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Report on Investigation of
Self-Supporting Telescopic Vertical
Antenna for use on Battleships 55 and 56

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Investigation of Self-Supporting Telescopic

Vertical Antenna for use on Battleships

55 and 56



BY

NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

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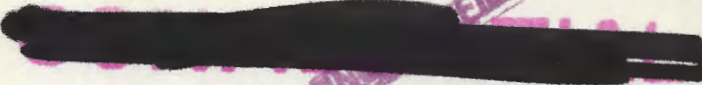
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NAVY DEPARTMENT

 Report on

Investigation of Self-Supporting Telescopic
Vertical Antenna for use on Battleships
55 and 56

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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INTRODUCTORY

1. One self-supporting telescopic vertical antenna in accordance with Navy Yard, New York Dr. No. BB-55-S67-81 was received at the Naval Research Laboratory on 9 January 1941. This antenna is designed to mount on base insulator CAL-61335. The antenna-insulator assembly was mounted on a supporting platform for test purposes, as illustrated in Plates 8, 9 and 10 appended hereto, and remained exposed to the weather during the period from 10 January to 10 March 1941. A duplicate antenna-insulator assembly, which was received at the Naval Research Laboratory on 13 November 1940 was transferred to the USS SEMMES on 22 November 1940 in accordance with telephonic instructions from the Bureau of Ships.

2. The Naval Research Laboratory undertook a series of tests or investigations with a view of determining the radio frequency characteristics of antennas of this type and in order to predict in some measure the results which may be expected in the intermediate and high frequency ranges.

3. The physical dimensions and construction of the telescopic antenna are such that maximum efficiency with respect to radiated power will obviously be obtained in the high frequency range, at approximately 4000 kc and above. However, extremely useful radiation is obtainable at lower frequencies and for emergency uses small values of radiated power may be obtained at frequencies as low as 200 kc, dependent upon the length of trunk and the type of transmitter employed. Experience has shown that on occasions submarines have employed the periscope antenna for intermediate frequencies. While this type of operation endangers the periscope antenna and has resulted in actual destruction of the insulation the emergency needs were of sufficient importance to overlook these factors. The design of the telescopic antenna for Battleship installation, however, is such that the antenna and its associated base insulator are in no danger of destruction from the potentials engendered. In this application the transmitter itself is most likely to be damaged and care will have to be exercised, or automatic protection in the form of safety gaps provided, to prevent injury to the antenna circuit of the transmitter. With this premise in mind, frequencies as low as 200 kc were studied during the course of this investigation.

AUTHORIZATION

4. The general investigation of antenna systems is authorized by Bureau of Ships Problem B-1R as covered by Bueng letter S67/66(7-27-R8) of 7-30-38. Additional pertinent references are listed below:

- Reference: (a) Buships ltr AG24/S67(DR3) of Jan. 22, 1941, to CO USS SEMMES (Copy to NRL).
(b) NRL ltr C-S67/66 of 8 March 1938 to Bueng, subject: "Radio - Antenna and Antenna Lead-in Systems for Battleships 55 and 56 - Transmitting Equipment."

- [REDACTED]
- (c) NRL Report No. R-1638 of 8 August 1940, "Radiation Characteristics of Vertical Antennas with Slanting Top Sections at Intermediate Frequencies."
 - (d) NRL Report No. R-1671 of 6 Dec. 1940, "Notes on the Calculation of Capacity of Intermediate Frequency Antennas."
 - (e) NRL ltr C-S67/66 of 7 October 1937 to SuEng, Subject: Radio - "Antenna and Transmission Line System for Battleships 55 and 56 - Transmitting Equipment."

NOTES ON PREVIOUS WORK

5. The operating characteristics of small self-supporting vertical antennas, when energized through the medium of a trunk 115 feet in electrical length in the frequency range of 2 to 18 megacycles, were reported upon in reference (b). The antennas reported upon in reference (b) varied in height from 20 to 30 feet. It was found that the radiation efficiency of such antennas compared favorably with that obtained with regular antennas of more conventional form, provided the frequency was approximately equal to, or greater than, the quarter-wave resonance frequency of the vertical self-supporting antenna. For frequencies less than $\lambda/8$ frequency of the antenna, the radiation efficiency decreases rapidly with the decrease in frequency. These facts are illustrated by the following data taken from reference (b). Using a TBK transmitter, which has a nominal rating of 500 watts output in the frequency range of 2 to 18.1 megacycles, for energizing a 20 foot vertical antenna through a 115 foot trunk, the radiated power at 2 megacycles was found to be 0.16 watt whereas the radiated power at 10 megacycles was 130 watts.

THEORY AT INTERMEDIATE FREQUENCIES

6. The operation of an intermediate frequency transmitter into a short vertical antenna, either with or without a trunk, may be divided into the following two frequency ranges:

- (a) From the minimum frequency of the transmitter to the frequency f_1 . Frequency f_1 is defined as that frequency at which the antenna voltage is equal to the maximum safe operating potential of the transmitter antenna circuits, when the transmitter is being operated at full power. In this frequency range the maximum power at which the transmitter can be operated is determined by the maximum transmitter antenna voltage. If the transmitter were operated at full power below frequency f_1 , then the maximum transmitter antenna voltage for which the transmitter was designed would be exceeded, and the transmitter may be damaged (loading coil destroyed).

(b) From frequency f_1 to the maximum frequency of the transmitter.

In this frequency range the transmitter can be operated at full power, since the antenna system voltage is always less than the maximum safe transmitter antenna voltage.

7. Radiated Power. First, consider the case in which the transmitter is operating at any frequency less than f_1 . In this frequency range the P.A. input power is restricted to less than full power, because the maximum transmitter antenna voltage determines the power at which the transmitter can be operated. If the maximum transmitter antenna voltage for any given transmitter is E_m , then the maximum antenna system current at any frequency f is

$$I_S = 2\pi f C_S \times 10^{-3} E_m \quad (1)$$

where f is the frequency in megacycles, C_S is the antenna system capacity in $\mu\mu\text{f}$. E_m is the maximum transmitter antenna voltage in rms kilovolts.

8. If the trunk is not too long, the antenna current can be computed from the antenna system current by the following formula:

$$I_A = I_S C_A / C_S \quad (2)$$

where I_A is the antenna current in amperes

I_S is the antenna system current

C_A is the antenna capacity in $\mu\mu\text{f}$

C_S is the antenna system capacity.

9. It can be shown from Eq. 24 of reference (c) that the radiation resistance of a simple vertical antenna in the clear is

$$R = 4.1 \times 10^{-4} L^2 f^2 \quad (3)$$

where R is the radiation resistance in ohms

L is the height of the antenna in feet

f is the frequency in megacycles.

10. The power radiated by the antenna is

$$P = I_A^2 R \quad (4)$$

where P is the radiated power in watts.

Substituting for I_S , I_A , and R from Eq. 1, 2, and 3 in Eq. 4, one obtains

$$P = 1.62 \times 10^{-8} C_A^2 E_m^2 \frac{L^2 f^4}{C_S^2} \quad (5)$$

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11. The capacity of a vertical antenna is (see Eq. 1 of reference (d)).

$$C_A = \frac{17L}{\left[\log_e \left(\frac{24L}{D} \right) - 1 \right] \left[1 - f^2/f_0^2 \right]} \quad (6)$$

where L is the height of the antenna in feet

D is the diameter of the antenna wire, cable, or cage in inches.

f_0 is the quarter-wave resonance frequency in mcs.

12. At the intermediate frequencies, the frequency correction term in Eq. 6 is negligible for short vertical antennas, thus

$$C_A = \frac{17L}{\left(\log_e \frac{24L}{D} \right) - 1} \quad (7)$$

Substituting Eq. 7 in Eq. 5, one obtains

$$P = \frac{4.7 \times 10^{-6} E_m^2 L^4 f^4}{\left[\left(\log_e \frac{24L}{D} \right) - 1 \right]^2} \quad (8)$$

where P is the radiated power in watts

E_m is the maximum transmitter antenna voltage in rms kilovolts.

L is the height of the antenna in feet

f is the frequency in mcs.

13. If the antenna is not in the clear, as is generally the case on board ship, the radiated power and the radiation resistance of the antenna are reduced by the partial shielding of the antenna. For a partially shielded vertical antenna, the radiated power is

$$P = 1.62 \times 10^{-8} C_A^2 E_m^2 L^2 f^4 S \quad (9)$$

or

$$P = \frac{4.7 \times 10^{-6} E_m^2 L^4 f^4 S}{\left[\left(\log_e \frac{24L}{D} \right) - 1 \right]^2} \quad (10)$$

where S is the shielding factor. For an antenna in the clear S = 1, while for partially shielded antennas S is less than 1. For any given antenna, S is independent of the frequency.

14. It will be noted from Eq. 9 and 10 that:

- (a) The radiated power is proportional to the 4th power of the frequency;
- (b) The radiated power is very nearly proportional to the 4th power of the antenna height;
- (c) The radiated power increases as the diameter of the antenna increases;
- (d) The radiated power is proportional to the square of the maximum transmitter antenna voltage;
- (e) The radiated power is independent of the length or capacity of the trunk;
- (f) The radiated power is independent of the antenna or antenna system resistance, providing the transmitter is operating at a frequency less than f_1 ; i.e., the maximum safe transmitter antenna voltage limits the operating power of the transmitter.

15. If the transmitter is operated at any frequency above f_1 , then the transmitter can be operated at full power, since the antenna system voltage will always be less than the maximum safe transmitter antenna voltage. In this frequency range the antenna system current is given by

$$I_S = \sqrt{\frac{P_t}{R_L + R_S}} \quad (11)$$

where P_t is P.A. tank power, or the R.F. power that can be delivered by the transmitter to the antenna loading coil and antenna system.

16. Substituting Eq. 11, 2, and 3 in Eq. 4, one obtains for the radiated power

$$P = \frac{4.1 \times 10^{-4} P_t C_A^2 L^2 f^2 S}{C_S^2 (R_L + R_S)} \quad (12)$$

or

$$P = \frac{4.1 \times 10^{-4} P_t L^2 f^2 S}{(R_L + R_S) (1 + C_T/C_A)^2} \quad (13)$$

[REDACTED]

where P is the radiated power in watts

P_t is the P. A. tank power in watts. P_c is approximately equal to 70% of the P. A. input power.

L is the height of the vertical antenna in feet

f is the frequency in mcs.

R_L is the antenna load coil resistance

R_S is the antenna system resistance

C_S is the antenna system capacity in μmf

C_A is the antenna capacity in μmf

C_T is the trunk capacity in μmf

S is the shielding factor.

A careful analysis of Eq. (12) and (13) shows that the radiated power is approximately proportional to the cube of the frequency and the cube of the antenna height for vertical antennas when used with a reasonable or an average length of trunk at the intermediate frequencies.

17. Field Strength. The field strength can be calculated from the physical dimensions of the antenna, the antenna current, and the transmission distance, and is given by

$$E = \frac{628 L I_A f S^{1/2}}{d} \quad (14)$$

where E is the field strength in millivolts per meter

L is the height of the antenna in feet

I_A is the antenna current in amperes

f is the frequency in megacycles

d is the transmission distance in feet

S is the shielding factor.

18. The field strength can also be computed from the radiated power and the transmission distance from the following formula:

$$E = \frac{31100 \sqrt{P}}{d} \quad (15)$$

where P is the radiated power in watts.

19. If the frequency is less than f_1 , then the transmitter cannot be operated at full power, and the radiated power can be computed from either Eq. 9 or Eq. 10. If one substitutes Eq. 9 or Eq. 10 for P in Eq. 15, one obtains for the field strength

$$E = \frac{3.95 C_A E_m L f^2 S^{1/2}}{d} \quad (16)$$

or

$$E = \frac{67.5 E_m L^2 f^2 S^{1/2}}{d \left[(\log_e \frac{24L}{D}) + 1 \right]} \quad (17)$$

20. If the frequency is greater than f_1 , then the transmitter can be operated at full power, and the radiated power is computed from either Eq. 12 or Eq. 13. If one substitutes for the radiated power in Eq. 15 either Eq. 12 or Eq. 13, one obtains

$$E = \frac{630 C_A L f}{C_S d} \sqrt{\frac{P_t S}{R_L + R_S}} \quad (18)$$

or

$$E = \frac{630 L f}{d (1 + C_T/C_A)} \sqrt{\frac{P_t S}{R_L + R_S}} \quad (19)$$

The transmission distance d must be in the region in which the field strength is inversely proportional to the distance.

MEASUREMENTS

21. TAJ-6 and the TBL-2 Transmitters were used with the 35-foot antenna under test. In both cases the 35-foot vertical antenna was fed through a 34-foot trunk. The diameter of the outer conductor was 12" while the inner conductor was 3/8" in diameter. The length of the lead-in from the trunk to the antenna terminal of the transmitter was three feet. It should be noted in Plates 8 and 9 that the base insulator of the whip antenna is several feet above the ground. Thus the radiation resistance of the whip antenna is greater than if the base insulator were mounted flush with the ground. The radiation resistance, as

[REDACTED]

tabulated in Tables 1 and 2, was computed for this antenna, which is effectively 41 feet high. On board ship the whip antenna will have a height of only 35 feet, and thus the radiation resistance will be less. The radiation characteristics of the 35 foot vertical antenna on board ship are discussed in par. (36).

22. The TBL-2 transmitter was operated at 90% of the maximum transmitter antenna voltage at frequencies less than f_1 , and 81% of full power at all frequencies above f_1 . The transmitter was operated below the full power rating and the maximum transmitter antenna voltage, as a safety measure. When the transmitter antenna voltage is 90% of the maximum, the power is 81% of the maximum permitted since the radiated power is proportional to the square of the transmitter antenna voltage. Thus the TBL-2 transmitter was operated at 81% of the maximum permitted power at all intermediate frequencies. The radiated power at the maximum permitted power operation would be 24% greater than the values tabulated in Table 1. The TAJ-6 transmitter was operated at a low power level. During the course of this work, the following measurements and computations were made:

- (a) Physical and electrical constants of the antenna and antenna system.
- (b) Resistance of the antenna loading coil and variometer of the TBL-2 and TAJ-6 transmitters.
- (c) Field strength measurements.
- (d) Field strength computed from the antenna current and physical dimensions of the antenna.
- (e) Calculated radiated power.
- (f) Power input to the power amplifier.
- (g) P.A. tank power.

23. Antenna Constants. The resistance and the reactance of the antenna and the antenna system were measured with the "Q"-meter, using the substitution method.

24. Antenna Loading Coil Resistance. The antenna loading coil and variometer resistance R_L was measured with the "Q"-meter for both the TBL-2 and the TAJ-6 transmitters.

25. Field Strength Measurements. The field strength measurements were made at the No. 1 compass house with the Western Electric 44a measuring equipment. The transmission distance from the antenna to the No. 1 compass house was about 1650 feet. The TBL-2 transmitter was operated at either 90% of the maximum transmitter antenna voltage of 13.1 rms kilovolts or 81% of full power. The TAJ-6 transmitter was operated at a known input power. The power amplifier plate current and plate voltage, transmitter or set antenna current, antenna system current, and antenna current were recorded. All these data are tabulated in Tables 1 and 2.

26. P.A. Tank Power. The P.A. tank power is given by the following equation.

$$P_t = I_S^2 (R_L + R_S) \quad (20)$$

where P_t is the P.A. tank power

I_S is the antenna system current

R_L is the antenna loading coil resistance

R_S is the antenna system resistance.

27. It has been shown experimentally that the P.A. tank power is approximately constant for any given intermediate frequency transmitter. The P.A. tank power and maximum transmitter antenna voltage E_M for a number of intermediate frequency transmitters are tabulated below:

<u>Transmitter</u>	<u>P.A. Tank Power</u>	<u>E_M - Kilovolts</u>
TAJ-6	720 watts	11.4 RMS
TBL-2	480 watts	13.1 RMS
TBL-4	480 watts	13.1 RMS
TAQ-5	3100 watts	25.4 RMS

RESULTS

28. Antenna Constants. The resistance of the 35-foot vertical antenna and antenna system are plotted as a function of the frequency in Plate 1. The resistance of the antenna is extremely high, due to the poor ground system. The high dielectric loss resistance for the antenna is evident from the fact that the antenna resistance increases as the frequency decreases. The antenna system resistance is greater than for the same antenna system on board ship in the frequency range 175 to 600 kcs.; but as will be shown later, it is possible from these measurements to calculate the radiated power for a similar antenna on board ship. For intermediate frequencies below f_1 , the radiated power is independent of the antenna system resistance (see par. 14). The frequency f_1 is a function of the antenna system capacity and resistance. At 5000¹kcs. the antenna system resistance is increasing rapidly with the frequency. This is to be expected, since the half-wave resonance for the antenna system is about 7000 kcs. and at this frequency the antenna system resistance should be very high.

29. In Plate 2 the antenna and antenna system capacity are plotted as a function of the frequency. The antenna capacity as

measured at the bottom end of base insulator is 115 μf at the intermediate frequencies. The base insulator was not grounded, but was mounted to a wooden platform, and thus the added capacity due to the effect of the base insulator was small (see Plates 9 and 10). The antenna current was measured at the lower terminal of the base insulator. However, in actual shipboard installations, the mounting ring on the base insulator is grounded to the ship and the capacity to ground of the base insulator section of the antenna is no longer negligible, and thus the antenna current should be either measured at the top side of the base insulator or measured at the bottom of the base insulator and then corrected for current shunted to ground in the base insulator.

30. In Plate 3 the reactance of the antenna and antenna system are plotted as a function of the frequency. The antenna and antenna system are a quarter-wave length at 6500 kcs. and 3500 kcs., respectively, as read from Plate 3 for zero reactance.

31. The capacity of the base insulator was measured when mounted on the wooden platform and found to be 22 μf . Thus the antenna capacity, C_A , to be used in Equation 9 would be 115 μf minus 22 μf or 93 μf . The capacity of the 35 foot telescopic antenna could be computed from Eq. (7) if the diameter D were known. The diameter of the telescopic antenna is not a constant, but varies from section to section. The diameter of the various sections are 2.5, 2.0, 1.5, 1.0, 0.6975 and 0.5 inches. The average geometric mean diameter is about 1.115 inches and this value will be used as the diameter D in Eq. (7). The capacity of the 35 foot telescopic antenna as computed from Eq. (7) is 91 μf , a value which is in good agreement with the experimentally measured antenna capacity of 93 μf . The capacity of the base insulator in the clear but with the mounting ring grounded is 37 μf . However, when the insulator is installed on board ship this value will be greater than 37 μf , since the mounting ring will not only be grounded but the inner conductor will be relatively close to grounded objects which will tend to increase the capacity. This insulator capacity is effectively a part of the trunk capacity.

32. Antenna Loading Coil Resistance. The resistance R_L of the antenna loading coil for the TBL-2 and TAJ-6 transmitters is tabulated in Tables 1 and 2, respectively. It should be noted that the resistance of the antenna loading coils is approximately inversely proportional to the frequency. The antenna loading coil resistance is many times the antenna system resistance, especially on board ship (see Tables 3 and 4). Thus the major part (in some cases as high as 90%) of the P.A. tank power is dissipated in the antenna loading coil.

33. P.A. Tank Power. The P.A. tank power as computed from Eq. (20) is tabulated in Tables 1 and 2. The P.A. tank power for the TBL-2 transmitter was not constant, because the P.A. input power increased with the frequency. The ratio of the P.A. tank power to the P.A. input power is approximately constant, as was to be expected.

34. Field Strengths. The measured and calculated field strengths are tabulated in Tables 1 and 2. The agreement between the measured and computed field strengths is within the absolute accuracy of the field strength measurements. Thus it can be concluded that Eq. (14), (16), (17), (18), and (19), for computing the field strength, and Eq. (9), (10), (12), and (13) for computing the radiated power, have been verified experimentally.

35. Radiated Power. The radiated power, as computed from Eq. (4) is tabulated in Tables 1 and 2 for the TBL-2 and TAJ-6 transmitters, when used with 34-foot trunk and 35-foot vertical antennas. For frequencies up to 355 kcs., the radiated power increases as the fourth power of the frequency. The radiated power at full power operation of the TBL-2 would be about 24% greater than the values tabulated in Table 1. The ratio of the radiated power to the P.A. tank power in Table 1 gives the radiation efficiency of the 35-foot antenna. This radiation efficiency is very low.

RADIATION EFFICIENCY OF TELESCOPIC ANTENNAS AT INTERMEDIATE FREQUENCIES ON BOARD SHIP.

36. The capacity of the 35 foot telescopic antenna is very low and thus, unless a relatively long trunk is used, the antenna system capacity will be less than the minimum stipulated in the specifications covering the design and construction of Model TBL and TAJ transmitters.

37. Transmitters are designed for a definite P.A. input power, a maximum value of transmitter antenna voltage, a minimum antenna system capacity and a small range in antenna system resistance. If the antenna system capacity is less than the minimum value called for in the transmitter specifications, the transmitter cannot be operated at full power at the low frequency end of the band without exceeding the maximum safe transmitter antenna voltage. Hence, for frequencies less than f_1 the transmitter cannot be operated at full power because of the maximum transmitter antenna voltage limitation, while for frequencies greater than f_1 the transmitter can be operated at full power. It has been shown in paragraph 34 that the radiated power can be calculated from Eq. (9) or (10) and Eq. (12) or (13) for frequencies below and above the frequency f_1 . On board ship the shielding factor S will generally be less than one, because the antennas are not in the clear. In the following computations, however, the shielding factor S is assumed to be unity.

38. Let it be assumed that the 35 foot telescopic antenna is mounted on the deck of a ship and is fed through a 34 foot trunk using TBL-2 and TAJ-6 transmitters. The inner and outer conductors of the trunk are $3/8$ " and 12 " in diameter, respectively. What is the radiated power at the intermediate frequencies?

39. The capacity of the antenna system will be assumed to be the same as given in Table 1. The capacity C_A of the vertical antenna is $93 \mu\text{af}$ (see par. 31). The antenna system resistance on board ship would

be much less than at the Laboratory. The values of antenna system resistance tabulated in Tables 3 and 4 are considered reasonable for such an antenna on board ship.

40. The P.A. tank power for the TBL-2 and TAJ-6 transmitters was taken as 480 and 720 watts, respectively. The antenna loading coil resistance for the TBL-2 and the TAJ-6 transmitters in Table 3 and 4 was assumed to be the same as for a similar antenna system at the Laboratory. This assumption is justified, since the antenna loading coil resistance depends upon the antenna system capacity and the frequency and is independent of the antenna resistance. Thus, all of the quantities in Eq. (9) and (12) are tabulated in Tables 3 and 4 for TAJ-6 or TBL-2 transmitters operating into a 34-foot trunk and a 35-foot vertical antenna on board ship. The radiated power, when operating the transmitter at maximum transmitter antenna voltage and at full power, as computed from Eq. (9) and (12), is tabulated in Tables 3 and 4 for the TBL-2 and the TAJ-6 transmitters, respectively. In Plates 4 and 5 the radiated power at maximum transmitter antenna voltage (Curve 1), and at full power operation (Curve 2), is plotted as a function of the frequency. The intersection of Curves 1 and 2 is the frequency f_1 and is 375 KC and 494 KC for the TBL-2 and the TAJ-6 transmitters, respectively. Curve 1 for frequencies greater than f_1 is actually non-existent, since the transmitter power is not sufficient to produce the maximum transmitter antenna voltage at these frequencies. For frequencies less than f_1 , the transmitter cannot be operated at full power, because the maximum transmitter antenna voltage would be exceeded under this operating condition. The maximum permissible power operation of the transmitter is thus always limited to the values given by Curve 1 for frequencies less than f_1 and to Curve 2 for frequencies above f_1 , as illustrated in Plates 4 and 5. In Curve 1 of Plates 4 and 5, the radiated power is proportional to the 4th power of the frequency, and is independent of the length or capacity of the trunk and resistance of the antenna system. On the other hand, Curve 2 is shifted to a lower radiated power level, as the length or capacity of the trunk increases or the resistance of the antenna system increases (see Eq. (13)). As Curve 2 shifts to a lower power level, the frequency f_1 becomes lower; and the radiated power at all frequencies greater than this new frequency f_1 is reduced to this new Curve 2. Thus the effect of increasing the length of the trunk is to decrease the frequency f_1 and to reduce the radiated power at all frequencies greater than f_1 ; however, the radiated power at all frequencies less than f_1 remains the same.

41. In Plate 6 the radiated power for the maximum permitted operating power of the TBL-2 and the TAJ-6 Transmitters is plotted as a function of the frequency. The break in the curves is at the frequency f_1 . It should be noted that below the frequency f_1 , the radiated power is greater for the TBL-2 than for the TAJ-6 transmitter. This was to be expected, since the maximum transmitter antenna voltage is greater for the TBL-2 than for the TAJ-6 transmitter (13.1 as compared to 11.4 rms kilovolts). The TBL-2 was operated at an antenna voltage of 13.1 kilovolts

without any sign of corona or voltage breakdown in the transmitter. On the other hand, a number of precautions had to be taken before the antenna system voltage could be raised to 11.4 kilovolts without corona or voltage breakdown in the TAJ-6 transmitter, and there was still a tendency for corona or voltage breakdown at 11.4 kilovolts.

42. It should be noted that for a given transmitter and antenna the radiated power can never be greater than that given by Eq. 9 or 10, and is less for all frequencies greater than f_1 . Curve 1 in Plates 4 and 5 gives the upper limit of the radiated power from a 35-foot telescopic antenna when used with the TBL-2 and TAJ-6 transmitters. The actual radiated power will be less for all frequencies greater than f_1 , and at all frequencies due to the partial shielding of the antenna. The radiated power at 355 kilocycles can never be greater than 0.48 and 0.36 watts for the TBL-2 and the TAJ-6 transmitters, when used with the 35-foot telescopic antenna (see Curve 1 of Plates 4 and 5).

43. A survey of the foregoing data reveals that the radiated power obtainable from the Model TBL-2 and TAJ-6 transmitters when operating into a 35-foot vertical antenna appears to be extremely small. However, attention is invited to the fact that the radiated power obtained on modern submarines using TBL transmitters operating at 355 kc. into the Main antenna is approximately 0.45 watt. When the periscope antenna is employed at this frequency for emergency communications, the radiated power realized falls between the limits of approximately 0.001 and 0.003 watts.

RADIATED POWER - AT HIGH FREQUENCIES

44. If an antenna is $\lambda/4$ in height at any given frequency f the antenna will have a relatively high radiation resistance and zero reactance. Under this condition the transmitter operates into a relatively high load resistance, the losses in the trunk are low, and most of the transmitter output power is radiated. If the frequency is greater than f , then the radiation resistance is always greater than the value for a quarter wave antenna. It was shown in Plates 14 to 21 of reference (e) that the losses in a trunk that is not over 100 feet long are less than 30% for all frequencies greater than the quarter wave frequency f of the antenna. It can also be shown that the effective load resistance that the transmitter loads into is several ohms or more at all frequencies greater than the frequency f , and thus the transmitter can operate efficiently into this load. Hence, for all frequencies greater than the quarter wave frequency f , the radiation efficiency of the transmitter antenna system is good. However, it must be pointed out that the radiation efficiency of the transmitter antenna system decreases rapidly with a decrease in frequency, for frequencies less than the quarter wave resonance frequency.

45. The principal difference between a regular and the telescopic antenna is that the quarter wave resonance frequency of the telescopic antenna is much higher than for the regular HF shipboard antennas. The quarter wave resonance frequency of the telescopic antenna is about 7000 KC, while the quarter wave resonance frequency for the average regular antenna is between 3000 and 4000 KC. Thus, the efficiency of the whip antenna between 7000 and 18,000 KC is as good as the regular antennas for frequencies between 3000 KC and 18,000 KC, but is much lower for the frequencies between 2000 KC and approximately 6000 KC.

46. The TBL-2 transmitter was operated at approximately full power over the frequency range of 2000 to 18,000 KC into the 34-foot trunk and 35-foot telescopic antenna. The P.A. input power, the antenna system current, the antenna current, and the radiated power are tabulated in Table 5. The base of the telescopic antenna was several feet above the ground (see Plate 8). The radiation resistance and radiated power, therefore, were computed for a 41-foot vertical antenna. The radiated power is plotted as a function of the frequency in Plate 7. It should be noted that the radiation efficiency for all frequencies below the quarter wave frequency (about 6000 KC) is still good. However, it must be emphasized that this radiation efficiency drops off very rapidly as the length of the trunk is increased. On board ship the telescopic antenna would be only 35 feet high, and thus the radiated power would be less than tabulated in Table 5. The radiated power at 2300 KC on board ship would be about the same as at 2000 KC in Table 5, if the antenna on board ship were in the clear. Since the antennas on board ship are partially shielded, the radiated power on board ship would be reduced by this additional factor. The measurements of antenna system and antenna resistance and current were found to vary from day to day at the laboratory due to changes in weather conditions. Hence, since the measurements were made on different days, the values shown in Table 5 are not sufficiently accurate for calculating antenna system and antenna power.

NOTES ON MECHANICAL CONSTRUCTION OF TELESCOPIC ANTENNA

47. The details of construction and design of the telescopic antenna under discussion are shown in Navy Yard, New York Drg. No. BB-55-S67-81. The antenna was installed and remained exposed to the weather for two months during the winter without failure of parts. It is understood that a duplicate antenna was installed and tested on the USS SEMMES in order to obtain information under actual service conditions. The conditions of test at the Naval Research Laboratory would normally be less severe than the conditions encountered afloat and hence the findings of the USS SEMMES will serve as a better guide as to the mechanical suitability of the telescopic antenna. However, during the period of test at the Naval Research Laboratory certain mechanical features were observed which appear to require correction. These features are discussed below.

48. The telescopic mast is constructed of monel metal and is in six sections of the following outer diameters:

No. 1 (Bottom)	2-1/2"
2	2"
3	1-1/2"
4	1"
5	11/16"
6 (Top)	1/2"

Sections No. 1 to 5 inclusive are telescopic and are 6', 11-1/2" long when housed. Section No. 6 does not telescope within the assembly and must be stored separately. The mast may be used either in five or six sections, having a total length when extended of 28 feet one inch or 34 feet one and one half inches respectively. A cap is provided for the top of section No. 5 when the mast is used in the shorter length.

49. The mast sections Nos. 2 to 5 are held in the extended position by means of knurled securing nuts which fit over a tapered portion at the top end of each section. These nuts are locked in position by knurled jam-nuts. Further support is provided by the use of a toggle pin passing through the junction of sections No. 1 and 2. Both the securing and jam-nuts are intended to be tightened by hand. It was found extremely difficult to tighten the securing nut on section No. 2 sufficiently to adequately support the remaining upper sections. It is recommended, therefore, that consideration be given to a means for securely tightening all the nuts. This could be accomplished by using either flatted or hexagonal nuts and drilling a through hole just below the threaded portion of sections No. 2 to 5 inclusive. These holes would permit the use of a pin or spud to prevent the mast sections from turning during assembly. All features of design should be such that sharp edges or points are avoided in order to prevent corona or arcing.

50. Section No. 6 is provided with a shouldered pin fastened to its lower end. This pin fits within the top of section No. 5 and is secured thereto by means of a coupling nut. This nut must be entirely removed in order to separate sections No. 5 and 6. As no jam-nut is provided at this point, section No. 5 is free to slide completely within section No. 4 when the securing nut on section No. 5 is loosened. When this occurs it becomes necessary to remove the entire structure from its supporting insulator in order to recover section No. 5. It is believed that a jam-nut should be provided for section No. 5 in order to prevent the occurrence noted above and also to prevent the loosening of the coupling nut which joins sections No. 5 and 6.

51. Upon the removal of the mast from its test position it was found that the bottom section was filled to the toggle-pin hole with water. It is suggested that a drainage hole be provided in the neck of the flange at the base of the mast. If the water which collects in section No. 1 should freeze, difficulty would be experienced in lowering the antenna.

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52. The toggle pin referred to above passes through holes drilled in sections No. 1 and 2. In order to insert this pin the holes must be aligned while the entire weight of the top five sections is being manually supported. This operation would be difficult under conditions afloat and it is recommended that the toggle pin be located at a point just clearing the bottom of section No. 2 in order to obviate the necessity of hole alignment. In this connection it may be noted that if means for adequately tightening all nuts is provided, the use of this toggle pin might be avoided.

53. The grade of monel metal used in the construction of the mast is not known, although it appears rather soft. This condition permits Section No. 6 to be deformed rather easily. A harder alloy would be superior and it is suggested that the grade designated as "K" be investigated for this purpose. Grade "K" contains about 3.75 per cent aluminum.

SUMMARY

54. High Frequency. If the 35-foot telescopic antenna is used with a short trunk and lead-in (less than 40 feet), the radiation efficiency in the frequency band 2.0 to 18.0 mcs. is good, especially for frequencies greater than 4.0 mcs. It has been shown in reference (e) that the power losses in trunk lengths up to 100 feet is less than 30% of the antenna system power. In reference (b) it was proven experimentally that the radiated power from a short vertical antenna for frequencies greater than the quarter-wave resonance frequency of the antenna was about the same as for a regular high frequency antenna when both antennas were used with a 100-foot trunk. Thus the radiation efficiency of the 35-foot telescopic antenna, when used with trunks up to 100 feet in length, would be about the same as a regular high-frequency antenna from 6.0 to 18.0 mcs. Below 6.0 mcs. the radiation efficiency decreases rapidly as the frequency decreases and as the length of the trunk increases. In general, the shielding of a short telescopic antenna by the superstructure on a ship will be greater than for a regular high-frequency antenna.

55. Intermediate Frequencies. This investigation has shown that the telescopic antenna can be used under restricted conditions at the intermediate frequencies. The capacity of a telescopic antenna is low compared to an intermediate frequency antenna, and thus for an average trunk, the antenna system capacity will be less than the values for which the intermediate frequency transmitters are designed. Hence the maximum transmitter antenna voltage for which the transmitters were designed would be exceeded at the low frequency end of the band if the transmitter were operated at full power. The frequency f_1 is defined as the frequency at which the antenna voltage is equal to the maximum safe transmitter antenna voltage when the transmitter is operated at full power. For frequencies less than f_1 , the transmitter cannot be operated at full power, because at full power operation the maximum safe transmitter antenna

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voltage would be exceeded. For frequencies greater than f_1 , the transmitter can be operated at full power. Formulas are derived and proven experimentally for computing the radiated power of any given transmitter antenna system for frequencies above and below the frequency f_1 .

56. Inspection and observation during the course of the tests revealed that certain features of design are subject to improvement as outlined in paragraphs 47 to 53, inclusive.

Table 1

Data on TBL-2 Transmitter operating into
34-foot trunk and 35-foot whip antenna
system, operating at 81% of the maximum
permitted power

Freq. - kcs.	<u>210</u>	<u>275</u>	<u>355</u>	<u>544</u>
Load coil resistance - ohms.	8.52	6.78	4.94	4.08
Antenna system resistance.	3.8	2.81	2.40	1.98
Calculated radiation resistance.	0.0304	0.052	0.086	0.20
Antenna system capacity, $\mu\mu\text{f}$.	296	296	297	301
Antenna capacity, including lead to trunk.	115	115	117	121
Antenna system current - amperes.	4.6	6.1	7.6	8.14
Antenna current.	1.7	2.3	2.8	3.08
P.A. Input watts.	360	435	566	566
Load coil power.	180	252	286	270
Antenna system power.	80	105	138	132
P. A. tank power.	260	357	424	402
Calculated radiated power	0.09	0.28	0.67	1.9
Measured field strength at 1650 feet in mv/m.	5.6	9.4	14.1	25.5
Calculated field strength at 1650 feet in mv/m. $\frac{\mu\mu\mu}{\mu}$	5.6	9.9	16.0	28.4
Calculated field strength at 1650 feet in mv/m. $\frac{\mu\mu\mu}{\mu}$	5.85	10.0	See Note 1	
Calculated field strength $\frac{\mu\mu\mu}{\mu}$	5.8	10.1	16.3	26.9

$\frac{\mu\mu}{\mu}$ Computed from Eq. 14.

$\frac{\mu\mu\mu}{\mu}$ Computed from Eq. 16.

$\frac{\mu\mu\mu}{\mu}$ Computed from Eq. 18.

Note 1. 355 and 544 kcs. are greater than f_1 .

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Table 2

Data on TAJ-6 transmitter operating
into a 34-foot trunk and 35-foot whip
antenna system

Freq. - kcs.	<u>222</u>	<u>275</u>	<u>355</u>	<u>544</u>
Load coil resistance, ohms.	9.42	6.47	5.90	5.25
Antenna system resistance.	3.57	3.06	2.56	2.13
Antenna resistance.	25.9	21.7	17.4	12.5
Calculated radiation resistance.	0.033	0.052	0.086	0.20
Antenna system capacity - μmf .	296	296	297	301
Antenna capacity, including lead to trunk.	115	115	117	121
Antenna system current, amperes.	4.6	5.4	5.6	6.6
Antenna current.	1.78	2.1	2.1	2.4
P.A. input watts	578	574	565	630
Load coil power	216	210	199	241
Antenna system power	76	89	80	93
Antenna power	82	96	77	72
P.A. tank power	292	299	279	334
Calculated radiated power	0.10	0.23	0.38	1.15
Measured field strength at 1650 feet in mv/m.	5.9	8.6	10.2	18.3
Calculated field strength at 1650 feet in mv/m. #	6.1	9.0	11.6	20.3
Calculated field strength. ##	6.2	9.0	12.1	21.8

Computed from Eq. 14.

Computed from Eq. 18.

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Table 3

Radiated power as calculated from Eq. (9) and (12) for a 35-foot whip antenna and 34-foot trunk when used with a TBL-2 transmitter.

Freq. - kcs.	<u>210</u>	<u>275</u>	<u>355</u>	<u>544</u>
R_S - Antenna system resistance.	0.8	0.8	0.9	1.0
C_A - Antenna capacity.	93	93	94	98
C_S - Antenna system capacity.	296	296	297	301
E_m - Max. transmitter antenna voltage in rms kilovolts.	13.1	13.1	13.1	13.1
L - Antenna height.	35	35	35	35
S - Shielding factor.	1.0	1.0	1.0	1.0
P_t - P.A. tank power.	480	480	480	480
R_L - Antenna load coil resistance	8.52	6.78	4.94	4.08
Radiated power, watts. #	0.057	0.168	0.48	2.86 $\frac{\#\#\#}{\#\#\#}$
Radiated power, watts. $\frac{\#\#\#}{\#\#\#}$	0.11	0.23	0.51	1.46

Radiated power at maximum transmitter antenna voltage, as computed from Eq. (9).

$\frac{\#\#\#}{\#\#\#}$ Radiated power at rated P.A. input power, or full power.

$\frac{\#\#\#}{\#\#\#}$ This power can not be obtained in practice, because the maximum radiated power is given in the row below.

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Table 4

Radiated power as calculated from Eq. (9) and (12) for a 35-foot whip antenna and 34-foot trunk when used with TAJ-6 transmitter.

Freq. - kcs.	<u>222</u>	<u>275</u>	<u>355</u>	<u>544</u>
R _S - Antenna system resistance.	0.8	0.8	0.9	1.0
C _A - Antenna capacity.	93	93	94	98 [#]
C _S - Antenna system capacity.	296	296	297	301
E _m - Maximum transmitter antenna voltage.	11.4	11.4	11.4	11.4
L - Antenna height.	35	35	35	35
S - Shielding factor.	1.0	1.0	1.0	1.0
P _t - P.A. tank power.	720	720	720	720
R _L - Antenna load coil resistance	9.42	6.47	5.90	5.25
Radiated power, watts. [#] / _{##}	0.054	0.127	0.36	2.16 [#] / _{###}
Radiated power - watts. [#] / _{###}	0.148	0.37	0.66	1.80

[#] Radiated power at maximum transmitter antenna voltage as computed from Eq. (9).

^{##} Radiated power at rated P.A. input power, or full power.

^{###} This power cannot be obtained in practice, because the maximum radiated power is given in the row below.

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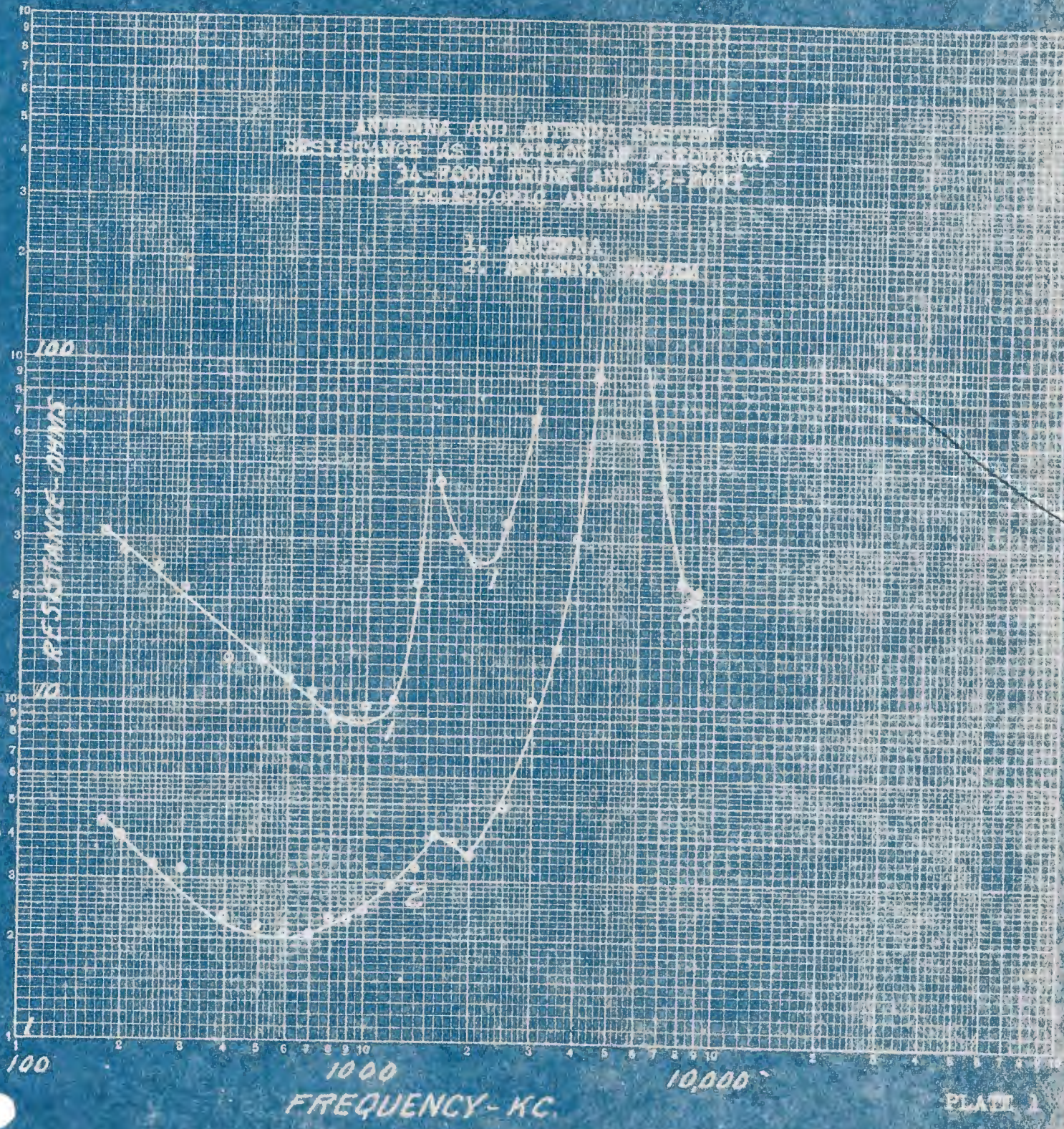
Table 5

Data on TBL-2 Transmitter operating into
34-foot trunk and 35-foot whip antenna
system.

<u>Freq.</u> <u>kcs.</u>	<u>PA</u> <u>Input</u> <u>Watts</u>	<u>Antenna</u> <u>System</u> <u>Current</u> <u>Amperes</u>	<u>Antenna</u> <u>Current</u> <u>Amperes</u>	<u>Radiated</u> <u>Power</u> <u>Watts</u>
2,000	700	9.2	4.0	49
3,000	711	6.5	3.6	94
4,000	700	4.85	3.5	171
5,000	690	1.61	2.66	165
6,000	684	1.05	2.57	263
7,000	630	1.84	2.1	264
8,000	692	4.8	2.05	
9,000	689	4.1	1.14	
10,000	700	3.5	0.41	
10,500	670	2.15	0.43	
11,000	723	2.72	0.60	
12,000	720	2.1	0.80	
13,000	704	1.9	0.65	
14,000	693	1.43	0.67	
15,000	700	0.59	0.91	
16,000	707	1.18	1.33	
17,000	690	2.15	1.52	
18,000	680	2.25	1.71	

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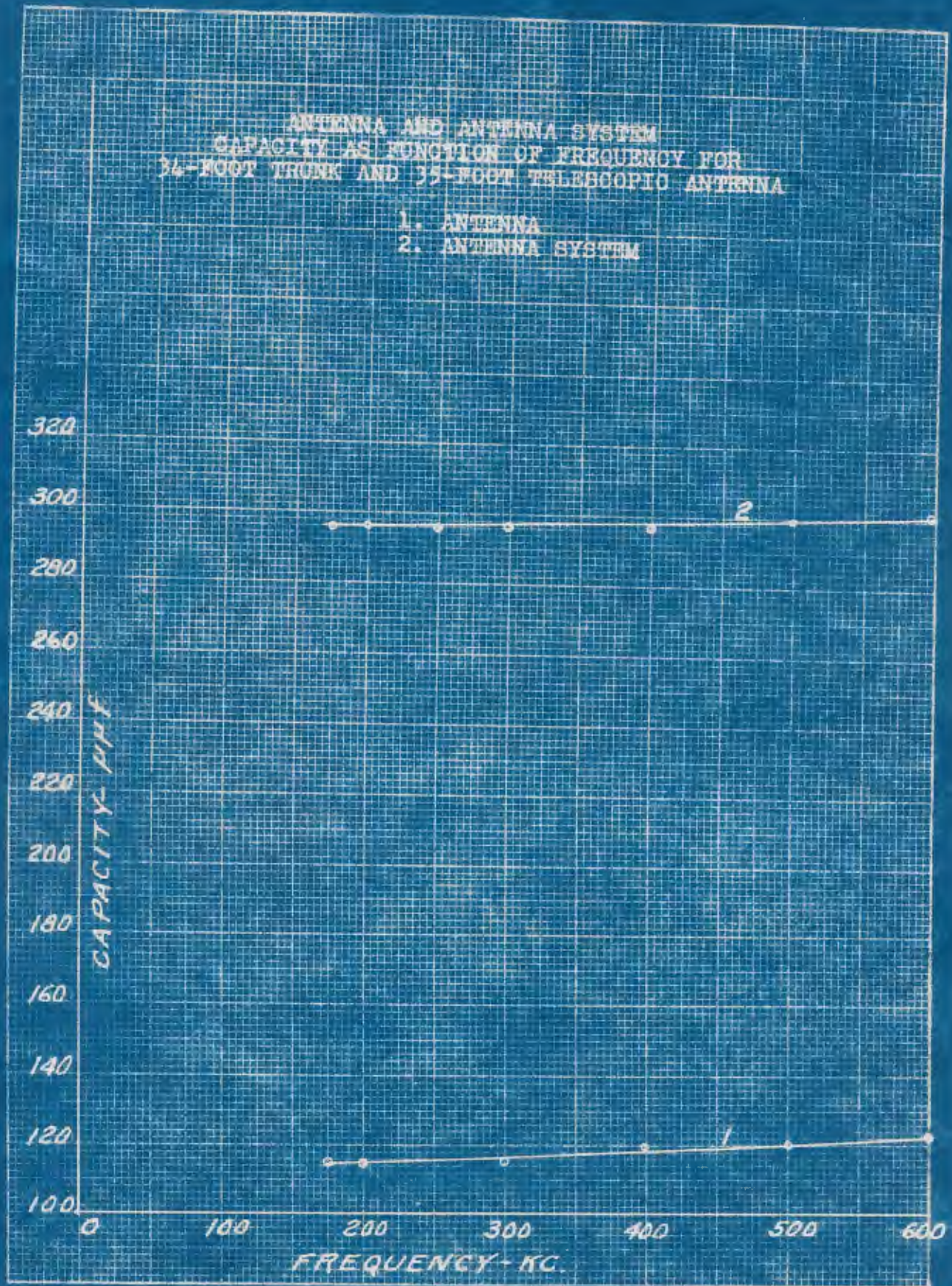
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ANTENNA AND ANTENNA SYSTEM
CAPACITY AS FUNCTION OF FREQUENCY FOR
34-FOOT TRUNK AND 35-FOOT TELESCOPIO ANTENNA

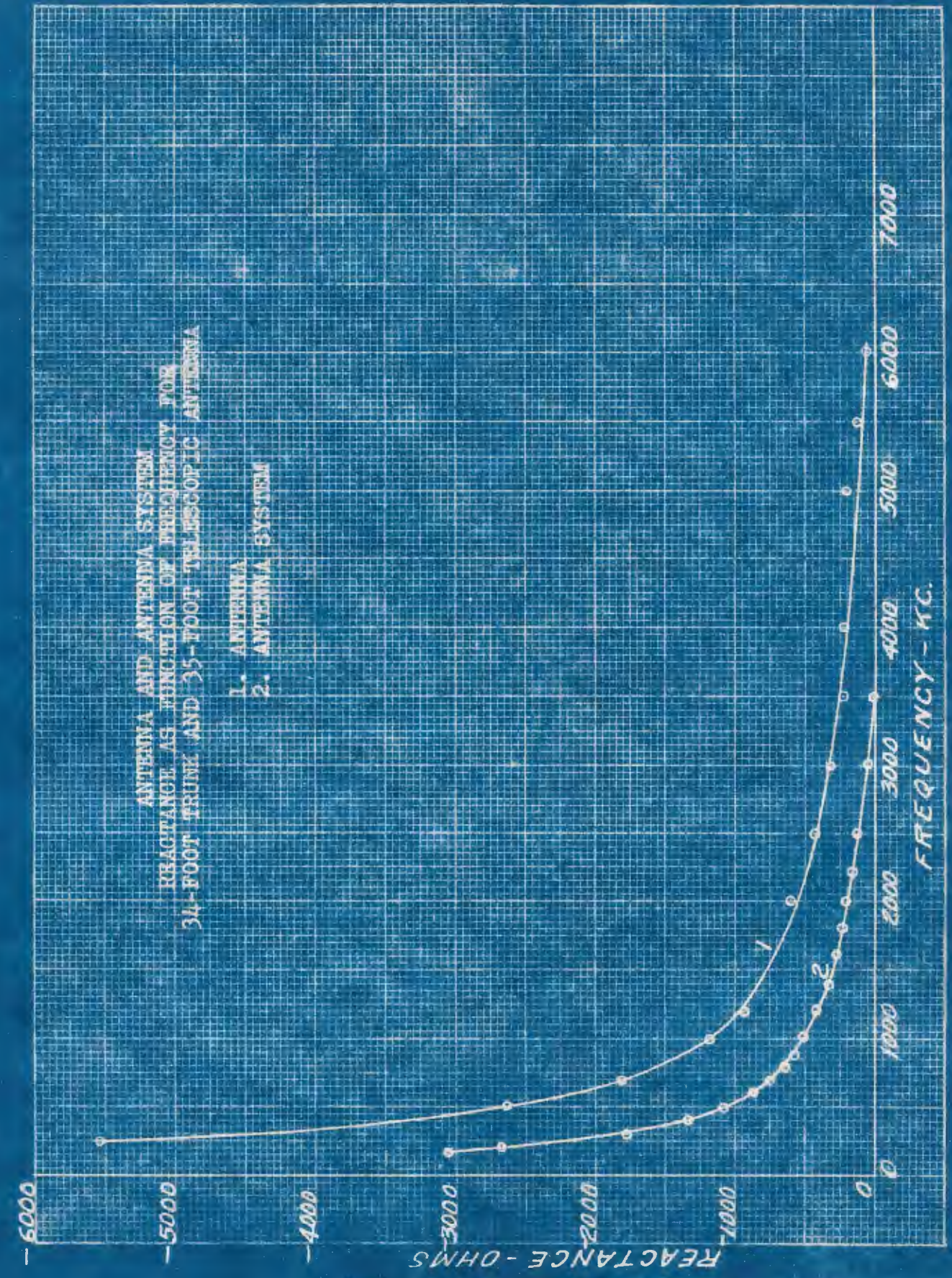
- 1. ANTENNA
- 2. ANTENNA SYSTEM



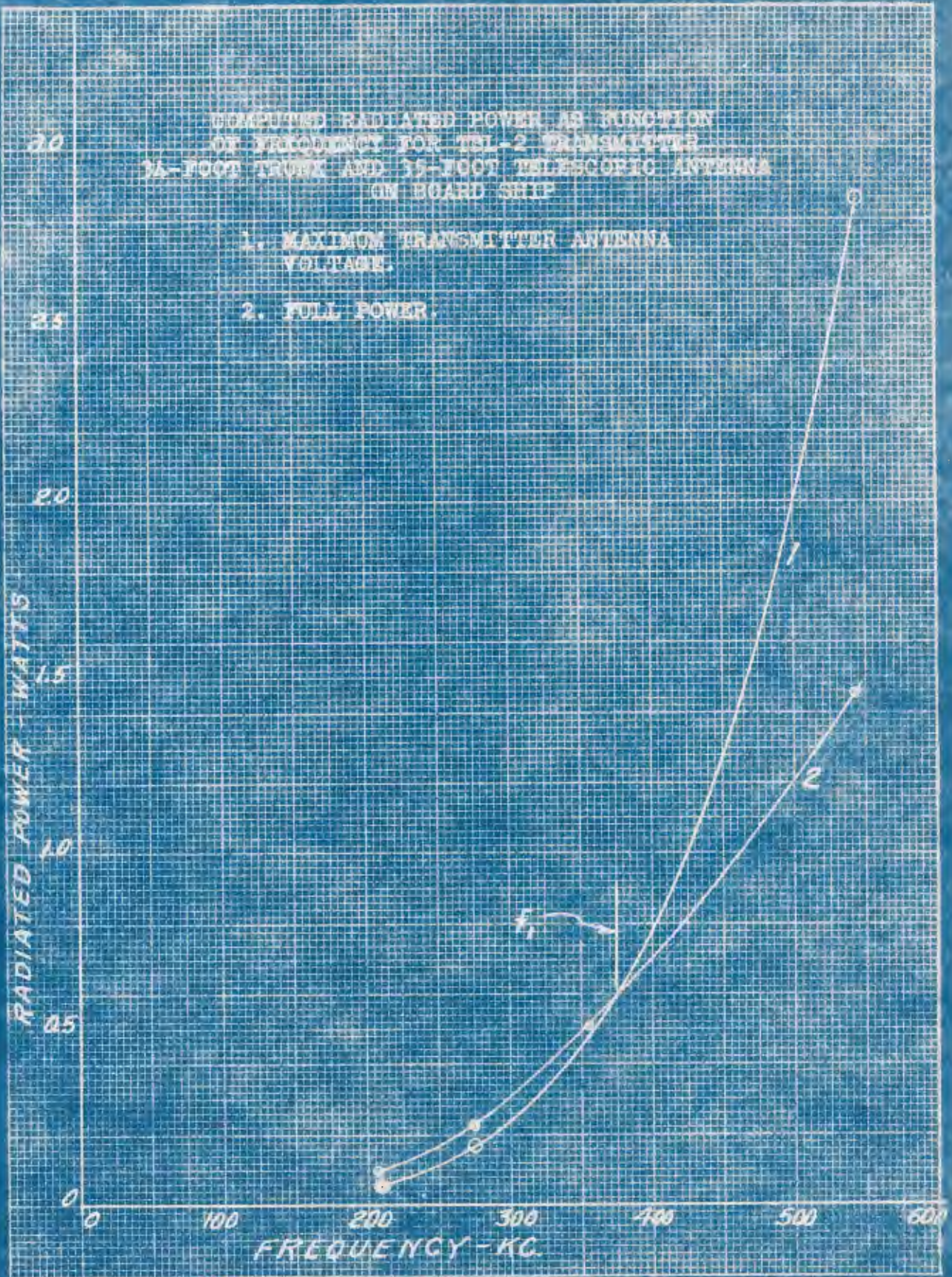
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R. L. 31A



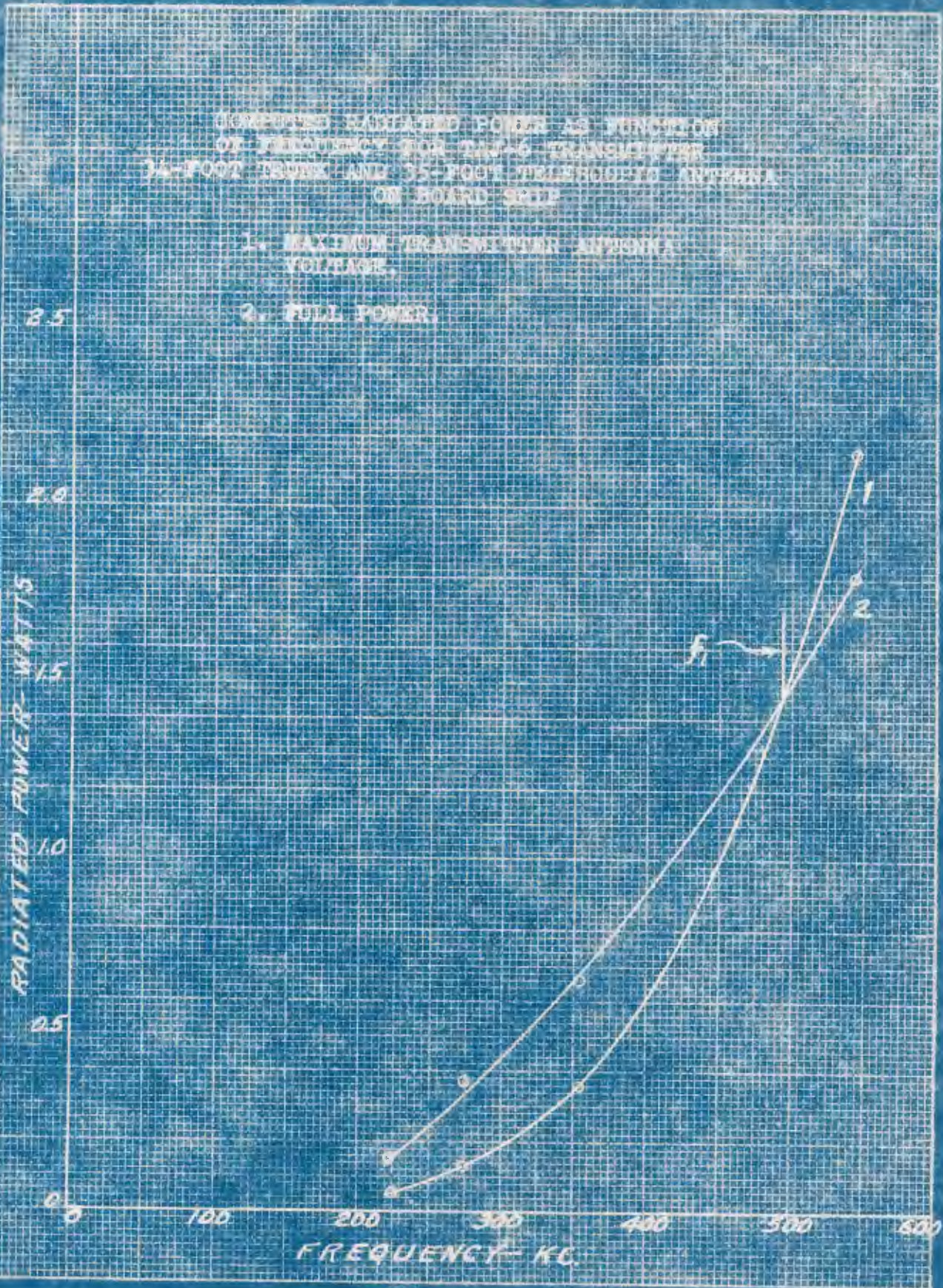
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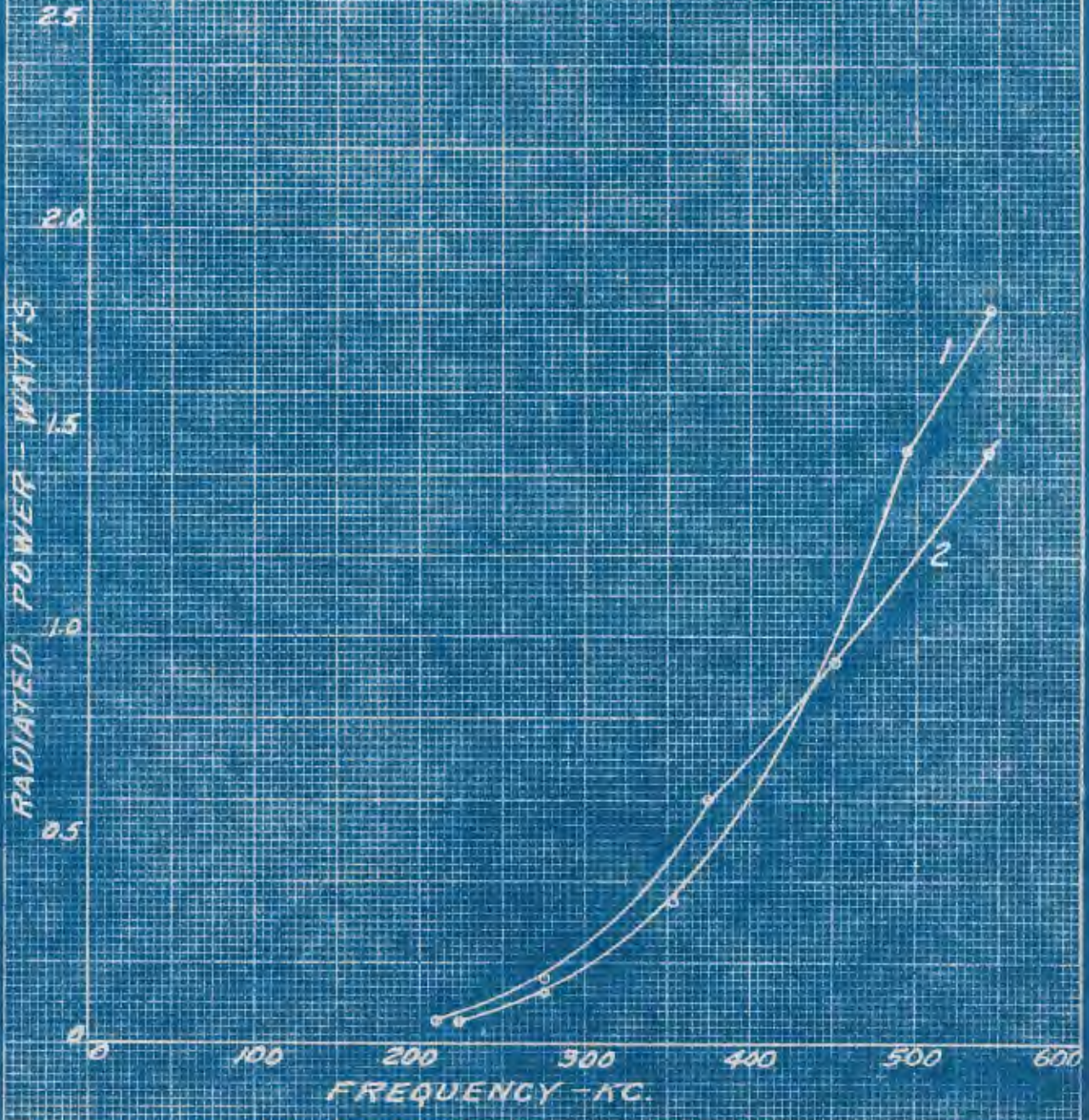


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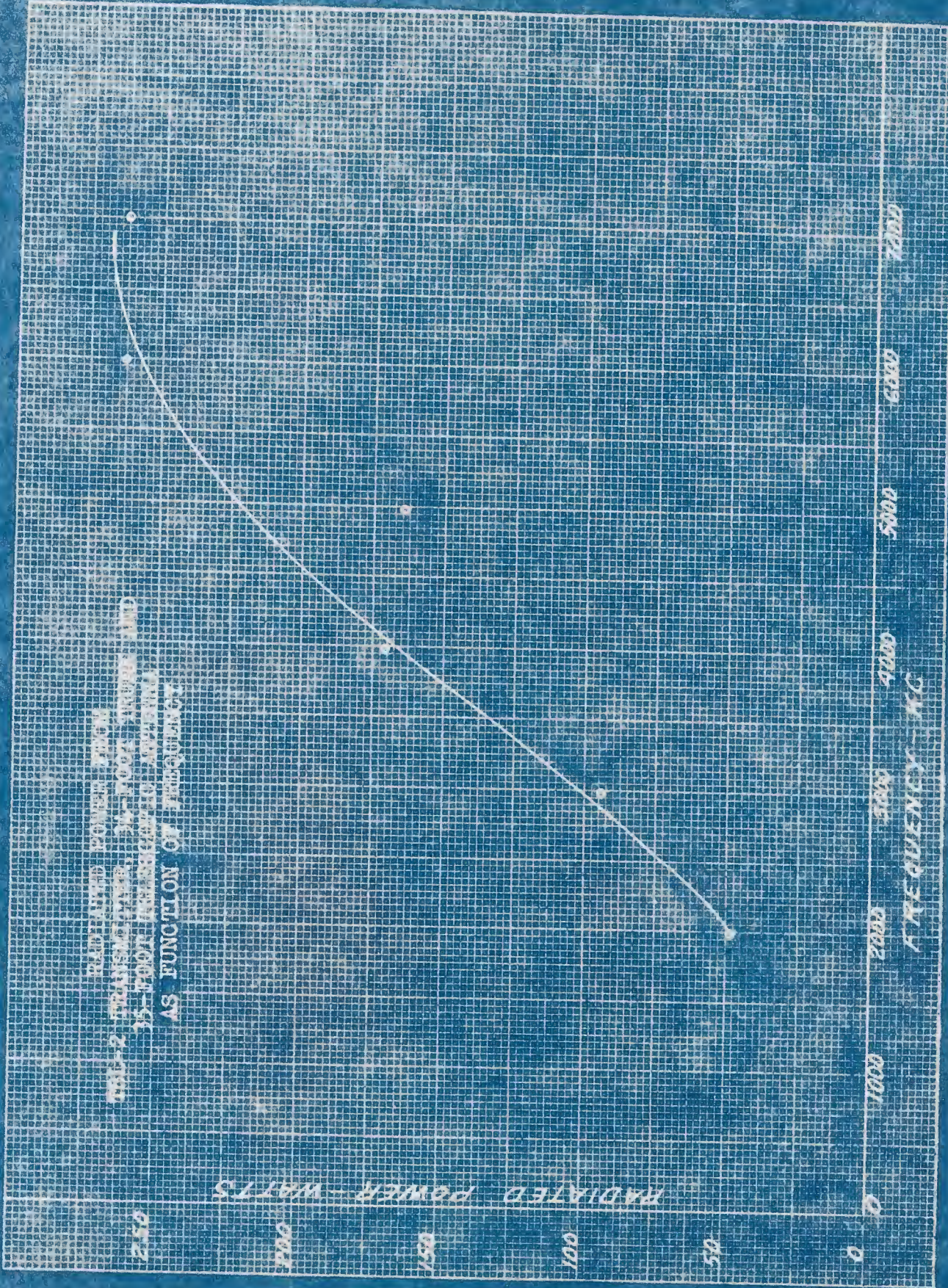
COMPUTED RADIATED POWER AS
FUNCTION OF FREQUENCY FOR 50-FOOT
MAST AND 35-FOOT TELESCOPIC ANTENNA
ON BOARD SHIP

- 1. TAJ-6 TRANSMITTER.
- 2. TEL-2 TRANSMITTER.



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