JOURNAL OF RESEARCH of the National Bureau of Standards—D. Radio Propagation
Vol. 66D, No. 1, January–February 1962

VHF Radio Propagation Data for the Cedar Rapids-Sterling, Anchorage-Barrow, and Fargo-Churchill Test Paths, April 1951 Through June 1958*

George R. Sugar and Kenneth W. Sullivan

Contribution From Central Radio Propagation Laboratory, National Bureau of Standards, Boulder, Colo.

(Received June 8, 1961; revised July 26, 1961)

The data tabulated herein are hourly median values of *system loss* for ionospheric scatter propagation and for sporadic-E propagation. In addition, the duration of each occurrence of sporadic-E propagation is indicated. The following data are included:

Ionospheric Scatter Propagation
- Cedar Rapids to Sterling
  - 27.775 Mc/s, April 1954 through January 1955, May 1955 through February 1956.
  - 49.800 Mc/s, April 1951 through June 1958.
  - 107.800 Mc/s, January 1952 through January 1953.
- Anchorage to Barrow
  - 48.870 Mc/s, September 1951 through June 1953.
- Fargo to Churchill
  - 49.700 Mc/s, September 1951 through March 1953.

Sporadic-E Propagation
- Cedar Rapids to Sterling
  - 49.800 Mc/s, April 1951 through June 1958.

The experimental techniques used are briefly described and the accuracy of the results is discussed.

1. Introduction

During the past nine years numerous studies of VHF ionospheric scatter propagation have been performed at the National Bureau of Standards and many of the results of this extensive program of research have already been published. However, thus far there has not been any publication of most of the basic signal strength data taken during the program. This note, containing the basic observations for some of the experimental paths, has been prepared in order to make these basic data readily available to those concerned with studies of ionospheric propagation.

The data tabulated are primarily the hourly values of *system loss* [1] for VHF ionospheric scatter propagation (D-region scatter) over the test paths listed in table 1. These data do not include all of the measurements made over these test paths, but represent a homogeneous set of results which can be readily intercompared since they were all made under similar experimental conditions.

A secondary result of the observing program was the collection of data on sporadic-E propagation. Included herein are tabulations of occurrences of sporadic-E propagation at 49.8 Mc/s over the Cedar Rapids to Sterling path during the period April 1951 through June 1958.

The description of the experimental arrangements and the general results of the observing program have already been published [Bailey, Bateman, and Kirby, 1955]. In addition, a recent paper [IRE—Joint Technical Advisory Committee, 1960] has included an extensive survey of ionospheric scatter research. In this note, therefore, no attempt will be made to summarize previous work on ionospheric scatter propagation. The discussion herein is limited to those aspects of the NBS program related to the gathering and reduction of the data.

2. Observing Techniques

General data on the various test paths are given in table 1. In establishing the basic observing program, considerable effort was devoted to setting up the test paths and equipment in a manner which would facilitate direct intercomparison of the data.

*A digest of NBS Technical Note 79.
[1] System loss is defined in section 5.

TABLE 1. *Details of experimental paths*

	Cedar Rapids-Sterling						Anchorage-Barrow		Fargo-Churchill	
Frequency, Mc/s	27.775		49.800[a]		107.800		48.870		49.700	
Date of Commencement	May 6, 1953		January 23, 1951		December 4, 1951		August 28, 1951		August 29, 1951	
Date of Termination	February 29, 1956		June 30, 1958		January 31, 1953		June 30, 1953		March 31, 1953	
Transmitter location coordinates of site	Cedar Rapids, Iowa 41°52'N; 91°41'W						Anchorage, Alaska 61°17'N; 149°42'W		Fargo, North Dakota 46°55'N; 96°46' W	
Receiver location coordinates of site	Sterling, Virginia 38°59'N; 77°29'W						Barrow, Alaska 71°18'N;156°45'W		Churchill, Manitoba 58°44'N; 94°05' W	
Surface path length (great circle)	1,243 km 773 st mi						1,156 km 718 st mi		1,326 km 824 st mi	
Geographic coordinates of path midpoint	40°39'N; 84°26'W						66°20'N;152°31'W		52°50'N; 95°36'W	
Geomagnetic latitude of path midpoint	51°38'N						65°02'N		62°42'N	
True azimuth of transmitter from receiver	289°30'						160°55'		188°56'	
True azimuth of receiver from transmitter	100°17'						347°24'		6°47'	
Antenna Design Data, rhombic type at all locations	Transmitting	Receiving	Transmitting	Receiving	Transmitting	Receiving	Transmitting	Receiving	Transmitting	Receiving
Ionospheric height at path midpoint, kilometers	105		105		105		83		95	
Elevation angle for above height, degrees	7.0		7.0		7.0		5.7		5.4	
Height, feet	73		40.5	41.2	18.7		35.5[b]	50.5	51.8	
Leg length, feet	897		500		231	230	500		500	
Tilt angle, degrees	83.0		83.0		83.0		81.8		82.1	
Gain relative to half-wave dipole at same height, decibels, Computed	17.2		17.2		17.2		17.8	18.3	18.1	
Measured	--	--	17.2	18.0	18.1	--	14[c]	--	18.9	--

[a] 49.600 Mc/s used from January 17, 1952 through March 31, 1952.
[b] Site had a 2.4° downgrade.
[c] The Anchorage site had a very irregular foreground.

Similar equipment was used wherever possible for the various paths and frequencies. The antennas for the various frequencies were all rhombic antennas with their critical dimensions chosen to be proportional to the operating wavelength. The receivers and strip-chart recorders were calibrated daily through the use of standard c-w signal generators which were themselves intercompared and checked against other standards. Transmitter power output was in most cases computed by applying an estimated efficiency factor to the measured power input to the final stage of the transmitter. The data were corrected to account for transmitter power output variations, losses in transmission lines, and to remove the effects of noise contamination at low signal-to-noise ratios.

3. Preparation of Data

The strip-chart records of received signal strength were manually scaled to determine the hourly median signal.[2] These hourly values were then corrected for transmission line losses, etc., and the monthly medians of the hourly medians were determined. (The data were not corrected for differences in antenna gains, since no straightforward way of doing so was apparent.) The data were prepared from tabulations of hourly and monthly data in the following manner: Hollerith cards were punched from the original tabulations and the accuracy of the card punching was verified. The data on cards were then processed to convert them to *system loss* and the results tabulated for publication. Detailed information on the format of these tabulations is given in section 5.

4. Validity of Data

The experimental factors which have affected the validity of the system loss data can be divided into three categories. First, there are the errors inherent in the calibration of the apparatus and the uncertainties in using the calibrations to correct the system loss data. For example, if the actual gain of an antenna differs significantly from the design value, how will this affect the received signal strength? The second category includes malfunctions in the apparatus such as receiver frequency drift, variations in antenna characteristics due to icing, etc. The third category includes problems associated with identification of the mode of propagation being observed. For example, auroral propagation was present at times in addition to ionospheric scatter propagation and its presence may have been not recognized.

[2] An unpublished study by J. C. Blair of NBS demonstrated that the averaging and scaling techniques used contribute no more than one decibel error to the determination of the median signal *voltage*. A direct measurement of the median received *power* has indicated that the conversion from *median voltage* to *median power* (using $P=E^2/R$) can give a result which is as much as two decibels less than the measured median power [Boggs and Hekimian, 1958].

4.1. Inherent System Errors

The measurement errors associated with a normal set of observations may be divided into three classes: calibration errors at the transmitting station, calibration errors at the receiving station, and errors associated with scaling the strip-chart records. The estimated rms error for each of these three classes is about 1 db and thus the rms error of a single observation is about 2 db. The error of one measurement relative to another, for observations with the same apparatus, will be slightly smaller in most cases.

4.2. Equipment Malfunctions

In cases where the performance of the apparatus was abnormal, the errors in system calibration were probably much greater than those given above. In some cases it was possible to correct the data to partially account for malfunctions. This was done whenever a suitable basis for applying the correction could be found. In a few cases corrections as large as 15 db were applied. (This was done for some of the Barrow data by using the observed galactic noise level as a calibration signal for the receiving system.)

The reliability of data from the Anchorage-Barrow path is substantially less than for the other two paths because of antenna siting and antenna icing problems. The rms error for a single observation on this path is estimated to be about 4 db.

4.3. Overall System Accuracy

An indication of the overall accuracy of the experimental data can be obtained by comparing the results from two similar but independent test paths. The opportunity to do so did not exist within the framework of the original scatter program at NBS, since the various test paths and frequencies were chosen to be quite different. However, toward the end of the observing program data became available from a 50 Mc/s ionospheric scatter test circuit between Long Branch, Ill., and Boulder, Colo., having apparatus similar to that in use for the Cedar Rapids to Sterling test path and having nearly the same midpoint latitude as the latter path. When a preliminary comparison was made between data from these two paths, differences as great as 10 db between corresponding values of monthly medians were noted, whereas much smaller differences were expected. A more complete comparison disclosed that over the 10-month period from September 1957 through June 1958, the median difference between signals on the two paths was 5 db, with the stronger signals being received over the Long Branch-Boulder path. The hour-by-hour differences between paths showed a large variation. For example, during June 1958, the median difference for the month was 4 db. However, the span between the upper and lower deciles of the individual hourly differences was 11 db. (The June data are illustrated in figure 1. The data have been edited to eliminate occurrences of E_s propagation and other unusual propagation effects.)

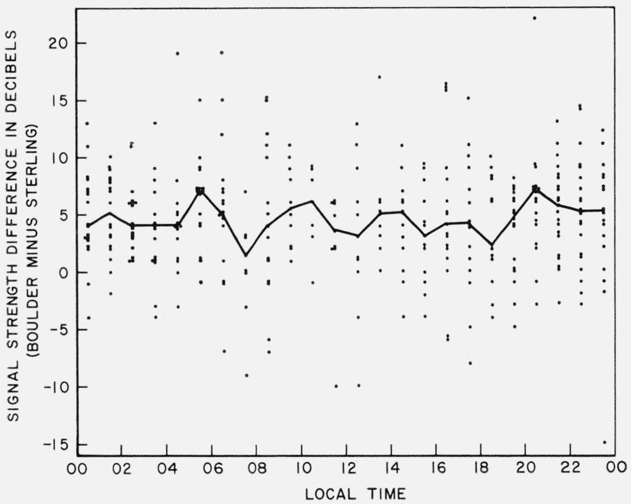

FIGURE 1. *Comparison of signal strengths over the Long Branch—Boulder and Cedar Rapids—Sterling paths for June 1958.*

The experimental arrangements and data for both paths have been examined in an attempt to reconcile the observed differences between paths. The following factors appear to contribute to the differences between the two paths.

a. Path Length

The Long Branch-Boulder path is 1295 km in length and the Cedar Rapids-Sterling path is 1245 km in length. It is estimated that signal decrease of 0.2 db will be associated with the increase in path length. (See figure I–2 in reference [IRE—Joint Technical Advisory Committee, 1960].)

b. Antenna Aiming

The antennas on the Cedar Rapids-Sterling path were designed for a scattering region centered at a height of 105 km whereas the antennas for the Long Branch-Boulder path were designed for a height of 85 km. Since the scattering region is in fact centered at the lower height, the antennas at Long Branch and Boulder are more favorably oriented than those at Cedar Rapids and Sterling. As a result, a larger scattering volume is utilized for the Long Branch-Boulder path. It is estimated that this increased scattering volume will account for an 0.8 db increase in signal on that path.

c. Antenna Gain

The rhombic antennas for the two paths are similar in that they have the same leg length. However, they are designed for different take-off angles and the designs have been optimized in different ways. This results in the Long Branch and Boulder antennas each having a design gain at the maximum of the main lobe which is 2.3 db greater than that of the Cedar Rapids and Sterling antennas. In addition, it is known that the sag of the wire for the Sterling antenna was substantially greater than that at Long Branch or Boulder. The sag—about 8 ft—is estimated to reduce the gain of the Sterling antenna by 1.2 db [Cottony, 1953] relative to the Boulder antenna, which has a sag of only 4 ft. (No information is available on the sag of the antenna at Cedar Rapids.) The net effect of these gain differences can be estimated by assuming that for scatter propagation the effective gain of each antenna will vary as the square root of its plane-wave gain. The estimated net gain is 2.9 db for the Long Branch-Boulder path relative to the Cedar Rapids-Sterling path.

The total contribution of these factors is 3.5 db favoring the Long Branch-Boulder path. This estimate is to be compared with the observed median difference between paths of 5 db in the same direction. It is estimated that the rms error associated with the median of all observations on either path is 1.6 db. The rms error of the difference between medians would then be about 2.2 db. It therefore appears that the 1.5 db disagreement between the observed path differences and the estimated path differences is less than the observing error.

5. Description of Tables

The basic data tabulated[3] are hourly median values of *system loss* for ionospheric scatter propagation and for sporadic-E propagation. In addition, the duration of each occurrence of sporadic-E propagation is indicated. The following data are included:

Ionospheric Scatter Propagation
- Cedar Rapids to Sterling
  - 27.775 Mc/s, April 1954 through January 1955, May 1955 through February 1956.
  - 49.800 Mc/s, April 1951 through June 1958.
  - 107.800 Mc/s, January 1952 through January 1953.
- Anchorage to Barrow
  - 48.870 Mc/s, September 1951 through June 1953.
- Fargo to Churchill
  - 49.700 Mc/s, September 1951 through March 1953.

Sporadic-E Propagation
- Cedar Rapids to Sterling
  - 49.800 Mc/s, April 1951 through June 1958.

5.1. Definition of System Loss

The basic quantity tabulated was chosen to be the *system loss* in order to facilitate the comparison of results for various paths and frequencies. If p_a is the radiofrequency signal power available at the ter-

[3] The appendix contains two examples of the data tabulations.

minals of a receiving antenna for a given power input, p_t, to the terminals of a transmitting antenna, then the ratio p_t/p_a is called the *system loss* [Norton, 1959]. The *system loss in decibels*, $10 \log_{10} (p_t/p_a)$, is the quantity listed in the tables.

In preparing the tabulations, all known corrections except for antennas gain differences, have been applied so that insofar as possible the data are free of variations due to differences, changes, or malfunctions in the equipment.

5.2. Description of Ionospheric Scatter Propagation Data

Each tabulation sheet contains all of the scatter observations for one month for a specific path and frequency. The hour of observation is given across the top of the table and the day at the left edge. Letters are included in some of the boxes to indicate various equipment malfunctions and other qualifications. The letters have the following meanings.

C indicates the presence of a signal due to tropospheric propagation as deduced from signal fading characteristics.

D indicates that the true value was greater than the given numerical value.

E indicates that the true value was less than the the given numerical value.

I indicates that the numerical value given was obtained by interpolation of data from adjacent hours.

P indicates that the numerical value given is for only part of an hour.

Q indicates the presence of manmade or atmospheric noise or interference.

R indicates a loss of data due to receiver malfunction.

T indicates a loss of data due to transmitter malfunction.

U indicates that the given numerical value is an uncertain one and may be inaccurate.

The absence of a numerical value in the box for a particular hour indicates that no observation was possible, and usually a qualifying letter is given in the box to indicate the reason for the lack of data. An empty box indicates that no scatter observation was possible, usually because of the presence of sporadic-E propagation during the whole hour.

Monthly medians of the hourly median values are given at the bottom of the tabulation sheet (MED) together with the count (NO) of the number of hourly values used in computing the monthly median. The median is defined here as the value equalled or exceeded by one-half of the hourly values. Uncertain values (U) were not used in computing these medians.

5.3. Description of Sporadic-E Propagation Data

Each table contains a listing of the system loss observed for the hours during which E_s propagation occurred during a month. The system loss given is the median for the hour, regardless of how long E_s propagation lasted. Where no E_s propagation occurred during a given hour, the corresponding box is left blank. The duration of each occurrence of E_s propagation, in tenths of an hour, is indicated in the upper right corner of the box. The numeral 1 indicates a duration of 1 through 6 min, 2 indicates a duration of 7 through 12 min, etc., with 10 indicating a duration of 55 through 60 min.

References

Bailey, D. K., R. Bateman, and R. C. Kirby, Radio transmission at VHF by scattering and other processes in the lower ionosphere, Proc. IRE **43,** 1181–1230 (October 1955).

Boggs, G. F., and N. C. Hekimian, informal communication, National Bureau of Standards (September 1958).

Cottony, H. V., informal communication, National Bureau of Standards (June 1953).

I.R.E. Joint Technical Advisory Committee, Radio transmission by ionospheric and tropospheric scatter: I. Ionospheric scatter transmission, Proc. IRE **48,** 5–29 (January 1960).

Norton, K. A., System loss in radio wave propagation, J. Research NBS **63D** (Radio Prop.), No. 1, 53–73 (July–August 1959).

6. Appendix—Examples of Data Tables

TABLE 2

IONOSPHERIC SCATTER PROPAGATION

CEDAR RAPIDS TO STERLING 49.800 MC/S MAY, 1954

HOURLY MEDIAN SYSTEM LOSS IN DECIBELS 75W TIME

	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
01	190	189	188	186	187	186	184	180	179	182	182	179	176	177	179	181	185	185	188	192	194	193	190	190
02	186	184	182	183	186	189	188	185	181	180	177	176	178	178	179	183	189	192	196	196	191	190	191	190
03	189	188	188	188	189	189	187	186	185	187	183	178	183	184	181	185	190	186	190	193	195	194	195	194
04	192	191	188	189	188	187	186	186	186	187	187	188	189	190	191	192	192	190	194	194	195	193	191	191
05	191	188	187	184	185	183	180	180	180	180	180	181	182	181	180	182	185	187	186	191	192	I 191		I 191
06	188	187	187	185	184	184	184	185	182	181	183	184	PR 181	R	R	184	188	192	193	193	194	194	192	190
07	188	186	186	188	187	185	186	184	183	182	T 183	T	PT 188	189	IT 190	192	193	195	196	196	196	194	193	193
08	192	191	190	189	189	189	188	188	188	188	188	187	189	189	190	193	194	195	198	197	198	195	194	194
09	193	191	190	189	188	187	186	185	185	184	180	176	176	175	178	183	182	183	188	192	194	193	192	190
10	186	187	185	183	182	183	IT 184	184	182	183	183	182	184	PT 183	T	T	T	187	184	192	194	190	188	188
11	185	185	185	184	184	181	178	177	177	180	PT 180	T	R	T	T	T	PT 182	187	179	185	190	189	191	189
12	188	188	187	185	185	183	176	176	I 176	172	179	178	180	182	178	176	185	184	187	I 188	190	190	190	190
13	189	188	187	185	184	183	179	175			182		I 174	174	179	177	182	181					189	189
14	187	187	184	184	184	185	180	182	IT 182	182	I 183	I 183	182	183	186	189	186	I 190				194	194	192
15	192	192	189	189	188	185	184	185	185	184	184	184	185	187	188	191	193	191	194	195	195	196	195	191
16	188	185	183	182	182	182	182	182	182	183	179	172	176	176	176	180	184	183	186	192	193	192	190	189
17	188	186	182	182	180	183	184	I 183	I 183	182	IT 180			I 172	177	178	180	187	187	191	192	194	193	193
18	191	191	189	187	184	186	182	181	182	I 181	I 181	I 181	I 178	177	IT 179	IT 181	178	182	IT 194	IT 195	IT 195	IT 194	187	191
19	191	189	187	185	186	187	186	185	183	180	180	IT 178	IT 177	173	183	180	182	180	187	192	193	192	191	187
20	185	184	182	184	184	183	181	180	181	180	176	176	179	178	182	183	IT 184	181	185	190	190	190	187	186
21	186	186	186	186	183	183	181	181	182	181	180	178	178	179	178	176	175	180	187	189	190	190	190	188
22	186	184	184	183	182	184	184	178	176	179	IT 176	173	173	176	177	178	181	187	189	190	190	188	188	187
23	186	184	184	185	185	186	187	186	183	179	I 179	179	175	178	177	176	180	182	186	190	193	194	190	187
24	185	185	179	180	181	181	181	181	181	181	180	181	IT 182	179	179	180	183	184	I 185	I 189	190	190	188	188
25	188	187	186	186	185	185	185	186	TP 186	182	IT 182	183	181	183	181	185	187	186	192	192	189	191	192	187
26	186	184	183	184	184	185	185	187	185	184	IT 182	IT 177	173	176	I 179		I 182	186	189	192	191	193	190	189
27	187	184	184	184	183	184	187	184	185	184	183	ITP 187	T	T	PT 181	T	PT 189	189	190	193	193	191	188	186
28	185	183	184	PT 186	T	PT 181	183	182	I 181	T	T	PT		I 182	184	185	188	188	190	191	192	190	187	188
29	185	185	183	183	182	181	181	181	178	180	182	182	178	178	177	177	181	185	188	189	190	189	189	187
30	186	181	182	182	176	179	176	177	178	178	176	174	171	170	174	178	179	183	184	186	187	186	184	181
31	180	180	183	183	182	180	180	178	179	179	179	180	181	183	184	184	187	190	192	191	193	192	189	182
MED	188	186	185	185	184	184	184	182	182	181	181	180	179	179	179	182	185	186	188	192	193	192	190	189
NO	31	31	31	31	30	31	31	30	30	29	30	26	27	28	28	27	30	31	29	29	29	30	30	31
RAN																								

Table 3

SPORADIC E PROPAGATION

CEDAR RAPIDS TO STERLING 49.800 MC/S MAY, 1954

HOURLY MEDIAN SYSTEM LOSS IN DECIBELS 75W TIME

	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
01																								
02																								
03																								
04																								
05																						6 160	E10 137	3 168
06																								
07																								
08																								
09																								
10																								
11																								
12																				8 173				
13									10 137	7 152		5 160	4 171						8 147	E10 137	5 171	4 175		
14											5 166	7 155						2 189	7 161	9 143	6 154			
15																								
16																								
17								1 182	2 183			6 160	E10 137	4 168										
18										3 178	2 179	3 180	6 171											
19																								
20																								
21																								
22																								
23											8 151													
24																			6 152	2 189				
25																								
26															2 178	E 8 137	3 182							
27																								
28									2 174	5 154		3 148	E10 137	3 179										
29																								
30																								
31																								
MED																								
NO																								
RAN																								

(Paper 66D1–179)