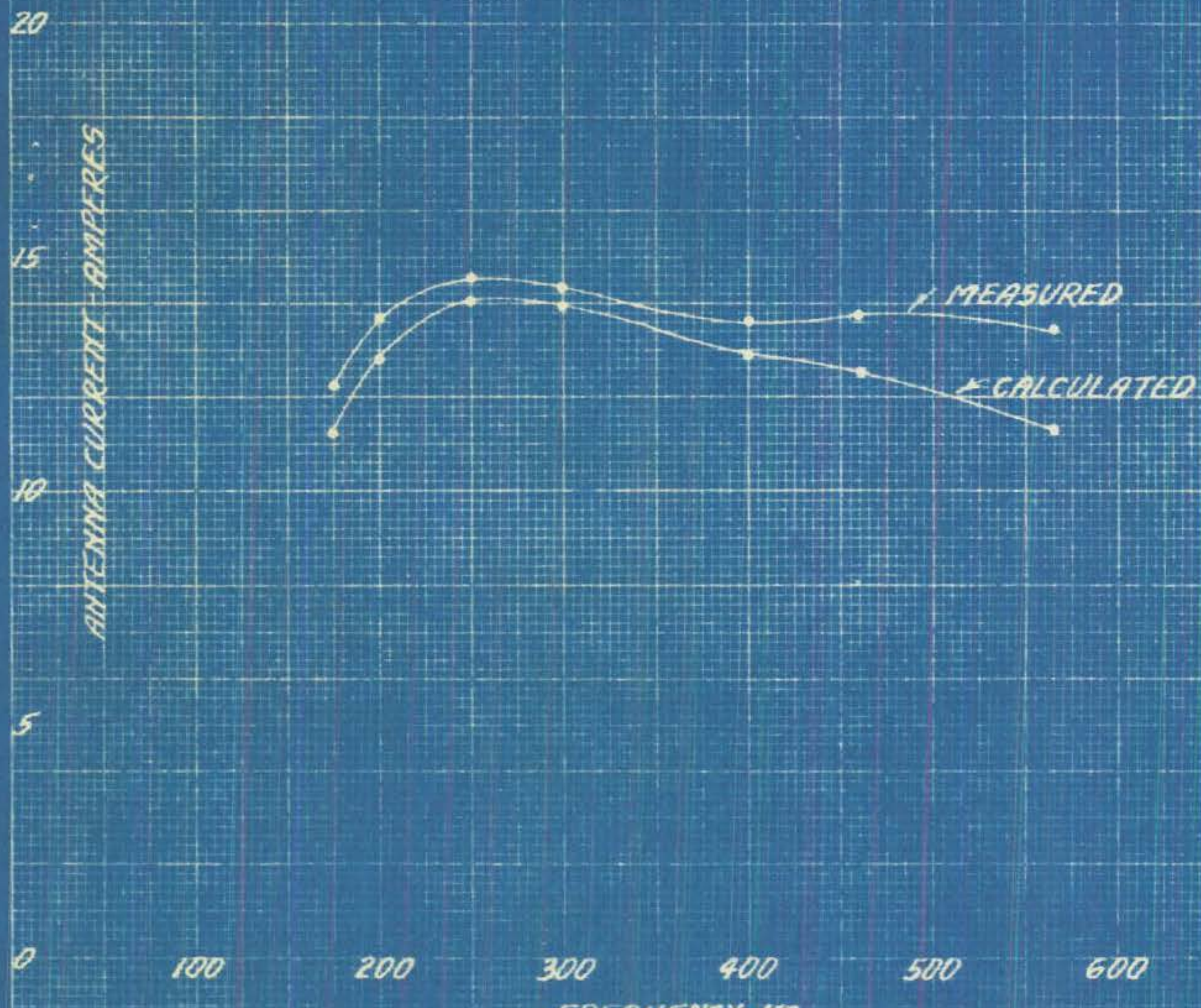
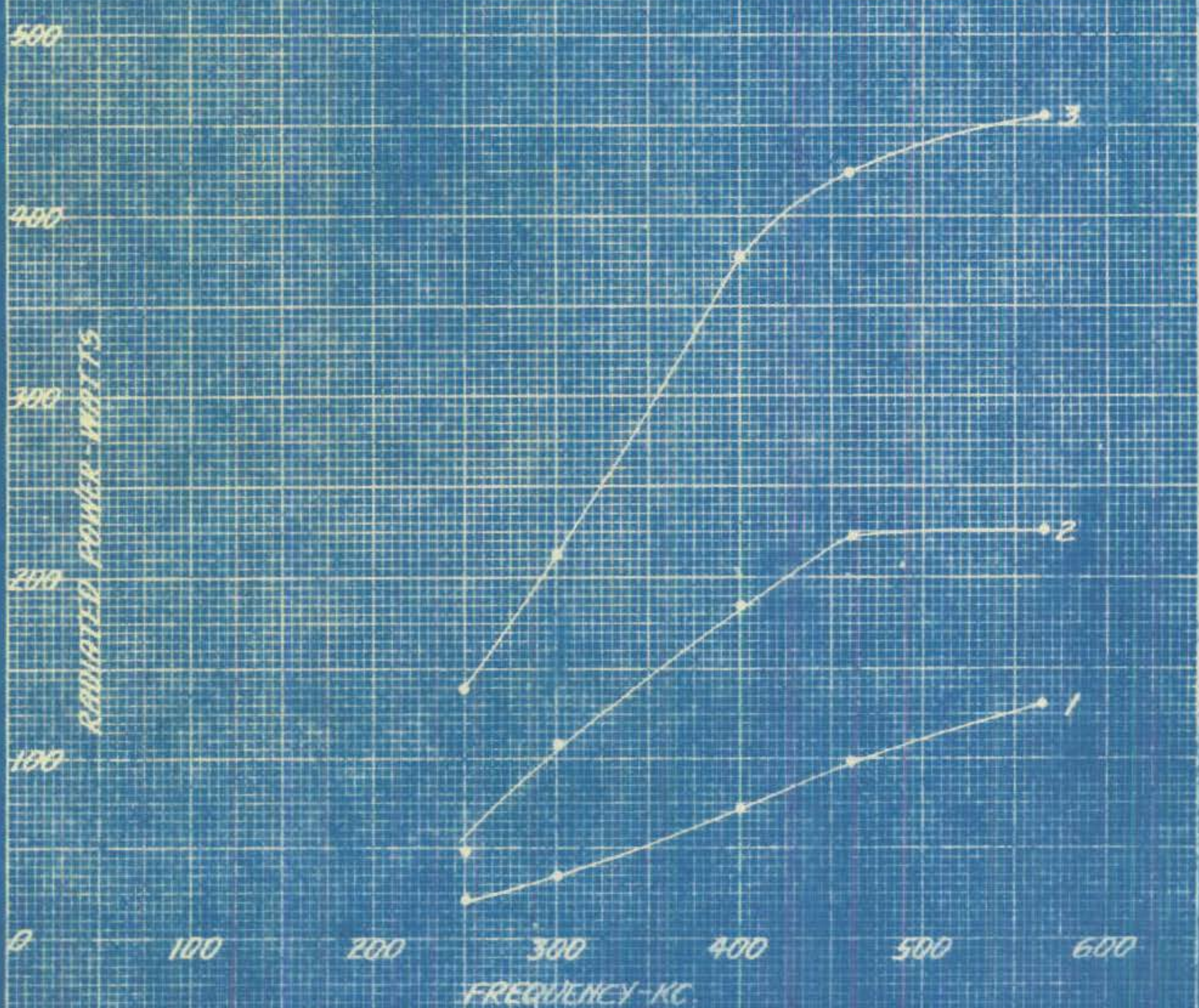


PLATE 22

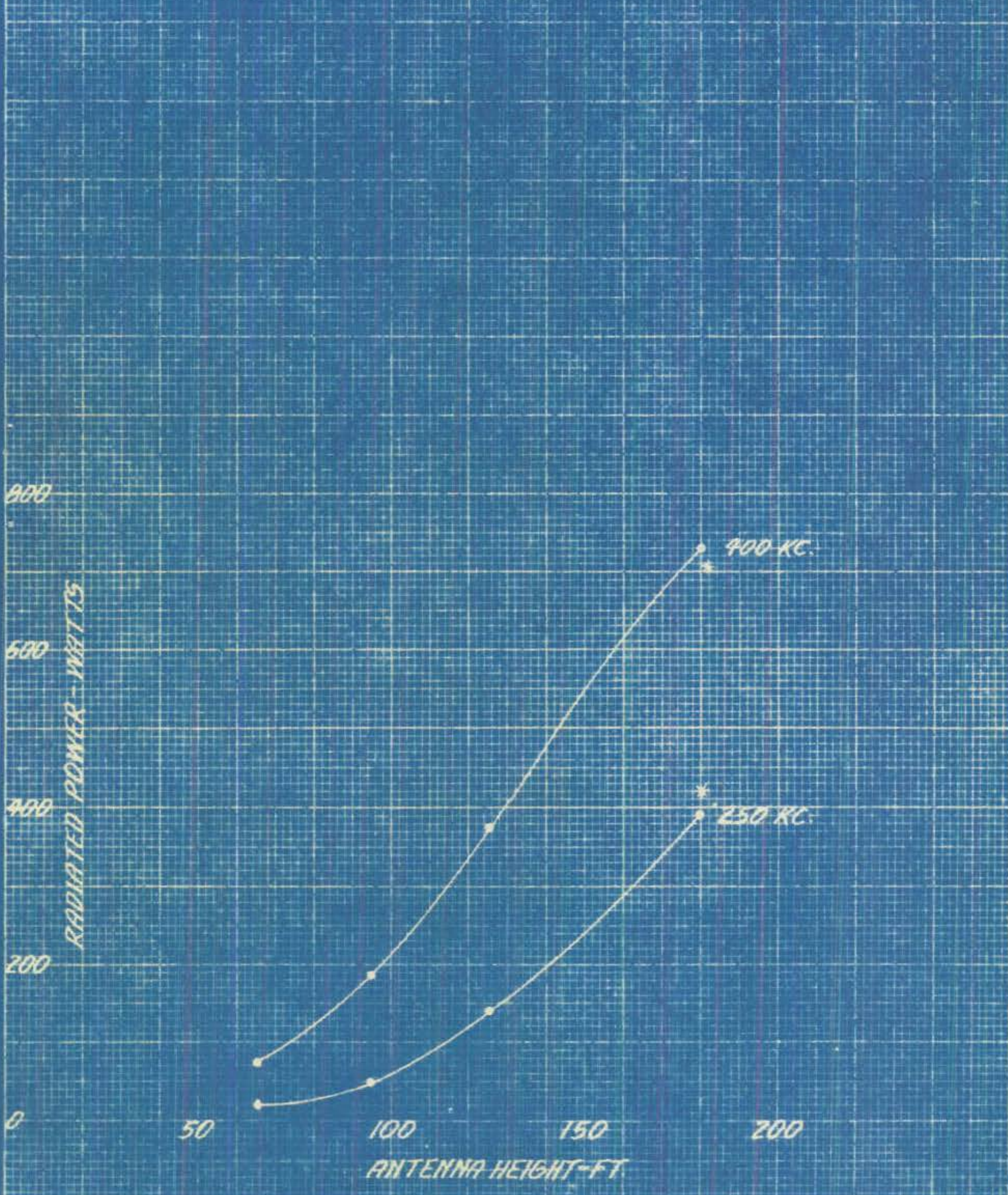
Radiated power as a function of frequency. Model XTAQ-5 transmitter operating at 82% of full power into the following antenna systems:

1. 13' lead-in, 65' vertical and 95' flat top.
2. 13' lead-in, 95' vertical and 95' flat top.
3. 13' lead-in, 125' vertical and 95' flat top.



Radiated power as a function of antenna height.
Model XTAQ-5 transmitter operating at 62% of full power into antenna with 95' flat top (no trunk).

*200' flat top.



Radiated power as a function of frequency. Model XTAQ-5 transmitter operating at 62% of full power into the following antenna systems.

1. 13' lead-in, 66' trunk, 65' vertical and 95' flat top.

2. 13' lead-in, 66' trunk, 95' vertical and 95' flat top.

3. 13' lead-in, 66' trunk, 125' vertical and 95' flat top.

(Trunks 18" OD; 3/4" ID)

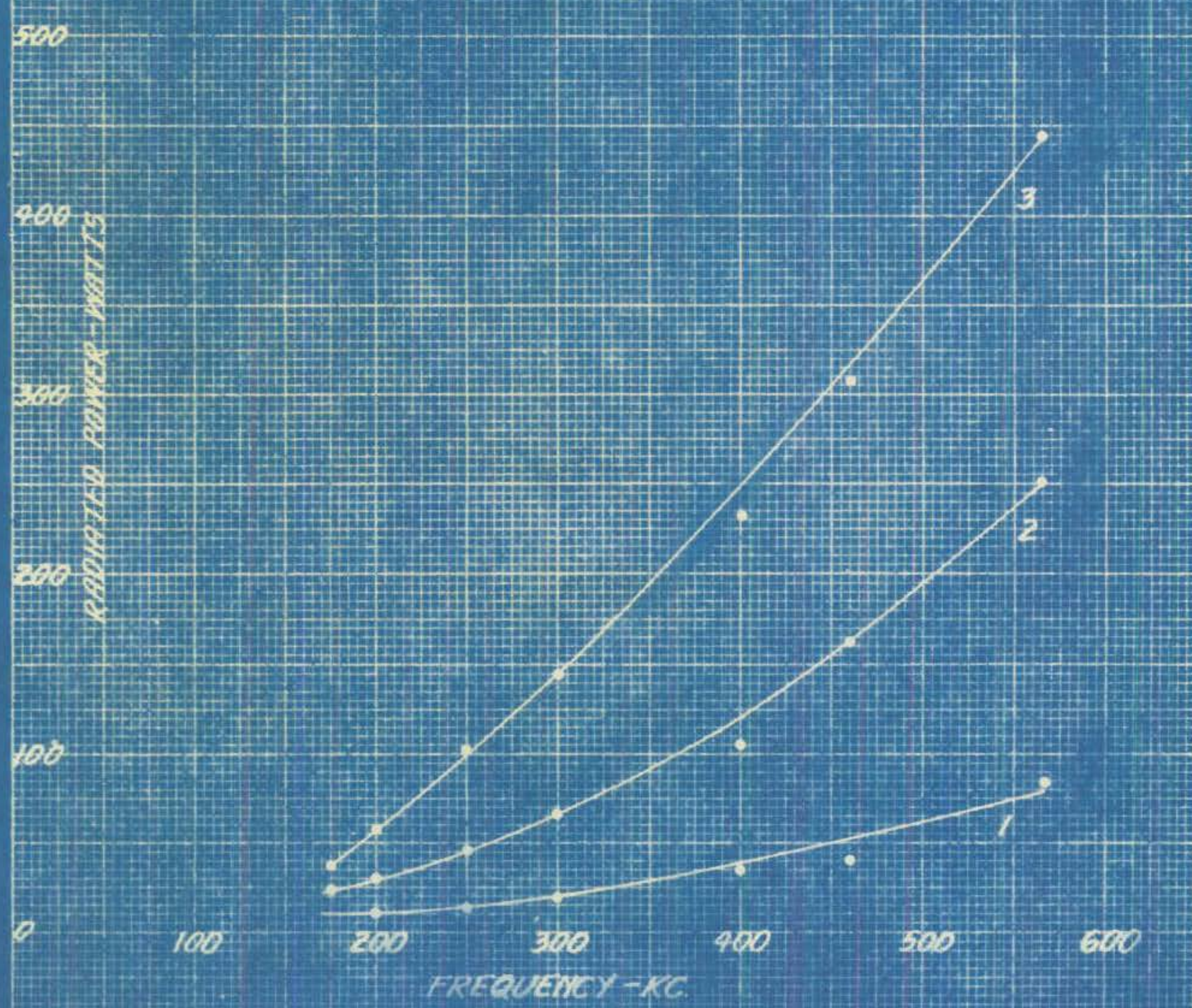


PLATE 25

Radiated power as a function of antenna height.
Model XTAQ-5 transmitter operating at 68% of full power
into a 66' trunk and antennas with a 95' flat top.

(Trunk 18" OD; 3/4" ID)

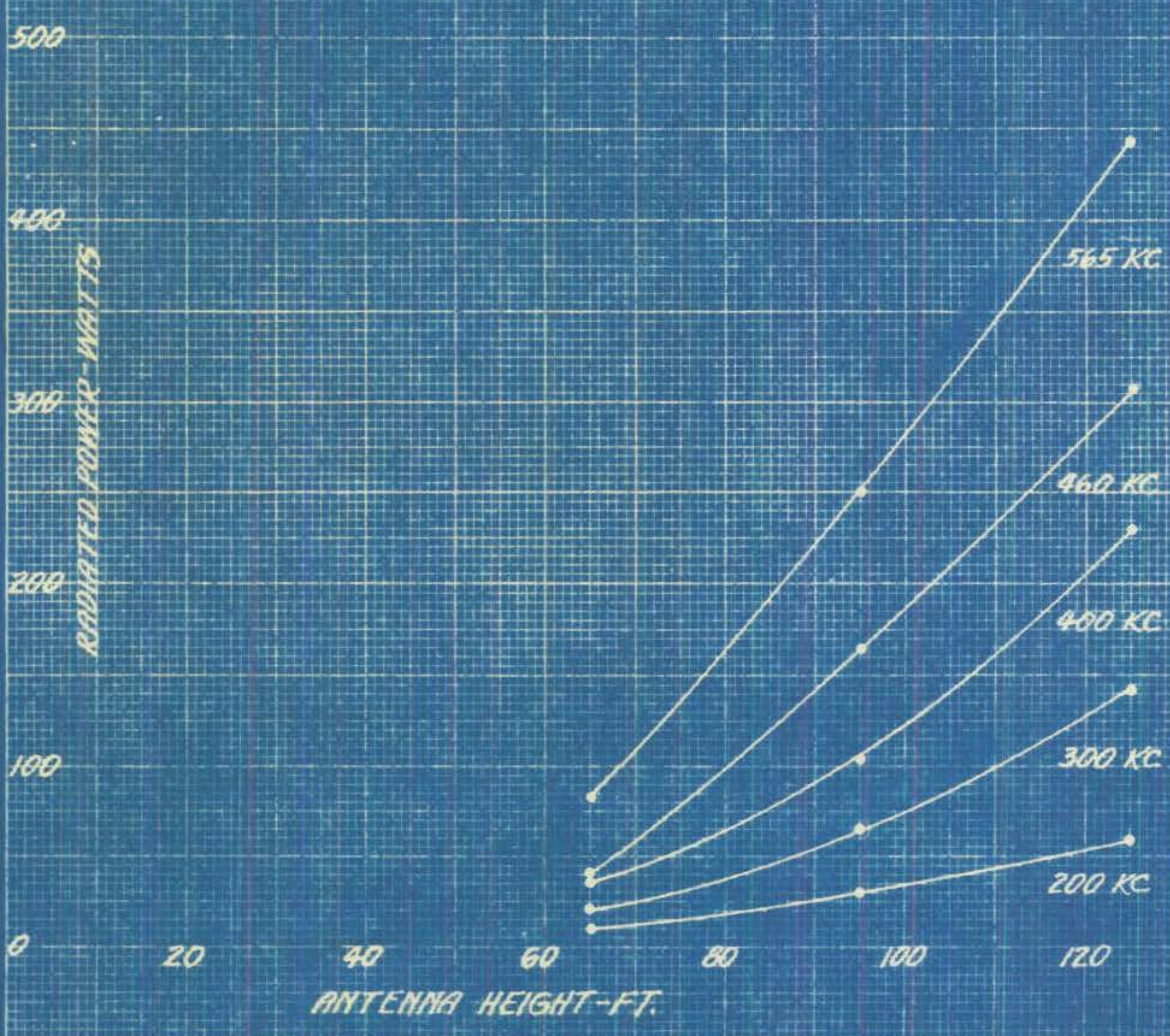


PLATE 26

Peak antenna voltage as a function of frequency.
Model XTAQ-5 transmitter operating at 62% of full power into the following antenna systems.

1. 13' lead-in, 65' vertical and 95' flat top.
2. 13' lead-in, 95' vertical and 95' flat top.
3. 13' lead-in, 125' vertical and 95' flat top.

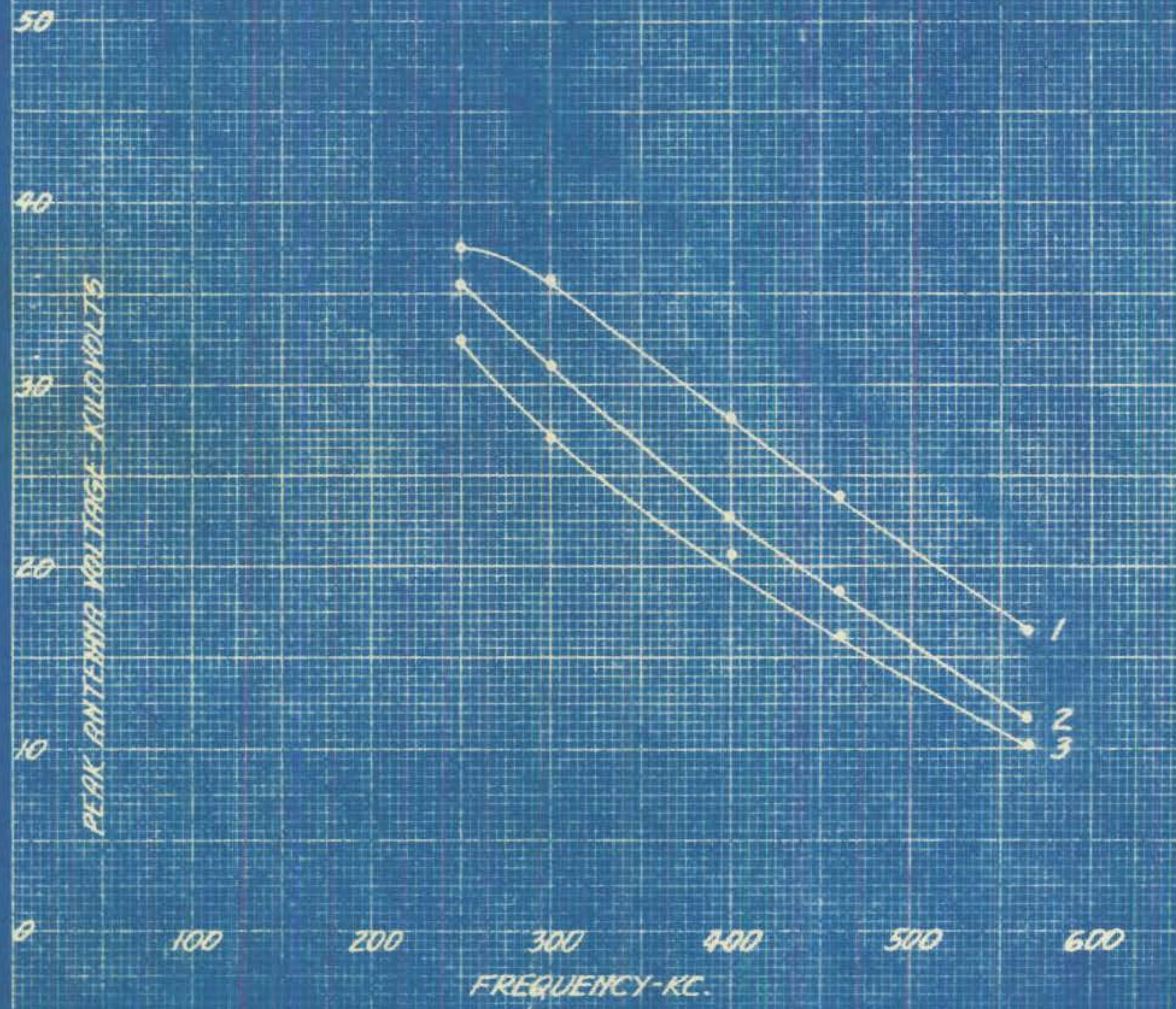


PLATE 27

Peak antenna voltage as a function of frequency.
Model XTAQ-5 transmitter operating at 62% of full power
into the following antenna systems.

1. 13' lead-in, 66' trunk, 65' vertical and 95' flat top.

2. 13' lead-in, 66' trunk, 95' vertical and 95' flat top.

3. 13' lead-in, 66' trunk, 125' vertical and 95' flat top.

(Trunk 18" OD; 3/4" ID)

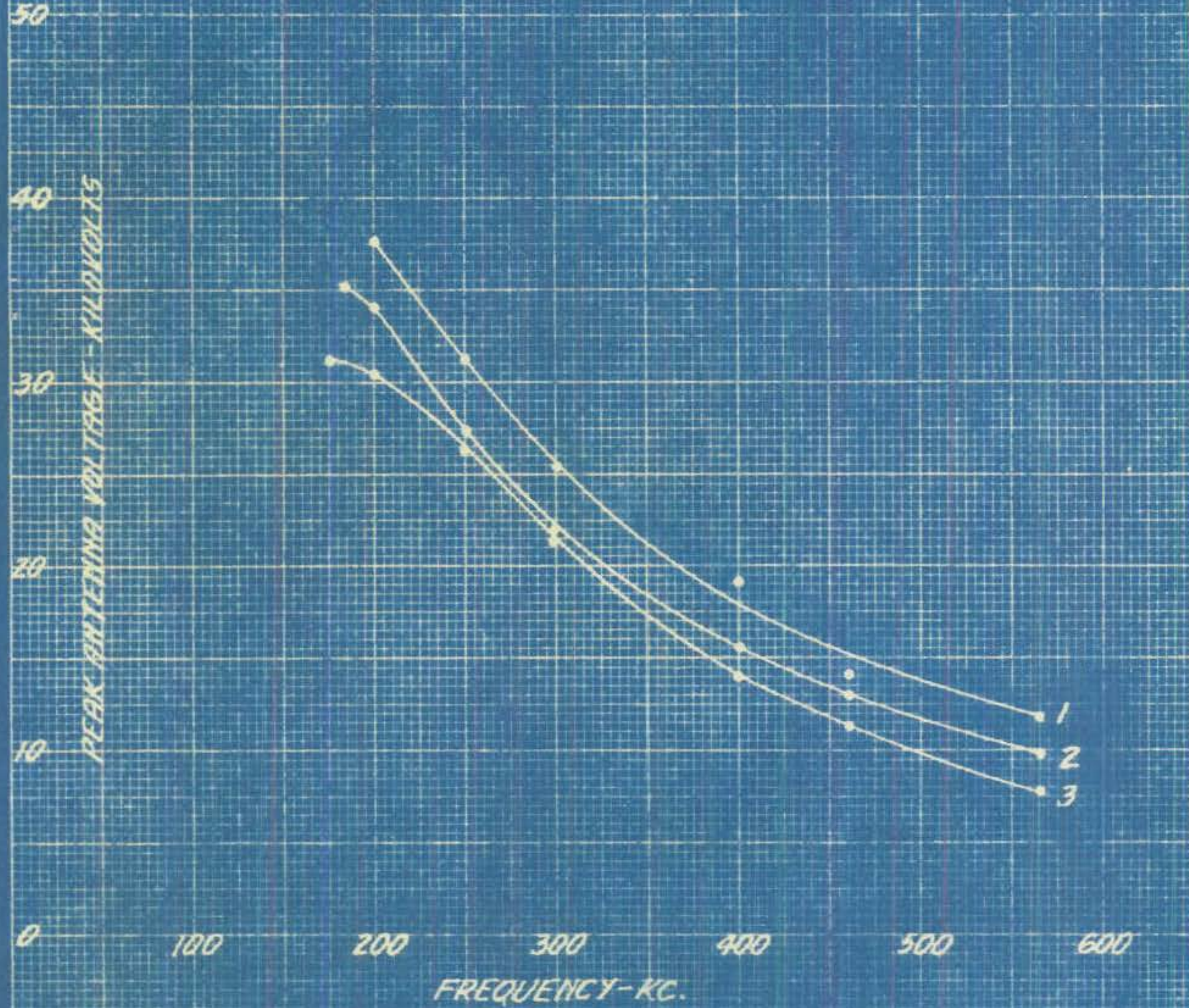
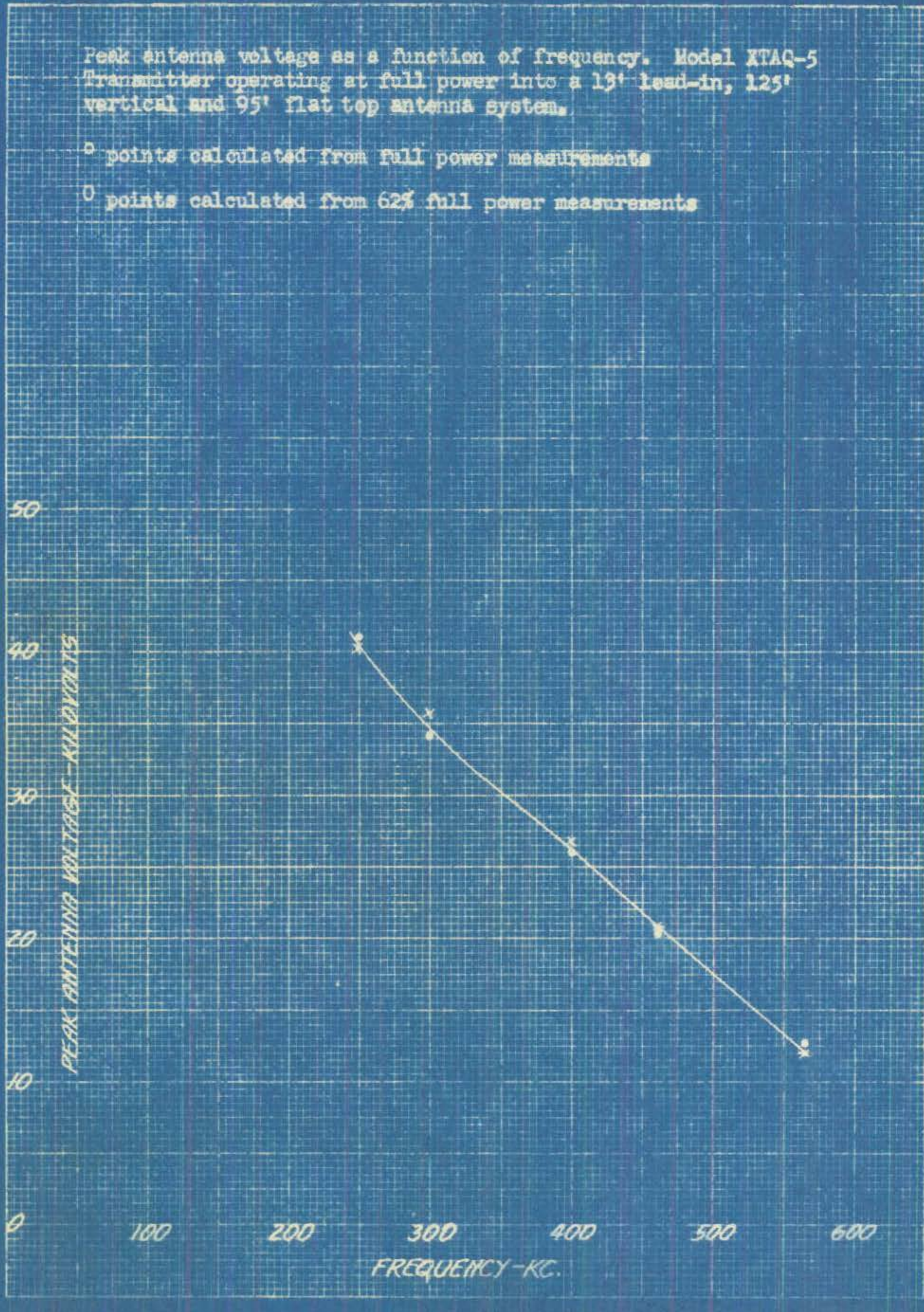


PLATE 28



Peak antenna voltage as a function of frequency. Model XTAQ-5 Transmitter operating at full power into a 13' lead-in, 125' vertical and 95' flat top antenna system.

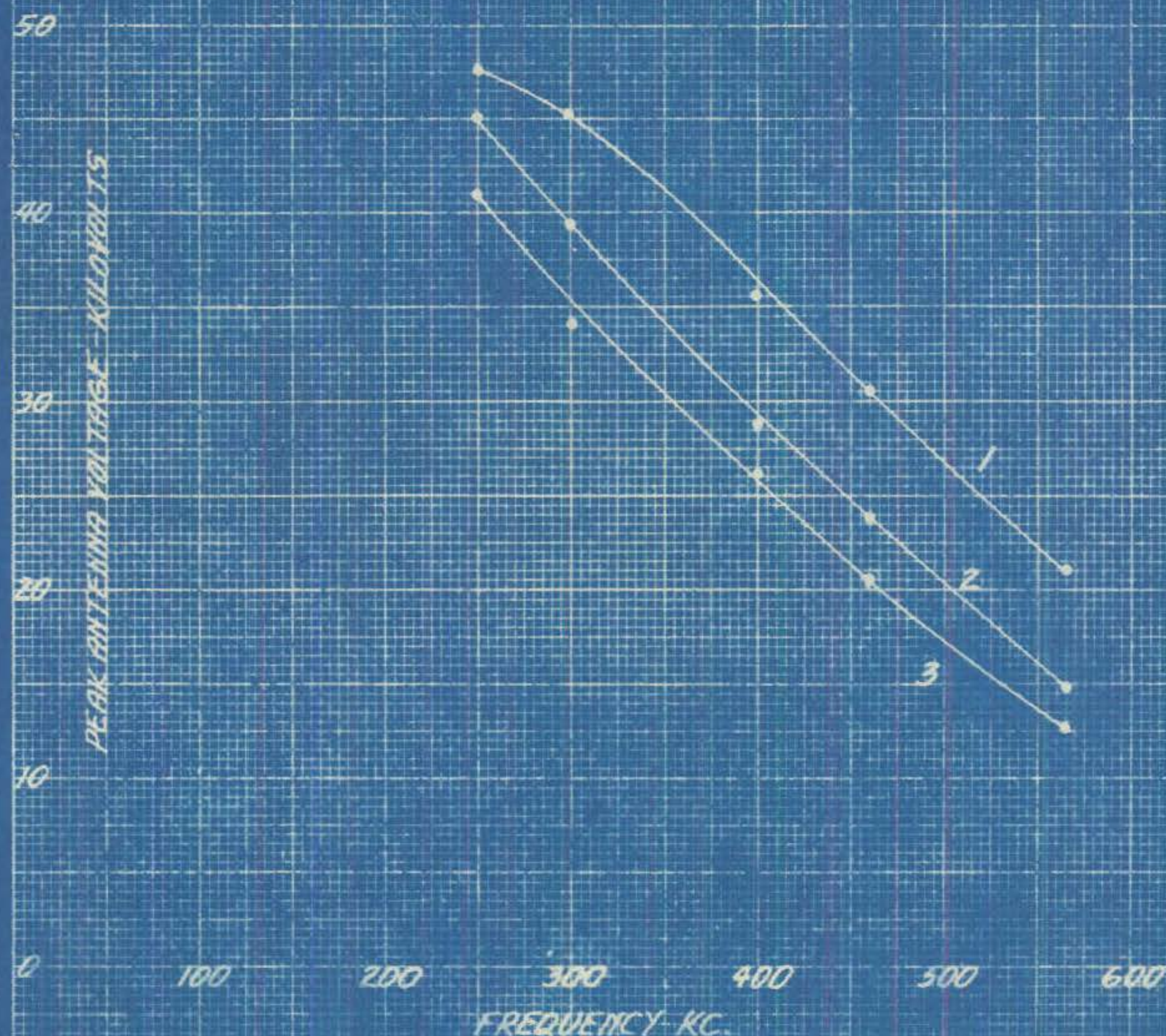
PLATE 29

Peak antenna voltage as a function of frequency. Model XTAQ-5 Transmitter operating at full power into the following antenna systems.

1. 13' lead-in, 65' vertical and 95' flat top.

2. 13' lead-in, 95' vertical and 95' flat top.

3. 13' lead-in, 125' vertical and 95' flat top.



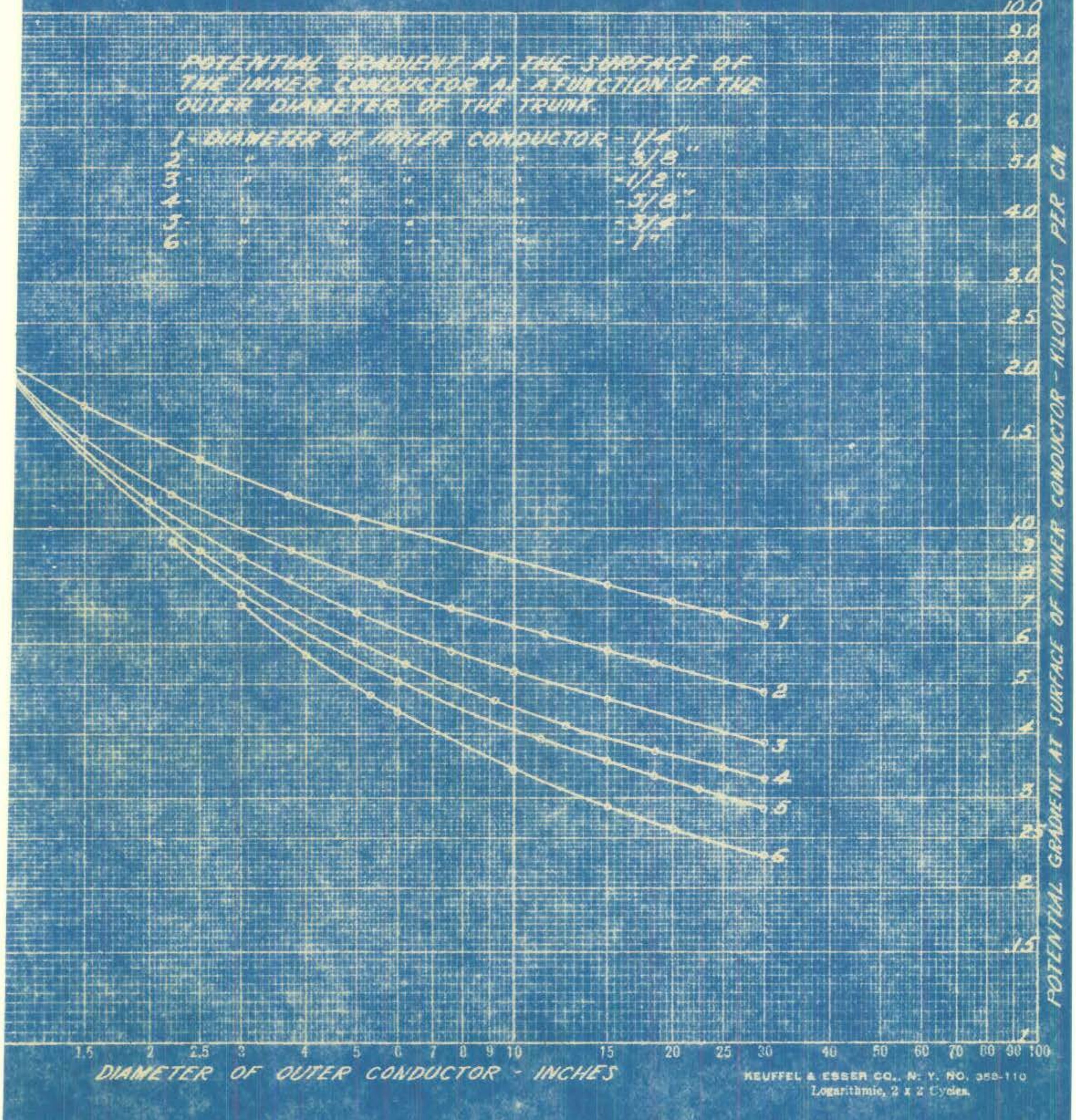
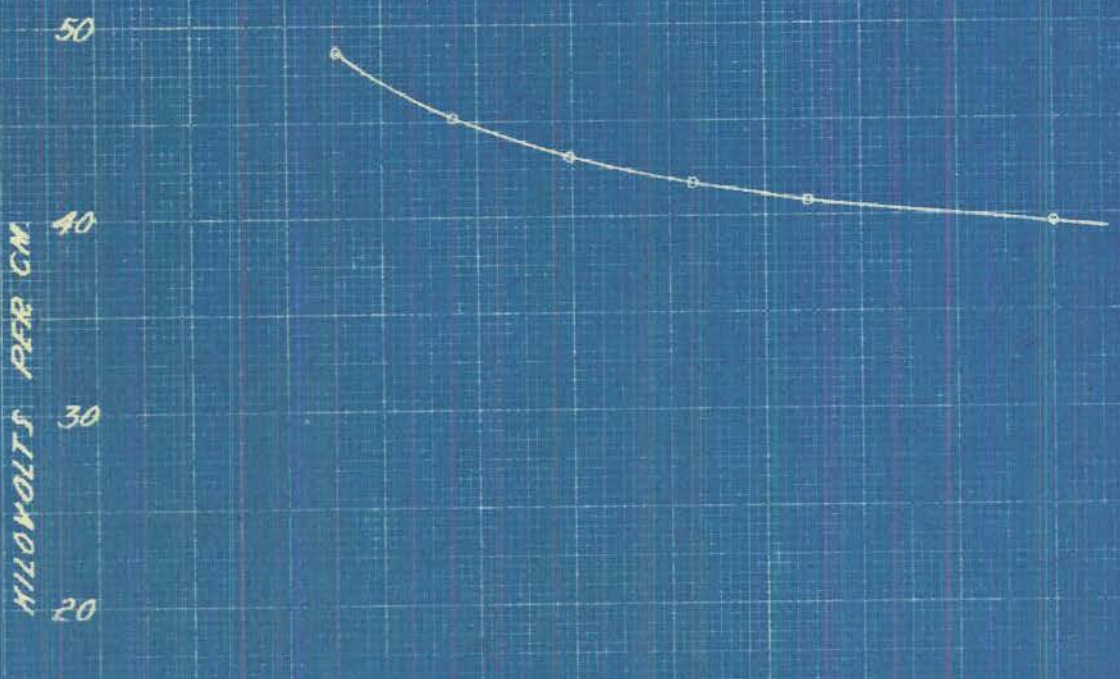

POTENTIAL GRADIENT AT THE SURFACE OF THE INNER CONDUCTOR AS A FUNCTION OF THE OUTER DIAMETER OF THE TRUNK.
1 - DIAMETER OF INNER CONDUCTOR - 1/4"
2 - " " " " - 3/8"
3 - " " " " - 1/2"
4 - " " " " - 3/8"
5 - " " " " - 3/4"
6 - " " " " - 1"
1
2
3
4
5
6
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.5
2.0
1.5
1.0
.9
.8
.7
.6
.5
.4
.3
.25
.2
.15
.1
1.5
2
2.5
3
4
5
6
7
8
9
10
15
20
25
30
40
50
60
70
80
90
100
DIAMETER OF OUTER CONDUCTOR - INCHES
POTENTIAL GRADIENT AT SURFACE OF INNER CONDUCTOR - KILOVOLTS PER CM.
KEUFFEL & ESSER CO., N. Y. NO. 358-110
Logarithmic, 2 x 2 Cycles.

PLATE 32

Potential gradient at the surface of the inner conductor at which visual corona appears, plotted as a function of the diameter of the inner conductor. Frequency - 60 cycles.



Relative Field Strength as a Function of the Antenna Current at 565 KC for Antenna System Number 5

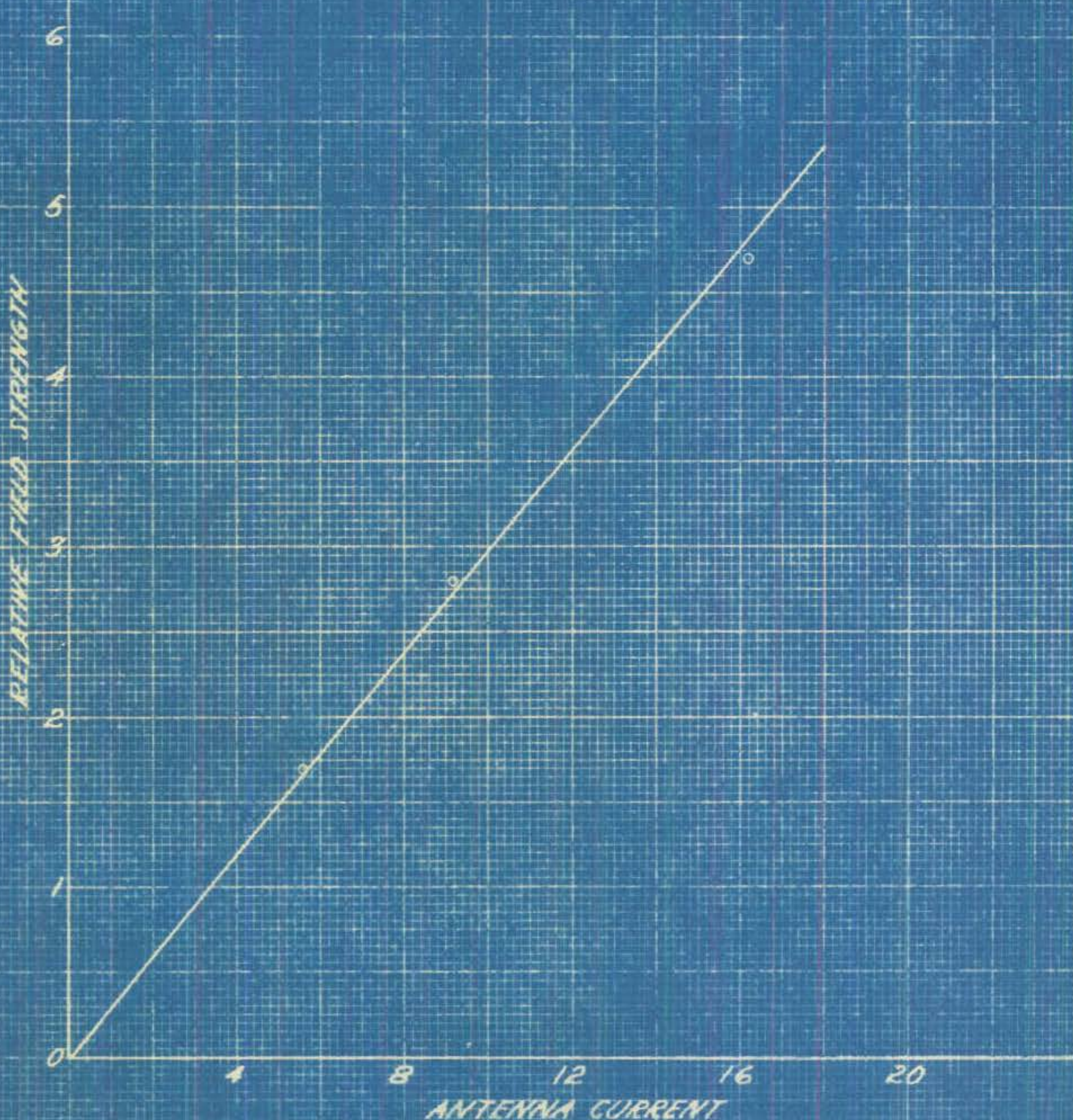


PLATE 34

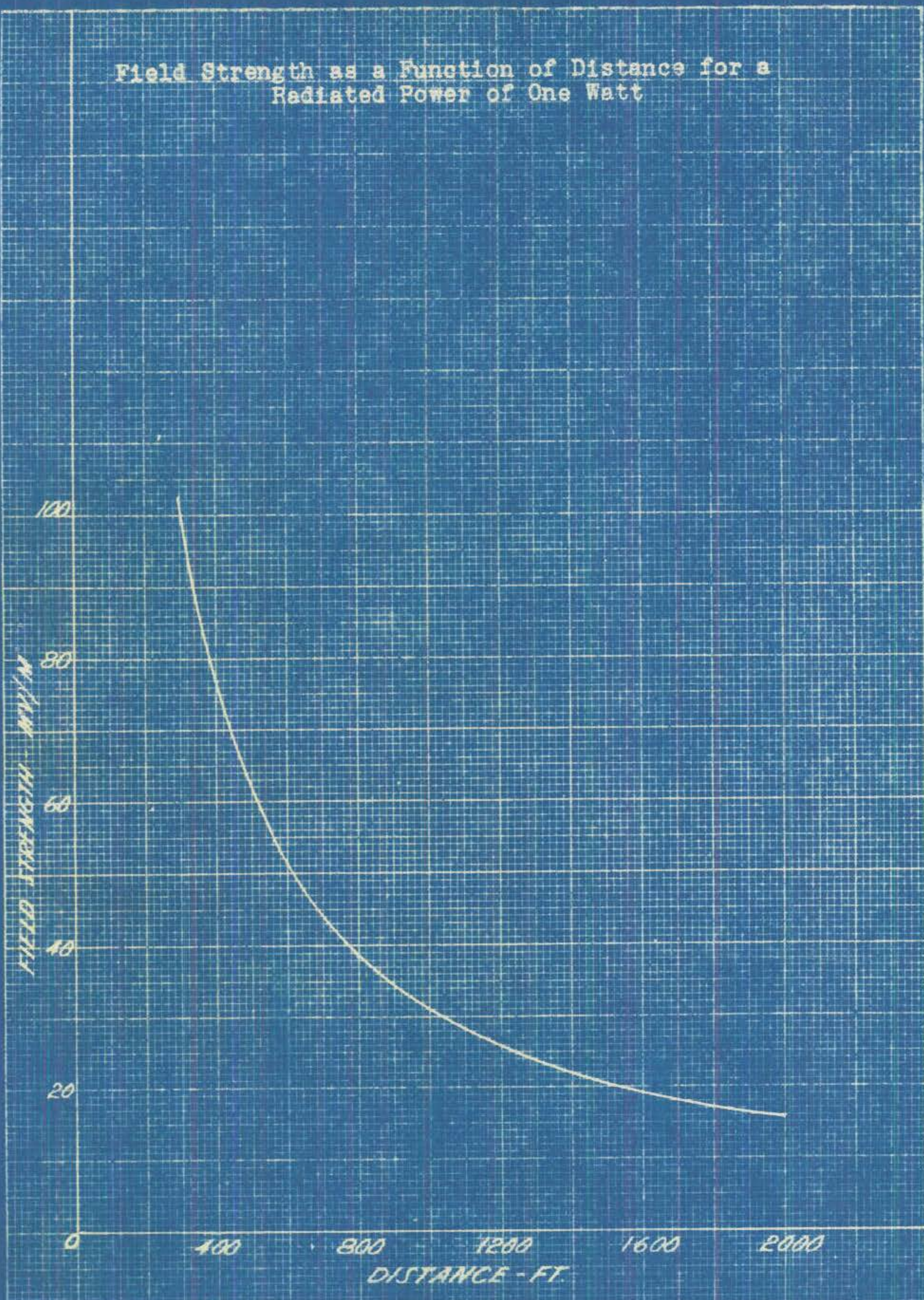
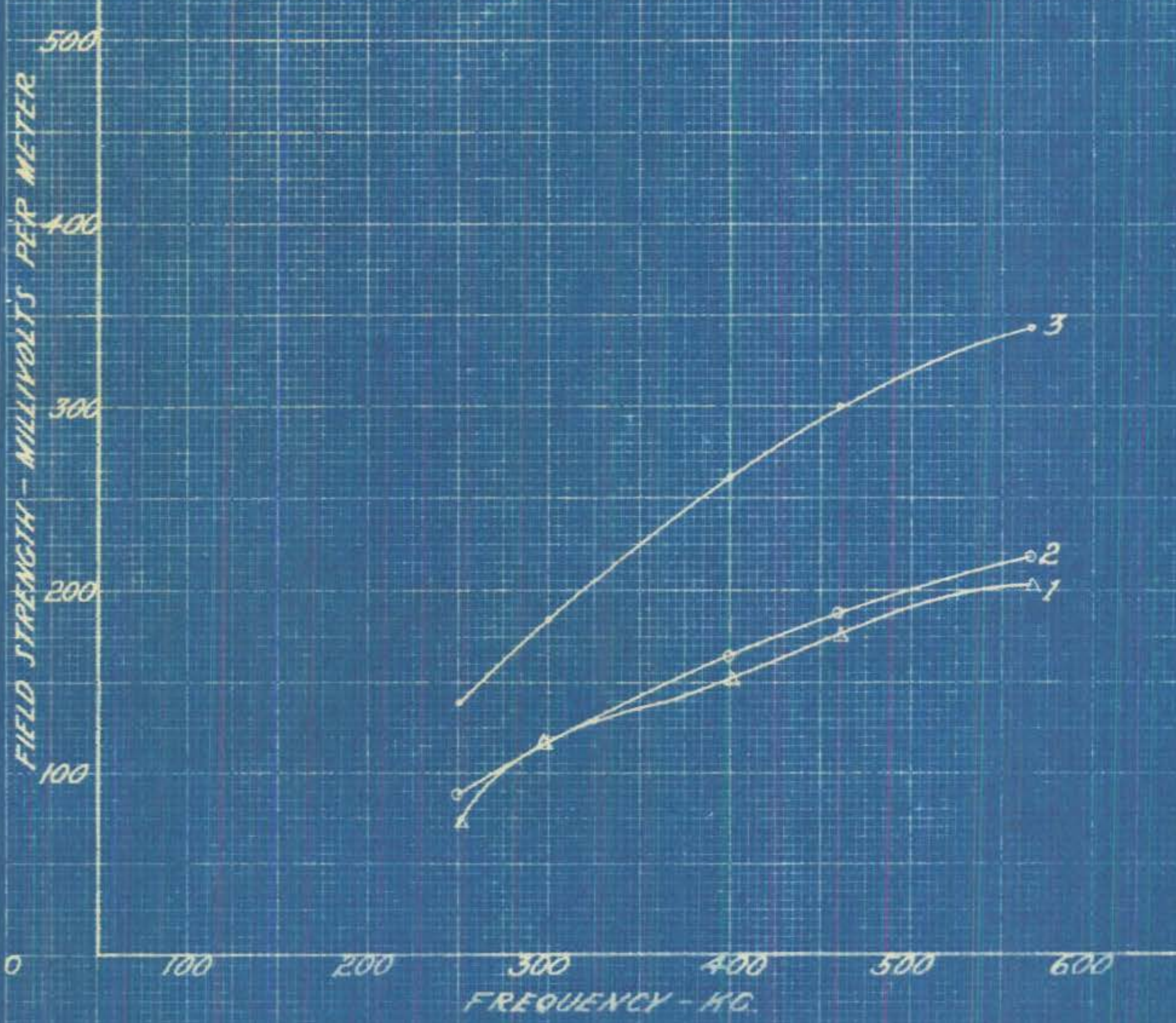

Field Strength as a Function of Distance for a
Radiated Power of One Watt
100
80
60
40
20
0
400
800
1200
1600
2000
DISTANCE - FT.
FIELD STRENGTH - MV/M

PLATE 35

Field Strength as a Function of Frequency at
505 Meters from XTAC-5 Transmitter Operating at
62% of Full Power into a 13' Lead-In, 65' Vertical
and 95' Flat Top Antenna System.

(1) Measured Field Strength
(2) Calculated Field Strength for a Shielded Antenna
(3) Calculated Field Strength Neglecting the Partial
Shielding of the Antenna



Field strength as a function of frequency at 505 meters from XTAQ-5 Transmitter operating at 62% of full power into a 13' lead-in, 95' vertical and 95' flat top antenna system.

1. Measured field strength.

2. Calculated field strength for shielded antenna.

3. Calculated field strength neglecting shielding.

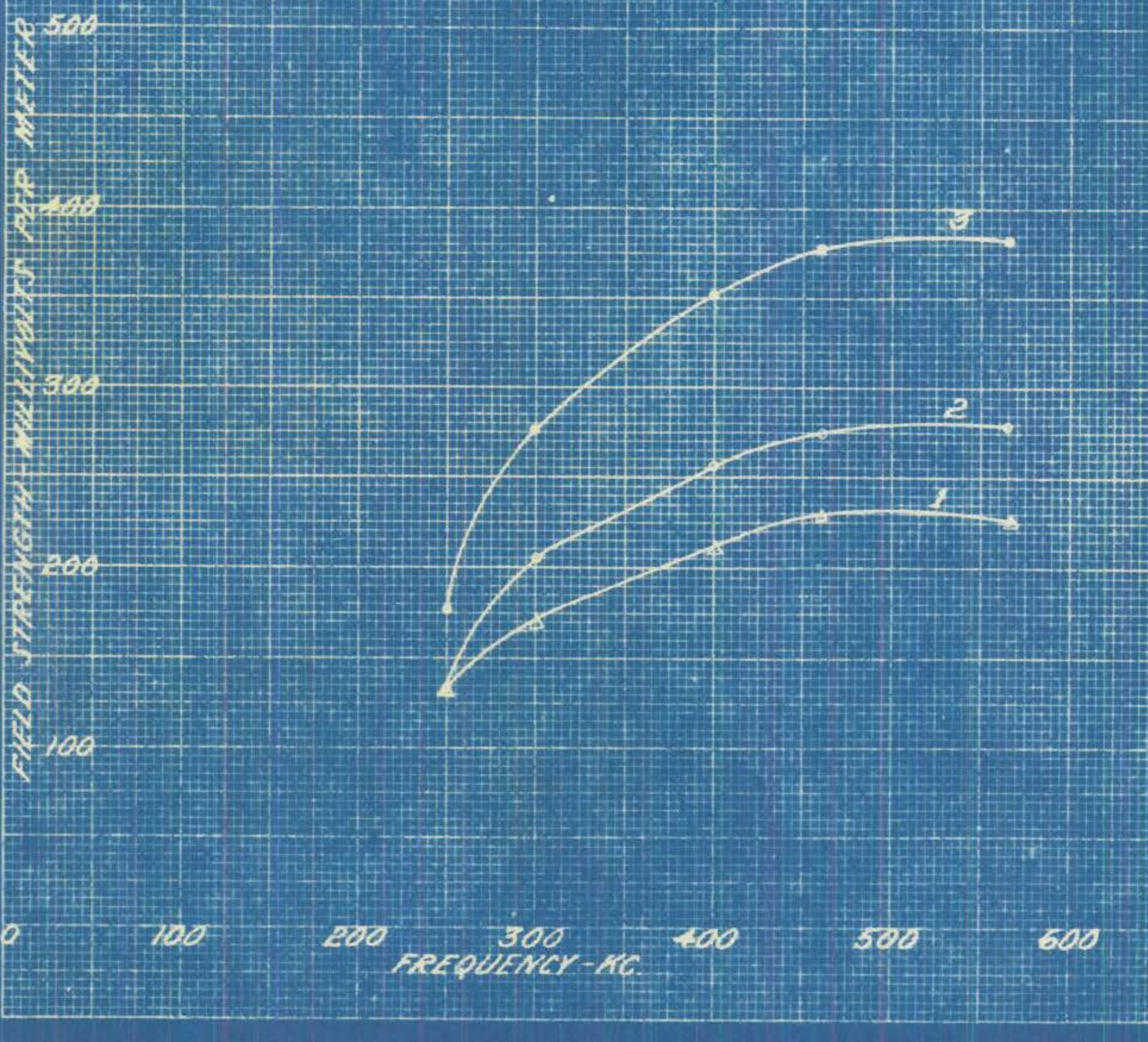


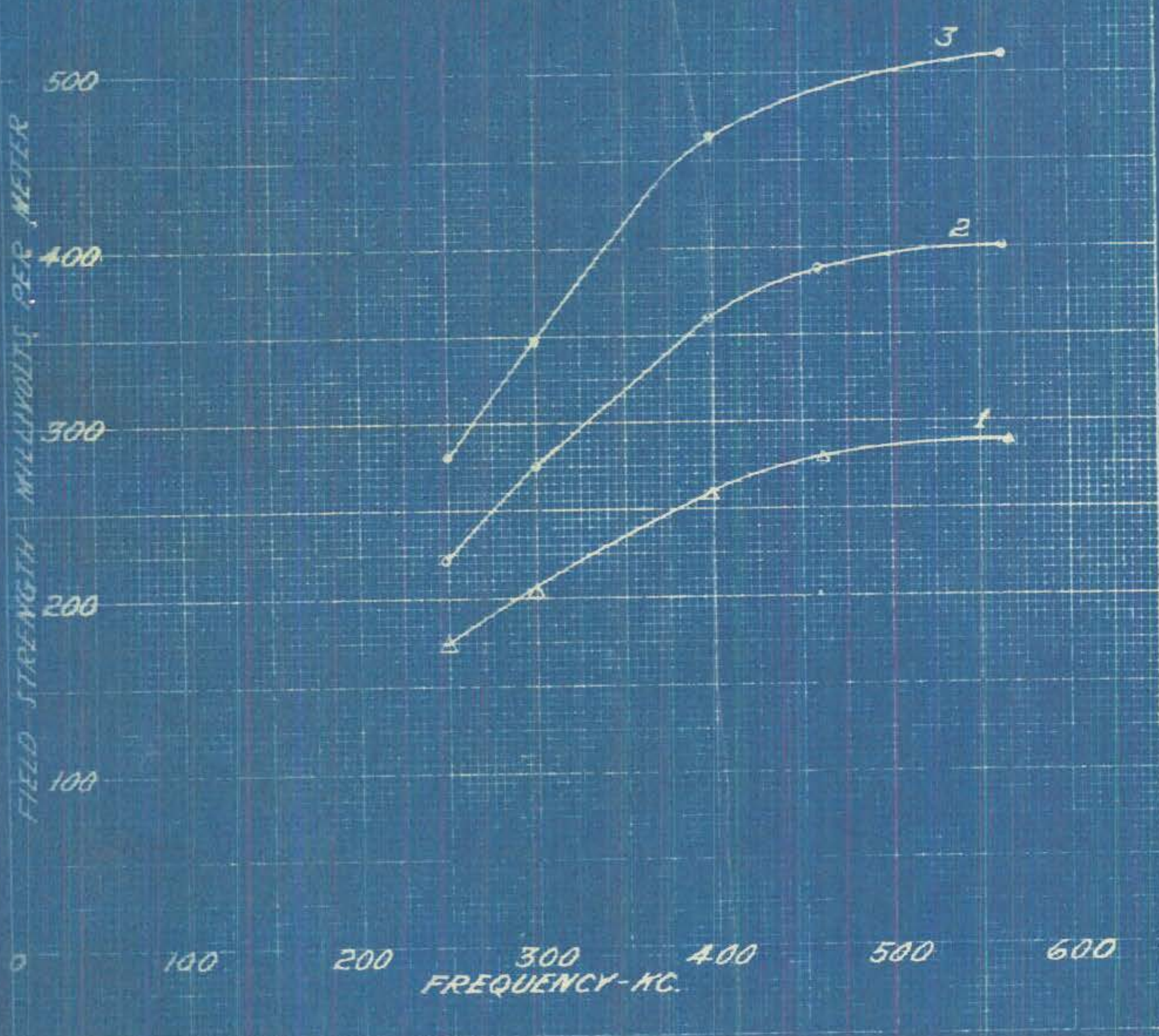
PLATE 37

Field strength as a function of frequency at 505 meters from XTAQ-5 Transmitter operating at 62% of full power into a 13' lead-in, 125' vertical and 95' flat top antenna system.

1. Measured field strength.

2. Calculated field strength for shielded antenna.

3. Calculated field strength neglecting shielding.



Field strength as a function of frequency at 505 meters from a XTAQ-5 Transmitter operating at 62% of full power into a 13' lead-in, 66' trunk, 65' vertical and 95' flat top antenna system. (Trunk 18" O.D.; 3/4" I.D.)

1. Measured field strength.

2. Calculated field strength for shielded antenna.

3. Calculated field strength neglecting shielding.

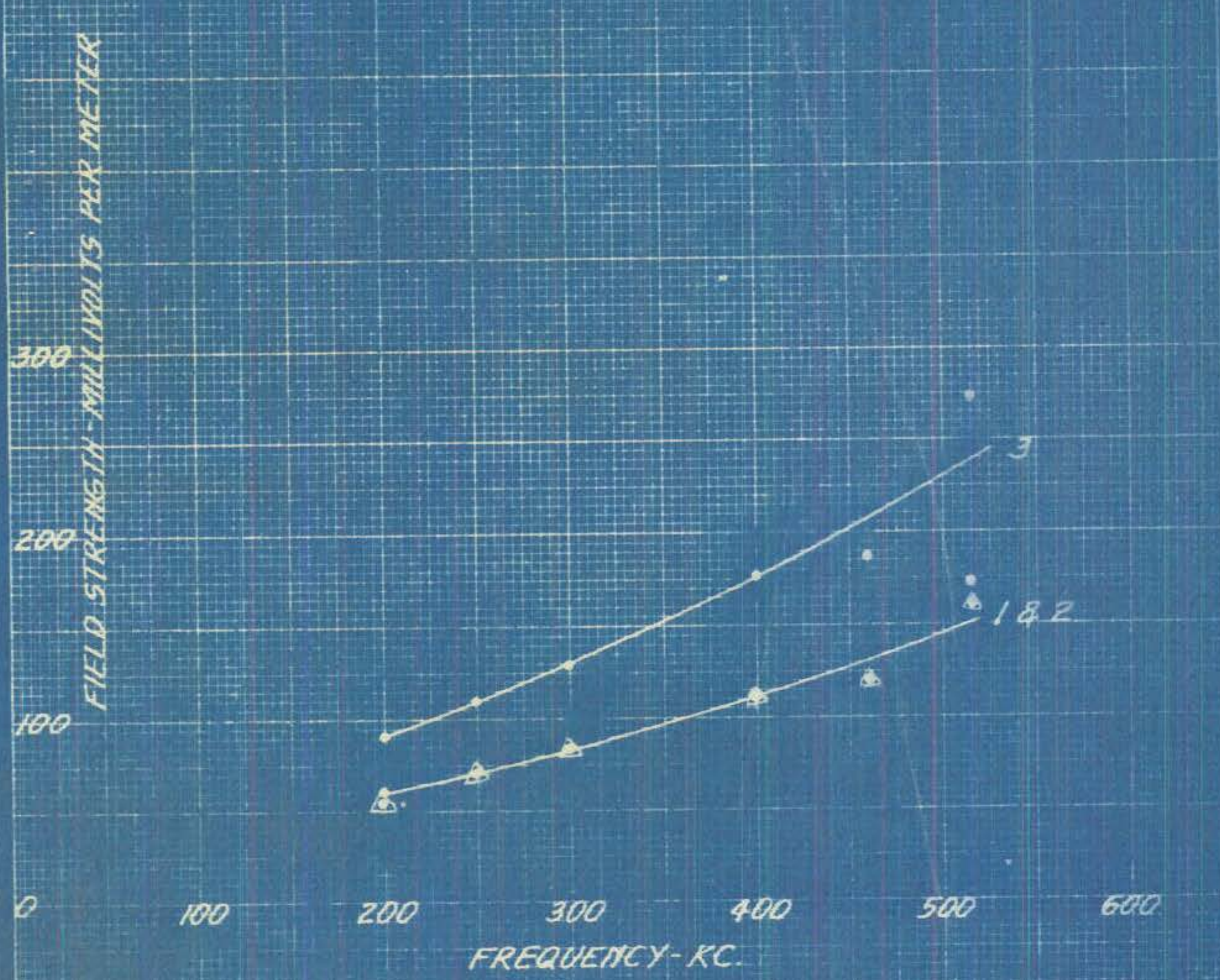


PLATE 39

Field strength as a function of frequency at 505 meters from XTA C-5 Transmitter operating at 62% of full power into a 13' lead-in, 66' trunk, 95' vertical and 95' flat top antenna system. (Trunk 18" O.D.; 3/4" I.D.)

1. Measured field strength.

2. Calculated field strength for shielded antenna.

3. Calculated field strength neglecting shielding.

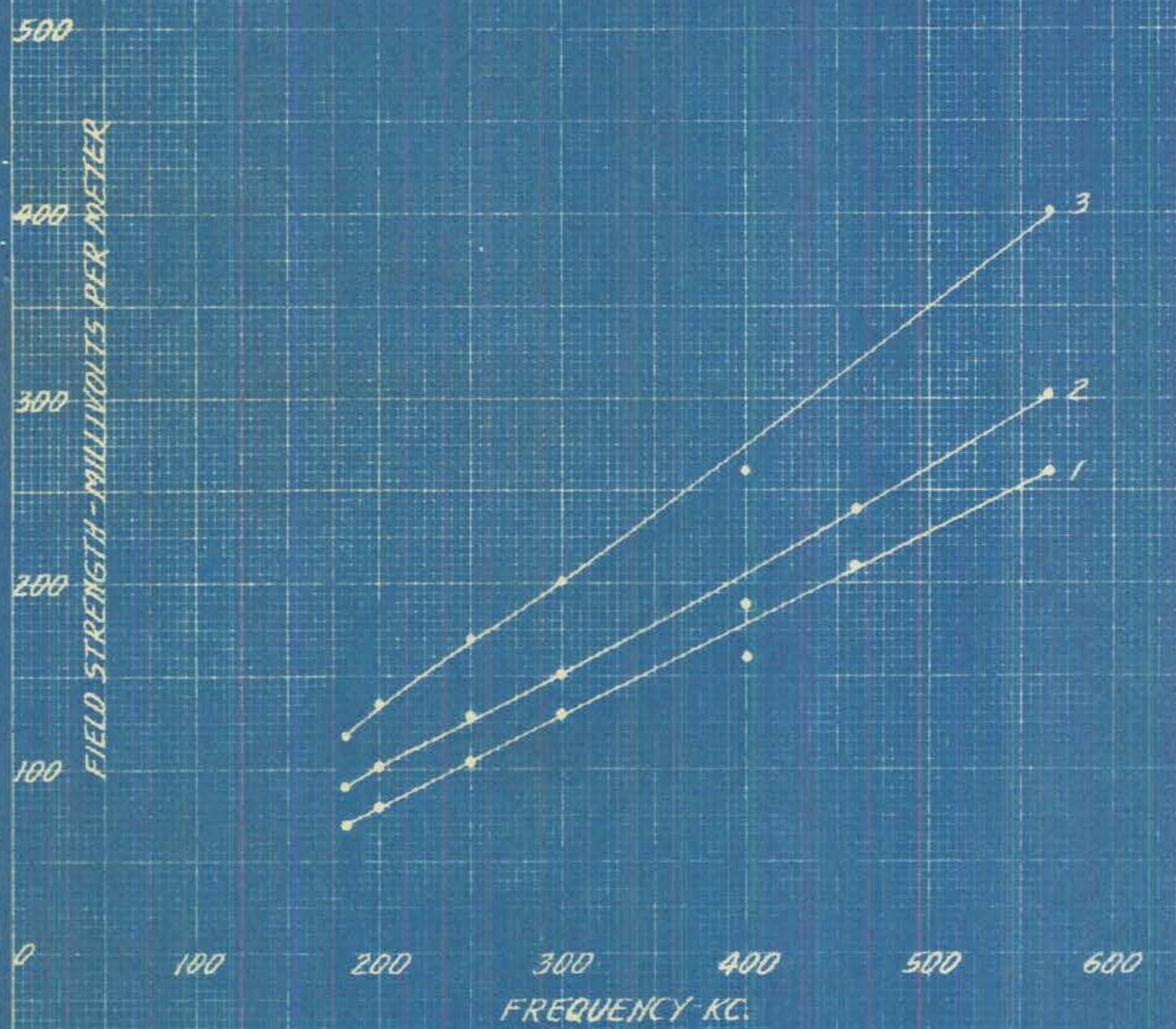


PLATE 90

Field strength as a function of frequency at 505 meters from XTAQ-5 Transmitter operating at 62% of full power into a 13' lead-in, 66' trunk, 125' vertical and 95' flat top antenna system.

1. Measured field strength.

2. Calculated field strength for shielded antenna.

3. Calculated field strength neglecting shielding (trunk 18" O.D.; 3/4" I.D.).

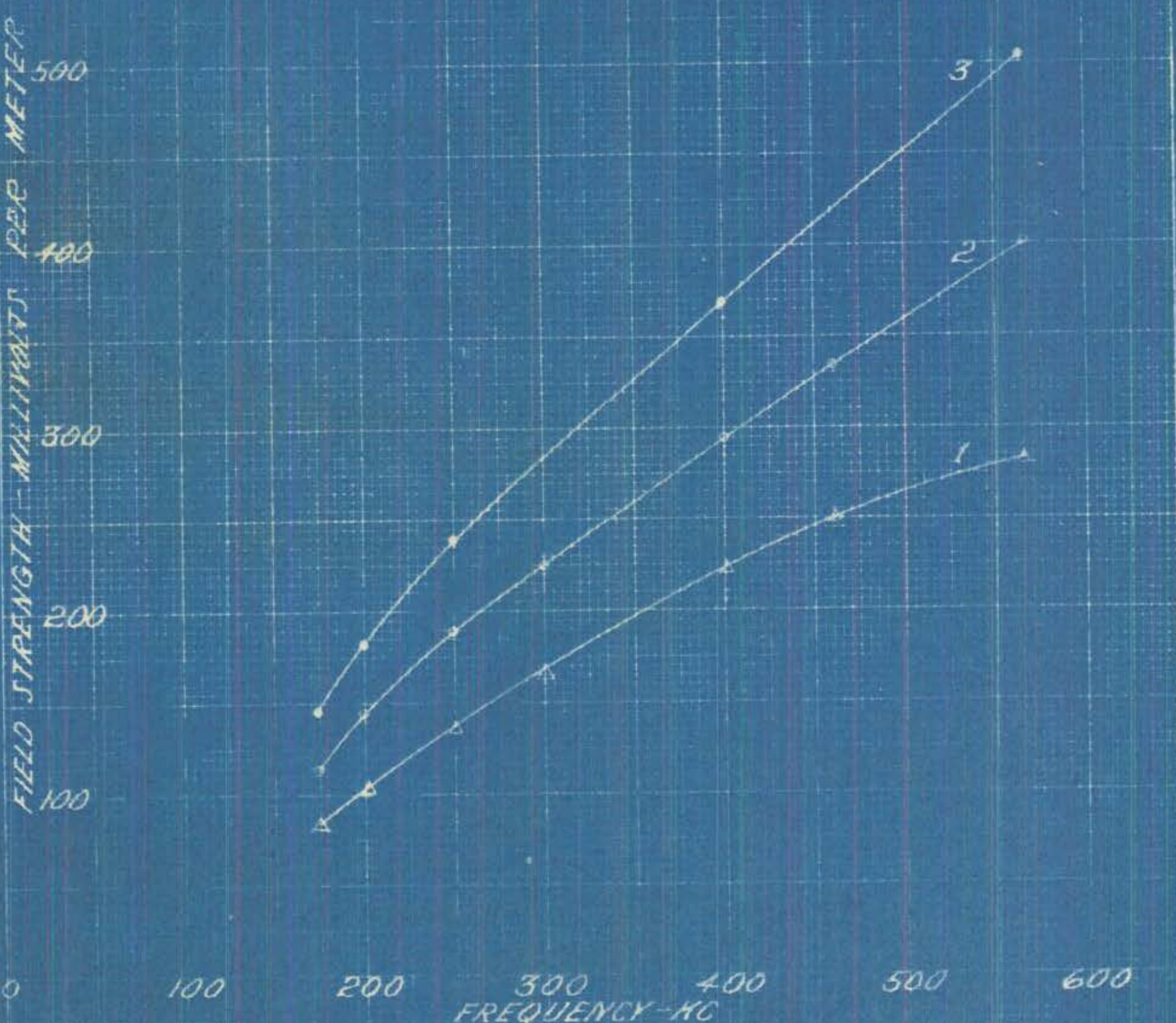


PLATE 41

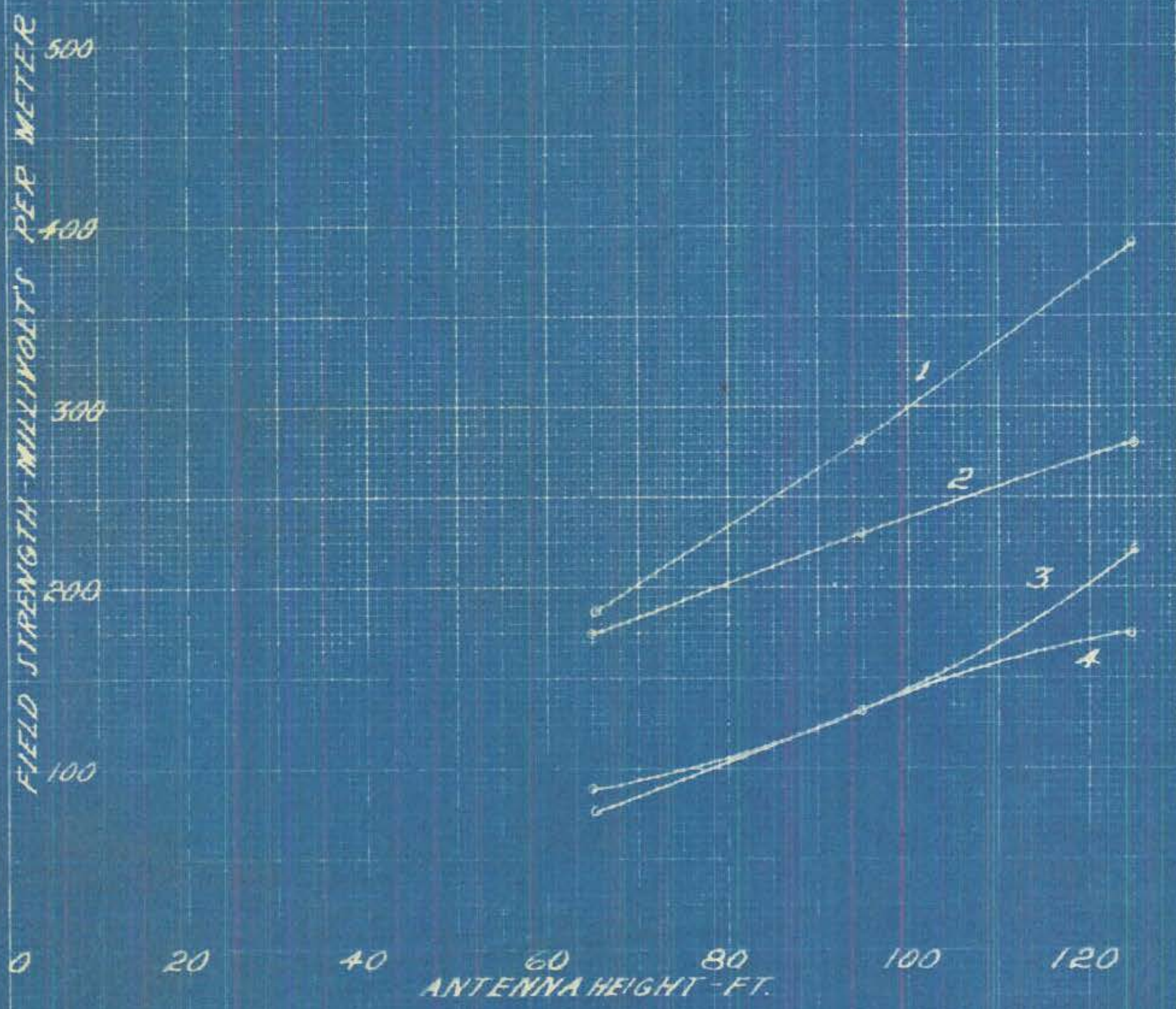
Field strength as a function of antenna height at 505 meters from XEAQ-5 Transmitter operating at 62% of full power into an antenna with 95' flat top (no trunk).

1. 460 KC - Calculated for shielded antenna.

2. 460 KC - Measured.

3. 250 KC - Calculated for shielded antenna.

4. 250 KC - Measured.



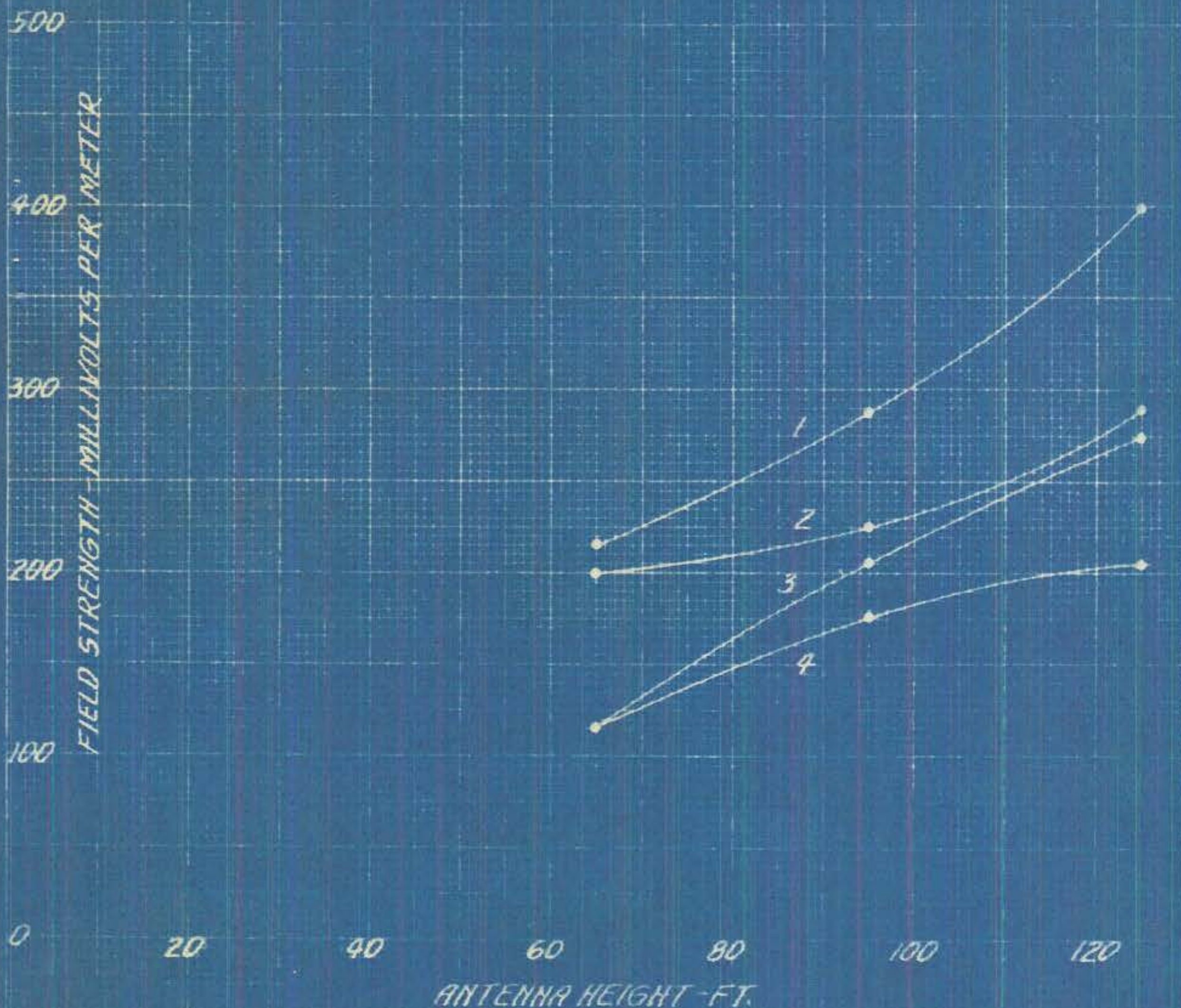
Field strength as a function of antenna height at 505 meters from XTAQ-5 Transmitter operating at 62% of full power into an antenna with 95' flat top (no trunk).

1. 565 KC - Calculated for shield antenna.

2. 565 KC - Measured.

3. 300 KC - Calculated for shield antenna.

4. 300 KC - Measured.

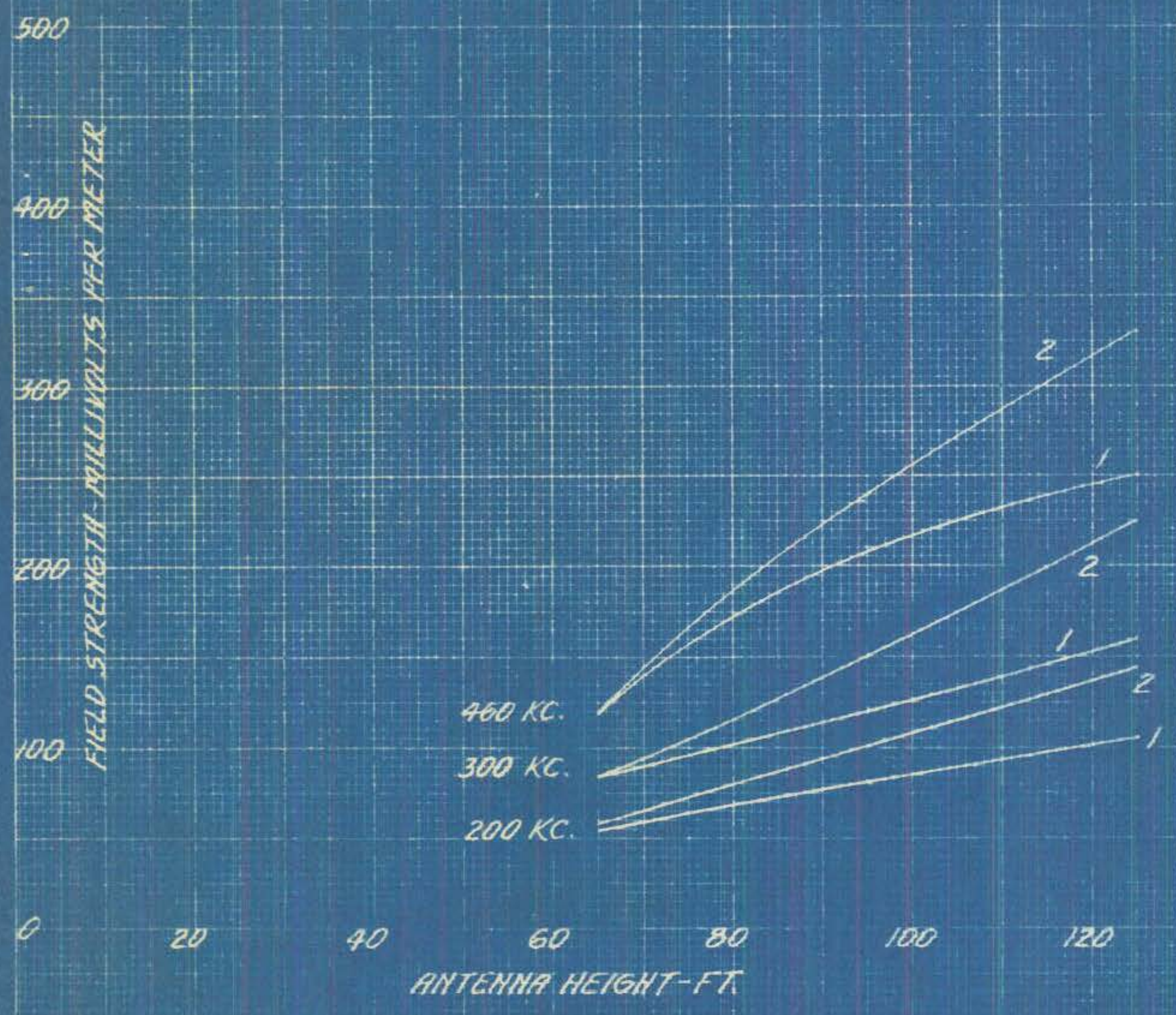


Field strength as a function of antenna height at 505 meters from XTAQ-5 transmitter operating at 62% of full power into a 66' trunk and antenna with a 95' flat top.

1. Measured field strength.

2. Calculated field strength for a shielded antenna.

(Trunk 18" O.D.; 3/4" I.D.)



Field strength as a function of the antenna height at 505 meters from XTAQ-5 Transmitter operating at 62% of full power into a 66' trunk and antenna with a 95' flat top. (Trunk 18" O.D.; 3/4"I.D.)

1. Measured field strength.

2. Calculated field strength for a shielded antenna.

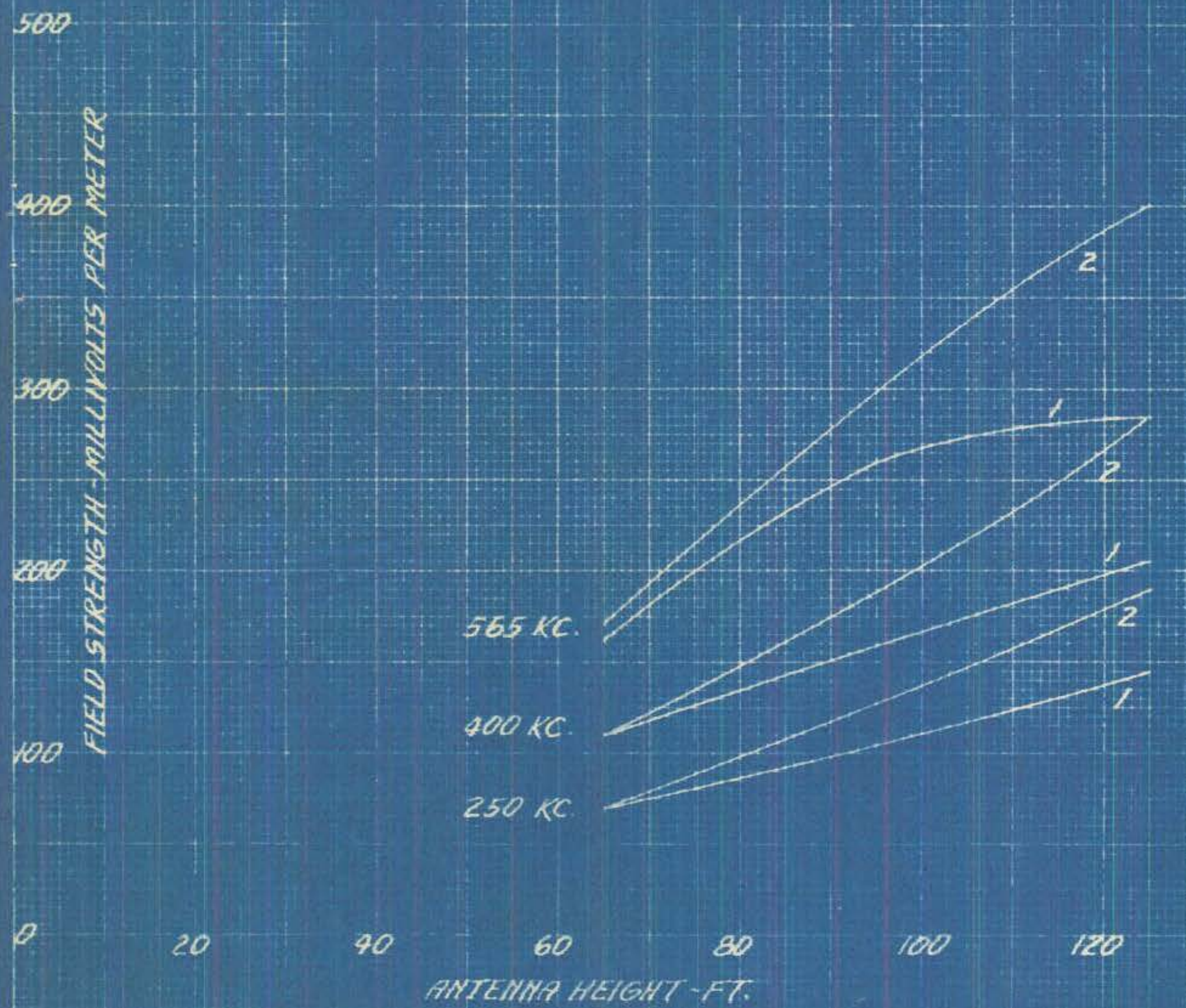


PLATE 45

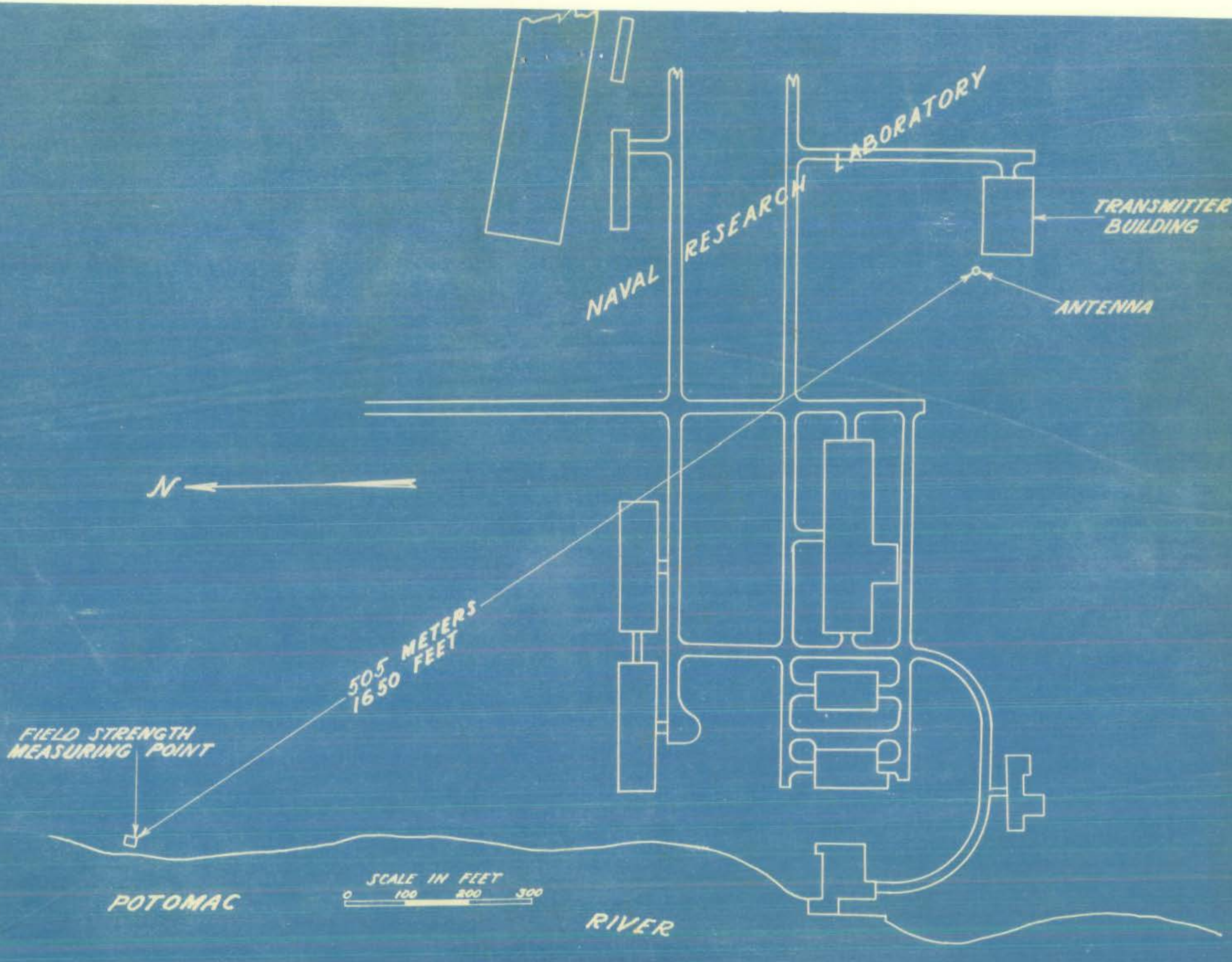

NAVAL RESEARCH LABORATORY
TRANSMITTER BUILDING
ANTENNA
N
505 METERS
1650 FEET
FIELD STRENGTH MEASURING POINT
SCALE IN FEET
0 100 200 300
POTOMAC
RIVER

PLATE 46

Plate 48

Plate 49

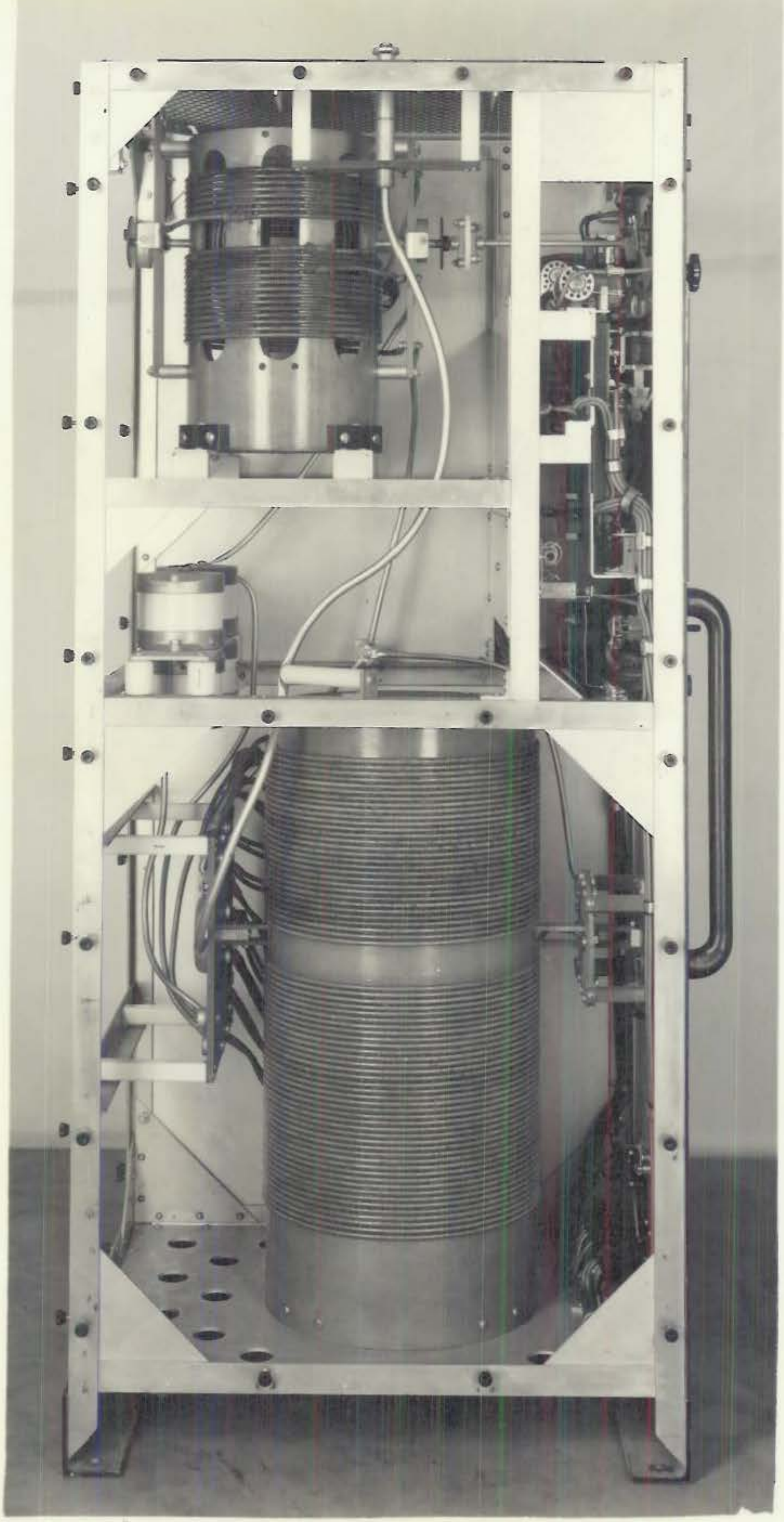


Plate 50

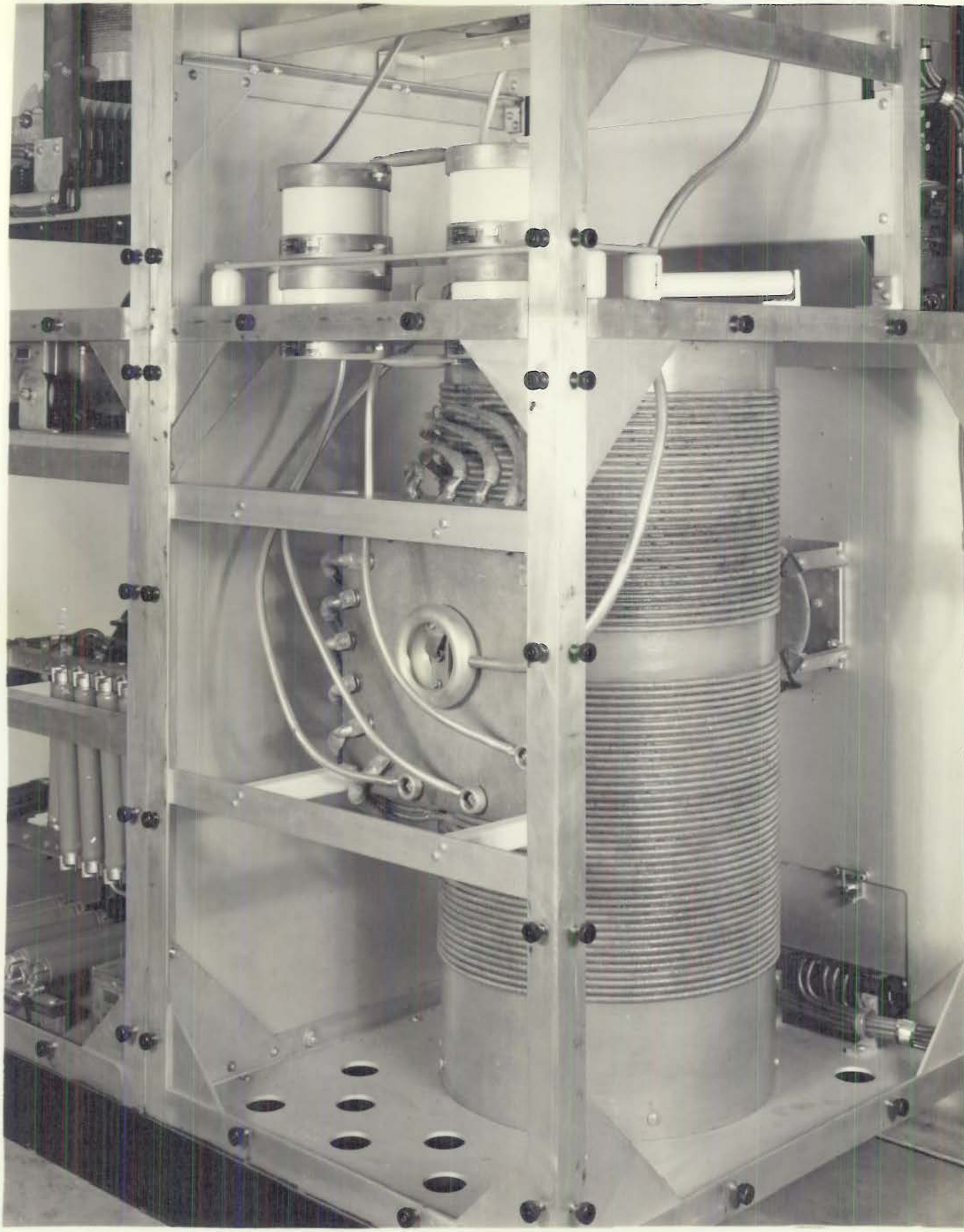


Plate 51

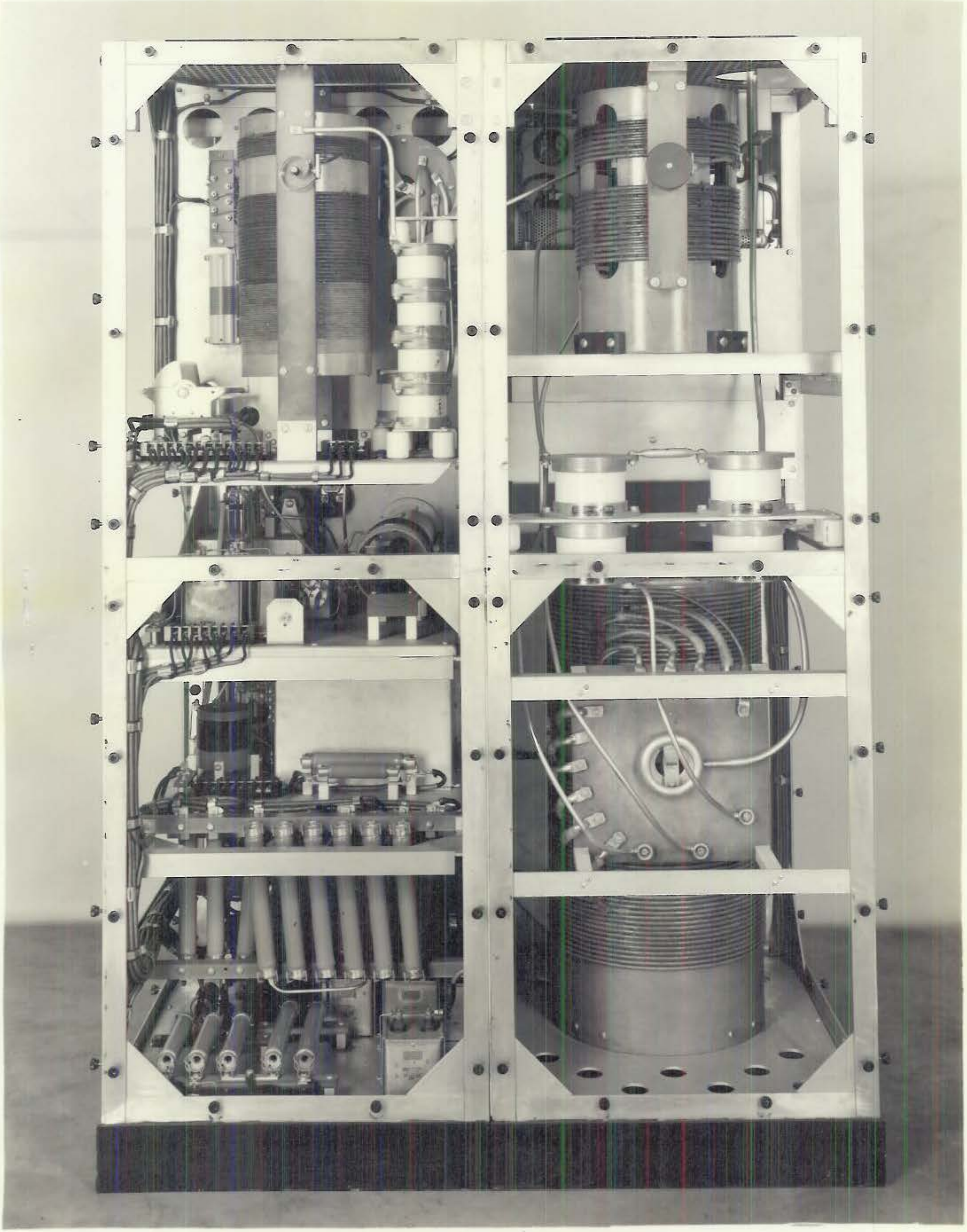


Plate 52

Plate 53