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A STATISTICAL STUDY OF CONDITIONS AFFECTING THE DISTANCE RANGE OF RADIO TELEPHONE BROADCASTING STATIONS

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ABSTRACT

The conditions affecting radio transmission are too complex to permit a simple analysis, and the most satisfactory method of studying such conditions and their variations is the analysis of a large number of similar observations taken by a large number of observers. This paper describes the organization of such a group of observers by the bureau, the methods used for making observations, and the forms used for recording 8,500 observations made over a period of a year (1922–23) on transmitting station KDKA, of the Westinghouse Electric & Manufacturing Co., located at East Pittsburgh, Pa. The data obtained were analyzed on automatic machines, and charts given showing (*a*) variation of strength of atmospherics, (*b*) variation of fading, (*c*) relative magnitude of obstacles to reception, (*d*) variation of interference from receiving sets, (*e*) relative magnitude of obstacles to reception grouped in bimonthly periods, and (*f*) mean reliability of reception as a function of distance.

The fact that great variations in transmitting and receiving conditions are met with in radio communication is well known. While conditions, such as sunlight, temperature, barometric pressure, humidity, etc., as well as factors due to human agencies, are of great importance in causing variations of conditions from season to season, day to day, and even hour to hour, the relationships are too complex to permit a simple analysis. Owing to this complexity, probably the most satisfactory method of obtaining practical information concerning the distance range of stations and the relative magnitude of the limiting factors concerned is by the analysis of a large number of similar observations taken by a number of observers over a considerable period of time. This paper describes such an investigation of conditions of transmission from a broadcasting station. The investigation was conducted by the Bureau of Standards with the aid of about 100 voluntary observers. The work was made possible only through the service rendered by these observers and the cooperation extended by the Westinghouse Electric & Manufacturing Co., owners of station KDKA, upon whose transmissions the observations were made.

Observers were selected with the view of obtaining as uniform a distribution around the transmitting station as possible. Numbers were assigned to the transmitting station and to each observer. Each number, in addition to designating the stations, shows its approximate location. Figure 1 shows Form 2, upon which the observer described his location and his receiving equipment. Figure 2 shows Form 3, used for recording data relative to a particular observation. One copy of this (Form 3) was used for each observation. Data were recorded by placing a check mark opposite the proper items in each form.

Schedule 23, Form 2 (fig. 1) lists the detector circuits in common use. This schedule, taken with Schedules 24 and 25, gives a complete description of the observer's receiving set. Thus, a receiving set using three steps of radio-frequency amplification, a nonregenerative electron-tube detector, and two steps of audio-frequency amplification would be indicated by checking item 3, Schedule 23; item 3, Schedule 24; and item 4, Schedule 25. Schedules 26 and 27 give a general description of the location of the receiving station. These factors are not of sufficient importance to warrant more detailed analysis. The items given under Schedules 28 and 29 give a simple description of the observer's antenna system.

The distance between the observer and the transmitting station is indicated in Schedule 8. An observer 101 miles away from the transmitting station is placed in the same zone as one 149 miles away. The mean distance of this zone is taken as 125 miles, and all observing stations in this zone are considered as located at this distance.

The divisions of the day given in Schedule 15 were chosen to take account of the variations of the seasons; for instance, during the winter months the period from 3 to 6 p. m. was considered as twilight, while the period from 6 to 9 p. m. was considered as nighttime. During the summer months the period from 6 to 9 p. m. was considered as twilight.

The number of items used in Schedules 16 to 19, inclusive, is small. A further subdivision would undoubtedly result in a different rating of identical conditions by different observers.

Schedule 20 was prepared with the view of including those types of obstacles to radio broadcasting which appeared to be most important at that time (August, 1922). The schedule is open to the objection that it permits the observer to record only the type of obstacle of greatest magnitude; this was changed in a revision of Form 3, used in later work, to include the greatest, second greatest, and third greatest obstacles. It is conceivable that one observer might be bothered with two or more obstacles of greater magnitude than a single obstacle encountered by another observer, in which case undue weight would be given the report of the observer who

FORM No. 2. BUREAU OF STANDARDS RADIO RANGE TESTS

[To be filled out and returned to the Bureau of Standards, Washington, D. C.]

Data on receiving station equipment

Operator's name and address _____

Call letters of station _____

(If you have a station license)

4–5–6–7. Receiving station number:

_____

23. Detector and circuit:
_____ (1) Single-circuit crystal.
_____ (2) Two-circuit crystal.
_____ (3) Single-circuit, with tube detector (nonregenerative).
_____ (4) Two-circuit, with tube (nonregenerative).
_____ (5) Single-circuit, tube, regenerative.
_____ (6) Two-circuit, tube, regenerative.

24. Audio-frequency amplification:
_____ (1) No amplification.
_____ (2) One step.
_____ (3) Two steps.
_____ (4) Three steps.

25. Radio-frequency amplification.
_____ (1) No amplification.
_____ (2) One step.
_____ (3) Two steps.
_____ (4) Three steps.

26. Location of station:
_____ (1) On a hill.
_____ (2) In a valley.
_____ (3) On a plain.

27. Immediate surroundings:
_____ (1) No buildings near (open country).
_____ (2) Buildings of moderate height (residential) in city or town.
_____ (3) High buildings (business district).

28–29. Antenna equipment:
_____ (11) Coil antenna or open antenna.

28. Height (if open antenna):
_____ (2) Not over 20 (feet).
_____ (3) Between 20–30.
_____ (4) Between 30–40.
_____ (5) Between 40–50.
_____ (6) Between 50–75.
_____ (7) Between 75–100.
_____ (8) Over 100.

29. Length (if open antenna):
_____ (2) Not over 50 (feet).
_____ (3) Between 50–75.
_____ (4) Between 75–100.
_____ (5) Between 100–125.
_____ (6) Between 125–150.
_____ (7) Over 150.

Do not mark here

4	5	6	7	-------	23	24	25	26	27	28	29

FIG. 1.—Form 2, describing observer's receiving equipment

encountered a single obstacle. However, some very interesting and valuable results have come from the analysis of data secured from this schedule.

Observers were instructed to take data at any time they desired to listen when the transmitting station was scheduled to be in operation. They were cautioned not to be guided in the choice of observation periods by any consideration as to whether or not conditions were likely to be favorable. After listening for the station under test for a period of about 15 minutes the observer filled out Form 3 regardless of whether or not the transmitting station was heard. Each observer took data on only one transmitting station.

Forms 2 and 3 were drawn up with the view of using tabulating cards and machines for the analysis of data. The numbered squares at the bottom of each form are for the purpose of editing and to facilitate the transfer of data from the form to the tabulating card. Each card as used in the tabulating machines contained all data describing a particular observation and all data describing the location, distance, and receiving equipment of the observer. The use of the tabulating machines and cards is described in Bureau of Standards Letter Circular No. 105, Application of Statistical Analysis to Radio Transmission Problems.[1]

During the months of August and September, 1922, a preliminary test was run on two transmitting stations—the University of Minnesota broadcasting station WLB, located at Minneapolis, Minn., and the Westinghouse Electric & Manufacturing Co. station KDKA, located at East Pittsburgh, Pa. About 60 observers for the Pittsburgh station were selected by the American Radio Relay League, and the names of about 70 observers for the Minneapolis station were obtained from the University of Minnesota. The purpose of the preliminary tests was to determine the suitability of the method and the forms shown in Figures 1 and 2. The results obtained from these preliminary tests, however, were such as to lead to the continuance of those begun on the Pittsburgh station with the view of obtaining data covering an entire year. The number of observers was increased by the efforts of the Westinghouse Electric & Manufacturing Co.

This paper contains the results of the analysis of over 8,500 observations taken by 101 observers on signals from station KDKA. The period of time covered is from August 1, 1922, to August 1, 1923. A frequency of 833 kilocycles (360 meters) was in use up to May 22, 1923, at which time a change was made to 950 kilocycles (316 meters). During the period covered by these observations the station normally

[1] A copy of this letter circular, which is a mimeographed pamphlet, may be obtained by anyone engaged in work of this kind, upon application to the Bureau of Standards, Department of Commerce, Washington, D. C.

FORM No. 3. BUREAU OF STANDARDS RADIO RANGE TESTS

[Send in one sheet for every observation regardless of whether or not the transmitting station is heard]

Name of observer and address----------

1-2-3. Transmitting station number:

4-5-6-7. Receiving station number:

8-9. Distance in miles:
-------- (01) 0 to 15 miles.
-------- (02) 15 to 25 miles.
-------- (03) 25 to 50 miles.
-------- (04) 50 to 75 miles.
-------- (05) 75 to 100 miles.
-------- (06) 100 to 150 miles.
-------- (07) 150 to 200 miles.
-------- (08) 200 to 300 miles.
-------- (09) 300 to 400 miles.
-------- (10) 400 to 500 miles.
-------- (11) 500 to 600 miles.
-------- (12) 600 to 700 miles.
-------- (13) 700 to 800 miles.
-------- (14) 800 to 900 miles.
-------- (15) 900 to 1,000 miles.
-------- (16) 1,000 to 1,250 miles.
-------- (17) 1,250 to 1,500 miles.
-------- (18) 1,500 to 1,750 miles.
-------- (19) 1,750 to 2,000 miles.
-------- (20) 2,000 to 2,500 miles.
-------- (21) 2,500 to 3,000 miles.
-------- (22) 3,000 to 3,500 miles.
-------- (23) 3,500 to 4,000 miles.

10-11-12-13-14. Date:

Month Day Year

15. Hour (standard time at receiving station):
-------- (1) Between 9 a. m. and 3 p. m.
-------- (2) Between 3 p. m. and 6 p. m.
-------- (3) Between 6 p. m. and 9 p. m.
-------- (4) Between 9 p. m. and 6 a. m.
-------- (5) Between 6 a. m. and 9 a. m.

16. Severity of atmospherics (or "static"):
-------- (1) None.
-------- (2) Slight.
-------- (3) Bad.
-------- (4) Very bad.
-------- (5) Local lightning.

17. Severity of fading:
-------- (0) No data.
-------- (1) None.
-------- (2) Slight.
-------- (3) Bad.
-------- (4) Very bad.

18. Average signal strength from station under test with no interference:
-------- (1) Not heard.
-------- (2) Weak.
-------- (3) Strong.
-------- (4) Very strong.

19. Average readability through all interference:
-------- (1) Not readable.
-------- (2) Just readable, or occasionally readable.
-------- (3) But little difficulty.
-------- (4) Easily readable.

20. Greatest obstacle to receipt:
-------- (0) Nature of obstacles not known.
-------- (1) No obstacles.
-------- (2) Atmospherics ("static").
-------- (3) Fading.
-------- (4) Amateur damped wave "spark" interference.
-------- (5) Amateur continuous wave, interrupted continuous wave, and phone interference.
-------- (6) Commercial station interference.
-------- (7) Interference from other broadcast stations.
-------- (8) Interference from other receiving sets.
-------- (9) Interference from power lines, etc.

21. Weather conditions:
-------- (1) Clear.
-------- (2) Partly cloudy.
-------- (3) Very cloudy.
-------- (4) Fog.
-------- (5) Rain.
-------- (6) Snow.
-------- (7) Sleet.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

FIG. 2.—Form 3, data of observation

had a current of 9 amperes in an antenna 32 meters (105 feet) above the counterpoise. The antenna was of the inverted L type, the top portion being 62 meters (200 feet) long, 70 meters (235 feet) above the ground, and supported above factory buildings. The power delivered to the antenna was normally 1,000 watts, with a modulation of from 50 to 90 per cent.

Certain arbitrary definitions were found to be helpful in the interpretation of data. As all receiving stations within certain distance limits were grouped together, reference is made to the zone in which a particular station is situated. Thus, a receiving station 60 miles from the transmitter is in the fourth zone. The zone distance is the distance to a point midway between the limits of the zone. Thus, on a graph in which the distance between transmitting set and observer was used as one coordinate, data for all stations in the fourth zone was plotted as if taken 62½ miles from the transmitting station. It was found advisable to group all data for the first, second, and third zones together, renaming the new zone the first zone, and all data for the fourth and fifth zones together, renaming this the second zone, etc.

In the analysis of schedules entitled "severity of atmospherics," "severity of fading," "average signal strength," and "average readability," the terms "mean fading," "mean intensity of atmospherics," "mean signal strength," and "mean readability" were used. "Mean fading" was calculated by giving weights of 0, 1, 2, and 3 to observations showing no fading, slight fading, bad fading, and very bad fading, respectively, adding the resultant figures, dividing by three times the total number of observations, and then multiplying by 100. Thus, any number of observations all of which show no fading would give a mean fading of 0. Any number all of which show very bad fading would give a mean fading of 100. Any number all of which show slight fading would give a mean fading of 33.3. "Mean strength of atmospherics," "mean signal strength," and "mean readability" were defined in a similar way. The results of analyses of these schedules are also expressed in terms of per cent, as "per cent of observations showing bad atmospherics," "per cent showing bad fading," etc. In obtaining these figures the observations showing very bad atmospherics and local lightning were included with equal weight with those showing bad atmospherics. Those showing very bad fading were grouped with those showing bad fading in the case of the schedule on fading. The ratio of the "bad" group to the total number of observations giving data on the schedule was expressed in per cent.

Three degrees of "reliability of reception" may be defined and calculated from the data obtained from Schedule 19 on average readability. The ratio of the number of observations in a given

zone showing signals easily readable to the total number containing data on readability expressed in per cent was called "first degree reliability." "First degree reliability" must be used in figuring the distance range of a station transmitting important information that must be received at a given time. The ratio of the sum of those showing but little difficulty and those showing signals easily readable to the total number in that zone containing data on readability expressed in per cent was called "second-degree reliability." Such a degree of "reliability" is ordinarily sufficient for broadcast entertain-

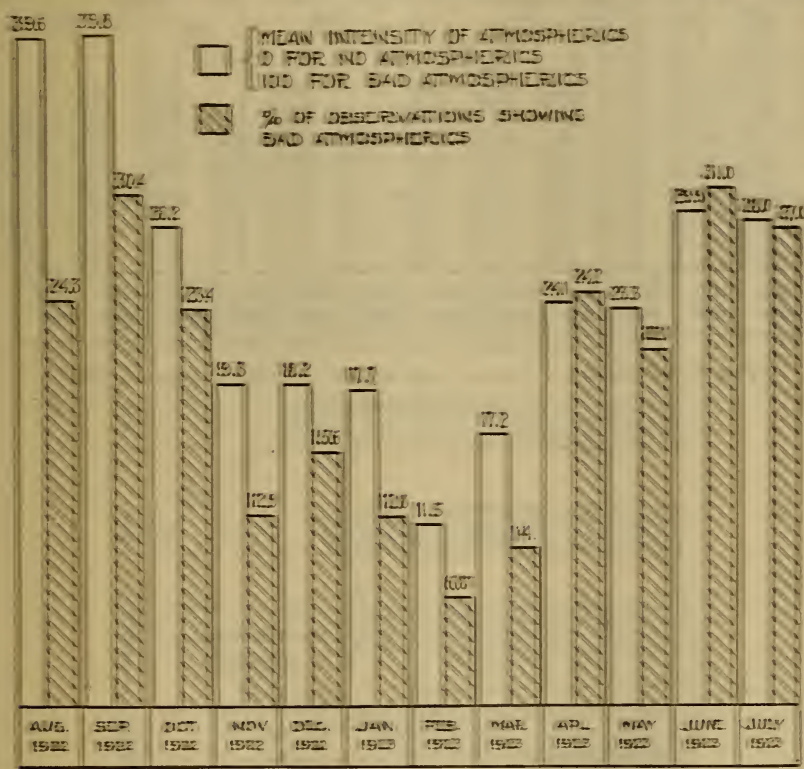

FIG. 3.—*Variation of strength of atmospherics, August 1, 1922, to July 27, 1923*

ment purposes. The ratio of all observations showing signals readable at all to the total number is defined as "third-degree reliability." Figures on "third-degree reliability" are of use in two-way communication, in which it is possible to ask for a repetition of what was missed on the first transmission.

The analysis of the data on obstacles to reception is expressed in terms of the ratio of the number of observations showing the prevalence of a given obstacle to the total number of observations giving data on this schedule.

Figures 3 and 4 show graphically the analysis of data obtained from the schedule on atmospherics (15) and the schedule on fading (17)

The figures show the variation of both "mean" and "percentage bad" atmospherics and fading throughout the year. Fading appears the worst during the fall months, although the variation is not great. The variation of atmospherics from month to month is much more marked.

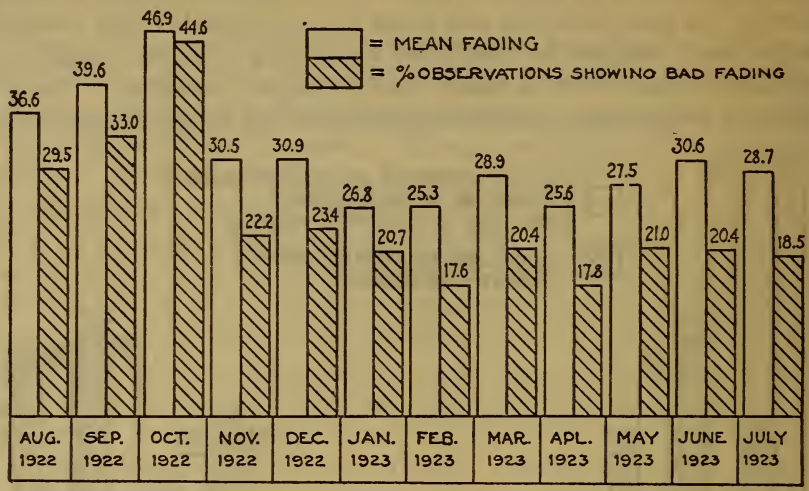

FIG. 4.—*Variation of fading, from August 1, 1922, to July 31, 1923*

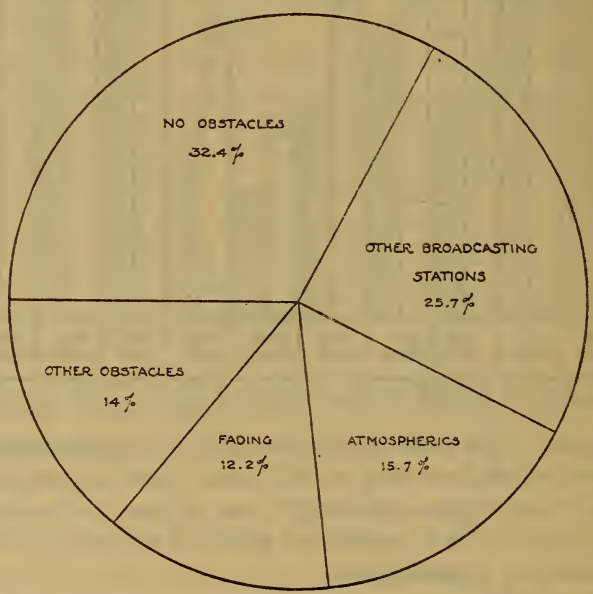

FIG. 5.—*Relative magnitude of obstacles to reception, August 1, 1922, to July 31, 1923, based on 7,372 observations*

Figure 5 shows the relative magnitude of obstacles to reception as shown by all observations taken throughout the year. Obstacles, such as interference from receiving sets, amateur transmitting sets, commercial transmitting sets, and power lines, were individually of

such small magnitude that they are grouped under the heading "other obstacles," which constitutes 14 per cent of the total. A

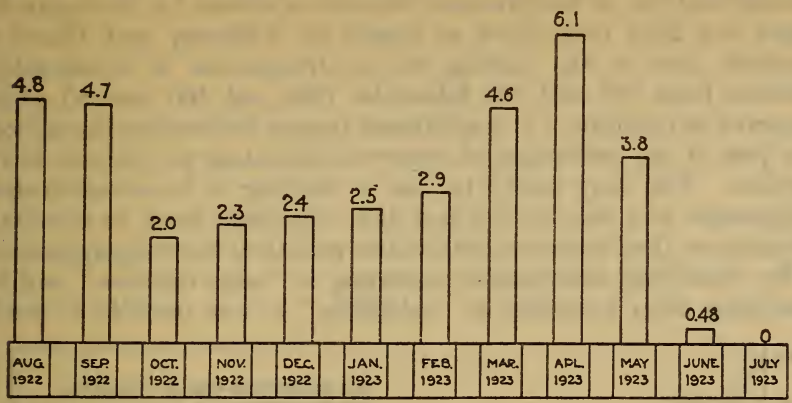

FIG. 6.—*Variation of interference from other receiving sets August 1, 1922, to July 31, 1923; percentage of observations showing this as greatest obstacle to reception*

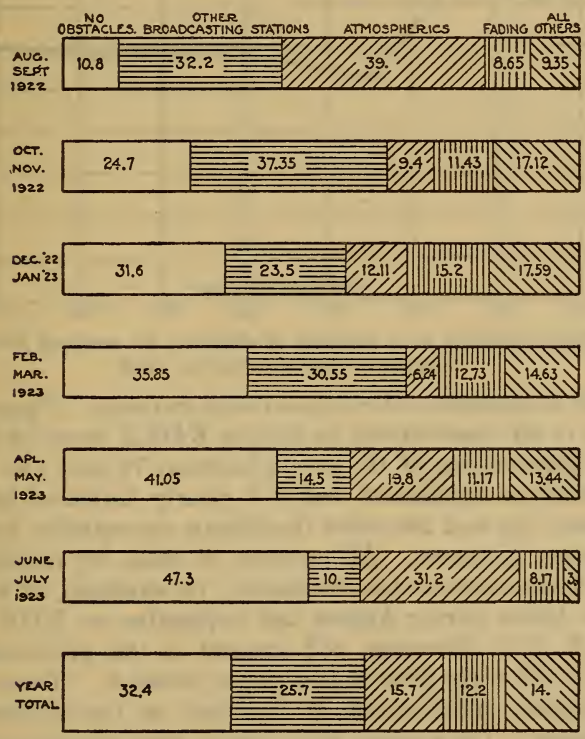

FIG. 7.—*Relative magnitude of obstacles to reception, grouped in bimonthly periods, August 1, 1922, to July 31, 1923, based on 7,352 observations*

special analysis of interference from receiving sets was made. Figure 6 shows the variation of the per cent of observations showing this type of interference by months. Figure 7 shows an analysis of the

same data as Figure 5 by bimonthly periods. The decrease in the percentage of observations recording interference from other broadcasting stations as the greatest obstacle as shown by the figure for April and May over those as shown for February and March is probably due to the shifting of the frequencies of broadcasting stations from 833 and 750 kilocycles (360 and 400 meters) which occurred at this time. It is of interest to note the increase throughout the year of the percentage of observers indicating no obstacle to reception. This may partly be due to shifting of broadcast-station frequencies and also to the fact that observers learn to eliminate obstacles as they become more familiar with their receiving apparatus.

By classifying observations according to "zone distance" and by analyzing them according to "reliability" it was possible to study

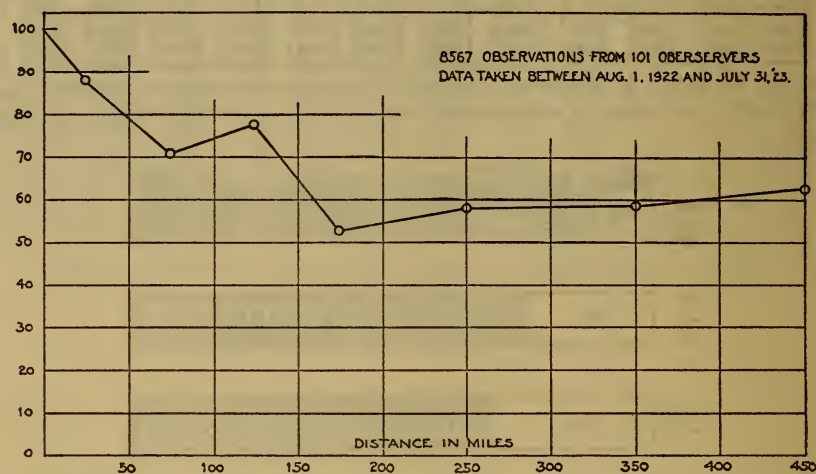

FIG. 8.—*Mean reliability as a function of distance, as averaged for the year August 1, 1922, to July 31, 1923*

the variation of reliability of reception with distance. Figure 8 shows the analysis of all observations on station KDKA covering the entire year. The fluctuations of the curve between 75 and 175 miles are not to be taken as significant, but it is clearly indicated that somewhere between 100 and 200 miles the signals are actually less reliable than at greater distances. All analyses of data for reliability as a function of distance show this peculiarity; for example, an analysis of observations taken during August and September on KDKA and on station WLB (619 kilocycles, 485 meters) in the preliminary tests mentioned in the early part of this paper shows it. These data are from two entirely different sets of observers on two different transmitting stations. The opinion that signals from distant stations are often of greater intensity than signals from stations of similar power, but located comparatively near the observer, has often been expressed. The data given here appear to verify this opinion.

WASHINGTON, June 2, 1925.