account of tropospheric effects, but are apparently based on Norton's curves, with appropriate values of required field intensity selected so as to overcome ignition noise and effects of terrain. The listening tests at distances up to 120 miles were made in the evening, when tropospheric fields are usually higher than average, but in no case can be taken as proof that a useful signal level will be exceeded for an acceptable percentage of the time at that distance. Antenna heights of 1000 feet or more will be the exception rather than the rule, and the average height is likely to be near 500 feet. Under these conditions I am inclined to agree with Mr. de Mars' estimate of a range of 70 to 75 miles at 50 megacycles. Present data indicate that the range at 100 megacycles will be somewhat less, but I do not feel that they are sufficiently comprehensive and reliable to make a real prediction as to what reduction will occur. Messrs. Carnahan's and Brown's estimate of a 55-mile radius is believed to be somewhat pessimistic, but even if this proves to be the case the resulting reduction in service area will be 40 per cent rather than the 60 per cent reduction which they estimated originally. Such estimates in the reduction of service areas do not apply to the majority of cases because the close spacing of stations, arising from the demand for facilities, will result in limitation of area by co-channel and adjacent-channel interference, rather than by failure of the signal from fading. On the other hand, the duplication will greatly increase the amount of interference within the protected area from sky-wave signals in the 50-megacycle band.

With regard to the reopening of British television on 41 and 45 megacycles, rather than on a higher frequency, I believe that a study of the situation will reveal that the primary consideration was the utilization of presently available television transmitting and receiving equipment, rather than the propagation characteristics of various frequencies. While the reception of the London television signals at Riverhead, Long Island, has entered into the discussions by way of comparison between experience and Bureau of Standards predictions for the last sunspot maximum, the probability of interference between 40 and 50 megacycles across the North Atlantic has not appeared to be too serious, as the path lies near the auroral zone and maximum usable frequencies are likely to be much lower than for other paths over which interference may be encountered. It is the areas of high maximum usable frequencies which constitute the principal problem of F_2-layer interference to this and other countries adjacent to such areas.

In making my comment upon the curves in Mr. de Mars' Figs. 6 and 7, the only assumption required, and I feel it to be a reasonable one, was that the data which he used in preparing his curves followed the same laws as the data which I have available to me. There appears to be good agreement generally between the data and the curves as to the range of fading, but the absolute values still appear to be low as compared to the standard-atmosphere curves, when both are based on smooth-earth conditions.

In his discussion of shadow effects Mr. de Mars loses sight of the fact that the comparison of service areas in my Fig. 9 was not made for hilly or mountainous conditions but upon an assumption of average conditions. The loss of additional areas due to shadow effects behind hills was discussed in the text, with greater losses expected at the higher frequencies. The nomograph submitted by Mr. de Mars shows a consistent 2-decibel difference in field intensity between the shadow loss on 50 and 100 megacycles, so that, even if the effects of scattering are neglected, the larger losses behind hills will apply almost to the same degree for both frequencies. Our experience has been that scattering does have a large effect and that there is no systematic difference between frequencies which is readily identifiable with features of terrain.

Field Intensities Beyond Line of Sight at 45.5 and 91 Megacycles*

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Summary—This paper presents the results of a field-intensity monitoring project initiated by the Federal Communications Commission during the summer of 1945. Field intensities on 45.5 and 91 megacycles from transmitters at Richfield, Wisconsin, were continuously monitored for a period of two months at Deerfield, Illinois, over a transmission path of 76 miles. The data is analyzed in terms of the average median field intensities and their diurnal variation. The number of hours of unsatisfactory broadcast reception due to fading is estimated for both frequencies, assuming representative transmitter power and receiver sensitivity. Comparison is made with similar analyses of data obtained by the Federal Communications Commission in the measurement of field intensities on 46.7, 83.75, and 107 megacycles at Andalusia, Pennsylvania.

INTRODUCTION

In May of 1945 the Federal Communications Commission elicited the aid of various interested parties in making a number of field-intensity recordings on the old frequency-modulation broadcast band, 42 to 50 megacycles, and the proposed new band, 88 to 108 megacycles. These tests were to furnish more

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* Decimal classification: R271. Original manuscript received by the Institute, March 6, 1946; Rochester Fall Meeting, November 12, 1945; Cosmic Terrestrial Research Laboratory, Needham, Mass.; Washington Section, January 14, 1946; presented, 1946 Winter Technical Meeting, January 24, 1946, New York, N. Y.; Chicago Section, February 15, 1946.

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information on comparative propagation conditions on these two frequency bands. Most of the program was abandoned at the end of June, 1945, when the Commission decided to allocate the higher band to frequency modulation without waiting for the results of the propagation tests.

The test setup between transmitters at Richfield, Wisconsin, and recorders at Deerfield, Illinois, was continued, however, and it is the purpose of this paper to present the results found during the recording period of two months, between July 20 and September 21, 1945.

DESCRIPTION OF TRANSMITTERS

The transmitters used were WMFM, the Milwaukee Journal station, at 45.5 megacycles and an experimental transmitter, W9XK, at 91 megacycles, both located at Richfield, Wisconsin.

The 45.5-megacycle antenna was a horizontally polarized two-bay turnstile with a power gain in the direction of the receiving station of 1.23. The antenna center was 508 feet above the average elevation of the transmission path. The effective radiated power in the direction of Deerfield was constant at 35 kilowatts during the recording period.

The 91-megacycle antenna was a horizontally polarized 60-degree corner reflector, with a power gain of 10 in the direction of Deerfield. The antenna center was 468 feet above average elevation. The effective radiated power towards Deerfield varied between 2.5 and 10 kilowatts during the recording period. Both transmitters were under the supervision of P. B. Laeser of WTMJ.

DESCRIPTION OF TRANSMISSION PATH

Fig. 1 shows a profile graph of the path between transmitters and recorders. The terrain is gently rolling, with no pronounced topographical features. The total distance was 76.3 miles. The transmitter site was on a hill, 1060 feet above sea level, or 278 feet above the average elevation of the transmission path. The average elevation for this transmission path was determined in accordance with the standards of good engineering practice of the Federal Communications Commission.[1]

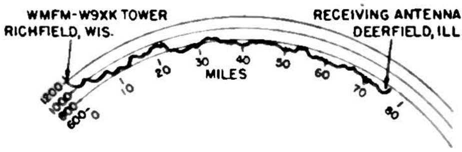

Fig. 1—Profile graph of the terrain between Richfield, Wisconsin and Deerfield, Illinois. The optical horizon from the transmitting antennas was at 25 miles from Richfield.

A different method of effective height calculation is prescribed in later standards of the Commission.[2] In this method, only distances between 2 and 10 miles are considered in determining the "average-terrain" level, above which the antenna height is computed. In our opinion, this later method is less accurate than the one we used, especially for distances greater than ten miles, because (a) terrain characteristics beyond ten miles are disregarded, and (b) the effects of azimuthal variation of terrain are completely disregarded. While this method may be suitable for calculation of average coverage at short range, it appears unsatisfactory for prediction of ground-wave propagation at distances involved in rural-service frequency-modulation stations.

The optical horizon for this path and antenna heights was approximately 25 miles.

DESCRIPTION OF RECORDING LOCATION AND EQUIPMENT

The receiving station at Deerfield, Illinois, was maintained by the Zenith Radio Corporation. The recorders were located in the second floor of a residence situated on a slight rise, overlooking a school playground in the direction of the transmitters, and there were no trees immediately in the transmission path.

The receiving antennas were half-wave folded dipoles mounted on ten-foot masts supported by guyed twenty-foot towers. Exploration of the area revealed no appreciable standing waves. Fig. 2 is a photograph of the receiving location looking from the transmitter, and Fig. 3 shows the 45.5-megacycle antenna. For the transmission lines, 300-ohm molded two-wire cable was used, supported by guys leading directly to the recorders.

Fig. 2—View of the building and antenna towers of the monitoring station at Deerfield, Illinois, looking from the transmitters.

The monitoring equipment consisted of a Hallicrafters S-27 receiver on 45.5 megacycles, and a Hallicrafters S-36 receiver on 91 megacycles. This latter receiver is a military version of the S-27 and has essentially the same circuit. Both receivers were modified for recording as recommended by the Federal Communications Commission. Esterline-Angus recorders, Ferris 18C signal generators for calibration, and voltage regulators were used in conjunction with both receivers.

Radio-frequency stages with balanced 300-ohm inputs were added to each receiver. To take care of signal variations, H-section attenuators were placed between each antenna and receiver input, wired to band switches so that they could be connected or disconnected. An

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[1] F.C.C. "Standards of Good Engineering Practice Concerning High Frequency Broadcast Stations," June 29, 1940 (41831), and "Proposed Standards of Good Engineering Practice Concerning FM Broadcast Stations," July 11, 1945 (83399).

[2] F.C.C. "Standards of Good Engineering Practice Concerning F-M Broadcast Stations," September 20, 1945.

additional permanent attenuator section was found necessary with the 45.5-megacycle receiver to bring the signals within recording range.

Fig. 3—Close-up view of the 45.5-megacycle half-wave folded dipole, used for monitoring.

Double-throw switches were placed before the attenuators to switch the receivers from the antenna leadins to the calibrating signal generators, which were wired in permanently with 150-ohm resistors between each generator terminal and the switch. The circuit of the 91-megacycle receiver was the same except for the omission of the second attenuator section.

Calibrations were put on the tapes at the beginning of each record. These calibrations were checked at frequent intervals, and if appreciable change was observed, an additional calibration was recorded. Calibrations were also recorded whenever the attenuator switch was changed.

REDUCTION OF DATA

The tape recordings give the microvolts at the antenna leadins, by comparison with the signal-generator calibrations. To relate these values to the actual field intensities at the antennas it is necessary to determine the recorder calibration constants, the factors by which the tape readings in signal generator microvolts must be multiplied to give the field intensities at the antennas.

The accepted method for determining this constant is to set up by means of a test oscillator a constant field with the correct polarization at the antenna. The intensity of this field is then measured by replacing the receiver antenna with the antenna of a field-intensity meter. The value of field intensity so obtained is compared with the signal-generator output required to give the same indication on the recorder.

If the receiving antenna, transmission line, and input circuit are perfectly balanced to ground, the measured recorder calibration constant should be independent of the polarization of the wave from the test oscillator. In the Deerfield arrangement it was found necessary to eliminate as completely as possible any vertical component in the test field before consistent results could be obtained. With the best arrangement of test oscillator, which turned out to be a half-wave dipole fed by a Ferris 18C signal generator, some variation of recorder constant with oscillator position was still noted. The final values decided upon were the averages of the results of three different positions.

Field intensities were measured independently by W. K. Roberts of the Federal Communications Commission and by P. B. Laeser of WTMJ. Two RCA Type 301 field-intensity meters were used, and the meter calibrations were checked by S. L. Bailey, of Jansky and Bailey, using his standard field oscillator.

The variation of recorder constant with test-oscillator position raised the possibility that the constant for the actual signals might be different. To check this, simultaneous fast recordings of the 45.5-megacycles signal were made, using the 45.5-megacycle recorder and a field-intensity meter with its dipole mounted on the 91-megacycle tower. Comparing the signal peaks for a period of fifteen minutes, the recorder constant obtained was found to be 20 per cent lower than with the test oscillator. Since the two antenna locations had been previously found to differ with regard to field intensity from the test oscillator by just this amount, it was concluded that this test was a satisfactory check on the recorder calibration procedure.

Since the 45.5-megacycle transmitter is a representative broadcast transmitter, it was decided to correct the 91-megacycle field intensities for assumed operation with the same power radiated at 91 megacycles. The power input to the 45.5-megacycle transmitter during most of the test was 50 kilowatts. Assuming an amplifier efficiency of 60 per cent, a transmission-line efficiency of 95 per cent, and an antenna power gain of 1.23, the effective radiated power on 45.5 megacycles was

$$50 \text{ kilowatts} \times 0.60 \times 0.95 \times 1.23 \doteq 35 \text{ kilowatts.}$$

This value was confirmed by the reading of a radiofrequency vacuum-tube voltmeter previously calibrated during a field-intensity survey.

The effective power radiated toward Deerfield on 91 megacycles was determined indirectly in a manner which requires some explanation. A direct measurement of the power at the 91-megacycle antenna was made by E. H. Armstrong and C. M. Jansky. A halfwave dipole was suspended at a distance of two wavelengths from the radiator and the current at the center of the dipole was measured on a Weston meter which had been carefully calibrated at 91 megacycles. The result was used in a computation by S. L. Bailey, taking into account the proximity effect of the measuring dipole, to give the effective radiated power. These computations are shown in the Appendix. With the same power input as used in the direct measurement, the reading of a simple monitoring diode meter on the ground near the tower was noted. The monitoring diode meter was calibrated against relative field intensity by placing an RCA Type 301 field-intensity meter a mile away from the tower, and then reading both meters simultaneously as the power input to the transmitter was varied. These calibrations were required, since the power input to the transmitter varied throughout the test period.

Having the monitoring diode reading for the measured value of radiated power, and the calibration of the diode in terms of relative field strength and power input, it was then possible to determine the effective radiated power as a function of the power input. As an example, an input power of 2.08 kilowatts gave a relative field strength of 9.2 on the 301 meter. The direct measurement gave 2.68 kilowatts effective radiated power for a relative field strength of 4.7, this latter value being obtained from the curve of diode readings versus relative field intensity. Then the effective radiated power at 2.08 kilowatts input was computed as 2.57 kilowatts $\times(9.2/4.7)^2=10.3$ kilowatts.

SUMMARY OF RESULTS

The daily tape recordings on both frequencies were studied in detail, and the hourly median values of the field intensities, or the values of field intensity which were just exceeded for thirty minutes out of an hour, were estimated for each hour recorded. The 91-megacycle field intensities were then corrected for an assumed effective radiated power of 35 kilowatts. All field intensities quoted in the text and figures assume this power on both frequencies.

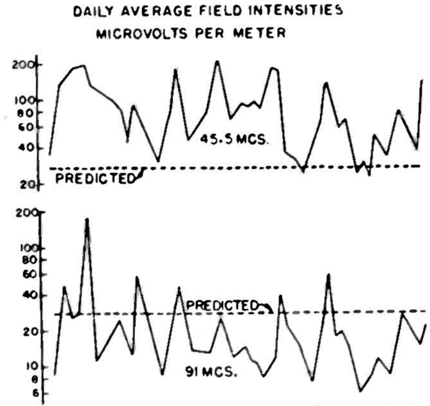

Fig. 4—Plots of daily averages of median hourly field intensities showing variations over the recording period. Predicted values are 26.9 microvolts per meter at 45.5 megacycles and 24.9 microvolts per meter at 91 megacycles.

Fig. 4 shows median hourly field intensities averaged over each day of operation for an effective radiated power of 35 kilowatts. The dotted lines indicate the values predicted using the F.C.C. curves and the data already given on effective antenna heights and distance. The predicted values were 26.9 microvolts per meter at 45.5 megacycles, and 24.9 microvolts per meter at 91 megacycles.

It will be seen that the 45.5-megacycle intensity is well above the predicted value for most of the time, while the 91-megacycle intensity is below.

These curves show the variation typical of tropospheric propagation for this time of year. The peaks and valleys are due to weather changes, and it will be seen that, in general, the trend of the intensities at the two frequencies agree quite well.

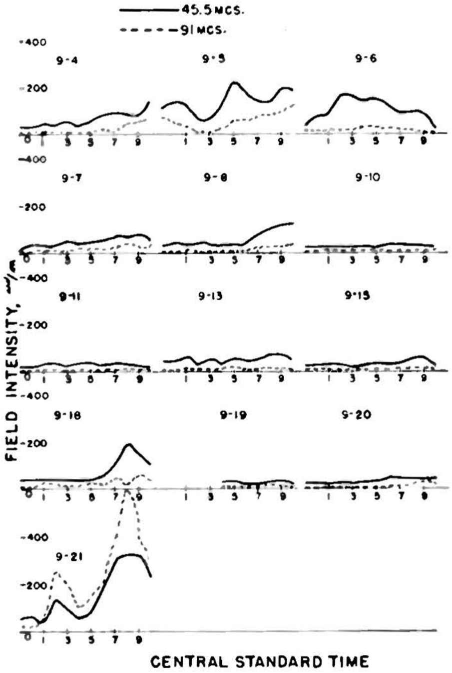

Fig. 5—Daily variation of median hourly field intensities for the last thirteen days of the recording period. Note the high fields on 91 megacycles for September 21.

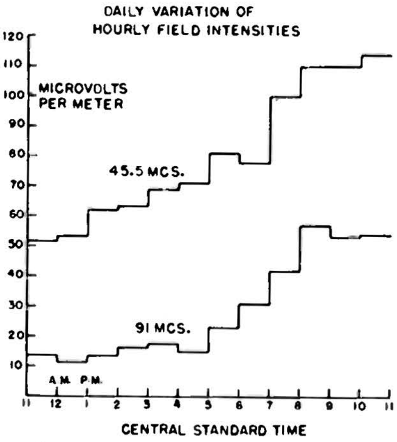

Fig. 6—Daily variation of median hourly field intensities, averaged over the entire recording period.

Fig. 5 shows the hourly median field intensities plotted against time of day for part of the recording period. These curves again emphasize the variable nature of tropospheric signals, not only from day to day, but in the course of a day. The agreement in trends on the two frequencies is not so apparent here. Of particular interest is the behavior on September 21. There was a strong temperature inversion present on this day, and the 91-megacycle field intensity exceeded that of the lower frequency for most of the day. This condition prevailed on several of the recording days and agrees with the theory that, in propagation through atmospheric ducts formed by temperature inversions, greater field intensities are found at higher frequencies because of better reflection conditions within the duct.

In Fig. 6 are plotted the hourly median field intensities averaged over the entire recording period, against time of day. The 45.5-megacycle field intensity shows a more or less steady rise during the day, with a variation of two to one between 11 A.M. and 11 P.M., Central Standard Time. The 91-megacycle signal remains low and fairly constant from 11 A.M. to 5 P.M. and then rises to five times this value between 5 P.M. and 11 P.M.

Figs. 7 and 8 shows the same average fields plotted on a logarithmic scale, with maximum and minimum values added to show the extent of variation on the two frequencies. The spread between the highest and lowest hourly median field intensities is about 35 times on 45.5 megacycles against 200 times on 91 megacycles.

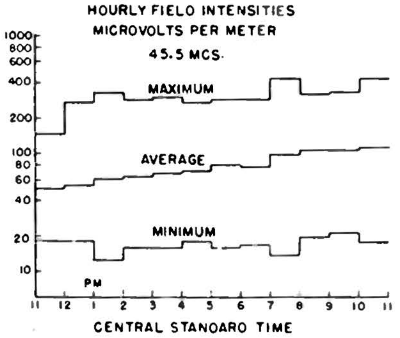

Fig. 7—Daily variation of median hourly field intensities at 45.5 megacycles, averaged over the entire recording period, showing the variation between maximum and minimum hourly values.

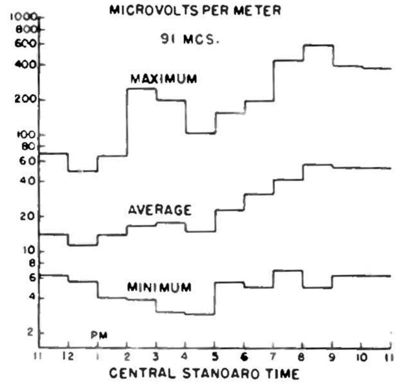

Fig. 8—Daily variation of median hourly field intensities at 91 megacycles, averaged over the entire recording period, showing the variation between maximum and minimum hourly values.

Fig. 9 shows the time distribution of the ratios of simultaneous hourly median field intensities. For 50 per cent of the total recording time the 45.5-megacycle field intensity was four times the 91-megacycle intensity.

The time distributions of the actual field intensities are shown in Fig. 10. The median values for the entire recording periods are given by the intersections of the curves with the 50 per cent abscissa. These figures are 54 microvolts per meter at 45.5 megacycles, or 200 per cent of the predicted ground-wave value of 26.9 microvolts per meter and 13 microvolts per meter at 91 megacycles, or 52 per cent of the predicted value of 24.9 microvolts per meter.

Since this test was set up to secure comparative data on the relative service afforded by the two frequency bands for frequency-modulation broadcasting, the recordings have been analyzed in terms of the performance of typical home receivers operating on both frequencies.

The hypothetical receivers were assumed to operate with half-wave dipole antennas and lossless transmission lines, with no mismatching. It was assumed that signals of 10 microvolts induced in the antenna would be sufficient for satisfactory limiting in the receiver. This is a conservative figure for a good broadcast receiver.

To obtain an induced signal of 10 microvolts at 45.5 megacycles requires a field intensity of 5 microvolts per meter, since the effective antenna length at this frequency is about two meters. To get the same signal at 91 megacycles requires a field of 10 microvolts per meter, because the effective antenna length is halved.

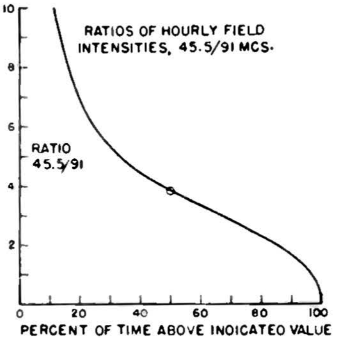

Fig. 9—The time distribution of the ratios of the simultaneous median hourly field intensities on 45.5 and 91 megacycles.

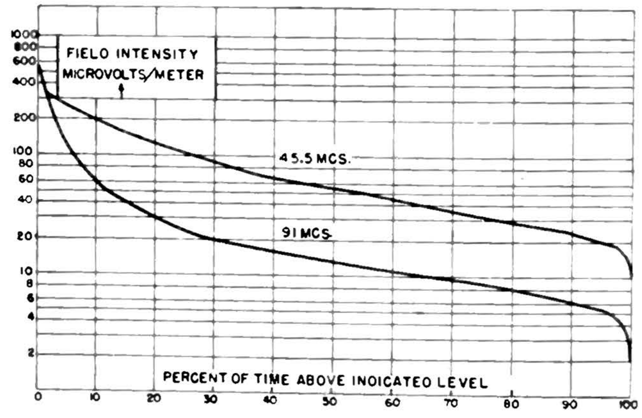

Fig. 10—The time distribution of the recorded median hourly field intensities. Effective radiated power is 35 kilowatts for both frequencies.

Assuming 35 kilowatts effective radiated power for a typical broadcast transmitter, the curves of Fig. 10 give some information on how well the minimum levels for typical receivers would be met, under the conditions of the test. From them we see that as far as average fields are concerned the minimum field of 5 microvolts per meter at 45.5 megacycles was obtained 100 per cent of the time, while at 91 megacycles the field was below the required 10 microvolts per meter for 35 per cent of the time.

The average signal is only part of the story, however. Fig. 11 shows sections of tape with simultaneous recordings of both field intensities. The sharp spikes represent fast fades. When these fades go below the minimum required intensity, the program disappears for intervals of ten or twenty seconds. These periods when the signal disappears have been termed "dropouts."

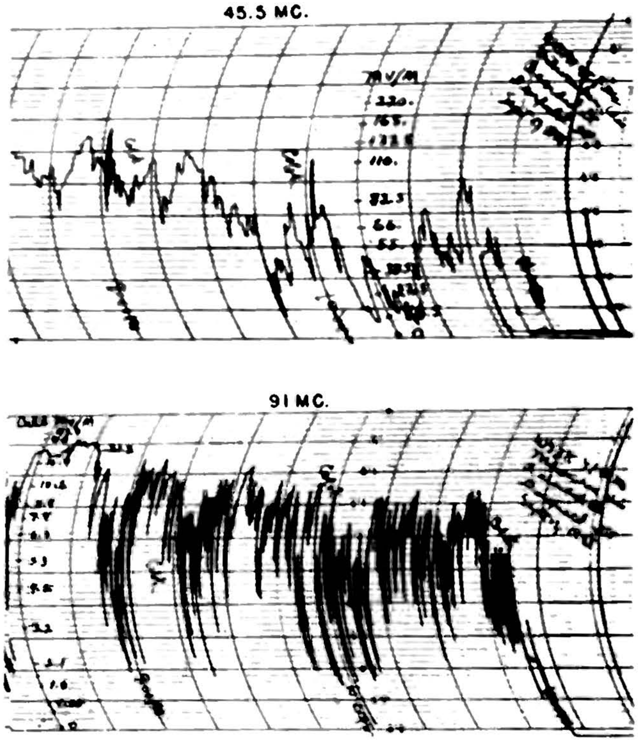

Fig. 11—Representative simultaneous tape sections on the two frequencies for comparison of the prevalence and degree of fading on the two frequencies.

The recorder tapes on both frequencies were analyzed in detail for the frequency of occurrence of dropouts. It is difficult to set a standard for satisfactory service, so it was decided that one dropout per hour would be considered unsatisfactory.

With this definition of unsatisfactory service it was found that, on 45.5 megacycles, 87 per cent of the total recording hours were satisfactory, while on 91 megacycles only 27 per cent of the total hours were free from dropouts. A further breakdown of the dropout situation revealed that in 90 per cent of the unsatisfactory hours on 91 megacycles the signal was below the minimum for at least 5 per cent, or three minutes, out of each hour, and for 50 per cent of the unsatisfactory hours it was below the minimum for 50 per cent, or thirty minutes out of each hour. On 45.5 megacycles, one half of the unsatisfactory hours had only several dropouts per hour, and in the other half the number of minutes lost out of an hour did not exceed six.

As part of the recording program the Federal Communications Commission monitored field intensities from transmitters in New York on 46.7, 83.75, and 107 megacycles, at Andalusia, Pennsylvania, a distance of 71 miles. The F.C.C. report on these measurements is available.[3]

Through the kindness of the Commission's engineers, Zenith Radio Corporation was furnished with copies of the recorder tapes and the hourly median values obtained from them. This made possible a direct comparison between the Deerfield and Andalusia measurements.

Table I shows the median field intensities, predicted and measured, for the two Deerfield frequencies and the two lower Andalusia frequencies, all corrected for 35 kilowatts effective radiated power at the transmitters. The median field intensities were averaged over the Deerfield recording period, from 11 A.M. to 11 P.M., Central Standard Time.

TABLE I

Frequency, megacycles	Recorder location	Theoretical field, microvolts per meter	Measured field, microvolts per meter	Per cent of theoretical field
45.5	Deerfield	26.9	54	200
46.7	Andalusia	77.5	35.3	45.5
83.75	Andalusia	56.8	41	72.2
91	Deerfield	24.9	13	52.2

The comparison shows fair agreement on the high frequencies, considering that in the Andalusia tests the antenna heights were greater and the distance shorter, so that predicted field intensities were two to three times greater than at Deerfield.

There is a pronounced disagreement between the observed percentages of theoretical fields at the lower frequencies. Assuming that this is due to site errors, the two measurements may represent the two extremes.

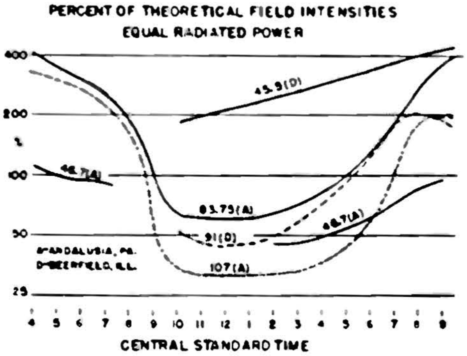

Fig. 12—Daily variation of median hourly field intensities on transmissions recorded at Deerfield, Illinois, and Andalusia, Pennsylvania, averaged over entire recording period and expressed as percentages of theoretical values for equal radiated power.

The Andalusia recordings were continuous from 4 A.M. to 9 P.M., C.S.T., except for the 46.7-megacycle frequency, which made it possible to show the diurnal variation over a complete day. Fig. 12 shows a combined plot of the average hourly median field intensities for both locations, assuming equal radiated power. The

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[3] Exhibit 650 of the Proceedings Before the Federal Communications Commission at Washington, D. C., January 18, 1945, in the matter of: "Allocation of Frequencies, etc." Docket No. 6651.

characteristic diurnal variation of tropospheric signals is clearly shown by these curves. High field intensities are found in the late afternoon and night hours, when temperature and humidity inversions build up, and low values are found in the middle of the day, when turbulence removes the inversions.

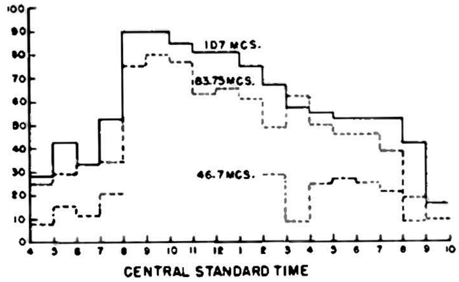
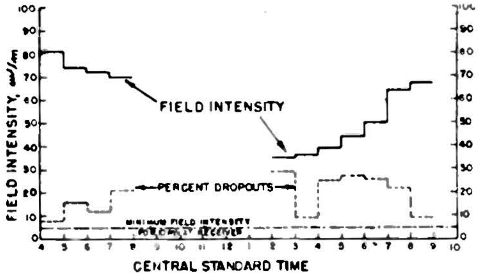


Fig. 13—Daily variation of percentage of total recorded hours having at least one dropout during the hour, for frequencies recorded at Andalusia, Pennsylvania, assuming 35 kilowatts effective radiated power.

Of particular interest is the downward progression of signal intensity with increasing frequency in this critical middle period of the day. During this period fading is a maximum, which tends to further degrade the service on the higher frequencies.

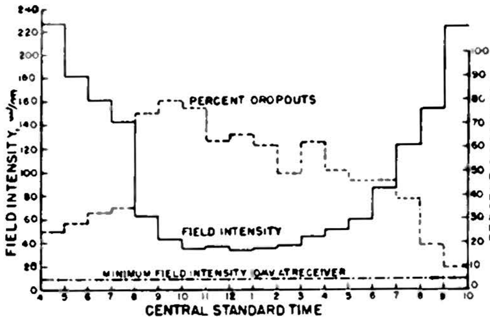
Fig. 13 shows the results of an analysis of the Andalusia recording from a dropout viewpoint. As in the Deerfield analysis, 35 kilowatts radiated power, half-wave dipole receiving antennas, and a minimum induced voltage of 10 microvolts was assumed. The prevalence of dropouts on the two high frequencies during the major part of the day was so great as to render broadcast service completely impossible.



ONE OR MORE DROPOUTS PER HOUR RECORDED FOR 19% OF TOTAL HOURS

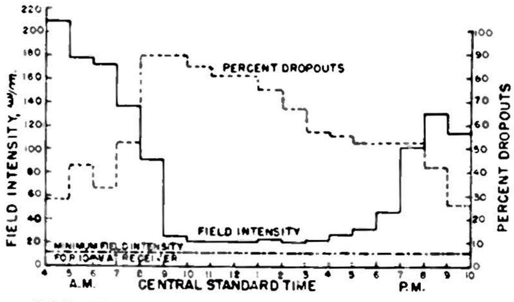
Fig. 14—Daily variation of hours unsatisfactory due to dropouts at Andalusia, Pennsylvania, on 46.7 megacycles, together with average median hourly field intensities, assuming 35 kilowatts effective radiated power.

It has been suggested that raising the power on the high frequencies will overcome these fading difficulties. Figs. 14, 15, and 16, where the percentage dropout curves are plotted together with the field strength for the three Andalusia frequencies, refute this idea. During the hours when the 46.7-megacycle transmitter was on, the field intensities at 83.75 and 107 megacycles were two to three times greater than that on 46.7 megacycles, but percentages of hours unsatisfactory because of the dropouts were larger by the same factors. To overcome the greater depth of fading on the high frequencies by raising the power is clearly uneconomical. In fact, the Andalusia recordings on 107 megacycles suggest that it would be practically impossible, since for several days the 107-megacycle signal disappeared into the noise level of the receiver for six or seven hours in the middle of the day.



ONE OR MORE DROPOUTS PER HOUR RECORDED FOR 49% OF TOTAL HOURS.
SIGNAL BELOW MINIMUM FOR MORE THAN 5% OF ONE HOUR FOR 24.5% OF TOTAL HOURS.

Fig. 15—Daily variation of hours unsatisfactory due to dropouts at Andalusia, Pennsylvania, on 83.75 megacycles, together with average median hourly field intensities, assuming 35 kilowatts effective radiated power.



ONE OR MORE DROPOUTS RECORDED PER HOUR FOR 59% OF TOTAL HOURS.
SIGNAL AT NOISE LEVEL FOR 12.2% OF TOTAL HOURS.
SIGNAL BELOW MINIMUM FOR 5% OF ONE HOUR FOR 30.6% OF TOTAL HOURS.

Fig. 16—Daily variation of hours unsatisfactory due to dropouts at Andalusia, Pennsylvania, on 107 megacycles, together with average median hourly field intensities, assuming 35 kilowatts effective radiated power.

DISCUSSION

While it will take many more measurements such as those described here to establish conclusively the average fields to be expected at these distances and frequencies, it is felt that certain conclusions can safely be drawn from the measurements. These are:

1. Actual measurements on tropospheric field intensities depart widely from predicted fields of surface ground waves.

2. Loss of service due to fading will render a frequency-modulation broadcast service in the 88 to 108 megacycle band practically impossible at distances of the order of 70 miles, while service in the 42 to 50-megacycle band is, on the whole, satisfactory at these distances.

3. In assessing the service value of a given frequency at distances where tropospheric propagation is encountered, the minimum field intensity during the middle period of the day should be considered as the deciding factor, along with extent of fading during this period. The median field intensity has no meaning if, during four or five hours out of the day, the received signal is unsatisfactory.

APPENDIX

NOTES ON MEASUREMENT OF POWER FROM A 60-DEGREE CORNER REFLECTOR USING A DIPOLE PROBE

The following computations were made by S. L. Bailey of Jansky and Bailey, Washington, D. C.

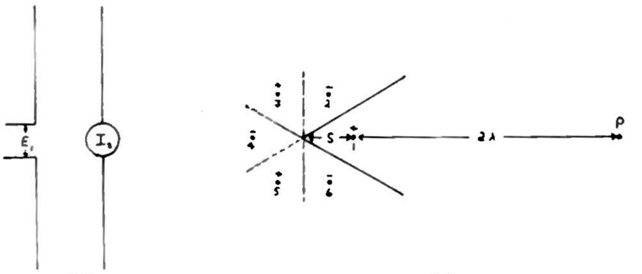
The mutual impedance between two antennas $\frac{1}{2}$-wavelength long spaced 2 wavelengths is, very nearly,

$$Z_{12} = 9\underline{/+90^\circ} \text{ ohms.}$$

Now, in a system of this type (Fig. 17 (a)) we can write

$$\begin{aligned} E_1 &= I_1 Z_{11} + I_2 Z_{12} \quad \text{and} \\ 0 &= I_1 Z_{12} + I_2 Z_{22} \end{aligned} \tag{1}$$

where Z_{11} and Z_{22} are the self impedances of elements (1) and (2), respectively, and Z_{12} is the mutual impedance. It is safe to assume that the impedance of a self-resonant dipole having finite cross-section is very nearly 68 ohms nonreactive.



(a) (b)

Fig. 17

$$E_1 = I_1 \times 68 + I_2 \times 9\underline{/+90^\circ} \tag{2}$$

$$0 = I_1 \times 9\underline{/+90^\circ} + I_2 \times 68 \tag{3}$$

$$Z_1 = \frac{E_1}{I_1} = 68 + \frac{I_2}{I_1} \times 9\underline{/+90^\circ} \tag{4}$$

but, from (3),

$$\frac{I_2}{I_1} = -\frac{9\underline{/+90^\circ}}{68} \tag{5}$$

$$\begin{aligned} Z_1 &= 68 - 1.2\underline{/+180^\circ} \\ &= 69.2 \text{ ohms} \end{aligned} \tag{6}$$

which means that the resistive component of the driven element is raised slightly for this spacing. For 1 kilowatt in element (1),

$$I_1 = \sqrt{\frac{1000}{69.2}} = 3.80 \text{ amperes.} \tag{7}$$

Calculating the magnitude of I_2 from (5), $I_2 = 3.80 \times 9/68 = 0.502$ ampere. (Note: This neglects any resistance added by the meter in element (2). If appreciable, this may be taken into account by modifying Z_{22} accordingly.)

As a check on the above, we know that 1 kilowatt in a $\frac{1}{2}$-wavelength dipole produces a free-space field of 137 millivolts per meter at one mile or 0.137 volts per meter. Inasmuch as the free-space field varies inversely as the distance, we can calculate for any frequency the free-space field at the receiving dipole.

At 91 megacycles, 1 wavelength = 10.8 feet = 3.3 meters.

At 91 megacycles, 2 wavelengths = 21.6 feet.

Hence, the field at a dipole 2 wavelengths away is

$$\frac{5280}{21.6} \times 0.137 \text{ volts per meter} = 33.5 \text{ volts per meter.}$$

The receiving dipole is $3.3 \times \frac{1}{2} \times 0.95$ meters long or 1.57 meters and the effective length is $0.636 \times 1.57 = 1.0$ meter. Therefore, the induced voltage is $33.5 \times 1.0 = 33.5$ volts and the current $33.5/68 = 0.495$ amperes, which compares with 0.502 amperes by the former method. A value of 0.50 amperes is a satisfactory value.

Now, considering a 60-degree corner reflector, we can calculate the gain in the forward direction by the method of images. The spacing S (Fig. 17(b)) of the driver element from the corner was 0.4 wavelength. Using the method of images, we find that at a *great* distance the amplitudes and phase relations of the driven element and the five images for the 0.4-wavelength condition are as follows:

Driven element (1) = $+1.0\underline{/0^\circ}$
Image (2) = $-1.0\underline{/-72^\circ}$
Image (3) = $+1.0\underline{/-216^\circ}$
Image (4) = $-1.0\underline{/-288^\circ}$
Image (5) = $+1.0\underline{/-216^\circ}$
Image (6) = $-\ \underline{/-72^\circ}$

The vector sum of these is $2.62\underline{/126}$ degrees.

We may now consider the effect of proximity of the dipole probe on the indicated power radiated. The vector fields from the driven dipole and the five images are modified both as to amplitude and phase, and have the following values:

Driven dipole (1) = $+1.0\underline{/0^\circ}$
Image (2) = $-0.9\underline{/-82^\circ}$
Image (3) = $+0.76\underline{/-225^\circ}$
Image (4) = $-0.715\underline{/-288^\circ}$
Image (5) = $+0.76\underline{/-225^\circ}$
Image (6) = $-0.9\underline{/-82^\circ}$

The vector sum of the above is $2.24\underline{/104.2}$ degrees, which may be compared directly with the value of 2.62 $\underline{/126}$ degrees which was obtained for a great distance. Thus the actual power in the direction of the probe is $(2.62)^2/(2.24)^2 = 1.37$ times as great as that indicated by the received current.

It has been shown that the current in a half-wavelength dipole 2 wavelengths from a driven dipole in free space radiating 1000 watts would be 0.5 ampere.

The received current in Milwaukee at the time of the tests was 0.7 ampere. Then the power in the beam is given by the following:

$$1000 \times \left(\frac{0.7}{0.5}\right)^2 \times 1.37 = 2680 \text{ watts.}$$