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RADIO FIELD-INTENSITY AND DISTANCE CHARACTERISTICS OF A HIGH, VERTICAL BROADCAST ANTENNA [1]

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ABSTRACT

During December 1934, field-intensity records of emissions from radio station WBT, Charlotte, N. C., were made at seven different distances from the transmitting station before and after the construction and use of a high-mast antenna. In addition, field-intensity measurements were made at eight points on a circle at a distance of 1 mile from the transmitting station. The results showed that the substitution of the mast antenna for the older T and L antennas produced much greater ground-wave field intensities near the transmitter and somewhat greater total field intensities at greater distances. At the same time the amplitude of the fading was reduced at the first three recording stations at distances 69 to 142 kilometers. The fading at these first three stations was of a more-rapid type than at the more-distant stations. The antenna change did not appreciably affect the frequency of the fading. Wires were added to the mast antenna to increase its top capacity and thus make the current distribution in this antenna more nearly sinusoidal. This change seemed to reduce the fading amplitude at the first three recording stations by the suppression of certain high-angle radiation rather than by an increase of the intensity of the ground wave.

With all conditions of the transmitting antennas used greater values of the averages of the 10-minute peak field intensities were recorded at the receiving station at Meadows, Md., 552 kilometers, than at any other station from 69 to 879 kilometers.

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I. INTRODUCTION

In December 1934 the antenna system of radio station WBT, 1080 kc/s, at Charlotte, N. C., was changed from a T antenna with a height of about 175 feet and a flat top with a length of 200 feet, to a vertical, guyed cantilever mast 429 feet or 0.47 wave length high. A short time before this, plans for a cooperative investigation of the effects of such a change were made by the Columbia Broadcasting System and the National Bureau of Standards. In accordance with these plans seven automatic field-intensity recorders [2] were set up at

[1] Presented at the Tenth Annual Convention of the Institute of Radio Engineers, Detroit, Mich., July 1, 2, and 3, 1935.

[2] K. A. Norton and S. E. Reymer. *A continuous recorder of radio field intensities.* BS J. Research **11**, 373 (1933) RP597.

various distances from the transmitting station, as shown by the map in figure 1. These recorder locations were Salisbury, Lexington, Greensboro, and Durham, N. C., Charlottesville, Va., Meadows, Md., and Boonton, N. J. It was intended to have the recording stations as nearly as possible on the same great-circle path. This condition was approximately satisfied, although Durham, N. C., was somewhat out of line. The recorders were set up during the latter part of November 1934 and ran for about 6 weeks with calibrations about twice per week.

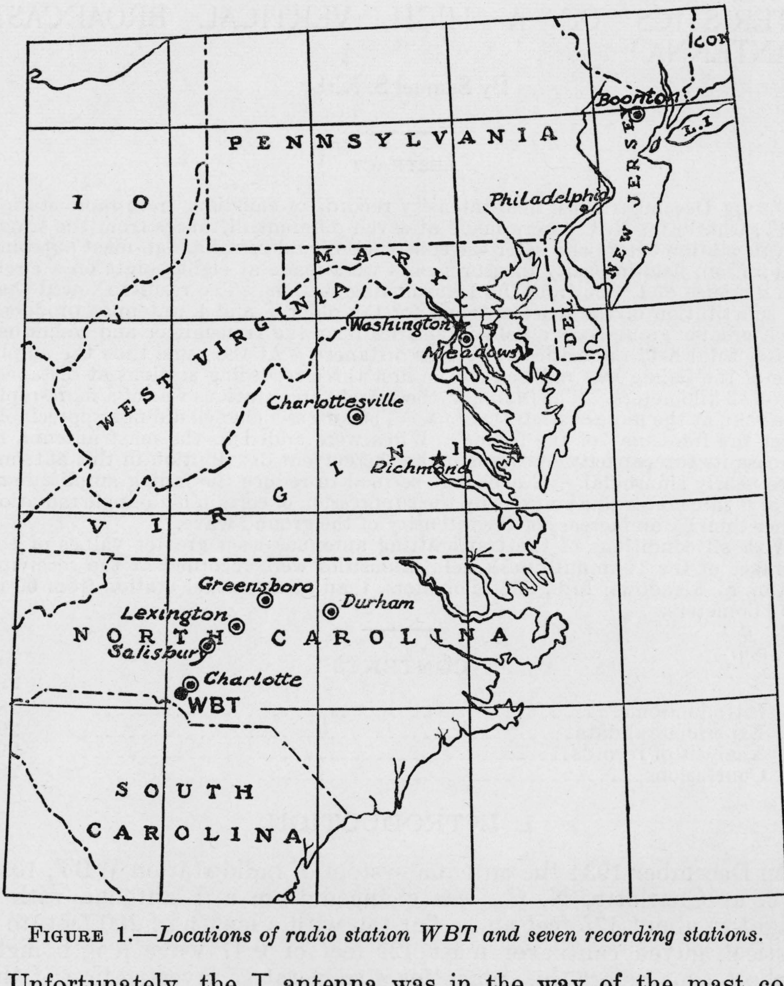

FIGURE 1.—*Locations of radio station WBT and seven recording stations.*

Unfortunately, the T antenna was in the way of the mast construction and had to be taken down about the middle of November. An unsatisfactory temporary antenna was used until December 4, after which time an inverted L antenna, 110 feet high with a flat top 200 feet long, was used. With this antenna the field intensity at 1 mile was about 0.88 that of the T. Otherwise it was believed that the characteristics of the L antenna were similar to those of the T.

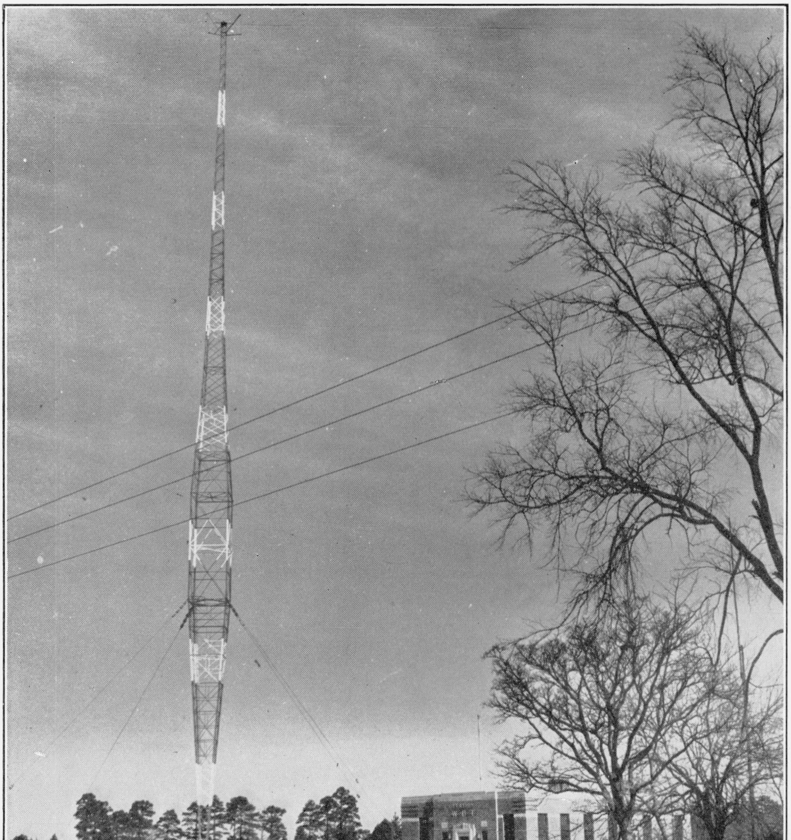

FIGURE 2.—*Radio Station WBT high-mast antenna.*

Until December 17 the sloping down lead of the L was between 50 and 100 feet from the mast, the construction of which was completed about December 13. On December 17, after the L antenna and the old towers supporting it were removed, a decrease of fading of the emissions from the mast was observed at Salisbury and Lexington. This was an indication that the proximity of the L affected the mast, so it might be expected that the proximity of the mast affected the L. The effect of any coupling between these two antennas, however, should have reduced the differences between their performances. In other words, the differences found would have been greater if each antenna had been operated without the presence of the other. Emissions from the mast were recorded only 2 days before the L was removed.

II. EXPERIMENTAL DATA

The WBT mast antenna is shown in Figure 2. The ground system consisted of 120 radials of no. 10 hard-drawn copper wire, each radial being 300 feet in length. The remote end of each radial was attached to a 0.5-inch ground rod driven to a depth of 4 feet.

Records of emissions from the L antenna were made from about December 5 to 15 and from the mast from about December 16 to 31. The mast was used both alone and with 4 wires added to increase its top capacity. These wires were stretched from crossarms at the top downward to the waist of the tower below the center and later nearly to the ground.

The field intensities at a distance of 1 mile are shown for the old T and the new mast in figure 3. These measurements were made by W. B. Lodge of the Columbia Broadcasting System. They show that the ground wave was increased about 1.75 times by the use of the mast instead of the T. The average field intensity at 1 mile from the L antenna was 760 mv/m, this being one-half the field intensity at 1 mile from the mast.

Figure 4 shows some night records from each of the seven recording stations and from each of the two antennas. The power input to the antenna in each case was 50 kw. The only changes at the transmitting station were the changes of antenna indicated in figure 4. At all of the receiving stations, excepting Durham, the night records shown in this figure were made simultaneously. Day records of emissions from the mast are also shown in this figure, M and L representing the mast and L, respectively.

An inspection of figure 4 will indicate the general characteristics of fading and field intensity as the distance from the transmitting station was increased. However, this inspection will also indicate that it is difficult and unsafe to judge the respective merits of the two antennas from a few short records taken with successive antenna changes.

Consider the records taken at Salisbury. The first three one-hour records of transmissions from the mast, the L, and the mast in turn indicate that the field intensity was increased and the fading decreased by the substitution of the mast for the L. This is the conclusion which will be drawn later from a consideration of all of the records from December 5 to 30. The last hour's record of transmissions from the L taken between 0210 and 0300 EST, however, would indicate that there was less fading of emissions from the L. It is believed that this change was brought about by a change of the ionosphere and that the first three one-hour records indicated the relative performance of the mast and the L antennas as observed at Salisbury. Whatever the change in the ionosphere after 0200 EST may have

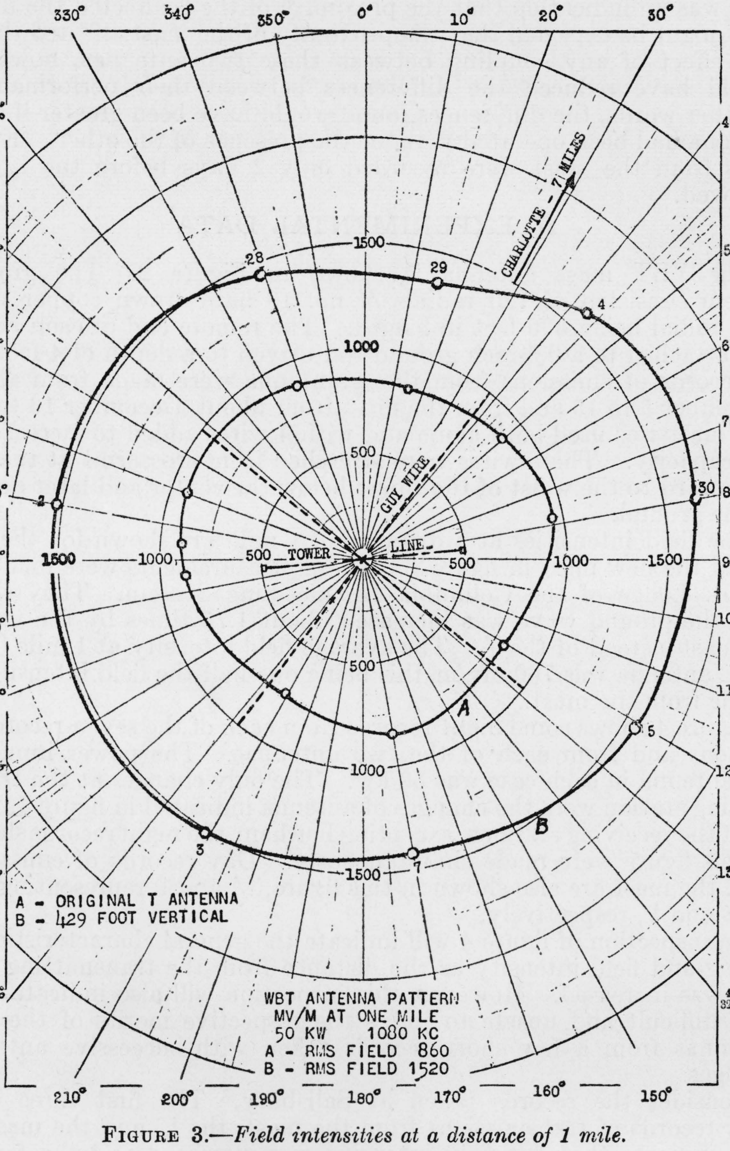

FIGURE 3.—*Field intensities at a distance of 1 mile.*

A indicates T antenna; B mast antenna.

been, its effect did not depend critically on the angle of incidence of the wave on the ionosphere, as the same effect was indicated at nearly all of the recording stations simultaneously.

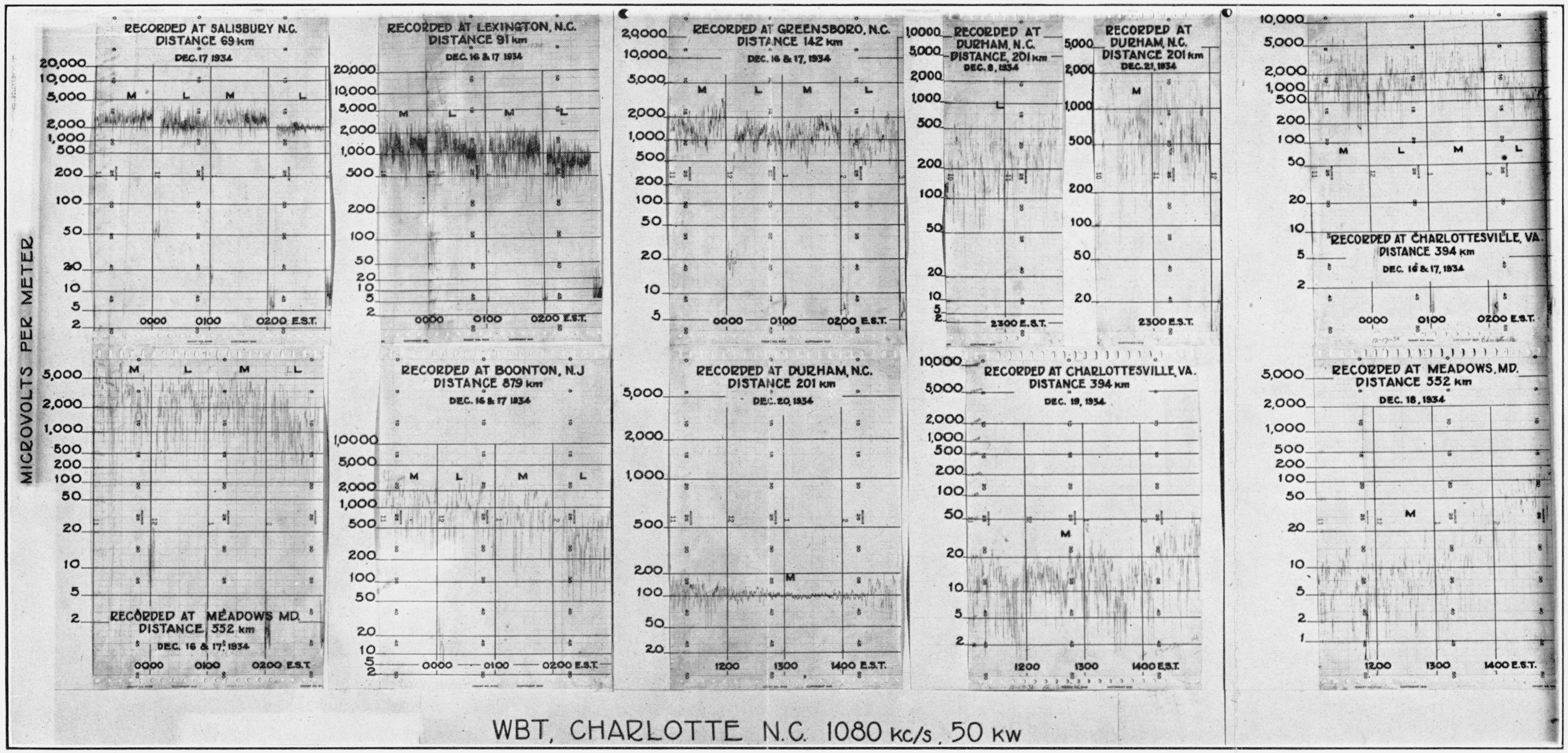

FIGURE 4.—*Field-intensity records of emissions from the* L *and mast* (M) *at night, and from the mast during the day.*

The records from 2300 December 16 to 0200 December 17 present, qualitatively, very well the relative performance of the two antennas as observed from different distances. Points to be noted are the field intensity, the amplitude of the fading, and the rapidity of the fading. It might be pointed out that on this night the peak values of field intensity were greater at Meadows, Md., than at any other recording station. Although the amplitude of the fading increased with the distance for some distance from the transmitting station, the fading at moderate distances was much more rapid and therefore more destructive. The fading at Lexington was an example of this.

Some day-records are included in this figure to show the distances at which sky wave became appreciable during the daytime. Considerable sky wave was found at Durham during most of the day, and at the more distant receiving points sky wave was predominant during the day was well as the night. By comparing the peak values of the day and night field intensities it will be seen that the night field intensities were about 250 and 350 times the day field intensities at Charlottesville and Meadows, respectively. This indicates that even when the daytime sky wave at this frequency is strongest as it is in midwinter that it is even then very highly absorbed in the ionosphere. Waves of this frequency could not pass through the E region of the ionosphere during the day.

III. ANALYSIS OF RECORDS

From the records given here it may be seen that it is difficult to draw satisfactory conclusions by simple inspection of the records or from records taken over short periods. These records have been analyzed by measuring the maxima and minima for each 10-minute period and averaging the day values and the night values separately for daily averages. The hours from 0800 to 1600 EST were arbitrarily used as day hours and 1800 to 0000 EST as night hours. The daily averages were again averaged over the period during which a particular antenna was used.

Figure 5 shows the averaged night field intensities for both the L and the mast plotted together for comparison. It should be noted that with the exception of the Lexington records the 10-minute maximum field intensities at all distances were greater in the case of the mast than in the case of the L. Part of this increase of field intensity was caused by an increase in the ratio of low-angle to high-angle radiation and part probably was caused by the increased radiation efficiency of the high-mast antenna. Similarly the minimum values in the case of the mast were greater than those in the case of the L at all recording stations. In this figure the graph labeled "Inverse distance, power 25 kw, radiated" indicates the inverse distance values of field intensity as given for the ground wave with no absorption, by the formula for a vertical infinitesimal doublet,

$$F = \frac{C\sqrt{P_r}}{D},$$

where F is the field intensity, in microvolts per meter, C is the velocity of light, in kilometers per second; P_r is the power radiated, in kilowatts; and D is the distance, in kilometers. The use of 25 kw for the radiated power is based on the assumption that the radiation efficiency of the antenna was 50 percent, and the distribution of energy the same as for the vertical infinitesimal doublet, which were the conditions assumed by Norton, Kirby, and Lester [3] for a large number of miscellaneous antennas. The graph labeled "Inverse distance-mast" was based on the average value of field intensity at 1 mile from the mast antenna. Similar graphs based on the average field intensity at 1 mile for the old T and L antennas are not shown but would have fallen below both of those plotted. The average

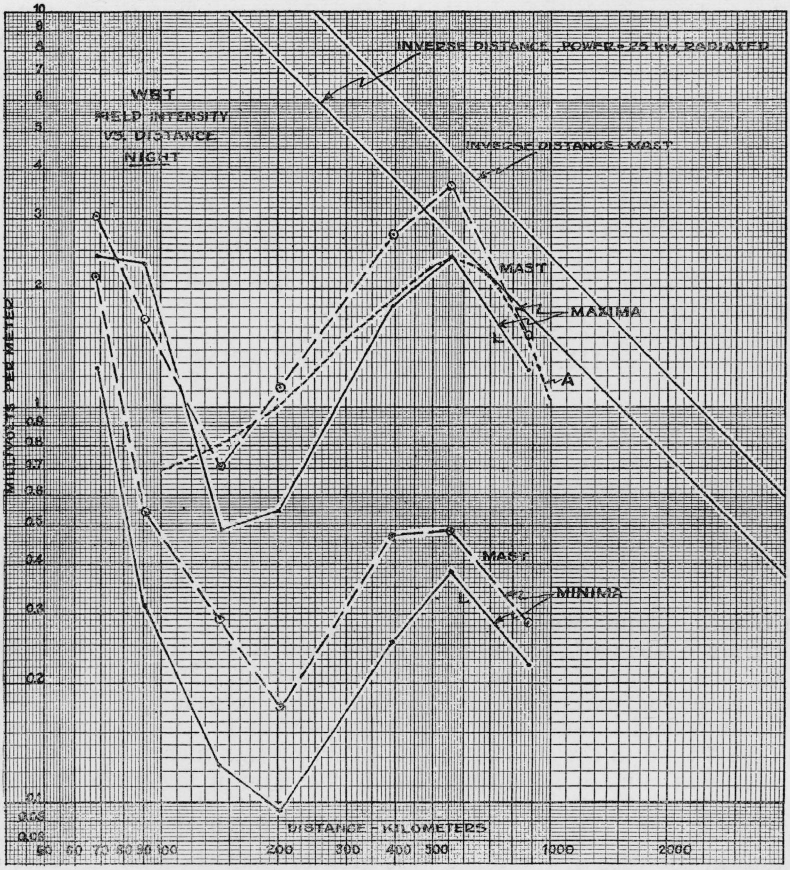

FIGURE 5.—*Average of 10-minute maximum and minimum field intensities of emissions from* L *and mast antennas.*

values of the 10-minute peak field intensities from the L antenna did not reach the inverse distance graph for 25 kw radiated at any of the receiving stations. However, many of the individual peaks did exceed the inverse distance values. In a similar manner the average 10-minute peak field intensities from the mast did not exceed the inverse distance values as calculated from the field intensities at 1 mile, but

[3] K. A. Norton, S. S. Kirby, and G. H. Lester. *An analysis of continuous records of field intensity at broadcast frequencies.* BS J. Research **11**, 897 (1934) RP752; Proc. Inst. Radio Eng. **23**, 1183 (1935).

many of the individual peak values did exceed the inverse distance values. The smooth dashed curve shown in this figure represents the empirical formula for 25 kw radiated, for sky-wave field intensities as given by Norton, Kirby, and Lester.[4] The sky-wave field intensities received at Meadows, 552 km, exceeded those recorded at any other station. The latter result corroborates the result found by Norton, Kirby, and Lester (see reference 3) that for a large number of miscellaneous broadcasting stations, the maximum sky-wave field intensities were produced at a distance of about 600 km.

Figure 6 shows the ratios of the amplitudes of night fading from the mast and the L antennas. The mast had a decided advantage over the three shortest paths and this result may reasonably be ascribed to an increase in the ratio of ground wave to sky wave.

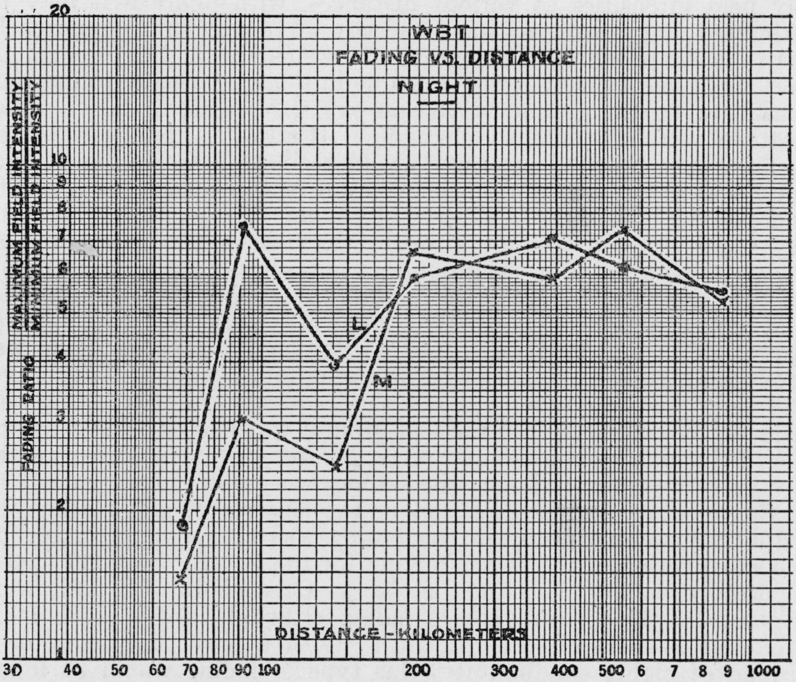

FIGURE 6.—*Amplitude ratios of night fading of emissions from L and mast antennas.*

The decrease of the amplitude of night fading over the three shortest paths by the use of the mast was a very great improvement. At Lexington the fading ratio for the mast as shown by an analysis of all the records obtained was only 0.4 that for the L, and at Greensboro, 0.6. Figure 4 does not show this clearly. These stations were in regions where night reception from the L was poor because of bad fading. It would be reasonable to conclude from these results that the night-service area was considerably increased by the use of the mast. At the more distant receiving stations the amplitudes of the fading ratios from the mast and the L were approximately equal. These latter fields were composed almost entirely of sky waves for

[4] See footnote 3.

both antennas. At the shorter distances the fields were composed of both sky waves and ground waves.

In addition to the amplitude of the fading ratios the rapidity of the fading is very important. It may be seen from figure 4 that fading at the closer receiving stations was much more rapid than at the more distant stations. This was especially noticeable at Lexington where the amplitude of the fading was great enough to be serious and the fading period was very short.

Fading may be produced in several ways, such as by phase interference between ground wave and sky wave or between two or more sky waves, by changing intensity of sky wave or rotation of the components of the field of sky waves. Ground waves are stable and sky waves unstable. By a comparison of figure 7, which shows the day field intensities at various distances, with figure 5 it may be estimated that the ground wave and sky wave were of approximately the same amplitude at Lexington. It seems reasonable to conclude that this rapid type of fading was due in a large measure to interference between the ground wave and sky wave whose relative phase relations were continuously changing. If all of the fading were due to this cause the field intensity would oscillate between fixed upper and lower limits. This condition did not exist, because the intensity and polarization of the sky wave also changed. At Greensboro the sky wave was considerably stronger than the ground wave and at the more distant points the ground wave is almost negligible at night.

From an analysis of all of the records obtained it may be concluded that over distances at which the ground wave and sky wave were of appreciably equal intensities, a rapid destructive type of fading was produced mainly by interference between ground wave and sky wave, and that the amplitude, but not the frequency, of this fading was reduced by increasing the ratio of ground wave to sky wave by the use of the high-mast antenna. Over greater distances, at which the sky wave was predominant, the fading was produced by variations of the intensity and polarization of the sky wave, and neither the amplitude nor frequency of the fading was altered appreciably by the substitution of the mast antenna for the L. In the WBT investigation, receiving points out as far as Greensboro (142 km) were affected by the former type of fading although it was much more pronounced at Lexington (91 km). With a lower frequency or a ground of higher conductivity, this type of fading would be found farther from the transmitting station. It seems that the frequency of the fading would be lower for a lower frequency.

Figure 7 shows the day field intensities from the mast and the L. The mast produced greater field intensities than the L at all recorder stations. The Boonton values are not shown on this graph.

As previously mentioned, the mast was used under several different conditions, i. e., with wires added to increase the top capacity and without the wires. The wires were used under two different conditions, i. e., half wires or wires from the top down to the waist of the tower and full wires or wires from the top nearly to the ground. In each case 4 wires were used and they were supported at the top by steel arms extending out horizontally. In studying the effect of the wires, records were available only for rather short periods for each condition, so that some of the variations are more likely to be accidental

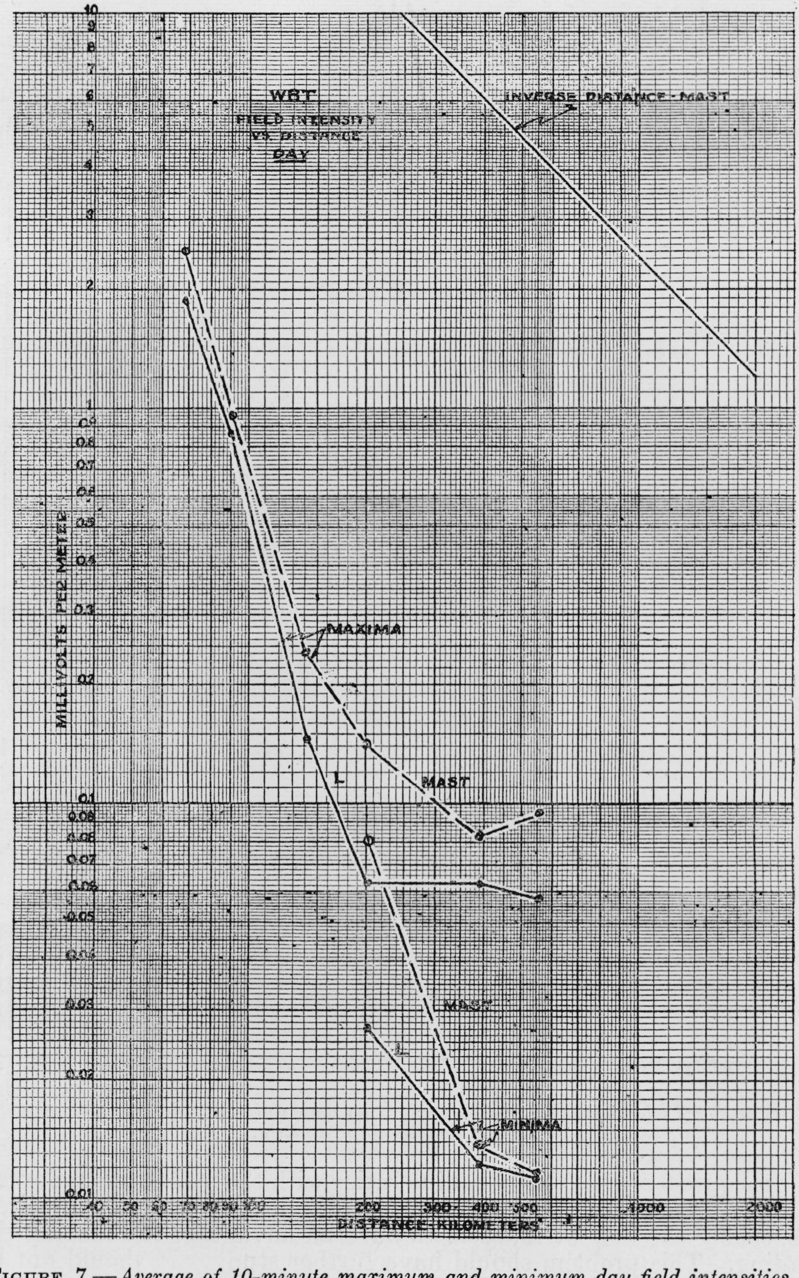

FIGURE 7.—*Average of 10-minute maximum and minimum day field intensities of emissions from* L *and mast antennas.*

than in the previous discussion. This is especially true for the Greensboro data because some of the late December records at this station were spoiled by receiving-set trouble.

In figure 8 are shown the field intensities with the mast antenna used under the different conditions described. The graph labeled "wires" includes the data for the days when both half wires and full wires were used. In general these results favor the use of the mast without the wires.

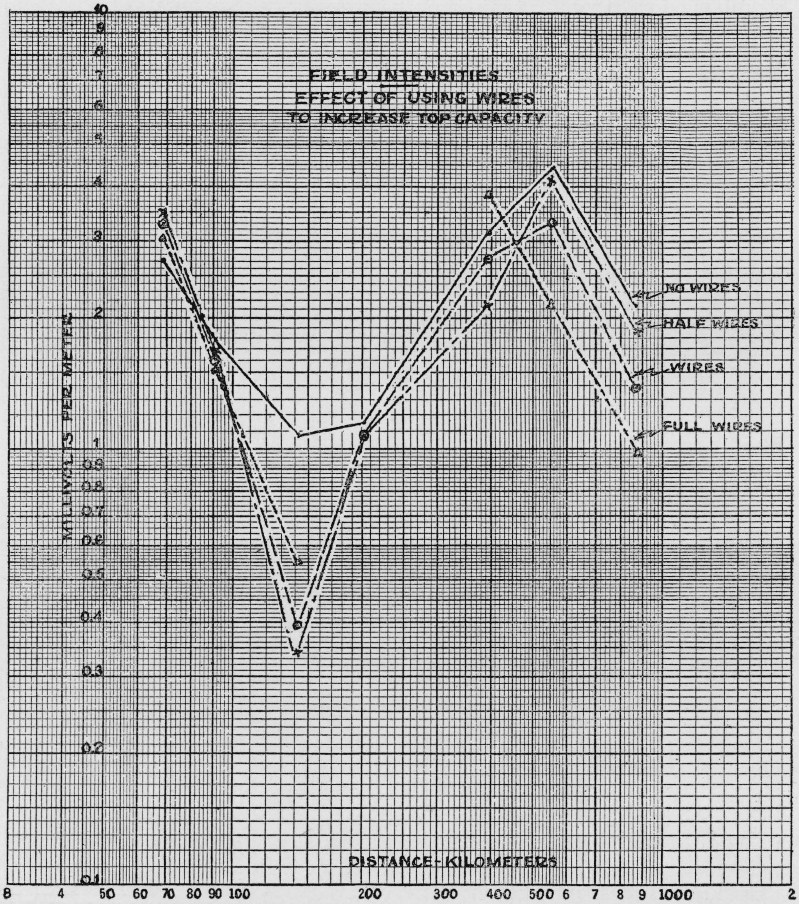

FIGURE 8.—*Field intensities of emissions from mast antenna with and without wires used to increase top capacity.*

In figure 9 are shown the fading ratios with the mast used under the different conditions. For the important nearby points the wires, especially the half wires, seem to have an advantage in reducing the fading. This problem should have further study. It should not be absolutely necessary to study the effect of antenna changes on the fading over a wide range of distances as was done in the WBT experiment, as much can be learned from a careful study at one well located station—Lexington, in the case at hand.

IV. CONCLUSIONS

The 429-foot mast antenna produced a ground-wave field intensity 1.75 times that produced by the old T, and twice that produced by the L.

The night field intensity at considerable distances was increased by a factor of about 1.5 by the substitution of the mast for the L.

The night-fading amplitude was decreased appreciably out to 150 km by the use of the mast. The fading amplitude was not appreciably decreased at distances over 200 km where sky wave was predominant from both antennas.

Fading was much more rapid and destructive within a distance of 150 km than for greater distances. The change of antennas did not appreciably affect the frequency of the fading but only the amplitude.

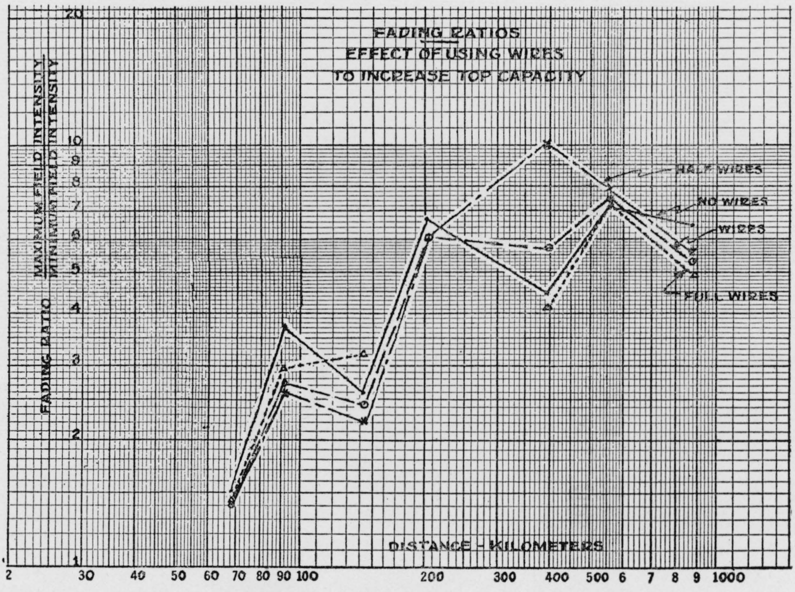

FIGURE 9.—*Amplitude ratios of night fading of emissions from mast antenna with and without wires to increase top capacity.*

The maximum sky-wave field intensity recorded was at Meadows, at a distance of 552 km from the transmitting station.

The use of wires to increase the top capacity and make the antenna current more nearly sinusoidal did not increase the field intensity, but there was some evidence that the fading was decreased over the first 150 km. The half wires were more effective than the full wires.

This investigation was made possible through the cooperation of the Columbia Broadcasting System, by arrangement with E. K. Cohan, Director of Engineering for that company. A. B. Chamberlin and W. B. Lodge, engineers for the Columbia Broadcasting System, assisted in the work.

S. E. Reymer of the National Bureau of Standards assisted in installing the recorders. Facilities for the installation of receiving equipment and recorders were furnished by T. M. Casey, Salisbury, N. C.; Fred Hunnicut and the firm Conrad, Linville, and Martin, Lexington, N. C.; Women's College, University of North Carolina, Greensboro, N. C.; Duke University, Durham, N. C.; University of Virginia, Charlottesville, Va.; and Ballantine Laboratories Inc., Boonton, N. J. S. Ballantine also operated the equipment installed in his laboratory.

WASHINGTON, January 29, 1936.