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A 600-Ohm Multiple-Wire Delta Antenna for Ionosphere Studies

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This paper describes the design and the performance of a multiple-wire delta antenna developed for use with high output impedance, vertical-incidence ionosphere sounding equipment. Graphs are presented showing the terminal impedance of this antenna over the separating frequency range (1 to 25 megacycles), using various lengths of open-wire transmission line. The results of pattern measurements using model techniques are given, showing the expected radiation characteristics of the full-scale antenna. A practical test of the comparative merits of the antenna is described in which ionosphere records obtained by the use of this antenna are compared with those obtained by the use of a larger antenna developed previously.

I. Introduction

During the past 20 years the technique of vertical-incidence ionosphere soundings by the use of pulse transmitters scanning over a wide frequency range has been adopted internationally for recording the virtual height of ionosphere layers and their degree of ionization. These are to be used in predicting the conditions for communication in the high-frequency band. One of the latest developments in the equipment employing this technique is exemplified by the model C–2 automatic ionosphere recorder. This instrument was developed at the Central Radio Propagation Laboratory of this Bureau. It scans through the frequency range of 1 to 25 Mc in an interval of time as short as 7½ secs. The performance requirements imposed by the equipment on the antenna system, including the associated transmission lines, which are to hold over the entire frequency range of 1 to 25 Mc, are as follows: (1) The impedance of the antenna system must be relatively uniform and, for purposes of maximum power transfer, as nearly equal to the output impedance of the transmitter (of the order of 1,000 ohms) as possible; (2) the radiation must be substantially in the vertical direction; (3) the antenna must be as efficient a radiator as possible. In addition to the operating requirements above, the physical dimensions of the antenna should be moderate, at least in the vertical dimension.

Numerous experimenters have worked on the problem of the design of antennas suitable for ionospheric recorders. Systems of several antennas, each operating over a fairly narrow frequency range and switched automatically by the equipment, have been tried. Some systems obtained satisfactory operation over a fairly wide frequency band by employing low-Q cage antennas. Even antennas that changed their dimensions in the course of operation are known to have been tried. The most generally satisfactory results have been obtained by the use of nonresonant antennas, such as rhombic and vee antennas. These are particularly suitable for use with the model C–2 ionosphere recorder because of their inherently high input impedances. Experimental work has been carried out at this Bureau looking toward the development of an effective antenna system for ionosphere sounding. Some of the results of this work have already been published.[1] Here, the results of the work performed since the date of that paper are described.

[1] H. N. Cones, Impedance characteristics of some experimental broadband antennas for vertical-incidence ionosphere sounding, J. Research NBS **43**, 71 (1949) RP2006.

II. Instrumentation

As mentioned previously, the important aspects of the antenna to be considered are its impedance, its radiation pattern, and its radiation efficiency. The last factor may be defined as the ratio of the power radiated in space by the antenna to the power delivered to it by the transmitter. This factor is of particular significance in a nonresonant, terminated antenna where actually more power is likely to be dissipated in the terminating resistor than radiated in space.

For measurements of antenna impedance, a balanced recording impedance meter developed at this Bureau was used. A description of this instrument was presented at the Winter 1946–47 IRE Convention in New York City.[2] Figure 1 is the block diagram of the instrument. Briefly, it is a beat frequency generator including a 57-Mc fixed-frequency oscillator beating with a variable frequency oscillator covering the band from 57 to 82 Mc. The difference frequency of 0 to 25 Mc is passed through a wide-band amplifier designed to have a constant current output. The output voltage is, therefore, directly proportional to the absolute magnitude of impedance connected across the output terminals. A voltage stabilizing circuit is incorporated for the purpose of maintaining reasonably constant output current. This voltage is rectified, amplified, and applied to a recording milliammeter. The recording milliammeter and the variable frequency oscillator are mechanically coupled, so that the impedance is plotted as a function of frequency. No direct indication of the phase angle of the impedance has thus far been provided. The instrument is calibrated by making several frequency sweeps using fixed noninductive resistors across the measuring terminals.

For measurement of the radiation pattern of the antenna, a model antenna technique has been employed. The principles of this technique consist briefly of constructing a model antenna having the configuration of the full-sized antenna under study, but with the linear dimensions reduced by some scaling factor n. The radiation pattern of this antenna is then measured in a conventional manner at a frequency n times the operating frequency of the full-sized antenna. It thus becomes possible to bring the target transmitter much closer physically to the antenna under test and still maintain a spacing of several wavelengths at the scaled-up frequency. The dimensional analysis of this technique shows that in addition to scaling the linear dimensions down by a factor n, and the frequency up by n, the conductivity should be increased by the same factor n. This scaling factor should be applied to all elements of the radiating system. The radiating system is not merely the antenna itself, but also the ground and, insofar as the conductivity is concerned, the scaling factor should, properly, be applied to both the material of the antenna (copper) and the soil. It is patently not possible to select a material having conductivity exceeding that of copper by any scaling factor n. However, at least in the present case where copper losses may reasonably be expected to be small compared with the radiated power and the terminal resistor losses, no significant error should be introduced by the failure to scale the conductivity.

In the case of the ground, the conductivity should be scaled if strictly accurate results are to be obtained. However, no completely satisfactory method for scaling the ground constants was available. Furthermore, since the ground constants change from one location to another, and, in general, will also change to some extent in a given location with time, no attempt was made in course of these tests to scale the ground constants. Instead, the ground was covered by a wire netting that effectively provided perfect reflector conditions at all frequencies. This, of course, is an approximation of the actual operating conditions. The principles of model technique are now well known and are described in the technical literature.[3 4]

The actual model range employed in these tests consists of a level gravelled surface, covered by a ½-in. wire mesh. In practice the model of the antenna was used as the receiver, while a target transmitter, powered by self-contained batteries, was swung about the antenna in an arc approximately 13 ft in radius. To simulate the frequencies of 9 to 25 Mc, a scaling factor of n equal to 30 was employed, the target transmitter operating between 270 and 750 Mc. To simulate operation

[2] H. V. Cottony, A method of rapid continuous measurement of antenna impedance over a wide frequency range, paper presented before IRE Convention (New York, N. Y., March 6, 1947).

[3] Ernest A. Jones, Final report on investigation of model techniques for determination of the characteristics of low-frequency antennas, Ohio State University Research Foundation (Columbus 10, Ohio).

[4] George Sinclair, Theory of models of electromagnetic systems, Proc. IRE **36**, No. 11, 1364 to 1370 (Nov. 1948).

between 5 and 9 Mc, a scaling factor of 85 was employed.

Figure 2 illustrates the terminology employed with reference to the radiation patterns presented in this paper. It is convenient, for reference purposes, to locate the antenna under test in the X-Z plane. That plane and the Y-Z plane at right angles to it are the principal planes of the antenna, and all radiation patterns were taken in one or the other of the two planes, and are so identified. In making the patterns of the antenna in the X-Z plane (path X-Z-X'), the plane of polarization of the target transmitter was always coincident with the X-Z plane, and its equatorial magnetic plane always passed through the Y-Y' axis. For patterns in the Y-Z plane, (path Y-Z-Y'), the X-X' axis was always in the plane of polarization, whereas the equatorial magnetic plane was coincident with the Y-Z plane.

No direct measurements of radiation efficiency were made. However, a measure of over-all performance of the antenna (including its radiation efficiency) was obtained in a series of tests, in which the antenna under discussion was compared with an earlier type of antenna and with a number of simple doublets. In these tests an ionosphere recorder was alternately switched from the multiple-wire delta to a double-W antenna (see footnote 1). In each test a number of records were obtained and the results compared with each other. This method does not permit measurement of small differences but is a useful check of relative effectiveness of the antennas.

III. Design of the Antenna

Nonresonant antennas, which are sometimes referred to as terminated or traveling-wave antennas, are, in general, of three types: (1) Beverage, (2) vee, and (3) rhombic. Of these, the Beverage antenna is suitable primarily for low-angle radiation. Of the vee and the rhombic antennas, the vee antenna can be shown to be more uniformly effective as a radiator over the frequency range than the rhombic antenna. However, the conventional-type vee antenna with the input terminals at the apex and the terminating resistors at the open end of the vee presents certain mechanical difficulties when designed to radiate in the vertical direction. It requires two full-height poles for its installation, and additional wires must be furnished for termination to ground. For these reasons rhombic antennas have frequently been used for ionosphere sounding.

A variation of a vee antennna commonly known as a delta was devised several years ago by J. W. Cox of the Baddow Research Laboratories of the British Marconi Co. Its principal features are that the termination is made at the vertex of the vee, and the extremities of the vee are brought together by two horizontal wires extending a few feet above ground. The radiation due to these horizontal wires is minimized by their proximity to the ground, and the radiation pattern should be approximately that of a vee antenna.

Practical considerations require a delta antenna to be designed for a much lower height than one having theoretically optimum size and proportions. To be very efficient a nonresonant antenna should be several wavelengths long. Since the equipment operates at frequencies down to 1 Mc, and since the desired direction of radiation is straight up, the antenna must necessarily be short (measured in the desired direction of propagation) as compared to the wavelength except at the upper end of the operating frequency band. This height was limited by the lengths of the readily available telephone poles to 70 ft. In addition, it was highly desirable that the antenna be capable of being connected to the equipment by transmission lines that might differ in length for each ionosphere station according to local conditions. In order that the transmission line need not accentuate the ratio of maximum to minimum impedances of the antenna proper, it is necessary that the geometric mean of these impedances be very close to the characteristic impedance of the line. The geometric mean of the impedance of a simple single-wire delta antenna is of the order of 800 ohms. An open-wire transmission line having this value of surge impedance has awkwardly large wire spacing. A 600-ohm transmission line is, on the other hand, a very common one for which standard commercial spacers are available. Furthermore, 600 ohms is a suitable load impedance for the type C–2 ionosphere recorder. It was, therefore, decided to reduce the mean impedance of the antenna to 600 ohms. Such reduction of impedance is readily accomplished without affecting either the radiation pattern or the mechanical construction by the use of multiple-wire elements. The use of multiple-wire construction offers the additional

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advantage of being able to reduce the impedance variations over the frequency range by varying the spacing of the wires that compose the individual elements.

The height of the apex having been set by practical considerations at 70 ft, it is possible to compute the base width of the antenna so that it is wide enough to give useful radiated power at 1 Mc and yet not so wide as to have the first null or minimum within the operating frequency range of the equipment. Guided by such computations, a number of scaled-down antennas having various base widths were constructed and tested on the model range. The final design selected was one with the largest base width, which had no nulls or minima in the vertical direction at any point in the frequency range. The width so selected was 130 ft measured corner-to-corner.

Following the determination of the major dimensions of the antenna, the task remaining consisted of adjusting the minor configuration of the antenna construction, so that the mean terminal impedance of the antenna would be as nearly 600 ohms as possible and that the impedance of the antenna would be as uniform over the whole frequency range as possible. The approach to this task was largely empirical. By using multiple-wire construction, the impedance was lowered; increasing the spacing between the wires provided an additional control of impedance. Further uniformity of impedance was obtained by varying the spacing between the wires along the length of the antenna. The principle of reducing the reflection along the electric path by varying the spacing between electrically paralleled conductors is well known, and the technique of its application is strictly empirical.

The end result of the experimental work is a 600-ohm multiple-wire delta antenna. Figure 3 shows the principal dimensions of this antenna. For comparison purposes a "double-*W*" antenna (see footnote 1), developed previously, is illustrated in figure 4.

IV. Performance of the Antenna System

The performance of the antenna system was evaluated by measuring its terminal impedance with three different lengths of 600-ohm transmission line; by measuring the radiation patterns of a model antenna constructed to scale; and by using the antenna in conjunction with a model C–2 automatic ionosphere recorder for making ionosphere records.

Figure 5 presents the terminal impedance of the multiple-wire delta antenna system with three lengths of 600-ohm transmission line, and, for comparison purposes, the terminal impedance of the double-*W* antenna including the exponential line transformer. As can be observed, the mean impedance of the antenna for all lengths of transmission lines is approximately 600 ohms, and the variations of impedance are between approximately 400 and 1,000 ohms. The performance of the doube-*W* antenna from the standpoint of terminal impedance is substantially the same; the mean impedance is also very nearly 600 ohms, and the impedance variations are between approximately 400 and 900 ohms. The greater number of impedance variations in the case of the double-*W* antenna is caused by the longer transmission-line system of that antenna. The exponential line transformer used in the latter is approximately 288 ft in length.

Figure 6, a and b, illustrates the expected radiation patterns of the multiple-wire delta antenna between the frequencies of 5 and 25 Mc, as obtained on the model antenna range. In the frequency range from 5 to 9 Mc a scaling factor of 85 was used, and in the frequency range from 9 to 25 Mc a scaling factor of 30 was used. At 9 Mc the results obtained by the two scaling factors can be checked against each other. It should be noted that the patterns shown are normalized, i. e., the gain of the pattern plotter was adjusted for each frequency to give a full-scale deflection at the point of maximum gain.

Examination of the radiation patterns shows that no significant side lobes are developed in the patterns for frequencies below 11 Mc. Some lobing is observed at the frequencies near 14 Mc. The maximum of the major side lobe is at 54° to the horizontal. It is believed that this lobe is caused by radiation from the horizontal wire.

On the basis of the model measurements, serious lobe splitting would not be expected below 23 Mc. Above this frequency the patterns should rapidly deteriorate. However, even at 25 Mc there can be expected to be considerable useful radiation in the vertical direction.

No patterns have been taken at frequencies corresponding to 12 and 13 Mc because no target transmitter was immediately available to operate at corresponding scaled frequencies. The patterns obtained at frequencies corresponding to 9 Mc (765 Mc using scaling factor of 85 and 270 Mc for that of 30) agree reasonably well. It should be noted that this is the point of least satisfactory operation for the model range since at a frequency of 270 Mc the target transmitter is only three and one-half wavelengths away from the antenna model under test.

Upon completion of the scale model tests, a practical test of antenna performance was attempted by comparing actual ionospheric records made using the various antenna systems. The comparison was principally between the multiple-wire delta and the double-*W* antennas, both used for transmission; initially horizontal doublets of various lengths were used for reception. A check was also made of the relative merit of the delta antenna as compared with a doublet when used for reception and of the effect of the length of the transmission line on the effectiveness of a multiple-wire delta antenna.

Unfortunately, the reflecting characteristics of the ionosphere may vary in a period of seconds, so that measurements made by comparing received pulse amplitudes by switching from one antenna to another are subject to error. However, it was considered that a series of as many as ten consecutive records using one antenna could be compared with two other series using another antenna—one recorded immediately before and the other immediately afterward. Both receiving antennas and transmitting antennas were compared separately by switching only one of the antennas at a time. Figures 7 through 11 show some of the ionosphere records made for these comparisons. All of the records for each comparison were made with the same receiver gain setting unless otherwise noted.

Figure 7 shows the multiple-wire delta compared with the double-*W* antenna when used for transmission. The records were made in the early morning hours so that observations on low frequencies would be more likely. A long receiving antenna was also used to favor the low frequencies. From the appearance of these records it is concluded that the multiple-wire delta is substantially equal in performance to the double-*W* antenna for transmission between 1.5 and about 3.5 Mc.

Figure 8 compares the same antennas as the previous figure, except that it is intended to compare the double-*W* and multiple-wire delta antennas at higher frequencies. This comparison was made with a shorter antenna for receiving and during a daytime period when critical frequencies were high. The conclusion is that these two antennas are also practically equivalent at frequencies between 3.0 and 12.0 Mc.

Figure 9 is the same as figure 8, except that a long receiving antenna was used. Both sets of records exhibit weaknesses that are primarily a characteristic of the receiving antenna. No conclusions were drawn from these records, but further tests illustrated by figure 10 were suggested by them.

Figure 10 shows the difference between the single-wire delta and a 500-ft doublet for receiving. The receiver gain setting was the same for each run. It may be noted that much greater pickup of both ionospheric signals and noise is obtained with the delta.

Figure 11 is a comparison between the effect of using long and short transmission lines to connect the transmitter to the multiple-wire delta. For receiving, a single-wire delta was erected in a plane perpendicular to that of the transmitting antenna. The records made with a 200-ft line and with a 20-ft line are substantially alike, and the slight differences observable are no greater than the variations from record to record caused by changes in the ionosphere.

V. Conclusions

On the basis of the preceding discussion the following conclusions were reached:

1. The impedance of the multiple-wire delta antenna is reasonably flat in its characteristics over the operating frequency range of 1 to 25 Mc. the ratio of maximum to minimum impedance being of the order of 2.5. This compares satisfactorily with the double-*W* antenna.

2. The mean impedance of the multiple-wire delta antenna is sufficiently close to 600 ohms to permit satisfactory operation with a 600-ohm transmission line of any moderate length. This is also confirmed by the service tests using the ionosphere recorder.

3. The model antenna study of the multiple-wire delta indicates that the radiation pattern to be expected from this design is such that the

direction of maximum intensity of radiation will be at the desired zenith angle over all of the operating frequency range below 23 Mc. However, even at 25 Mc. a substantial proportion of power is radiated in the vertical direction.

4. The ionosphere records obtained by the use of the automatic recorder indicate that, within the limits of the accuracy of this method of comparison, there is little difference in the effectiveness of the multiple-wire delta antenna when compared with the double-*W* antenna, either at the lower or the middle frequency portion of the operating frequency range.

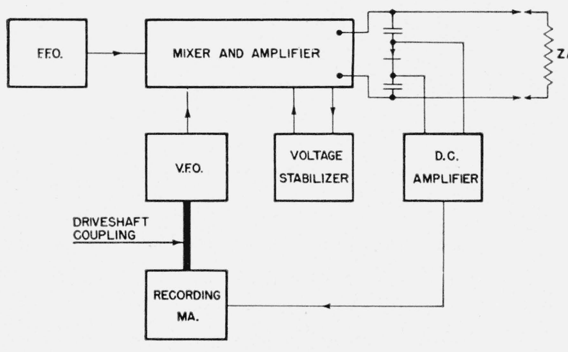

Figure 1. *Block diagram of impedance meter.*

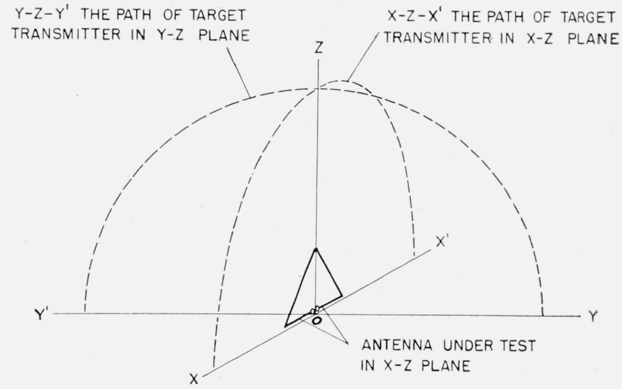

Figure 2. *Diagram of the model range showing the paths of the target transmitter with reference to the antenna under test.*

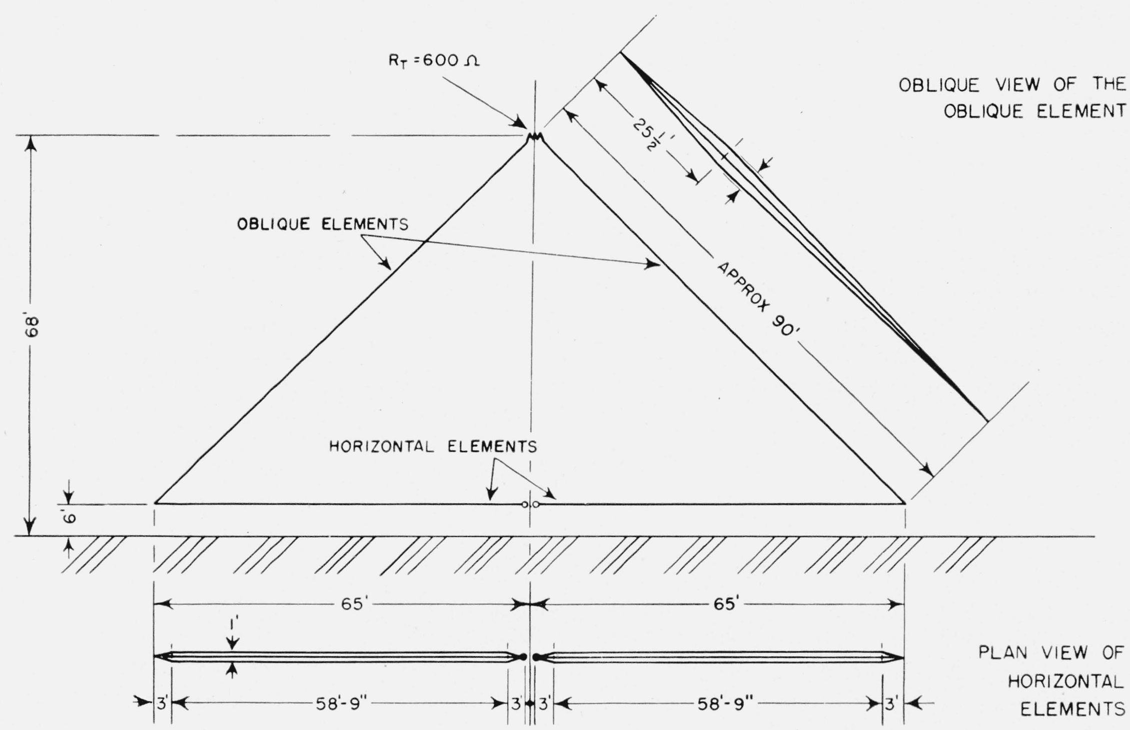

Figure 3. *Simplified diagram of the 600-ohm multiple-wire delta antenna.*

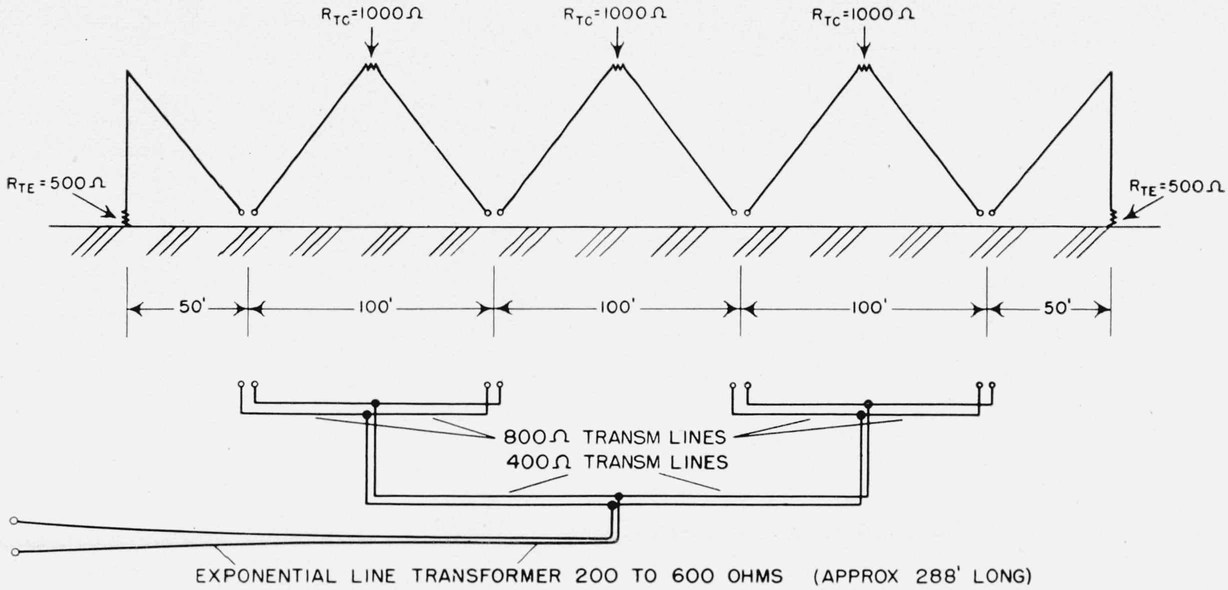

FIGURE 4. *Simplified diagram of the double-W antenna.*

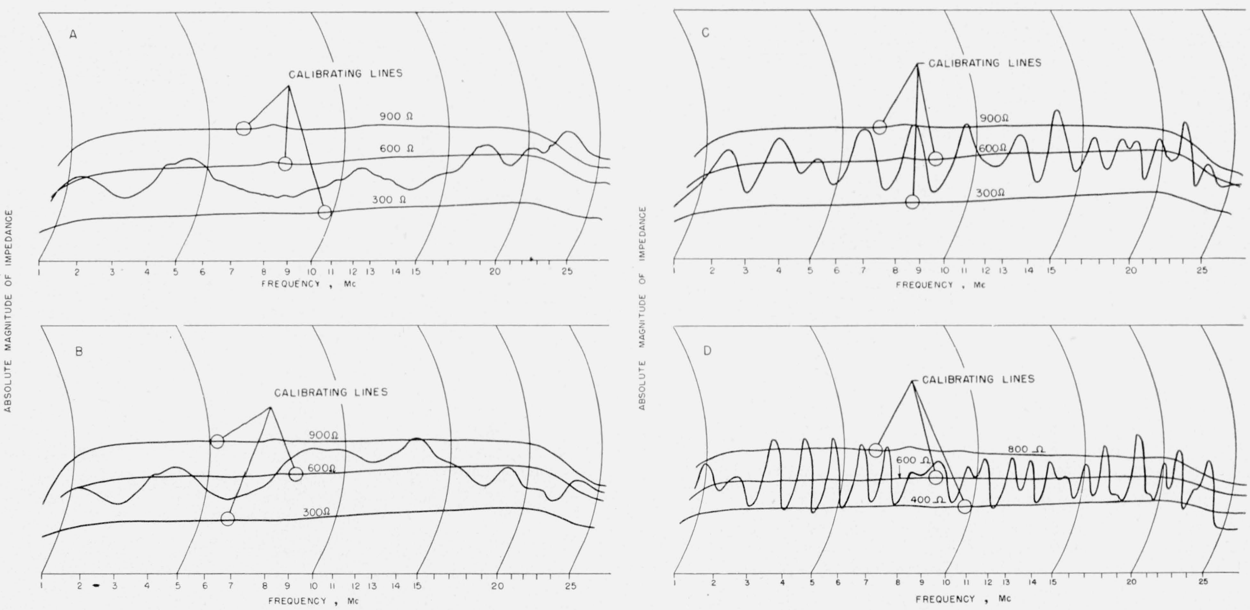

FIGURE 5. *Impedance of 600-ohm multiple-wire delta using three different lengths of 600-ohm transmission line and that of single-wire double-W antenna including exponential line transformer.*

A, Impedance of multiple-wire delta antenna when used with a 4-ft length of 600-ohm transmission line. R_t=600 ohms. *B*, Impedance of multiple-wire delta antenna when used with a 20-ft length of 600-ohm transmission line. R_t=600 ohms. *C*, Impedance of multiple-wire delta antenna when used with a 200-ft length of 600-ohm transmission line. R_t=600 ohms. *D*, Impedance of double-*W* antenna for optimum termination of 1,000 ohms.

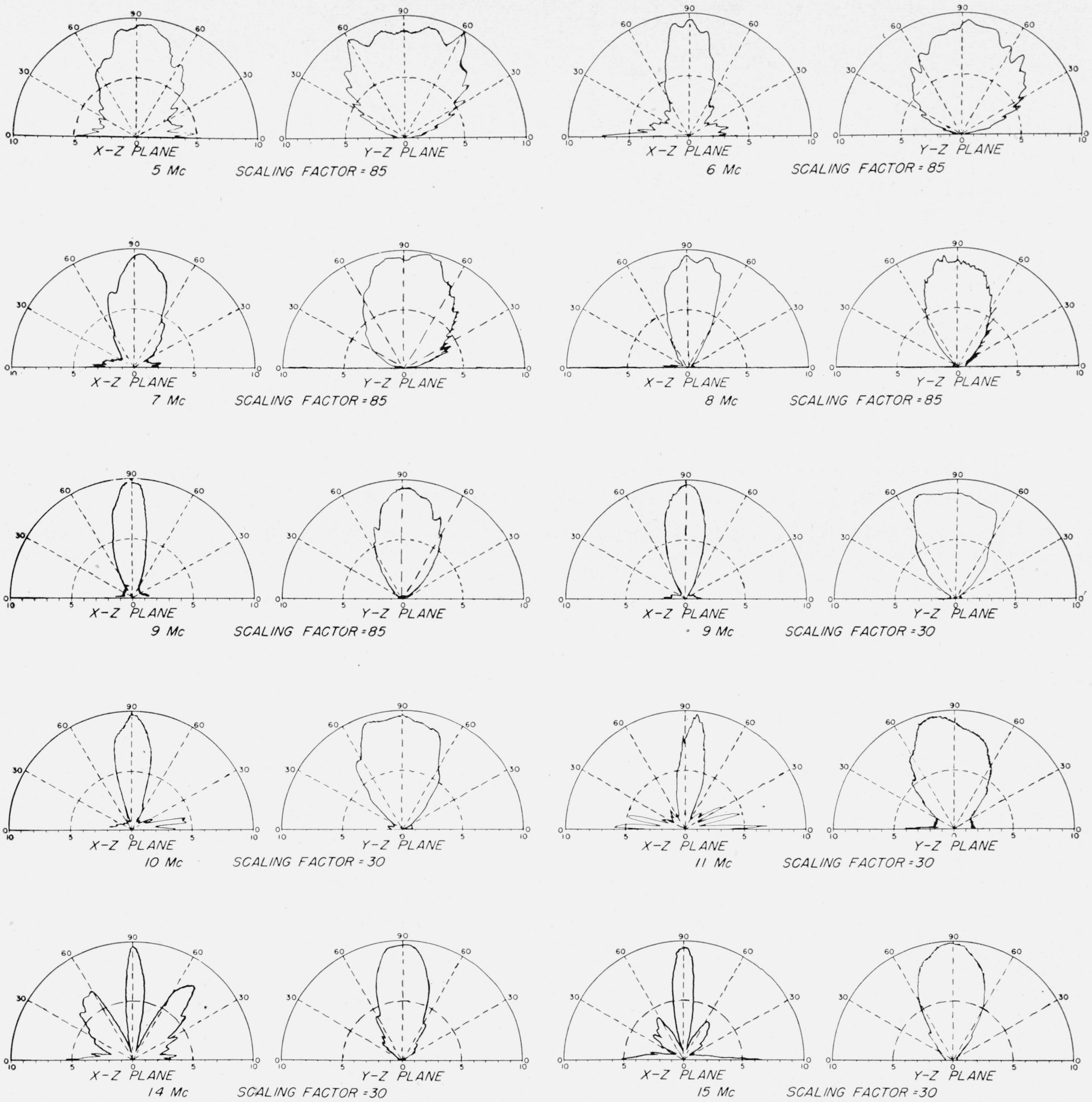

FIGURE 6a. *Normalized radiation patterns in space for multiple-wire delta antenna as obtained by the use of model antenna technique.*

The scaling factor is equal to 30 or 85, as noted at each pattern. The antenna is in the *X–Z* plane. The radial displacement is linear with power.

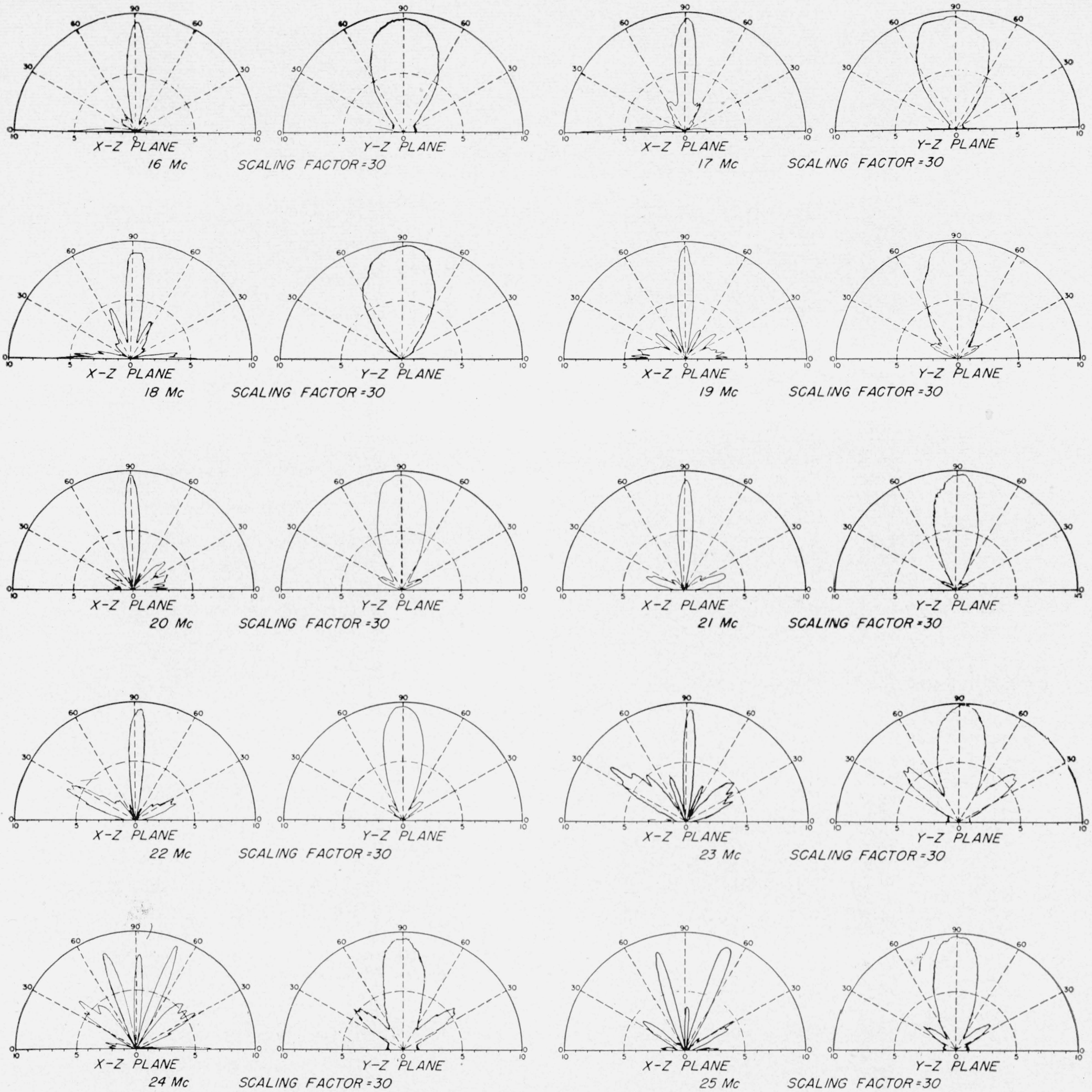

FIGURE 6b. *Normalized radiation patterns in space for multiple-wire delta antenna as obtained by the use of model antenna technique.*

The scaling factor is equal to 30. The antenna is in the *X–Z* plane. The radial displacement is linear with power.

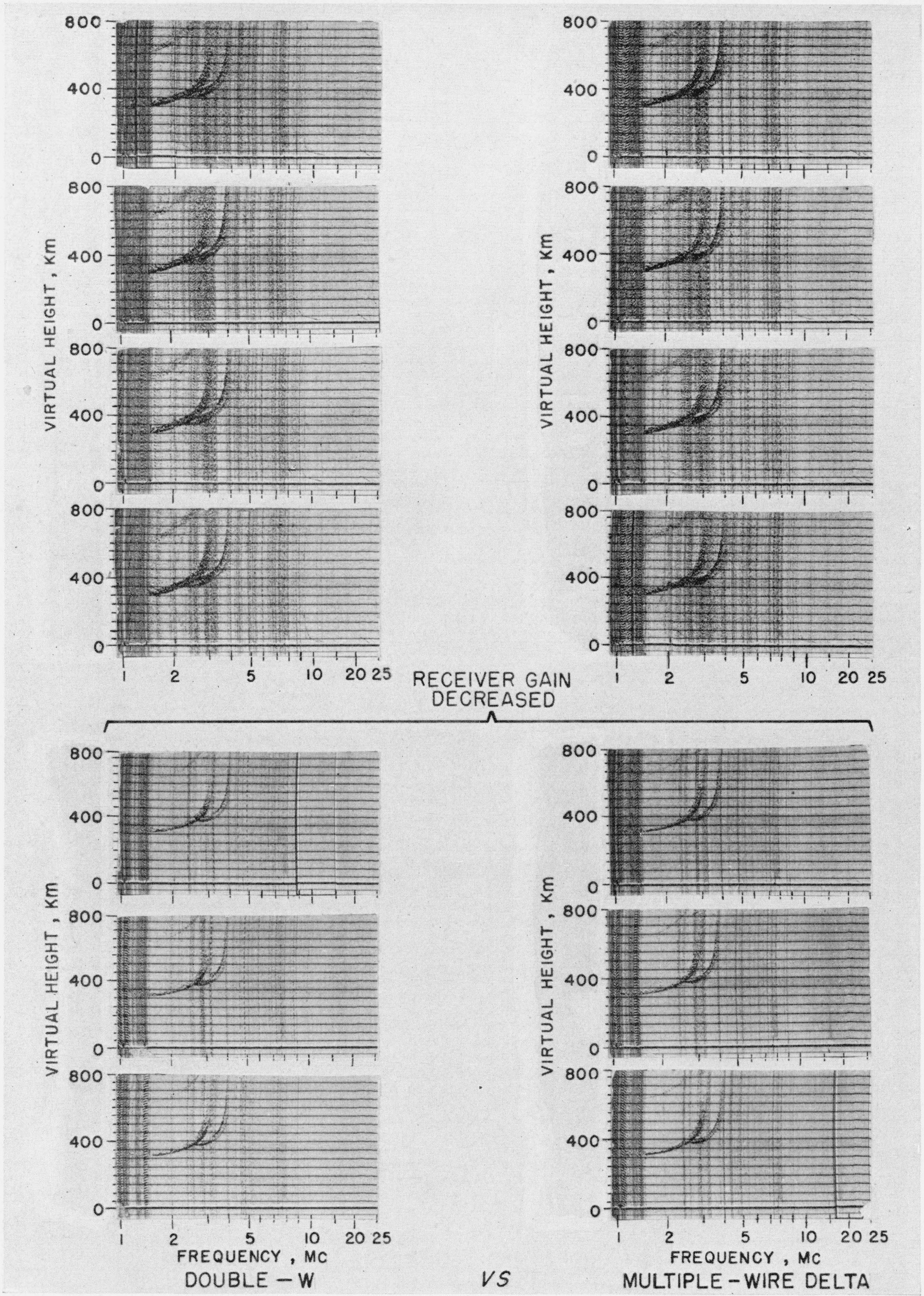

FIGURE 7. *Nighttime comparison of multiple-wire delta with double-W antenna, each used for transmission.*

A 500-ft horizontal doublet, 25 ft above ground was used as a receiving antenna.

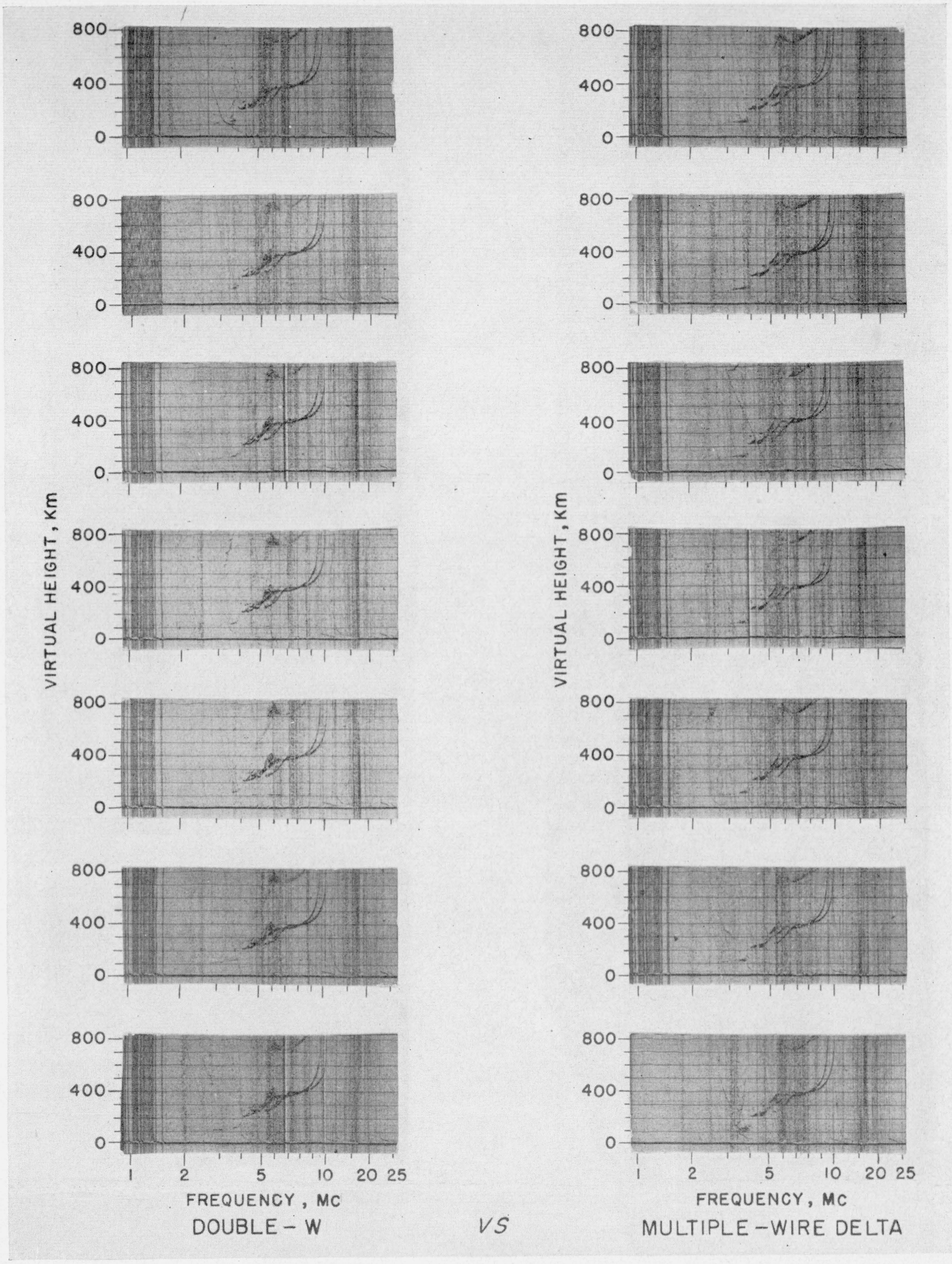

FIGURE 8. *Daytime comparison of multiple-wire delta with double-W antenna, each used for transmission.*

A 150-ft horizontal doublet, 7 ft above ground was used as a receiving antenna.

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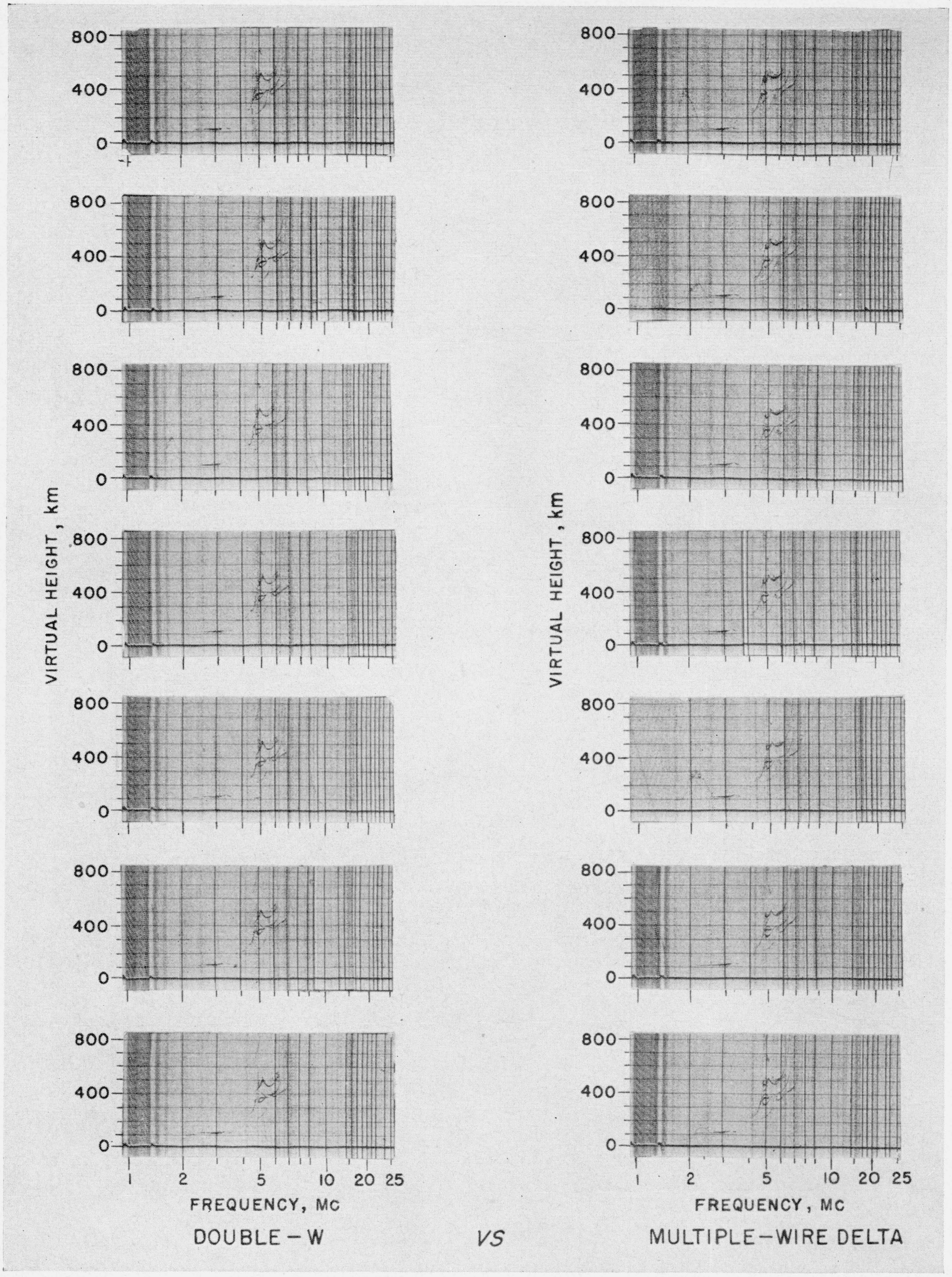

FIGURE 9. *Daytime comparison of multiple-wire delta with double-W antenna, each used for transmission.*

A 500-ft horizontal doublet, 25 ft above ground was used as a receiving antenna.

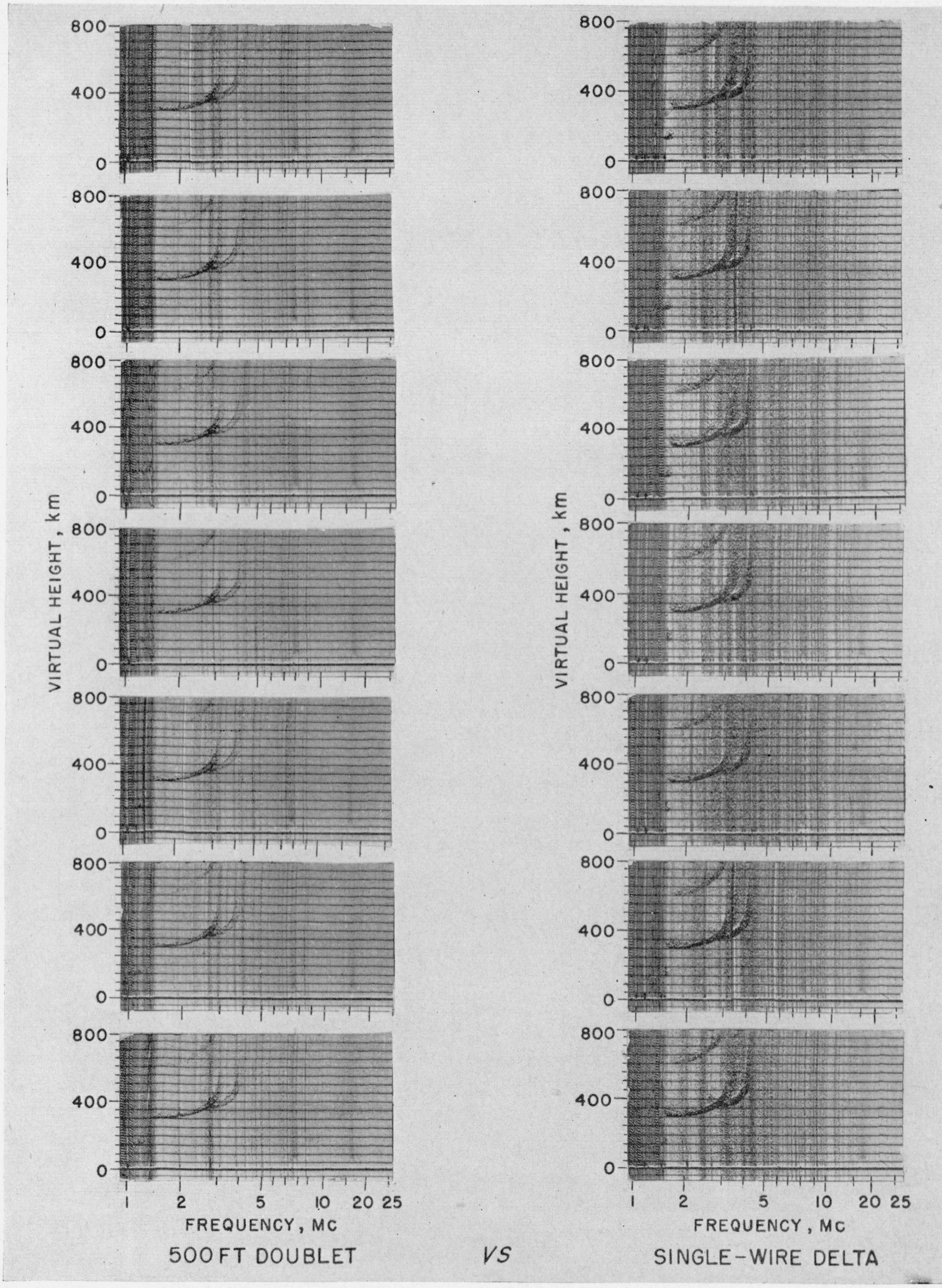

FIGURE 10. *Comparison of single-wire delta antenna with 500-ft doublet each used for reception.*
The multiple-wire delta antenna was used for transmission.

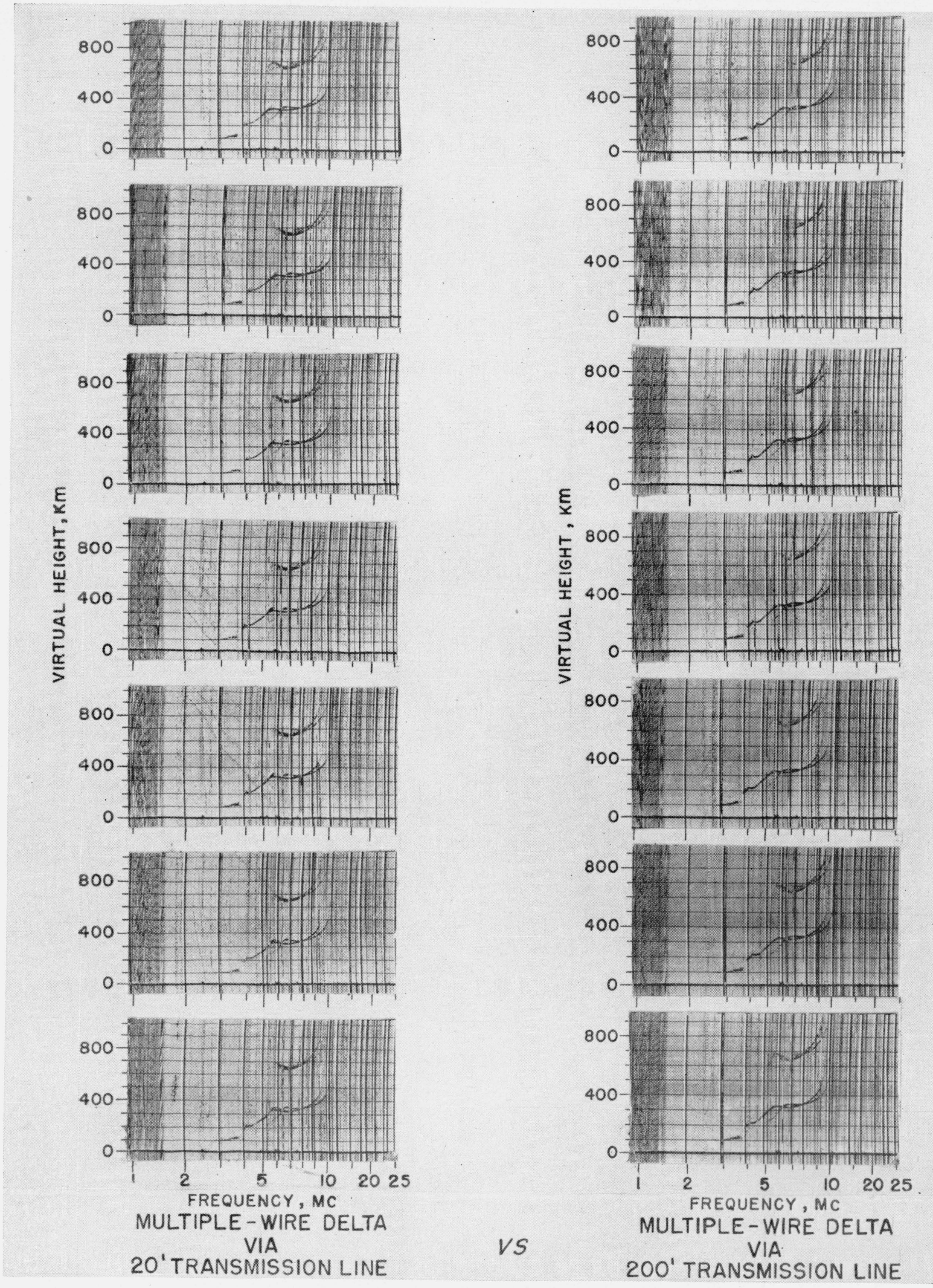

FIGURE 11. *Comparison of multiple wire delta antenna with 20- and with 200-ft lengths of 600-ohm transmission line, in each case used for transmission.*

A single-wire delta was used for receiving.

WASHINGTON, September 20, 1949.