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Electrical Engineering Research Laboratory
The University of Texas

Report No. 69

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Propagation Studies at 8.6-Millimeter Wavelength
on 3.5-, 7- and 12-Mile Paths

Prepared Under Office of Naval Research Contract Nonr 375(01)

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.76 cm = 3500 mc

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PROPAGATION STUDIES AT 8.6-MILLIMETER WAVELENGTH
ON 3.5-, 7- AND 12-MILE PATHS

by

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ABSTRACT

This report describes the results of radio propagation studies at 8.6-millimeter wavelength over paths of approximately 3.5, 7 and 12 miles. The transmission over these paths was only a decibel or two below the free space values, with a large part of the difference explained by the oxygen and water vapor absorption. Light rain showers along the path caused a large attenuation of the signal and heavy showers eliminated transmission.

A summary of the results of the measurements is tabulated below:

Path length in miles	3.5	7.2	7.2	12.1
Number of samples	6	10	9	11
Antenna gain in db	30	33/27	30	30
Median measured signal in db below free space	0.8	1.3	2.0	2.4
Median water vapor and oxygen absorption	0.4	0.7	0.8	1.6
Median difference between measured and calculated signals in db	0.4	0.6	1.2	0.8
Median maximum to minimum of time variation in db	0.8	0.7	1.4	2.4

I. INTRODUCTION

This study of the propagation of 8.6-millimeter wave was carried out for the purpose of determining basic data on the propagation of this wavelength over considerable distances.

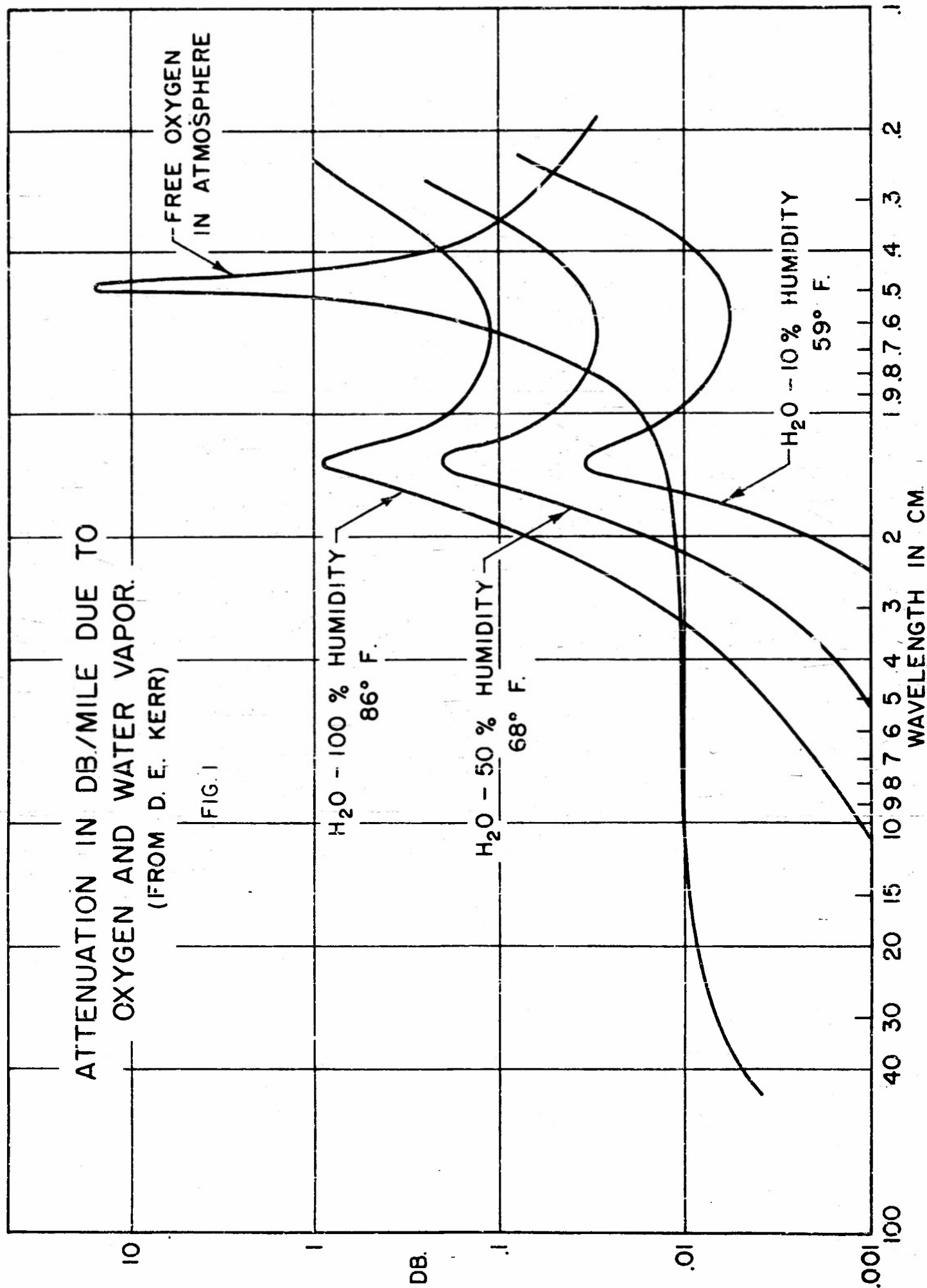
This particular wavelength falls between the wavelength of 1.2 centimeter for which absorption due to water vapor is maximum and the wavelength of 0.5 centimeter for which absorption due to the free oxygen is maximum. The variations of the water vapor and oxygen absorption as a function of frequency as obtained from data given by Kerr [1] are shown in Figure 1. This curve indicates that a small but significant amount of absorption would be caused by both the water vapor and the oxygen.

The scattering of the radio wave by rain drop causes, however, a very large loss of signal at this wavelength, as shown in Figure 2, taken from a paper by G. E. Mueller [2]. Mueller's measurements taken over a 1200-foot path show that moderate rains would produce large signal losses over the path lengths used in this present study.

ATTENUATION IN DB/MILE DUE TO OXYGEN AND WATER VAPOR.

(FROM D. E. KERR)

FIG. 1



In fog, however, the loss due to water drop scattering would be comparatively small. This means that the 8.6-millimeter link would be expected to be satisfactory a greater percentage of time than an optical link.

II. RADIO PATHS

The transmitter for each of the three paths used was located on the 25th floor of the Main Building Tower of The University at an elevation of approximately 250 feet above the local ground.

For the 3.5-mile path, the receiving equipment was on top of a truck on Mount Larson, site of KTBC-TV antenna, approximately west of the transmitter.

For the 7.2-mile path, the receiver was located on a 50-foot tower with an elevator for taking measurements from about 3 to 48 feet above ground. The receiver was north of the transmitter.

For the 12.1-mile path, the receiver was located on a 10-ft tower adjacent to the Bell System Microwave Relay tower at Three Points, near Pflugerville, Texas. This small tower permitted measurements for receiver heights between 3 and 12 feet.

Profiles of the three paths are shown in Figure 3.

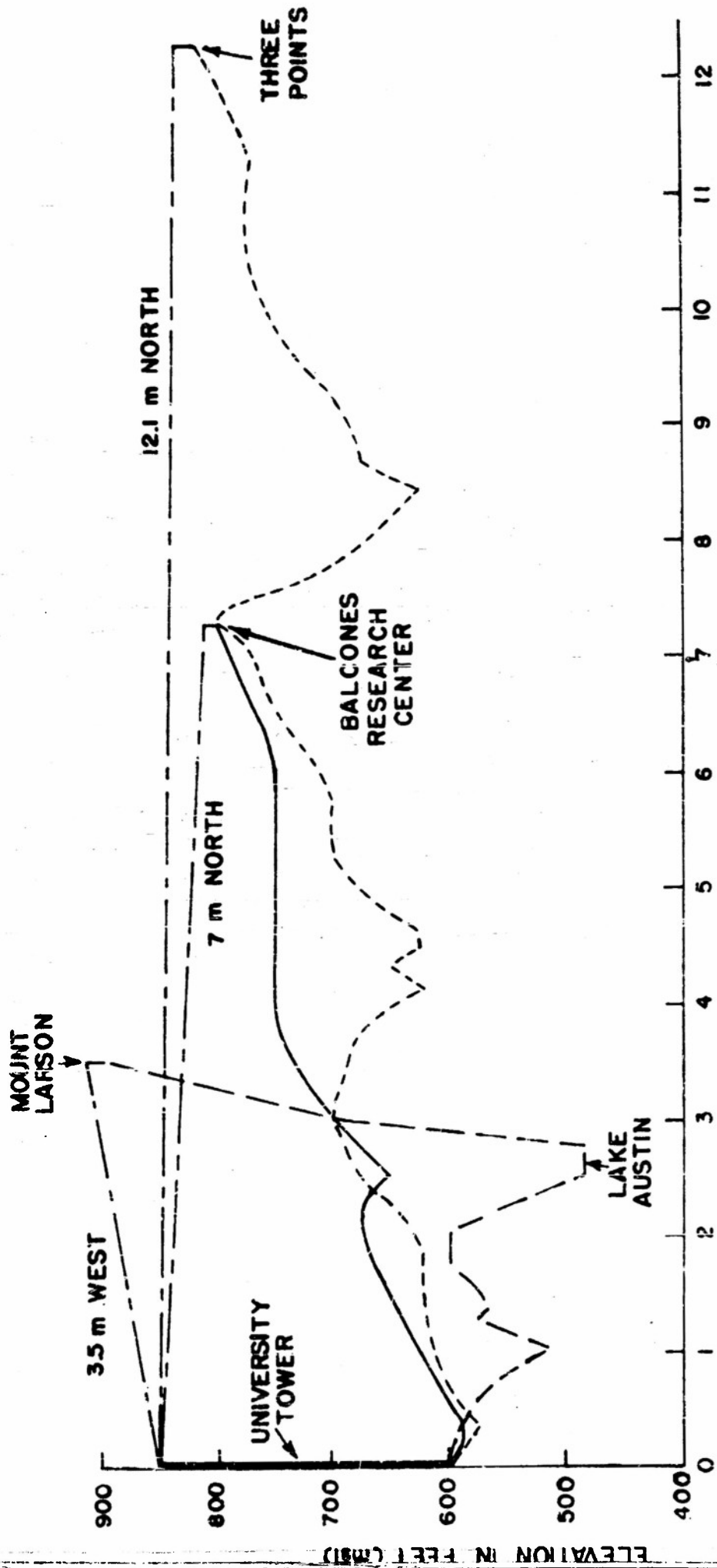
III. RADIO EQUIPMENT

The transmitter and receiver have been described in a previous report [3]. A reflex klystron (Raytheon QK 291) operating as a cw generator was used as a signal source at the transmitter. Relative power output was monitored by a bolometer and a conventional bridge circuit.

Another reflex klystron (Raytheon QK 291) used as the local oscillator in the receiver was frequency modulated at a rate of 120 cycles per second over a frequency range of 20 megacycles. The mean frequency of the local oscillator was adjusted to heterodyne with the signal from the transmitter at the mid-frequency of the i-f amplifier in the receiver. The resulting pulses, which were a function of the i-f pass band, were demodulated and integrated and applied to a vacuum tube voltmeter which drove an Esterline-Angus Recorder.

For reference purposes, a 1000-ft path was set-up adjacent to the Electrical Engineering Research Laboratory buildings. The transmitter was 15 feet above ground and the receiver was on the elevator of the 50-foot tower. As described in a previous report for this short path [4], the reflection coefficient of the ground was a maximum of 0.2 for low receiver heights and decreased sharply with increasing angle of incidence of the wave on the ground. The free space signal for the 1000-ft path was taken as the average of the maxima and minima near the ground where the height-gain curve was fairly well established. No time variations at a given height were noted on the 1000-ft path.

For each of the three paths, measurements were made with identical conical horn antennas each having a gain of approximately 30 decibels. In addition,



DISTANCE FROM TRANSMITTER IN MILES

FIGURE 3

PATH PROFILES

measurements were made on the 7-mile path using a parabolic reflector at the transmitter with a gain of 33 decibels and a small horn at the receiver with a gain of 27 decibels. The antenna gains for this system will be indicated by 33/27.

IV. HEIGHT-GAIN CURVES

Receiver height-gain curves were taken for the 7- and 12-mile paths, where open fields near the receiving sites indicated the possibility of a significant amount of ground reflection. Typical curves of signal-strength as a function of receiver heights up to 12 feet are shown in Figure 4 for these two paths.

This lower portion of the 7-mile path curves showed some characteristics of specular reflection, but the upper portion did not. The maximum reflection coefficient appeared to be about 0.2 at the lower receiver height and distinctly less at higher receiver positions. The limited range of receiver height on the 12-mile path showed the same characteristics as the lower portion of the 7-mile path.

The curves were reproducible on any single day when the time variations did not obscure their features. The curves were, in general reproducible from day to day, although occasionally, there was vertical shift in the lobe structure.

The direct ray signal level was determined as the average of the maxima and minima field strengths in the region of receiver heights where the lobe structure was well defined. The values thus obtained are those assigned to the particular day and compared to the free space values determined from the 1000-ft measurement using the inverse distance relationship.

V. TIME VARIATIONS

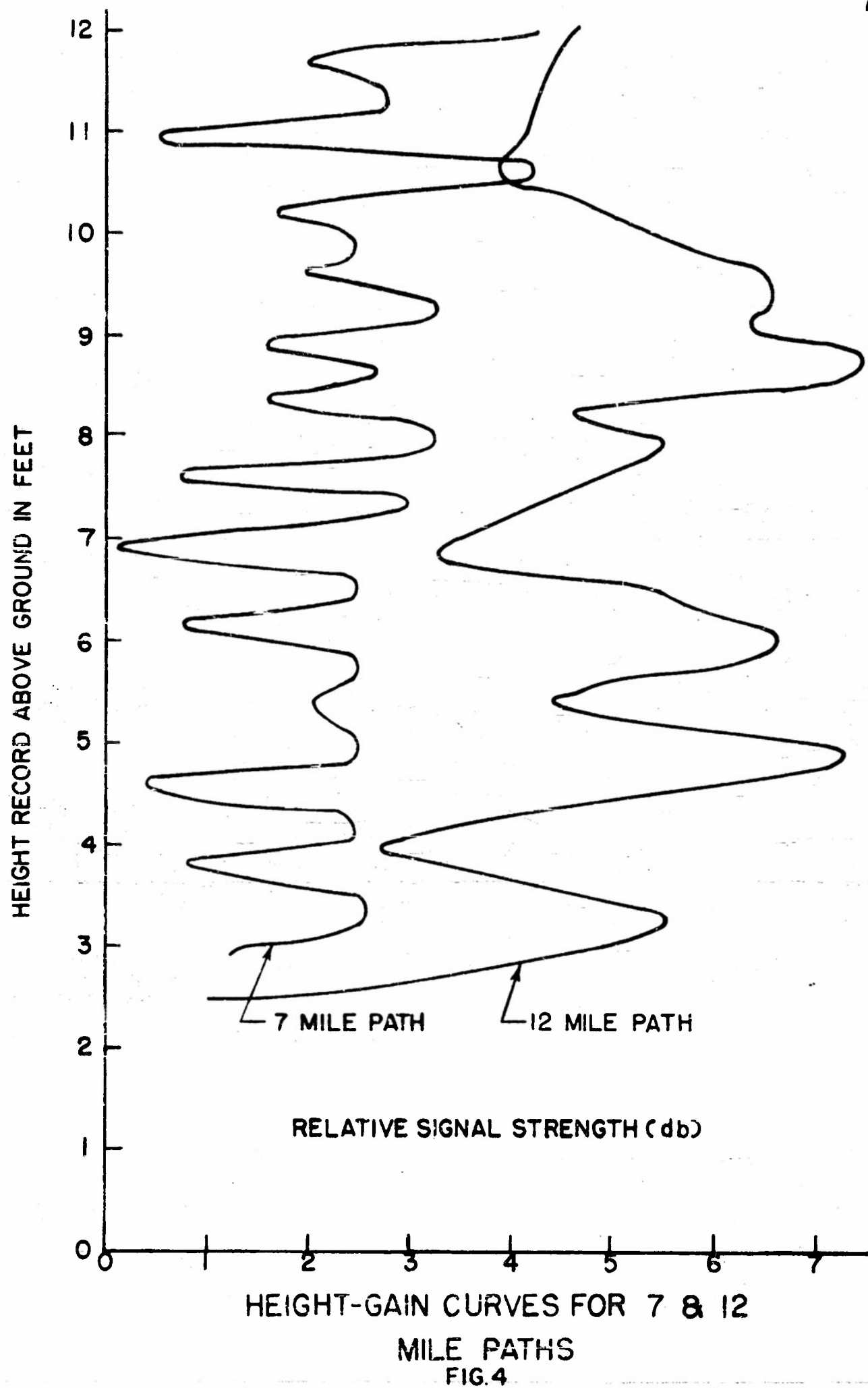
The time variation for each day of measurement was taken with the receiver at the first maximum in the height-gain curve. Samples of the time variations are shown in Figure 5.

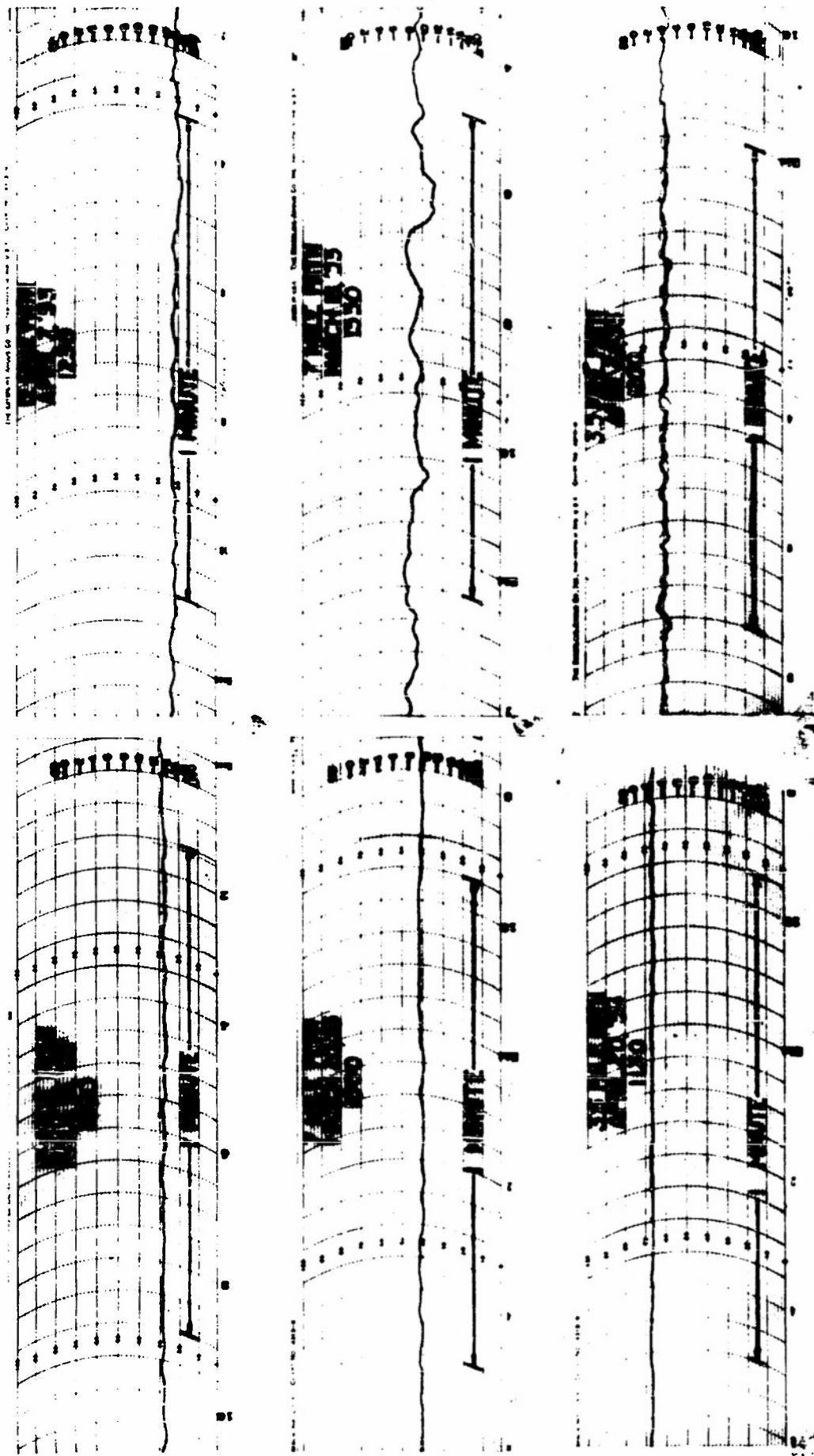
The maximum fluctuation ratio which was equalled or exceeded on half of the tests for the various path lengths was as follows:

Path length in miles	3.5	7.2	7.2	12.1
Antenna gain in db	30	33/27	30	30
Fluctuations in db				
Median	0.8	0.7	1.4	2.4
Range	0.4 to 1.8	0.2 to 2.2	0.6 to 4.6	0.8 to 5.0

It is noted that for the 30-db gain antenna that the median fluctuation was directly proportional to distance. Although it is difficult to draw a general conclusion from the limited number of samples, it appears that this relationship is probably a correct one.

The data taken with the 33/27-db antennas at seven miles show a distinctly smaller fluctuation than did the 30-db antenna measurement at this distance. The cause of this difference is not fully apparent, although the moisture content of the air was a little lower for the first tests.





SAMPLES OF TIME RUNS
FIG. 5

The largest fluctuations were noted on the days when the ground was moist and the air was dry. Refractive index measurements taken with the Crain Atmospheric Refractometer [5] have shown that large intensity fluctuations are to be expected under these conditions.

VI. AVERAGE SIGNAL STRENGTH

The median of the measured signal was below the free space field for each path. Approximately half of the difference between the measured and the free space field may be explained by the water vapor and oxygen absorption. The oxygen absorption was calculated on the basis of dew point data obtained from the local weather bureau for the time of the measurements. The signal level data are shown in the following table.

Path length in miles	3.5	7.2	7.2	12.1
Antenna gain in db	30	33/27	30	30
Median measured signal in db				
below free space value	0.8	1.3	2.0	2.4
Range of signal levels	0.7-1.2	0.8-2.0	1.5-2.5	0.7-3.2
Median water vapor and oxygen				
absorption in db	0.4	.7	.8	1.6
Difference between calculated				
and measured signal in db	0.4	.6	1.2	.8

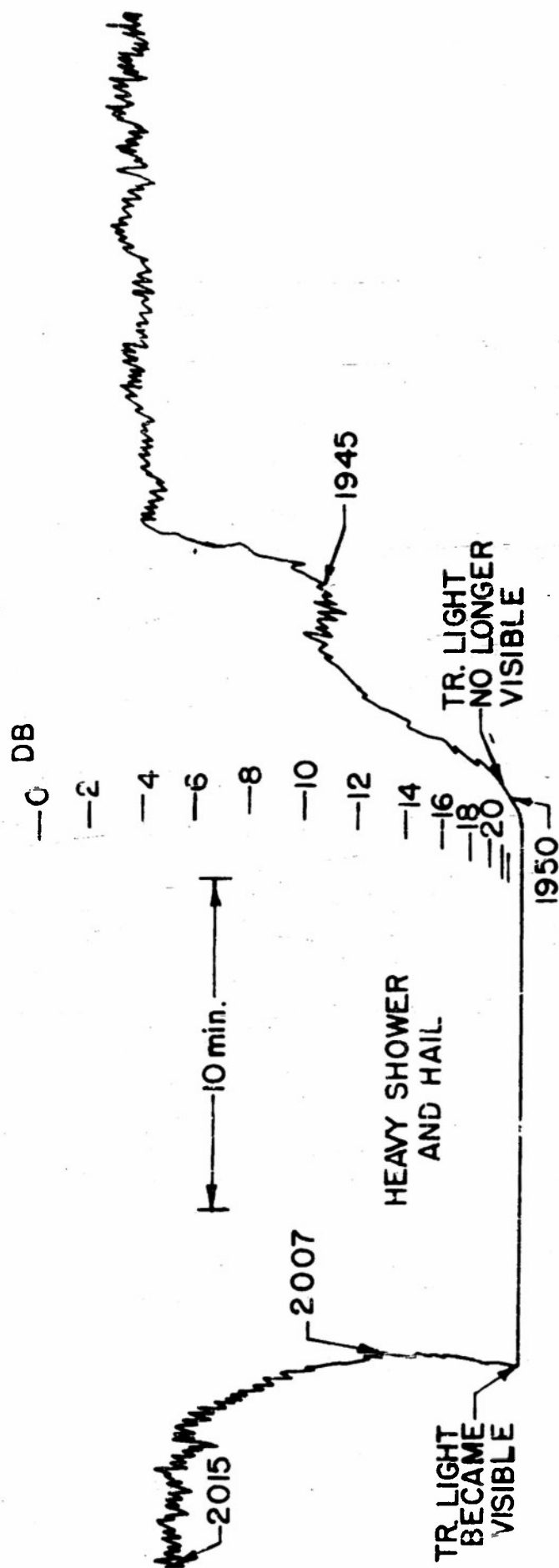
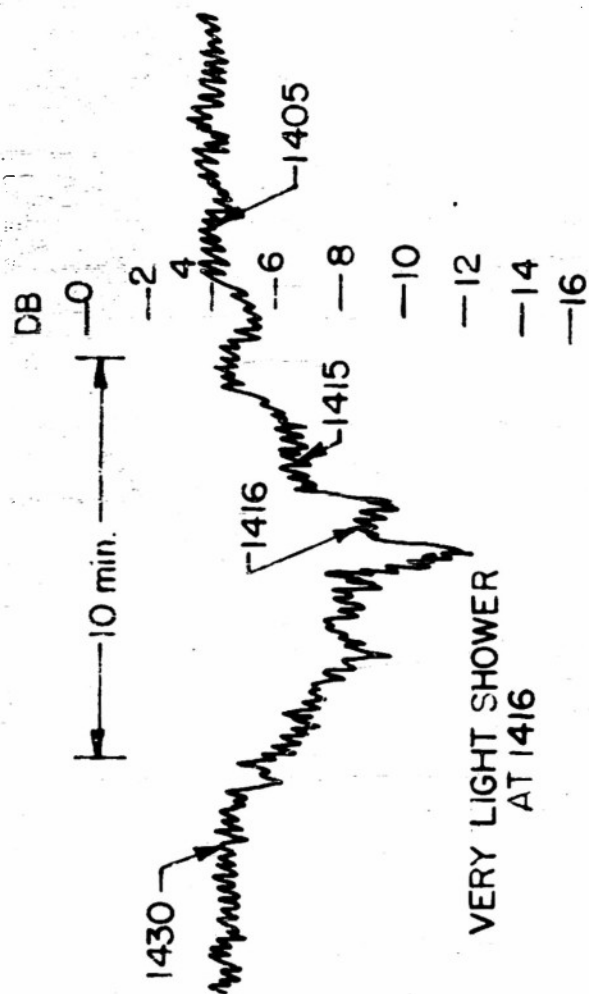
The complete data are shown in the Appendix

VII. PROPAGATION THROUGH FOG

On March 9, 1953 at 1520, propagation measurements were made on the 7-mile path through a fairly heavy fog. Visibility was reduced to about one thousand feet. The measured signal was 2 db below the free space value and ~~was~~^{was} very steady. From an estimate of drop size in the fog, a loss of 0.5 db was determined from the formula given by Kerr [1]. When this correction was added to the water vapor and oxygen, the difference between the calculated and measured signal strength was only 0.5 db. It therefore appears that the transmission losses through the fog could be predicted quite satisfactorily.

VIII. PROPAGATION THROUGH RAIN

When rain showers occurred between the transmitter and receiver, the signal was greatly attenuated. Samples of this occurrence on the 3.5-mile path are shown in Figure 6. The first signal drop-out occurred when the rain shower was so light that it could not be observed from either end of the path and visibility over the path was maintained during the shower. The shower produced a maximum attenuation of 10 db. The presence of the shower was noted by observers near the middle of the path.



EXAMPLES OF ATTENUATION
DUE TO RAIN ON APRIL 23, 1953

FIG. 6

The second drop-out occurred when a heavy shower fell on the path. Visibility over the path was lost at about the same time that radio signal was lost and the two returned simultaneously. This shower caused a complete loss of signal.

IX. CONCLUSION

Transmission of 8.6-millimeter radio waves over 3.5-, 7- and 12-mile paths were within 3.5 db of the free space value for 36 sets of measurements when no rain occurred. A large transmission loss was caused by showers along the path. Transmission losses in a fog were small and were of the order of magnitude given by Kerr [1].

The measured signal strength was lower in 34 out of 36 cases than the value determined by subtracting the water vapor and oxygen absorption loss from the free space values. The difference from the calculated value did not exceed 1.7 db.

The time fluctuation ranged from 0.2 to 5 db with the larger variations associated with days on which large-intensity fluctuations of the index of refraction would be expected.

APPENDIX

Data for 3.5-Mile Path, 30-db Gain Antennas

Date	Time	Signal Strength in db below free space			Fluctuation Range in db	Water Content of Atmosphere g/m ³
		Measured	Calculated	Difference		
April 17, 1953	1430	1.2	1.0	0.2	0.8	15.2
20	1130	1.0	0.2	0.8	0.4	5.6
21	1130	1.1	0.3	0.8	0.7	7.3
22	1130	0.8	0.5	0.3	0.9	15.1
23	1130	0.9	0.6	0.3	0.8	18.3
24	1030	0.7	0.4	0.3	1.8	13.6

Data for 7.2-Mile Path, 33/27-db Gain Antennas

Feb. 25, 1953	1300	1.3	0.7	0.6	0.2	8.4
March 3, 1953	1130	1.0	0.8	0.2	1.2	10.8
4	1130	1.4	0.4	1.0	0.2	3.7
5	0930	1.0	0.4	.6	1.0	3.6
6	1030	1.3	0.7	.6	0.2	8.7
9	0930	1.1	0.7	.4	0.6	9.1
9	1530	2.0	1.5	.5	0.2	11.2 Fog
10	1300	1.4	0.9	.5	0.2	12.8
11	1430	1.7	1.1	.6	1.0	16.8
12	1530	0.8	1.1	.3	2.2	16.2

Data for 7.2-Mile Path, 30-db Gain Antennas

March 16, 1953	1300	1.5	0.8	0.7	1.0	9.7
17	1300	2.3	1.1	1.2	0.6	15.7
18	1330	1.9	0.8	1.1	4.6	10.4
19	1300	2.2	0.9	1.3	1.2	12.8
20	1100	2.4	1.0	1.4	0.8	14.6
23	1100	1.7	0.6	1.1	1.6	6.2
24	1200	1.8	0.6	1.2	1.2	5.9
25	1100	2.0	0.7	1.3	1.4	8.0
26	1030	2.5	1.0	1.5	0.6	14.7

Data for 12.1-Mile Path, 30 db Gain Antennas

March 27, 1953	1100	2.7	1.6	1.3	1.3	13.3
30	1100	3.1	1.8	1.5	0.8	15.4
31	1430	0.7	1.2	-0.5	5.0	8.7
April 1, 1953	1100	2.2	1.8	0.4	3.2	15.9
2	1130	2.5	1.5	1.0	2.8	12.8
7	1230	2.5	1.9	0.6	2.4	16.2
8	1130	2.6	1.8	0.8	3.6	15.8
9	1130	3.1	1.8	1.5	1.7	15.8
10	1030	2.4	1.1	1.3	2.8	7.6
13	1030	2.1	0.9	1.2	0.9	6.3
14	1130	3.2	1.4	1.8	1.4	12.4

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