Performance of Short Antennas*

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Summary—The purpose of this paper is to present experimental data on the performance of vertical antennas having a physical height of less than one-eighth wavelength. These data cover many conditions of top loading performed on a 300-foot, self-supporting, tapered vertical tower with measurements of antenna resistance and reactance from 120 to 400 kilocycles. For these conditions, field-intensity measurements were made to determine the unattenuated field intensity at one mile over a frequency range from 139 to 260 kilocycles. Field-intensity measurements along eight radials were made to determine the horizontal pattern and root-mean-square field intensity.

The best results are obtained when adequate top loading is used in conjunction with a good ground system. Such top loading increases the value of the radiation-resistance component and lowers the capacitive-reactance component of the driving point impedance. Since the loss resistance remains essentially constant with various types of loading, the radiation efficiency of the antenna is materially improved by raising the value of the radiation resistance. Increasing the radiation resistance and lowering the capacitive reactance both tend to lower the effective Q of the antenna circuit. In wide-frequency-band applications a low value of Q is very important.

With short antennas having a small resistance and a large capacitive reactance, extra precautions should be taken to minimize base insulator losses. With high humidity, mist, fog, or rain the input loss resistance of a short unloaded tower may increase several times over its normal dry value. Extensive ground systems and high-Q loading coils are also of prime importance.

I. INTRODUCTION

A REVIEW of the literature regarding vertical antennas reveals that most investigations in the past few years have been made on antennas having a height of from one-eighth wavelength to the order of one-half wavelength.[1–3] Most of these studies have been directed toward improving broadcasting coverage by increasing the ground-wave signal and reducing the fading caused by the sky wave.

In the past, it has been rather common practice at the low frequencies to use antennas about one-quarter wavelength in height, where possible, or to use loading of the T or inverted-L types for very short antennas. It has been the opinion of the authors for some time that other types of top loading would be practical. It is the purpose of this paper to discuss this problem and to report on a series of experiments that were made to prove or disprove the validity of top loading to improve the performance of short antennas.

II. THEORETICAL CONSIDERATIONS

1. *Vertical Patterns*

An antenna of infinitesimal height, assuming no loss, will radiate a field having an intensity of 186 millivolts per meter at one mile in the horizontal plane for 1.0 kilowatt input. An antenna one-eighth wavelength in height under similar conditions provides 189 millivolts per meter at one mile, an improvement of only 1.6 per cent. A one-fourth wavelength antenna has a field intensity of only 195 millivolts per meter at one mile, which is an improvement of 4.8 per cent over an antenna of infinitesimal height. The vertical patterns have essentially the same semicircular shape, which accounts for the horizontal fields having nearly the same strength.

2. *Power Radiated and Dissipated*

In actual practice the above theoretical values of the field intensity can not be realized because of loss resistance in the conductors of the antenna and coupling network, finite conductivity of the ground system, and dielectric losses in the insulators. Due to the fact that the radiation resistance approaches zero as the height is reduced and the loss resistance increases due to the dielectric losses in the base insulators, the efficiency of the antenna system must approach zero.

The ratio of power radiated to power input to the antenna system can be taken as the criterion of over-all performance of the antenna system. In equation form:

$$\text{antenna system efficiency} = \frac{P_R}{P_I} 100 \text{ per cent} \qquad (1)$$

where P_R = antenna power radiated in watts and P_I = antenna-system input power in watts.

The power radiated from the antenna can be determined by measuring the unattenuated root-mean-square field intensity at one mile and comparing it with the theoretical unattenuated field intensity which can be computed for a given antenna configuration. Thus,

$$P_R = 1000\left[\frac{E_m}{E_t}\right]^2 \qquad (2)$$

where E_m = measured unattenuated field intensity at one mile in millivolts per meter for 1.0 kilowatt input and E_t = theoretical unattenuated field intensity at one mile in millivolts per meter for 1.0 kilowatt input.

The antenna-system input power can also be considered as the transmitter output power since the input power supplies the losses in the antenna-system coupling

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[1] W. L. McPherson, "Electrical properties of aerials for medium and long wave broadcasting," *Elec. Commun.*, vol. 16, pp. 306–320; April, 1938; and vol. 17, pp. 44–65: July, 1938.

[2] G. H. Brown, R. F. Lewis, and J. Epstein, "Ground systems as a factor in antenna efficiency," PROC. I.R.E., vol. 25, pp. 753–787; June, 1937.

[3] C. E. Smith, "A critical study of two broadcast antennas," PROC. I.R.E., vol. 24, pp. 1329–1341; October, 1936.

network between the transmitter terminals and the antenna as shown in Fig. 1. The total power lost in the antenna system can be expressed as follows:

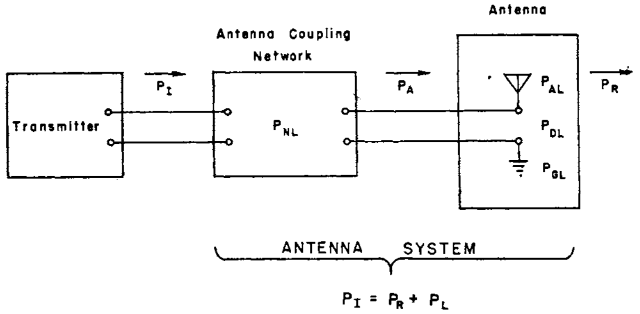

Fig. 1—Power in various parts of the antenna system.

$$P_L = P_{NL} + P_{AL} + P_{DL} + P_{GL} \qquad (3)$$

where P_L = total power lost in the antenna system measured in watts, P_{NL} = antenna-system coupling-network power lost measured in watts, P_{AL} = antenna-resistance power lost measured in watts, P_{DL} = insulator-dielectric power lost measured in watts, and P_{GL} = ground-system power lost measured in watts.

The power lost in the antenna-system coupling network can be determined by measuring the input and output power and using the equation:

$$P_{NL} = P_I - P_A \qquad (4)$$

where P_A = antenna input in watts measured at the antenna terminals as shown in Fig. 1.

The power lost in the antenna itself, P_{AL}, in the insulator dielectric, P_{DL}, and the ground system, P_{GL}, can be lumped together and determined from the following equation:

$$P_A - P_R = P_{AL} + P_{DL} + P_{GL}. \qquad (5)$$

3. *Antenna Impedance*

For an antenna without top loading that is shorter than one-eighth wavelength (45 degrees), the radiation resistance is small and approximately proportional to the square of the height. A useful approximation is

$$R_R \doteq \frac{h^2}{312} \qquad (6)$$

where R_R = base radiation resistance in ohms, and h = height of antenna in degrees.

This equation has been plotted (see Fig. 13) to show its accuracy as compared with the theoretical radiation-resistance curve for a thin vertical wire with sinusoidal current distribution. Equation (6) gives fair accuracy up to one-eighth wavelength. Above this wavelength the values are too low. As the top loading is increased the slope of the radiation-resistance curve increases and this approximation loses its accuracy.

The reactance of a short antenna is capacitive and becomes larger with decreasing height. An approximate formula is

$$X_c \doteq Z_0 \cot h \qquad (7)$$

where X_c = base capacitive reactance in ohms, $Z_0 = 60(\log_e(h/r) - 1)$ ohms, h = height of antenna in degrees, and r = radius of antenna in degrees.

This equation assumes a uniform cross-section tower with sinusoidal current distribution and no shunting insulator capacitance at the base.

4. *Antenna-System Performance*

The performance of a nondirectional antenna system depends upon the vertical directivity gain of the antenna and the losses in the system. For short antennas the directivity gain will not change appreciably from one condition to another so long as there is not a reversal of current on the antenna. The vertical pattern for most cases will be somewhere between that of an infinitesimal antenna and a quarter-wave antenna.

The term "antenna system" is used in this discussion to include the coupling network between the transmitter and the antenna proper as shown in Fig. 1. It is important to include this network since its losses P_{NL} may be an appreciable factor in determining the over-all efficiency of the antenna system. In both the theoretical and practical case, as the antenna is made shorter the radiation resistance decreases and the capacitive reactance increases. To transform this antenna impedance to a value that will properly load the transmitter, it is common practice to insert a coil in series with the antenna that will neutralize the capacitive reactance and leave enough inductive reactance so that a capacitor in parallel will antiresonate the circuit to give the desired value of impedance for the transmission line or transmitter as the case may be. The losses in this network can be determined by capacitor (3). Since the loss in this network may be large for very short antennas, it is desirable to take measures to increase the antenna terminal resistance and lower the capacitive-reactance component. Both of these conditions are improved by proper top loading of the antenna.

The power P_{AL} lost in heating the antenna itself will usually be quite small providing the conductor surface is large, the antenna-tower members are thoroughly bonded and the material of the tower is itself a good conductor. In any event, it would be difficult to separate this loss from that of the ground-system loss P_{GL} and the insulator loss P_{DL}.

During the course of these experiments, measurements indicated that the reactance of the base insulator was small in comparison to its loss-resistance component. Under these conditions the power lost in the insulator P_{DL} may be considered separately if it is first considered that the equivalent circuit of a short antenna consists of a resistance R and a capacitive reactance X in series, as shown in Fig. 2(a). The resistance R is assumed to be made up of all resistances as measured at the antenna terminals except the insulator loss resistance. The impedance of this circuit is given by,

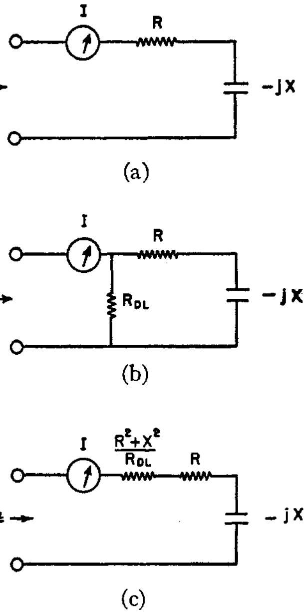

Fig. 2—Equivalent circuits for determining power loss in base insulators: (a) assuming no insulator loss, (b) insulator shunting antenna terminals with resistance R_{DL}, and (c) insulator effective series loss resistance R^2+X^2/R_{DL}.

$$Z_1 = R - jX. \tag{8}$$

If the antenna circuit is shunted with a lossy insulator represented by a resistance R_{DL}, the circuit becomes that shown in Fig. 2(b), with impedance Z_2 given by

$$Z_2 = \frac{R^2R_{DL} + X^2R_{DL} + RR_{DL}^2 - jXR_{DL}^2}{(R + R_{DL})^2 + X^2} \cdot \tag{9}$$

In practice the insulator loss resistance R_{DL} is usually very much greater than the resistance R and the reactance X, so that the equivalent circuit may, to a very close approximation, be represented by Fig. 2(c) and the equation for Z_2 simplifies to,

$$Z_2 \doteq \frac{R^2 + X^2}{R_{DL}} + R - jX. \tag{10}$$

Comparing (8) and (10), it may be seen that they differ only in the term $(R^2+X^2)/R_{DL}$, the insulator effective series loss resistance. Since the antenna current I must flow through both resistances, $(R^2+X^2)/R_{DL}$ and R, the power is divided between them and the power lost in the insulator P_{DL} is given by

$$P_{DL} = I^2 \frac{R^2 + X^2}{R_{DL}} \cdot \tag{11}$$

The percentage of the antenna input power P_A lost in the insulator is equal to

$$P_{DL} = \frac{100}{1 + \frac{RR_{DL}}{R^2 + X^2}} \cdot \tag{12}$$

An adequate ground system is of extreme importance where short antennas are employed. The per cent power loss for various types of buried-copper-wire radial ground systems, expressed as a function of antenna height for an unloaded tower, is shown in Fig. 3. These curves are derived from field-intensity measurements made in the standard broadcast band and on file with the Federal Communications Commission and from those shown in the paper of Brown, Lewis, and Epstein.[2]

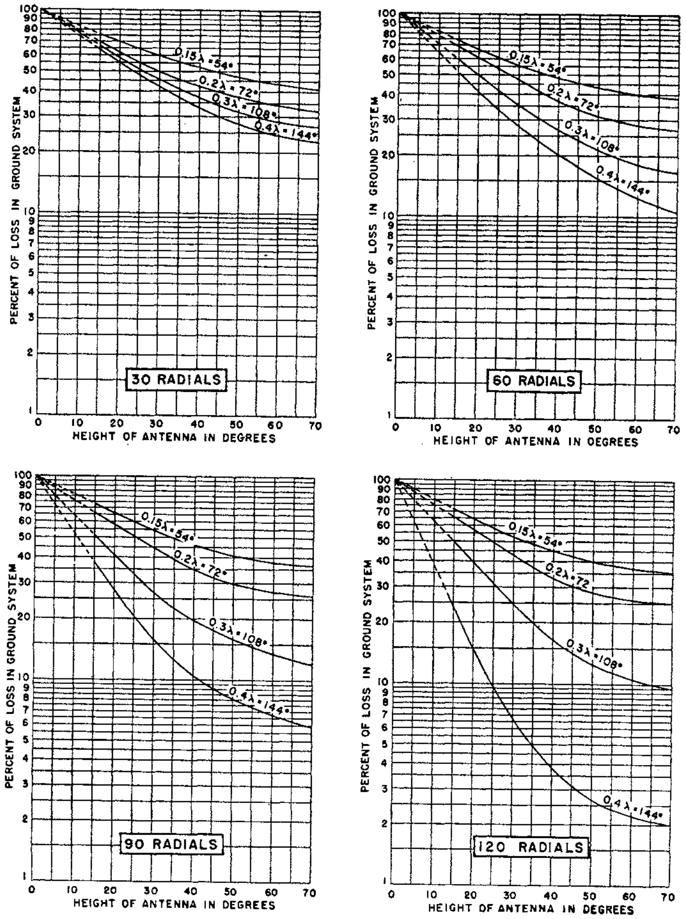

Fig. 3—Per cent power loss in the ground system for various lengths of buried-copper-wire radials, as identified on the curves, plotted as a function of antenna height for the indicated number of radials.

The effect of conductivity in the immediate vicinity of the transmitter becomes very important when poor ground systems are used. Under such conditions the losses will be different from those shown in Fig. 3, which are for average soil conductivities. On low frequencies, where physical limitations may prevent the installation of an ideal ground system, careful selection of transmitter sites is essential. Whenever possible, a site having a high conductivity for the first few miles should be selected.

It should be noted that these curves have been prepared for an unloaded vertical tower. Where top loading is used, it is necessary to determine the radiation resistance for that structure and select an unloaded tower having a height that will give the same radiation resistance. The equivalent unloaded height is then used to estimate the power lost in the ground system. This procedure assumes that the ground-loss resistance R_{GL} remains constant for loaded and unloaded towers. Although there is some change in R_{GL} with loading, it is generally not of sufficient magnitude to alter the results appreciably.

Preparation of the curves to indicate the per cent power loss in the ground system allows direct addition of this loss in (3) for determination of over-all antenna-system loss P_L.

For a given quantity of copper wire, less loss will occur if the ground radials are made in the order of 0.4-wavelength long rather than placing this same quantity of wire in a greater number of shorter radials. Due to the physical dimensions of a 0.4-wavelength ground system, it may not always be practical to install such a system. Where the number of ground radials is limited, the use of a ground screen will improve stability as well as reduce losses.

In many applications of radio, the effective Q or bandwidth of the antenna circuit is of greater significance than the efficiency of the system. The bandwidth of the antenna may be determined from the resistance and reactance measurements made at the base of the tower. If the bandwidth is considered to be the frequency band within which the power is equal to or greater than one-half the power at resonance, then in equation form

$$\Delta f = \frac{2R_A}{\dfrac{dX}{df}} \tag{13}$$

where Δf = bandwidth in kilocycles between half-power points, R_A = measured antenna resistance in ohms, and dX/df = slope of reactance curve at resonant frequency.

This equation assumes a generator impedance of zero ohms. When the generator is matched to the antenna circuit, the effective bandwidth will be doubled.

III. EXPERIMENTAL DATA

1. *Impedance-Measuring Equipment*

A General Radio type 516-C radio-frequency bridge was modified with a type 578-C low-frequency transformer and a ratio arm with 1000 ohms in each arm to give better sensitivity in this frequency range. A specially constructed composite oscillator having an output up to 25 volts was used as the generator voltage for the bridge. A Hammarlund receiver with two low-frequency bands was used as the bridge detector. The operating frequency was measured with a type SCR-211 frequency meter.

In making the measurements over a range of frequencies from 120 to 400 kilocycles, care was taken to get accurate values of the resistance component. Corrections were made to take into account the loss in the capacitor placed in series with the unknown. The loss of this capacitor varied considerably over the frequency range. The generator signal was unmodulated and the null point was determined by the dip of the "R" meter in the Hammarlund receiver.

2. *Determination of the Unattenuated Root-Mean-Square Field Intensity at 1 Mile*

The initial tests were made on a 300-foot self-supporting tower without top loading. A photograph of this tower with the eight umbrella wires connected is shown in Fig. 4. The ground system installed consisted of 500 buried-copper-wire radials out to a distance of 75 feet, and 250 buried-copper-wire radials out to a distance of 400 feet. To measure the performance of this antenna, a rather complete survey was made to determine the unattenuated root-mean-square field intensity at one mile when operating on a frequency of 170 kilocycles. Top-loading conditions were then referred to this unloaded condition of operation.

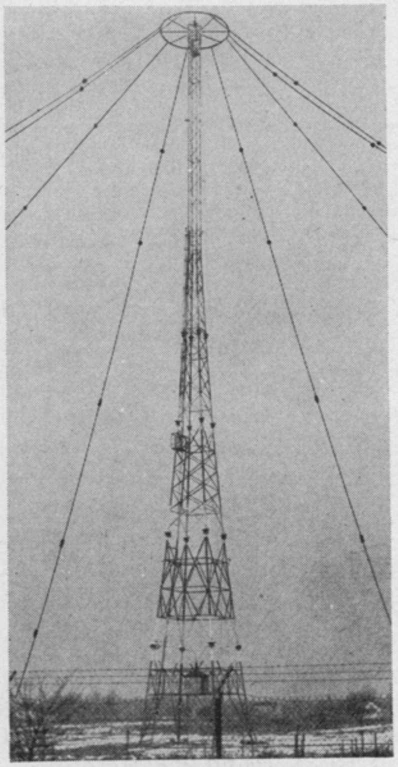

Fig. 4—View of WHK's 300-foot tower with the eight umbrella wires in place.

The antenna was driven with a type BC-191 transmitter. The field-intensity measurements were made with a Radio Corporation of America type 308-A field-intensity meter mounted in a four-wheel-drive carry-all truck. This truck was also equipped with two-way radio-communication equipment.

In order to determine the power radiated, field-intensity measurements were made along 8 radials. A plot of the measurements along the respective radials was used to determine the unattenuated field intensity at one mile. From these data the horizontal pattern was constructed as shown in Fig. 5.

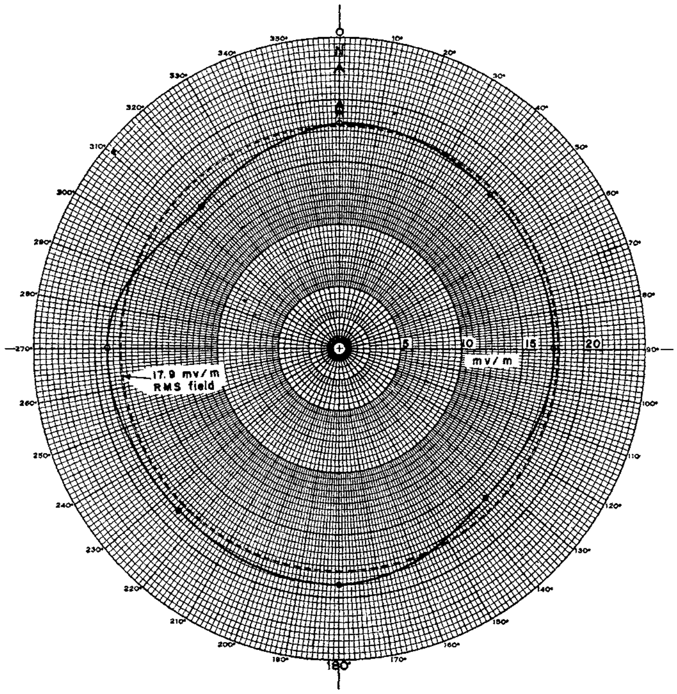

FIG. 5—Plot of unattenuated field intensity at 1 mile: frequency, 170 kilocycles; antenna, 300-foot self-supporting tower with top loading; ground system, 500 radials under asphalt pavement out 75 feet, plus 250 radials out 400 feet; impedance, 2.5 $-j$ 465 ohms; antenna current, 3.8 amperes; and root-mean-square field, 17.9 millivolts per meter.

3. *Ratio Method of Determining the Root-Mean-Square Field Intensity for the Tower with the 30-Foot-Diameter Capacitive Hat*

The capacitive hat was connected to the top of the tower through the contacts of a relay which could be readily controlled from the tuning house at the base of the tower. Resistance and reactance measurements for both conditions were made over the frequency range 120 to 400 kilocycles. Field-intensity measurements were then made at a few established points along each radial, first with the capacitive hat on and then with it off. The work was speeded up with the aid of two-way radio communication between the tuning house and the field car. Enough measurements were made to establish the fact that the horizontal patterns were essentially the same for both conditions of operation. At 170 kilocycles and with the same input current the field intensity with the capacitive hat was 11 per cent greater than for the tower without top loading.

4. *Ratio Method of Determining the Root-Mean-Square Field Intensity for the Various Conditions of Operation over a Frequency Range*

To determine the performance for numerous conditions of loading, a reference point was selected 1.5 miles from the antenna. Field-intensity measurements were made at this point on the following frequencies: 139, 150, 159, 170, 183, 193, 230, and 260 kilocycles, for each condition of loading. During these measurements, the antenna current was maintained at 3.0 amperes or the field measurements were corrected to correspond to this value of antenna current. This method gives a check on measurements at a given frequency in addition to adding the frequency-range parameter.

Field-intensity measurements indicated that the horizontal pattern remains substantially unchanged from the condition of zero top loading; hence, the unattenuated root-mean-square field intensity at one mile and the radiation resistance can be computed over a frequency range for each condition of top loading.

5. *Top Loading with Eight Umbrella Wires*

The loading afforded by the use of the 30-foot-diameter capacitive hat, although increasing the power radiated, did not appear to offer the optimum degree of loading. The mechanical difficulties involved in enlarging the size of the hat made such a procedure impractical. As a means of increasing the amount of loading, eight umbrella wires were fastened between the top of the tower and ground. These wires were uniformly spaced in the horizontal plane and were made taut by means of blocks and tackles fastened to stakes driven in the ground 350 feet from the center of the tower. Each wire was broken with insulators at regular intervals. By opening and shorting pertinent insulators, it was possible to vary the length of these wires so as to present different amounts of top loading. Two types of umbrella loading were tried. The first involved varying the length of the eight umbrella wires, so that their lengths were 100, 200, 300, 375, and 450 feet. The second involved connecting the outer or free ends of the umbrella wires with a wire skirt and varying the radial length to 100, 200, and 300 feet.

Resistance, reactance, and field-intensity measurements were made over a frequency range for each of the nine conditions of umbrella loading. The radiation resistances were determined and are plotted along with the measured base resistance and reactance in Figs. 6 and 7. A sketch of the installation is shown on each curve. For comparison purposes, the values of reactance have been replotted as families of curves in Figs. 8 and 9.

If the measured base resistance is plotted against length of umbrella wires for the lower frequencies, considerable variation will be observed. This arises from the fact that resistance measurements for the

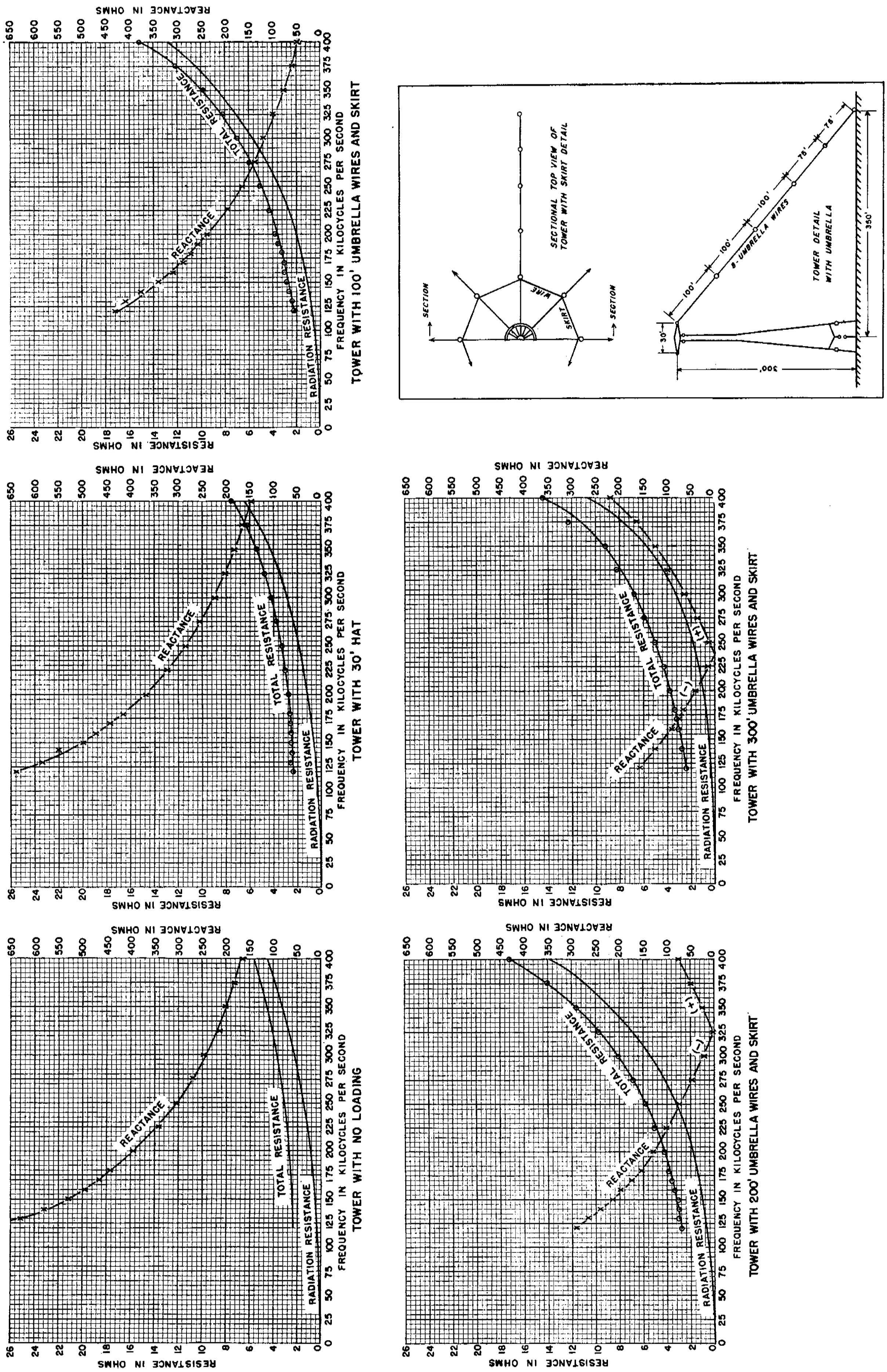

Fig. 6—Plot of resistance and reactance measurements on a 300-foot self-supporting tower, top-loaded with eight uniformly spaced umbrella wires connected at the ends with a wire skirt as shown in the sketch.

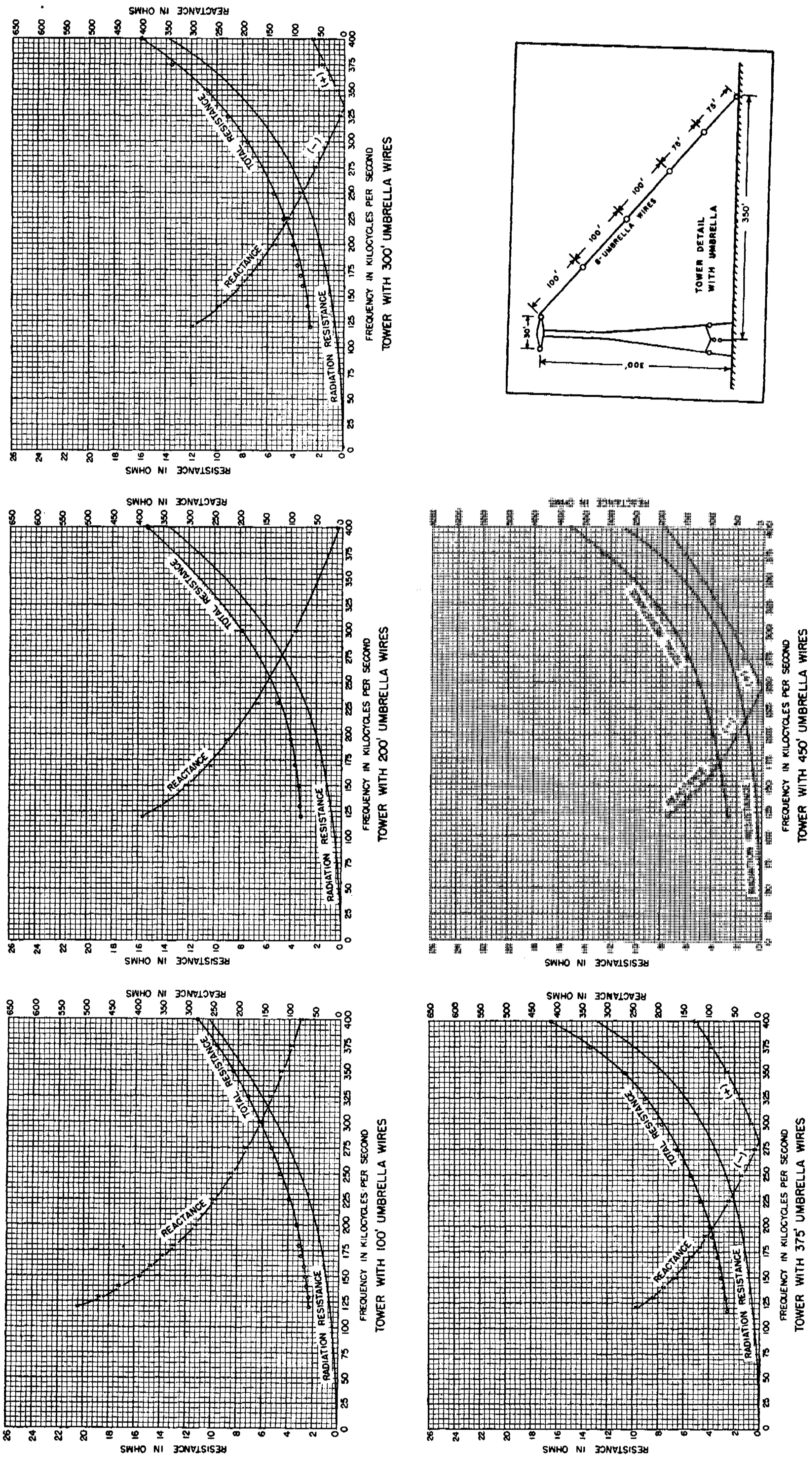

Fig. 7—Plot of resistance and reactance measurements on a 300-foot self-supporting tower, top-loaded with eight uniformly spaced umbrella wires.

various amounts of loading were made on different nights under different weather conditions, and thus at variable values of insulator dielectric loss P_{DL}.

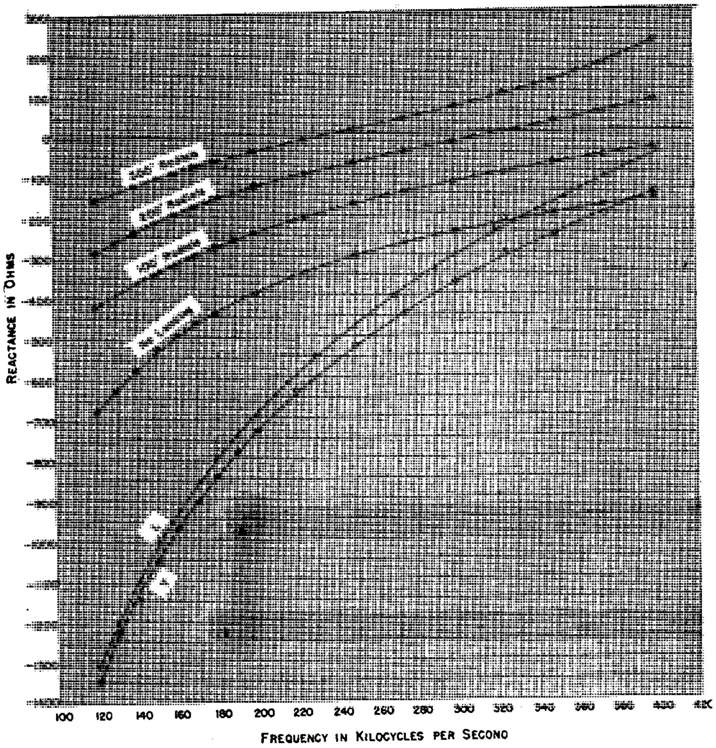

Fig. 8—Reactance curves of inverted-L- and T-type antennas compared with various lengths of eight umbrella wires, with skirt wire connecting the outer extremity, used as top loading on a self-supporting tower.

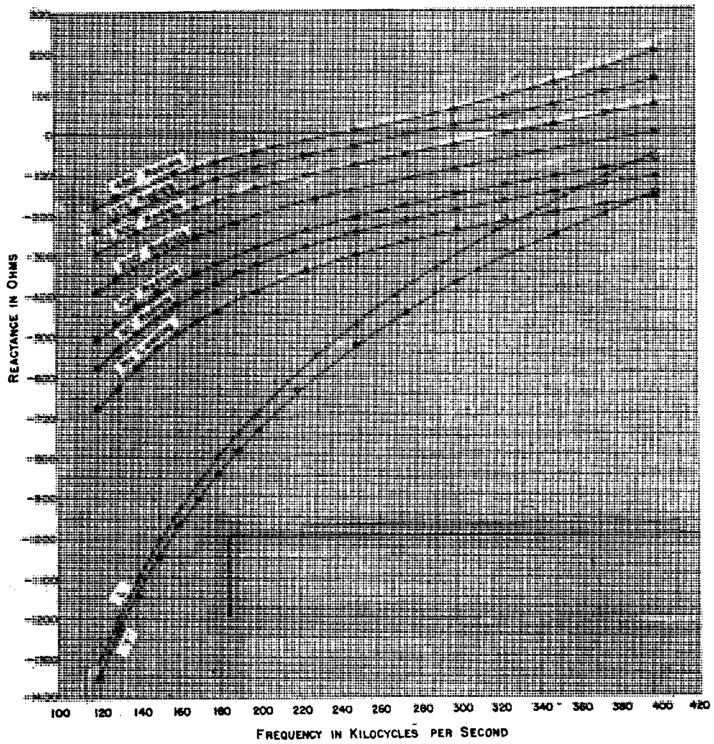

Fig. 9—Reactance curves of inverted-L- and T-type antennas compared with umbrella-type loading with eight radial wires of various lengths, as indicated.

Fig. 10 gives the calculated percentage of antenna input power P_A lost in the insulator-dielectric loss resistance R_{DL} as a function of the amount of loading at a number of frequencies and for a number of assumed values of leakage resistance for the measured tower. The diagrams in this figure demonstrate the importance of having insulators with low leakage resistance when using antennas with high base reactance and low radiation resistance.

The tower insulators consisted of six porcelain compression members and two bakelite strain members at each of the four tower legs. The insulators were in need of maintenance since the surface of the bakelite strain members had become rough and dirty from exposure to the weather. Measurements were made of actual leakage resistance to determine the order of magnitude of insulator leakage resistance which may be encountered in practice with dirty insulators when adverse weather conditions exist.

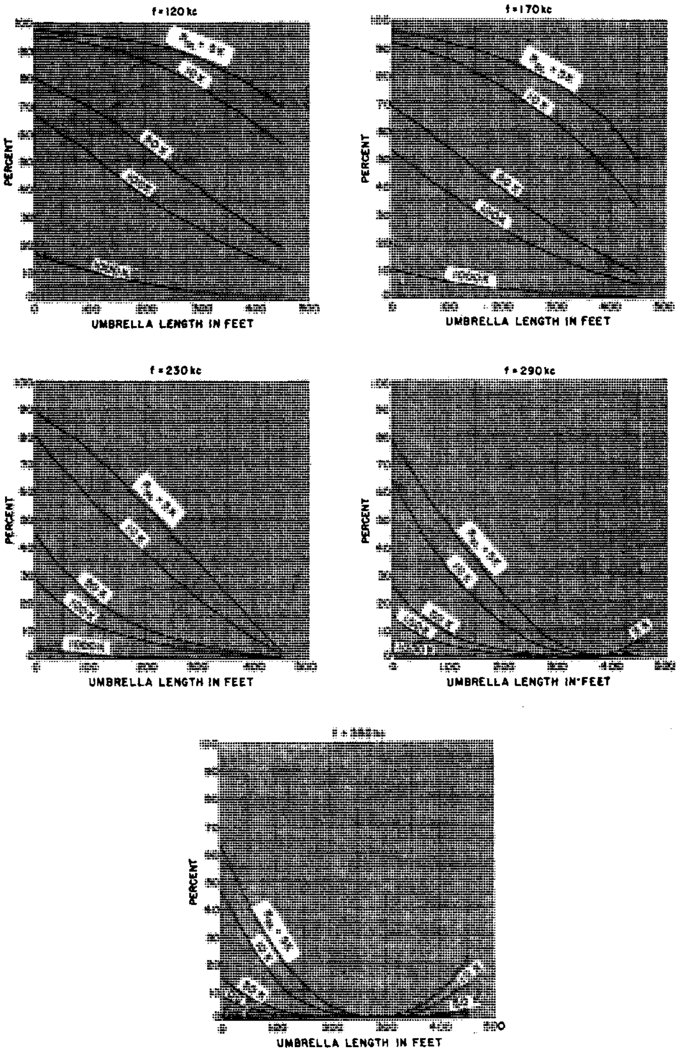

Fig. 10—Per cent antenna input power lost in base insulator versus length of eight umbrella wires for various values of insulator leakage resistance shunted across measured base impedance of antenna at low operating frequencies.

Under particularly bad foggy or sleety weather conditions, the series base resistance at 170 kilocycles was measured to be 12.8 ohms; whereas the measured value under dry conditions was only 2.8 ohms. The measured reactance was 391 ohms and was not appreciably different than under dry conditions. This increase in base resistance represents an equivalent insulator leakage resistance R_{DL} of approximately 15,000 ohms, as determined by solving for R_{DL} in (10). The fact that the insulator leakage was responsible for this effect was definitely ascertained by throwing a pitcher of water on one of the base insulators and observing the measured base resistance increase from 2.6 to 7.6 ohms at 130 kilocycles. This represents an insulator loss resistance of approximately 200,000 ohms. Insulator leakage losses can be kept at a minimum by the selection of proper insulators and regular maintenance. In this connection, the use of heated insulators having water shields and surfaces which tend to prevent the formation of water films may prove beneficial.

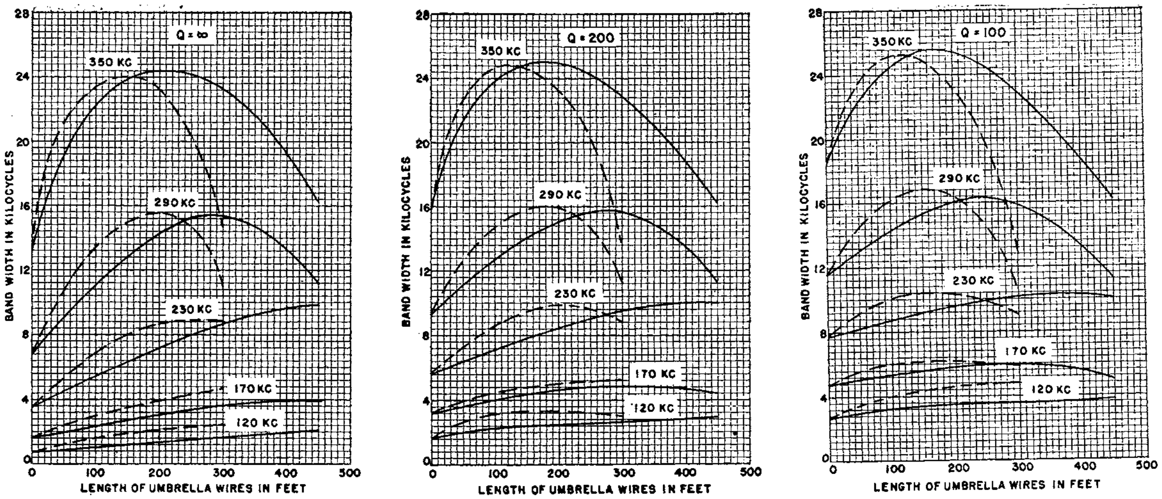

Fig. 11—Bandwidth in kilocycles for a 300-foot self-supporting tower, top-loaded with eight umbrella wires, as a function of length of umbrella wires for five frequencies, with loading coils having Q's of ∞, 200, and 100.
(— — — with skirt, ——— without skirt.)

At standard broadcast frequencies, where the base resistance of this tower is comparatively high and the reactance low, the dielectric losses in the insulator are so small that they are of no practical importance.

The effective bandwidth has been calculated for each condition of umbrella loading. Since the Q of the antenna-loading coil will alter the results, the calculations have been made for coils having a Q of ∞, 200, and 100. A plot of bandwidth versus length of umbrella wires for frequencies of 120, 170, 230, 290, and 350 kilocycles is shown in Fig. 11. From these curves it can be seen that, for maximum bandwidth, the optimum length of umbrella wires is dependent upon both the frequency involved and the Q of the loading coil.

The field-intensity measurements have been analyzed and the radiation resistance calculated for the above five frequencies. A plot of the resistance versus length of umbrella wires for each of these frequencies is shown in Fig. 12. It is interesting to note that the degree of top loading which produces maximum radiation resistance is essentially independent of frequency.

The radiation resistance of a thin, vertical wire top-loaded with a nonradiating capacitive hat has been calculated for a number of conditions as shown in Fig. 13. The formula for these calculations is given in the figure. These curves have been prepared to show the correlation with the experimental results plotted in Figs. 6 and 7. It will be noted that for the unloaded tower the radiation resistance curve is approximately a squared function up to 45 degrees. As the degree of top loading is increased, the radiation resistance increases at an exponential rate greater than the squared power.

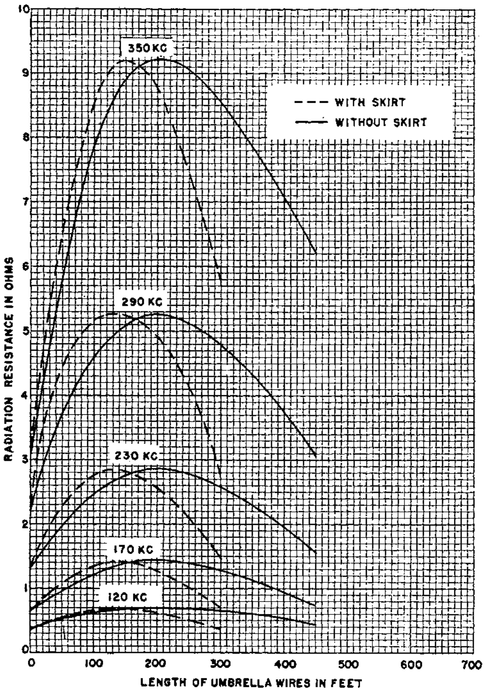

Fig. 12—Radiation resistance for various conditions of umbrella top loading.

The unattenuated field intensity at one mile has been determined for each condition of top loading for the frequencies 120, 170, 230, 290, and 350 kilocycles. A

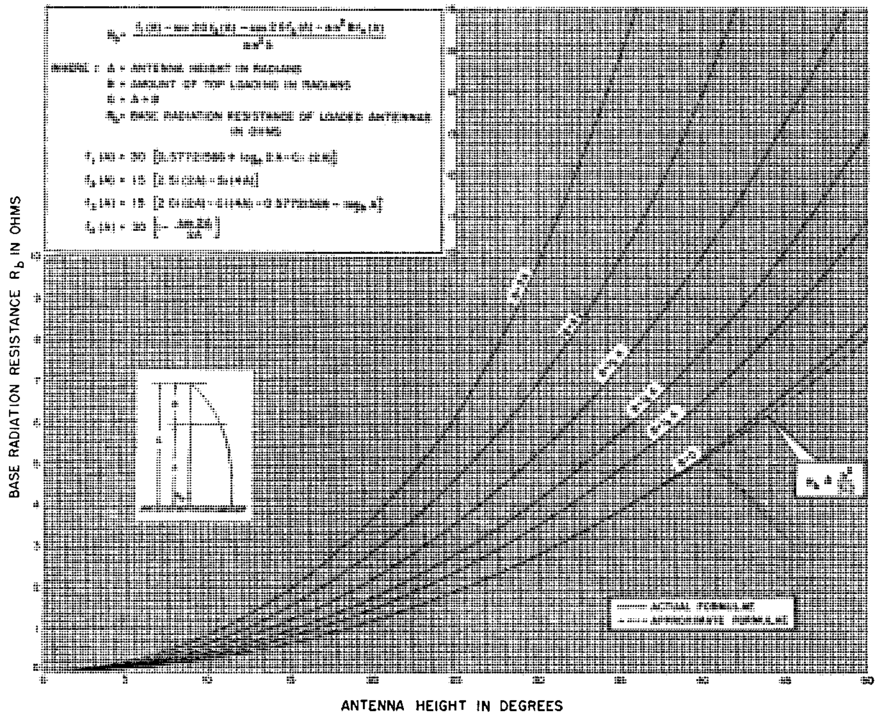

Fig. 13—Theoretical radiation resistance for various degrees of top loading.

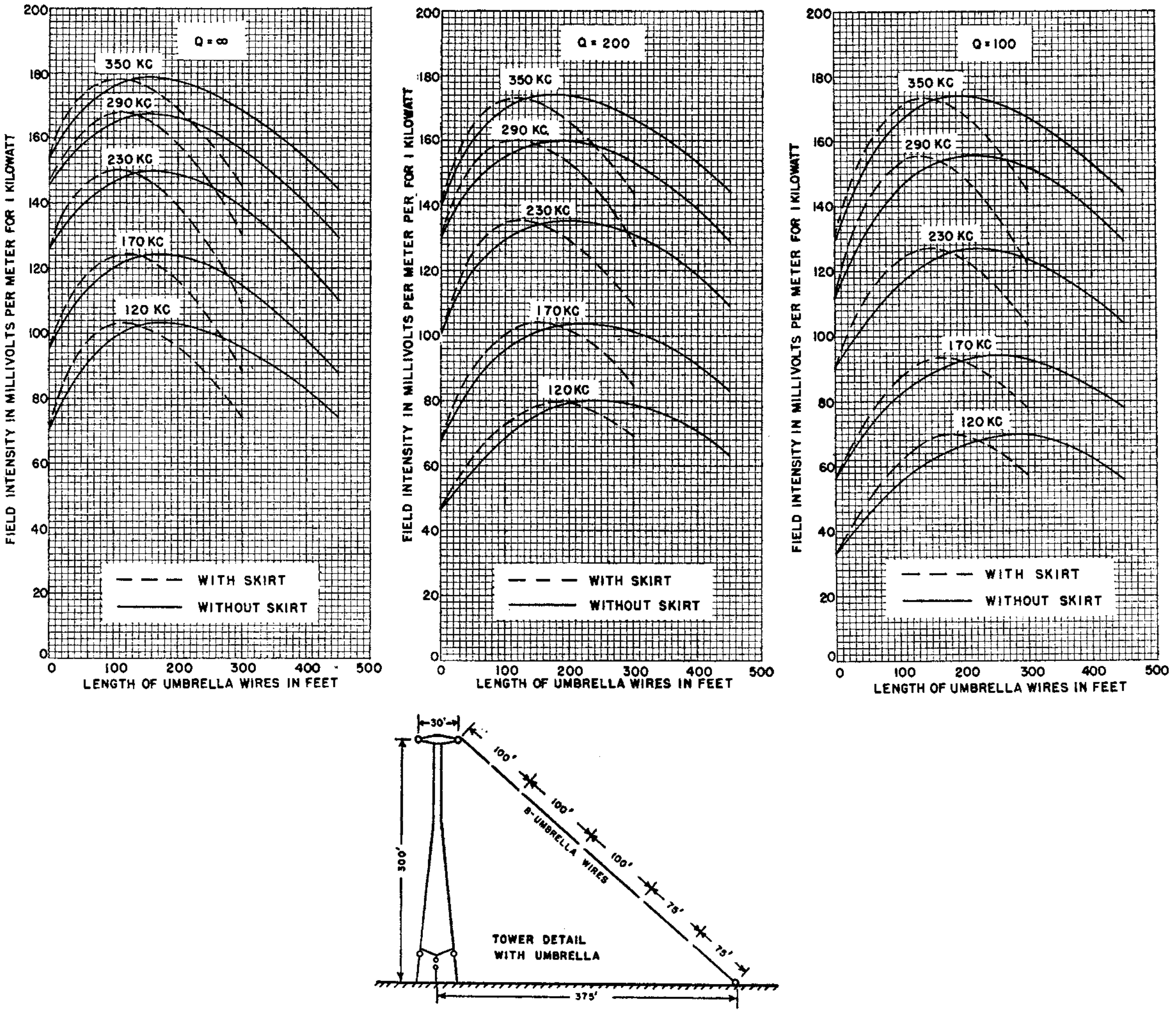

Fig. 14—Unattenuated field intensity at 1 mile radiated in millivolts per meter for 1.0 kilowatt from a 300-foot self-supporting tower, employing umbrella-type loading, as a function of length of eight umbrella wires for five frequencies with loading coils having a Q of ∞, 200, and 100.

plot of the unattenuated field as a function of length of umbrella wires for loading coils having Q's of ∞, 200, and 100 is shown in Fig. 14. In viewing these curves, it is necessary to keep in mind that the ground system as well as the antenna increases in electrical length with increasing frequency.

The amount of gain to be realized from top loading of a short antenna is dependent upon the losses in the system. If there are no losses in the system, the gain in field intensity is negligible. However, with optimum top loading at 120 kilocycles, the experimental results indicate that, when using a loading coil having a Q of 100, a gain of 6.5 decibels, which is equivalent to a power increase of 4.5, is realized. On 350 kilocycles, using a coil having the same Q, the gain is 2.6 decibels, or a power increase of 1.8.

The results indicate that substantial gains in power radiated and bandwidth acceptance can be realized with umbrella-type loading on short towers. It is an easy and inexpensive way to buy power and improve performance. The placing of a wire skirt around the outer end of the umbrella wires shortens the radial length of the umbrella wires required to produce a particular result, as shown in Figs. 11, 12, and 14. Where high powers are involved, a wire skirt is a useful method of reducing corona losses. Another method of accomplishing substantially the same results would be to increase the number of umbrella wires. Also, if the size of the umbrella wires is increased, the corona loss will be further decreased. The formation of wire cages is a common method of increasing the effective size of conductors. The construction and maintenance of an umbrella with a wire skirt is more difficult than increasing the number or size of umbrella wires.

6. *Top Loading by Means of Inverted-L- and T-Type Antennas*

Inverted-L- and T-type antennas were erected between two 300-foot towers spaced 410 feet apart. The height of the vertical lead of the inverted-L-type antenna was 290 feet and the T-type was 280 feet. The length of the flat-top in each case was 350 feet. Resistance, reactance, and field-intensity measurements were made for both types of antennas. A plot of the resistance and reactance measurements is shown in Fig. 15. At the lower frequencies, where loading afforded by

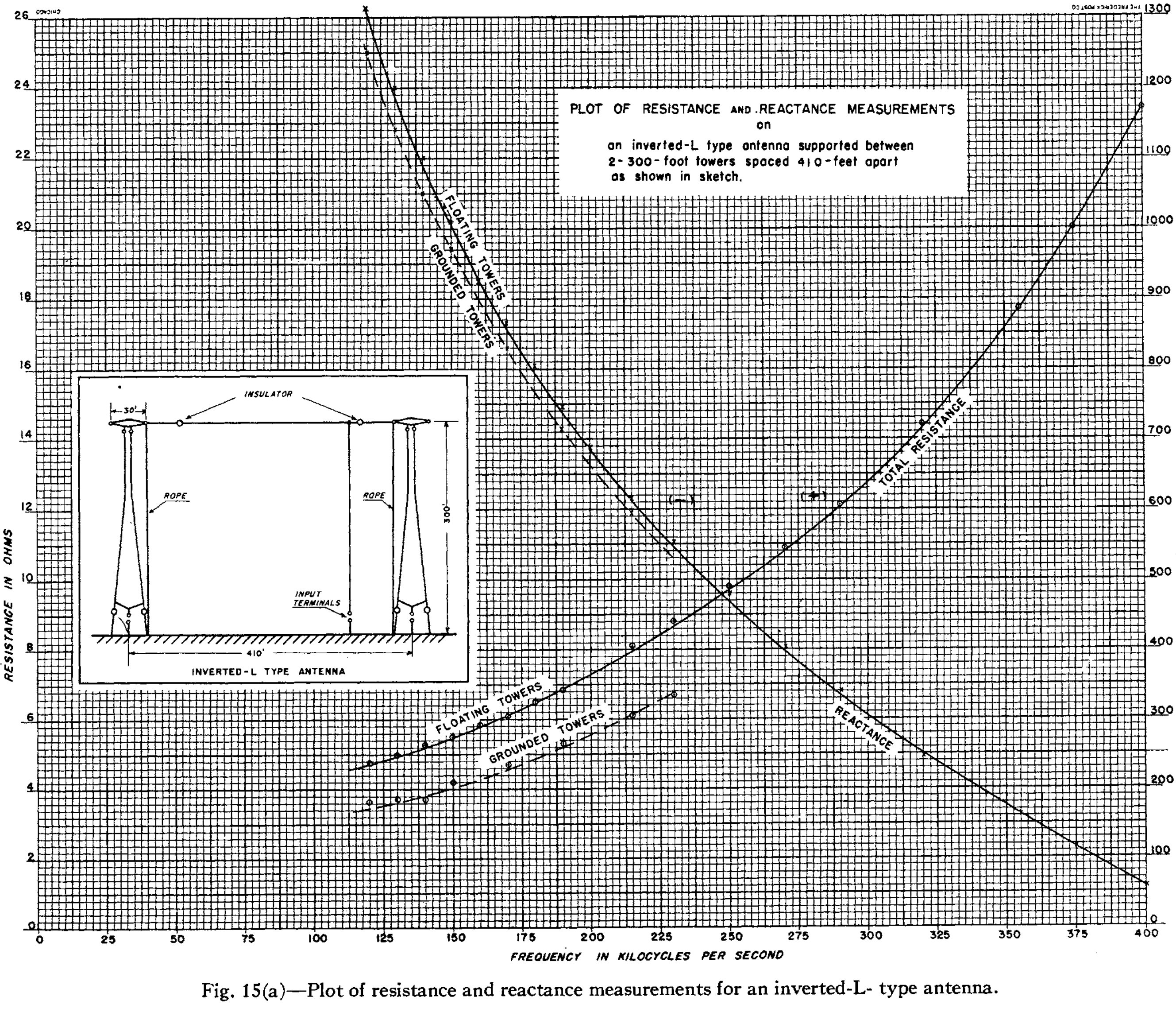

Fig. 15(a)—Plot of resistance and reactance measurements for an inverted-L- type antenna.

the 350-foot flat-top is inadequate, the reactance component of both the inverted-L- and the T-type antennas is appreciably higher than that offered by umbrella-type loading. This is as expected, since the characteristic impedance of a thin wire is much higher than of a tower having considerable cross section. Where wide-band transmission is of importance, the cross section of the antenna should be as large as practical. The bandwidth of both the inverted-L- and T-type antennas have been plotted as a function of frequency in Fig. 16.

The field-intensity measurements indicate that, over the frequency range considered, the unattenuated field for both the inverted-L- and T-type antennas were inferior to the optimum afforded by umbrella-type loading as shown in Table I. Had a larger flat-top been used, the efficiencies of the various types of loading would probably be about the same. However, the bandwidth afforded by umbrella-type loading will be superior unless cages having dimensions comparable to a tower are used. Both the inverted-L- and T-type antennas require the installation of two towers. In addition to the extra cost involved, there are certain other disadvantages of requiring two towers. As pointed out early in this paper, it is important to have an area of good conductivity immediately surrounding the antenna. In certain instances, it might be possible to erect a single tower where an effective salt-water ground would prevail but, due to physical limitations, it might not be feasible to install a second tower with the required separation. In the case of the inverted-L-type antenna, there is also the problem of radiation from the flat-top. When the length of the flat-top is less than the height of vertical lead and the combined electrical length is less than 90 degrees, the radiation from the flat-top will be a small percentage of the total power radiated.

TABLE I

FIELD INTENSITY AT ONE MILE FOR 1.0 KILOWATT ON 170 KILOCYCLES FOR LOADING COILS HAVING Q'S AS INDICATED

Type of Antenna	$Q=\infty$	$Q=200$	$Q=100$
Inverted L	103	78.5	66
T	115	76.6	61.4
Tower with no loading	94	67	56
Tower with optimum umbrella loading	125	104	92

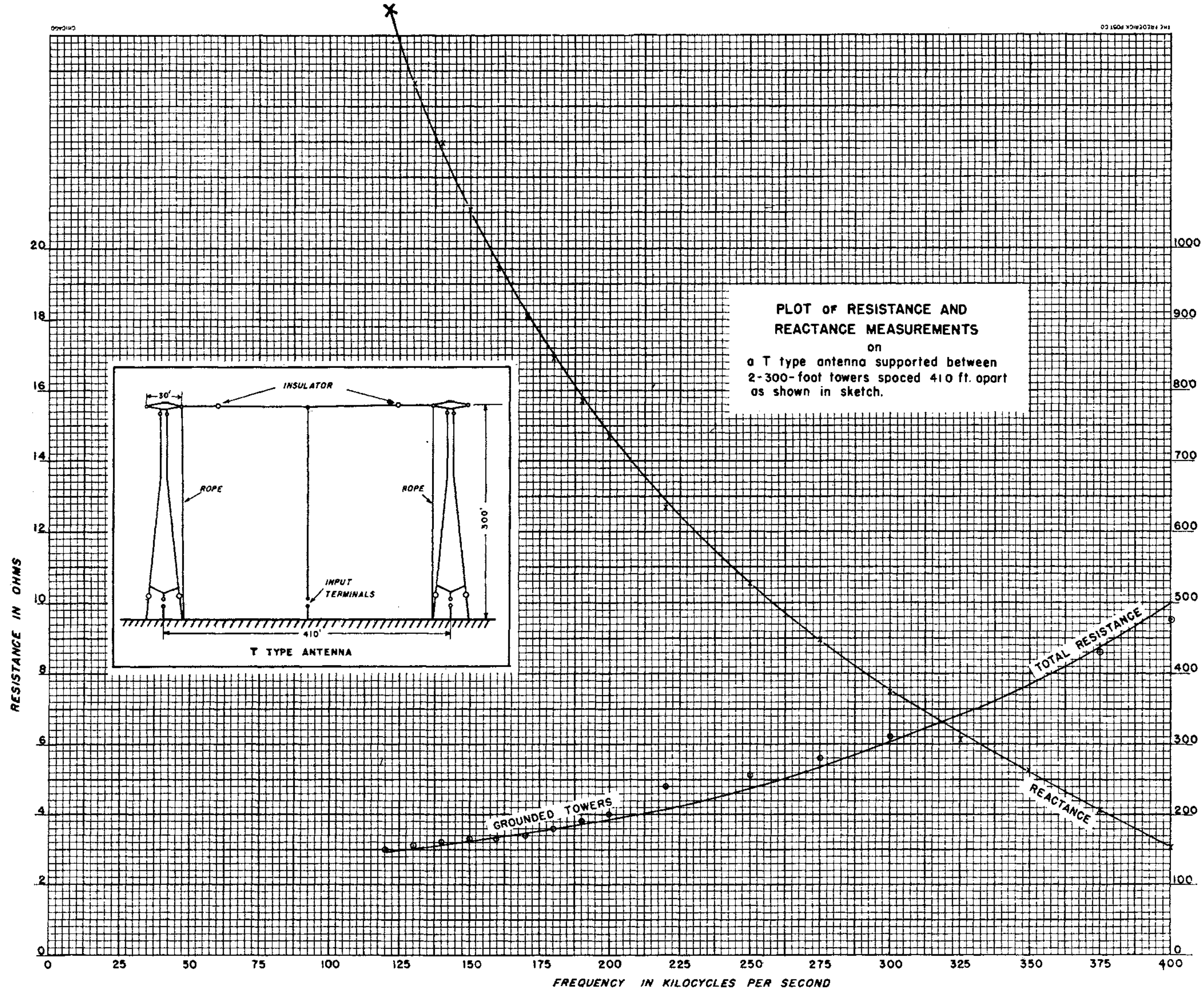

Fig. 15(b)—Plot of resistance and reactance measurements for a T-type antenna.

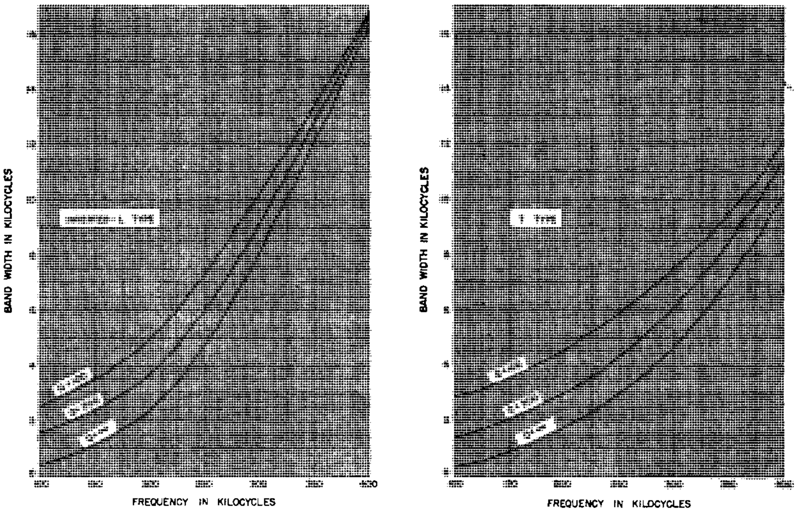

Fig. 16—Bandwidth for various conditions of inverted-L- and T-type antennas.

7. *Top Leading With Capacitive Hat and Coil*

To increase the degree of loading afforded by the 30-foot diameter hat, a coil was connected between the capacitive hat and top of the tower. This coil had a Q of approximately 100 and an inductance range up to 1.9 millihenries. The amount of coil inserted was varied by means of a slider connection. Resistance, reactance, and field-intensity measurements were made at 170 kilocycles for each condition of loading. A plot of the measured base resistance and reactance and the radiation resistance at 170 kilocycles as a function of the amount of reactance in the coil is shown in Fig. 17; the unattenuated field at one mile has been plotted against the reactance of the top-loading coil in Fig. 17. It is seen that an increase in power radiated is obtained by inserting a small portion of the coil. However, on increasing the amount of coil, the antenna efficiency is reduced. Above a certain quantity of coil the reflected loss resistance more than offsets the gain made by increasing radiation resistance. Unless a coil having a Q considerably greater than 100 is used, the results obtained do not appear to justify such an installation. Similar measurements were made for the coil between the tower and the 100-foot umbrella wires connected with a wire skirt. A plot of these measurements is also shown in Fig. 17.

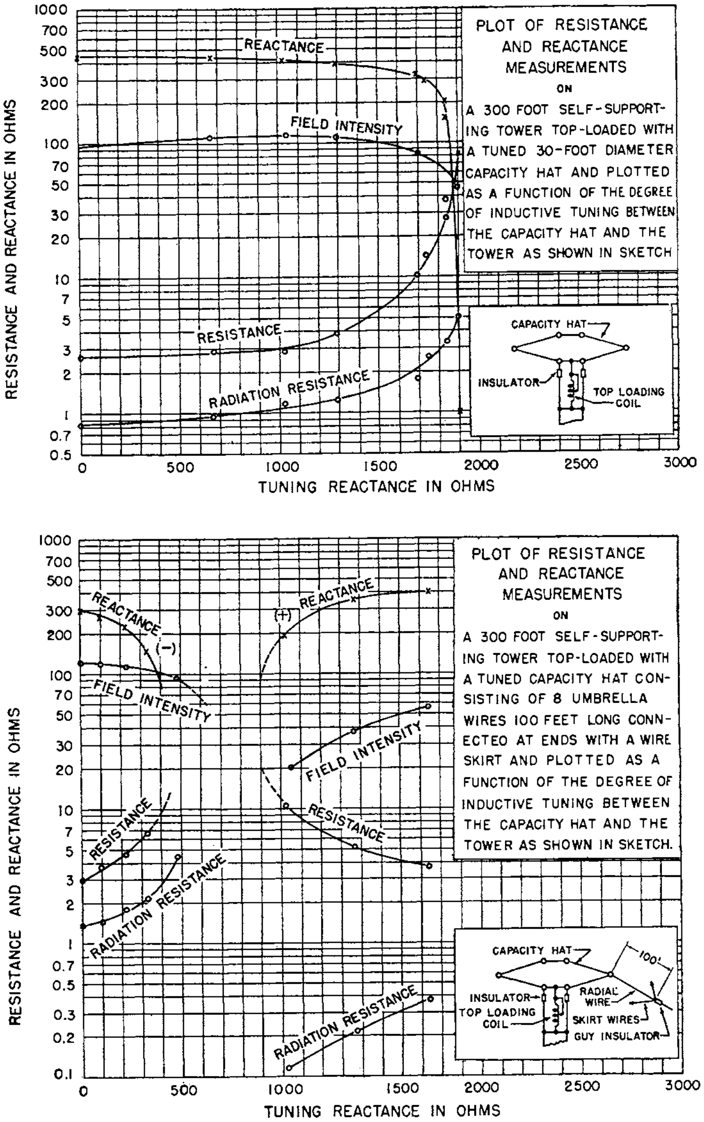

Fig. 17—Plot of resistance, reactance, and field intensity for various degrees of tuning a top-loaded tower.

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