Satellite System Interference Tests at Andover, Maine

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(Manuscript received July 3, 1963)

Because of the shortage of suitable frequencies, it appears that it will be necessary for satellite communication systems and ground microwave systems to operate in the same frequency band. To do this without excessive interference between them requires that stringent criteria be met. This paper presents the results of radio interference tests from two test transmitter sites into the Andover, Maine, earth station receiver for experimental satellite communications. Although these sites were only 23.5 miles and 55 miles from Andover, an analysis of the results indicated that they could be used as locations for ground microwave systems with few limitations.

I. INTRODUCTION

In order that satellite communication systems and terrestrial microwave systems may share successfully the same frequency band, it is in general necessary that the earth station of the satellite system and microwave station be separated physically so that line-of-sight transmission between them is not possible. Under these conditions, either the scatter mode or diffraction mode of transmission predominates, depending on the path profile. While a considerable amount of data on such transmission is available with transmitting and receiving antennas pointed at one another and only elevated sufficiently to graze the horizon, very little data have been taken with one of the antennas, the earth station antenna in this case, randomly oriented in azimuth and elevation.

Predictions[1,2] have been made that it should be possible to operate point-to-point microwave systems in the same radio frequency band as the satellite system at distances of some 45 to 150 miles removed from the earth station, or even less, provided that (a) the earth station antenna is not operated at an elevation angle less than some minimum value, for which 7.5 degrees has been suggested, (b) suitable terrain blocking exists, and/or (c) a certain amount of angular discrimination is provided by the antenna of the radio relay terrestrial station.

Thus, one purpose of the tests to be described and evaluated was to examine critically the received interfering signal strength as a function of elevation and azimuth angle of the earth station antenna beam. A second purpose was to record for an extended length of time the received signal with the earth station antenna elevated in angle somewhat above the elevation value for maximum received interference to see if reflections from cloud masses, airplanes, birds, etc., could produce signal enhancements of sufficient magnitude and frequency of occurrence to degrade significantly the performance of the satellite communication system.

The American Telephone and Telegraph Company already had commercial operating sites at Cornish, Maine, and at West Paris, Maine — 55 miles and 23.5 miles, respectively, from the earth station at Andover, Maine — and these appeared to be suitable locations at which to place test transmitters for the interference tests. A contour map of the area is shown on Fig. 1. The interference path profiles (Figs. 2 and 3) indicated that these sites would be appropriate for evaluating the required miminum antenna discrimination toward Andover of an operating TD-2 station[3] at these sites and/or the required limitation on minimum antenna elevation at Andover for compatible operation on a frequency sharing basis.

Although the results of these tests and the conclusions based thereon may not be valid for other sites and equipments, they do show that it is possible by careful choice of the earth station site to operate microwave radio stations in the same frequency band without undue physical separation between them.

Because of the considerable international interest in the question of frequency sharing, the criteria of permissible interference are those recommended by the Xth Plenary Assembly of the International Radio Consultative Committee (C.C.I.R.) held in 1963.

II. RECORDING SETUP

A sketch of the experimental setup for recording the received signal at Andover for the various test conditions is shown on Fig. 4. It consisted of the earth station antenna whose output was fed to a maser followed by a receiver-converter, pre-amplifier and main IF amplifier normally associated with the earth station receiver. At this point a 4170-mc RF input signal appeared as a signal whose nominal frequency was approximately 74.1 mc. The dynamic range of the entire receiver from antenna to strip chart was approximately 40 db when the gains of the various amplifiers were properly adjusted. This IF signal was then

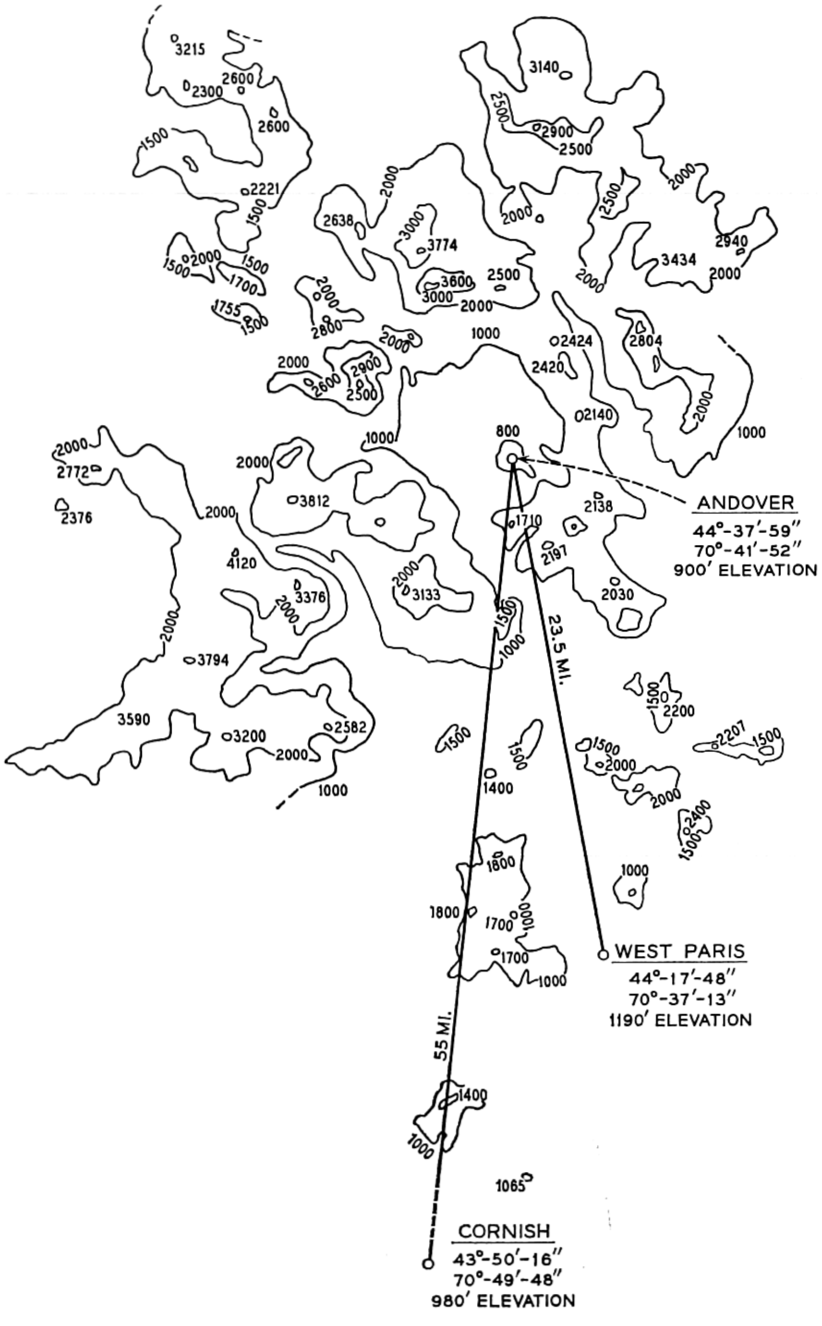

Fig. 1 — Topography surrounding site at Andover, Maine.

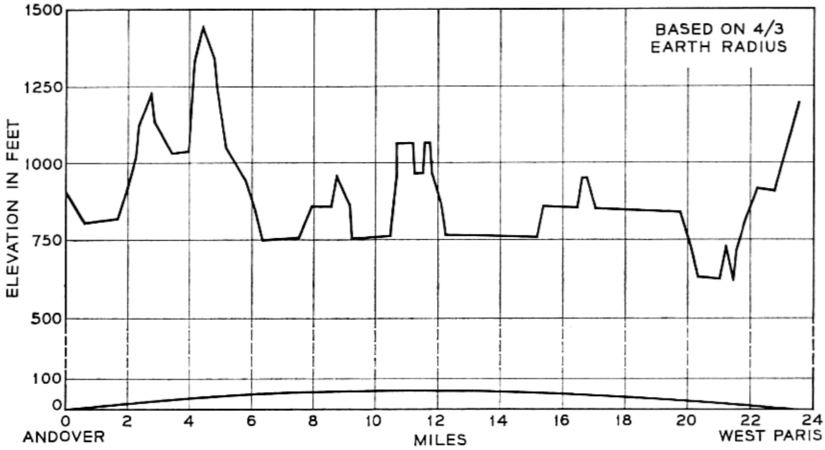

Fig. 2 — Profile of West Paris-Andover path.

detected by a variable frequency analyzer with a 10-kc bandwidth and the rectified output recorded on a strip chart after passing through a logarithmic amplifier. No automatic gain control was used, so that the amplitude of the 74.1-mc signal was directly proportional to the amplitude of the 4170-mc input signal, within the boundaries of noise and overload.

Provision was made, as shown on Fig. 4, for calibrating the recorder in terms of received RF power. The chart range was approximately 40 db, but the over-all sensitivity of the setup could be changed, if required,

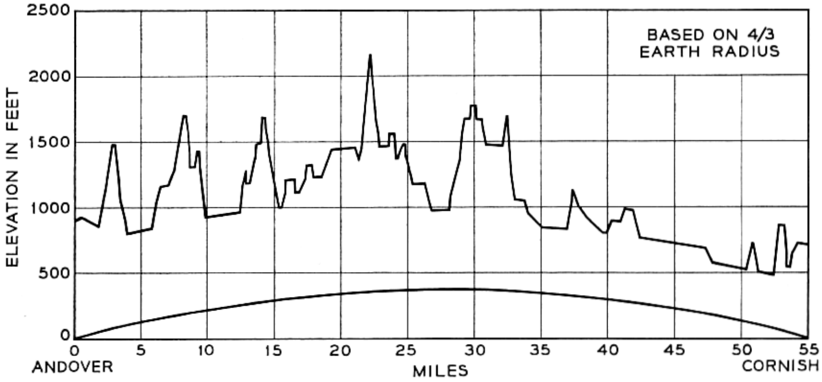

Fig. 3 — Profile of Cornish-Andover path.

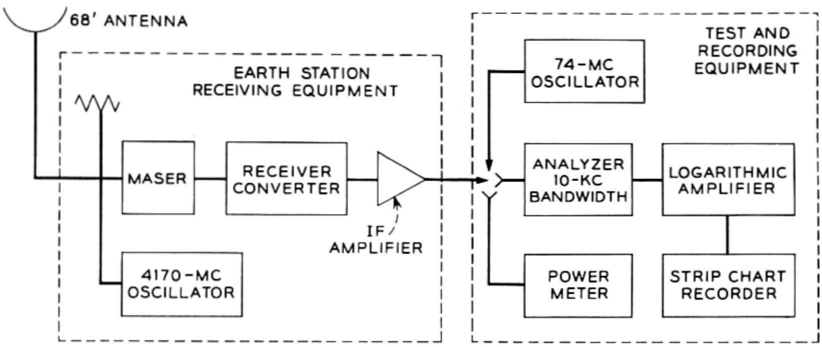

Fig. 4 — Test setup.

by the insertion of an IF pad of suitable value. The total range covered was from about −142 dbm (noise only) to about −70 dbm. The frequency response of the receiving system was limited by the strip chart recorder and was in the order of 60 cycles per second.

It will be noted that the gain of the RF-IF portion and the sensitivity of the analyzer-recorder portion of the system were calibrated separately. This was necessary because the RF calibrating oscillator was not stable enough in frequency to stay within the 10-kc band of the analyzer. However, the frequencies of the test transmitters at Cornish and West Paris were adequately stable, and only occasional checks of the tuning of the analyzer were required during an extended run.

All of the values of received signal power given herein are, strictly speaking, referred to the input point of the maser amplifier. In view of the fact that the loss of the waveguide and associated circuitry connecting the maser to the receiving antenna is only about 0.1 db, they are also essentially the same as would have been observed at the antenna output. Table I presents information pertinent to these tests.

III. PATH PROFILES

The profiles of the West Paris–Andover and Cornish–Andover paths are shown on Figs. 2 and 3, respectively. An analysis of the first path indicates that, because of the mountain 4.4 miles from Andover, the diffraction mode would be expected to predominate over the scatter mode. The opposite is true for the Cornish–Andover path.

The Andover antenna, as will be noted on Fig. 1, is located in a relatively flat area surrounded by low mountains. Elevation scans of noise only were available at 5-degree intervals in azimuth using the Andover

TABLE I—PERTINENT INFORMATION

Station	Andover, Maine	West Paris, Maine	Cornish, Maine
Status	Earth Station	Test transmitter	Test transmitter
Latitude	44° 37′ 59″	44° 17′ 48″	43° 50′ 16″
Longitude	70° 41′ 52″	70° 37′ 13″	70° 49′ 48″
Path length	—	23.5 miles	55.0 miles
Frequency source	—	Crystal oscillator	Crystal oscillator
Frequency, RF	—	4170 mc	4170 mc
Antenna diameter (actual)	68 feet	10 feet	16 feet
Effective radiated power	—	+64 dbm	+78 dbm
Antenna gain (free-space)	54 db*	40 db	43 db
Orientation			
Azimuth	Variable	Toward Andover	Toward Andover
Elevation	Variable	Toward horizon	Toward horizon
Bandwidth of test setup	10 kc	—	—
Noise (at zenith)	−142 dbm	—	—
Elevation†	—	1.57°	2.43°
Azimuth†	—	170.69°	184.92°

* The Andover antenna is arranged normally to receive a circularly polarized wave, and for this condition the maximum response is 57 db referred to an isotropic antenna. The response of the antenna to a linearly polarized incident wave under the same condition is 3 db less.

† These are the elevation and azimuth angles of the Andover, Maine, antenna for maximum received signal as determined experimentally. The elevation angle is referred to the horizontal in all cases unless specifically stated otherwise.

antenna, and the elevation angle of the antenna at which the noise abruptly changed was noted as the "electrical" horizon. A 360-degree azimuth profile thus obtained is shown on Fig. 5.

IV. ANTENNA DIRECTIVITY PATTERNS

Figs. 6 and 7 show vertical and horizontal directivity patterns about the main beam of the 68-foot horn-reflector antenna at Andover, as measured by J. N. Hines of Bell Telephone Laboratories. A circularly polarized signal was transmitted from a reference point at Black Mountain about 4.9 miles away, and the vertical component of the electrical field out of the antenna was recorded as the beam of the antenna at Andover was swung in azimuth or raised in elevation about the bearing of the reference point. The azimuth and elevation angles of the reference point relative to the Andover antenna were 142.097 degrees and 3.977 degrees, respectively, and the path was line-of-sight.

The maximum response of the antenna arranged to receive in this fashion is about 54 db referred to an isotropic antenna. It will be noted

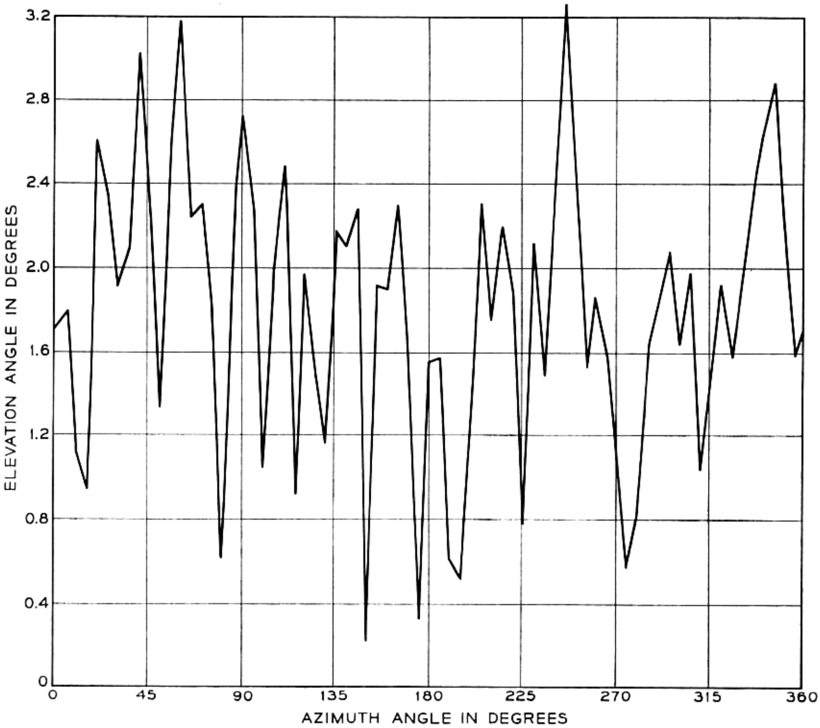

Fig. 5 — Azimuth profile based on noise measurements.

that the antenna beam had to be elevated about 10 degrees relative to the reference direction, in order to reduce the gain to that of an isotropic antenna.

Since the noise power in the measuring equipment was also about 54 db below the maximum received signal, the maximum value of antenna directivity discrimination that could be measured was also limited to this same value.

V. EXPECTED RECEIVED SIGNAL

5.1 *West Paris–Andover Path*

1. Transmitter power	=	+27 dbm
2. Waveguide and filter loss	=	3 db
3. Antenna gain – vertical polarization	=	40 db
4. Effective radiated power	=	+64 dbm

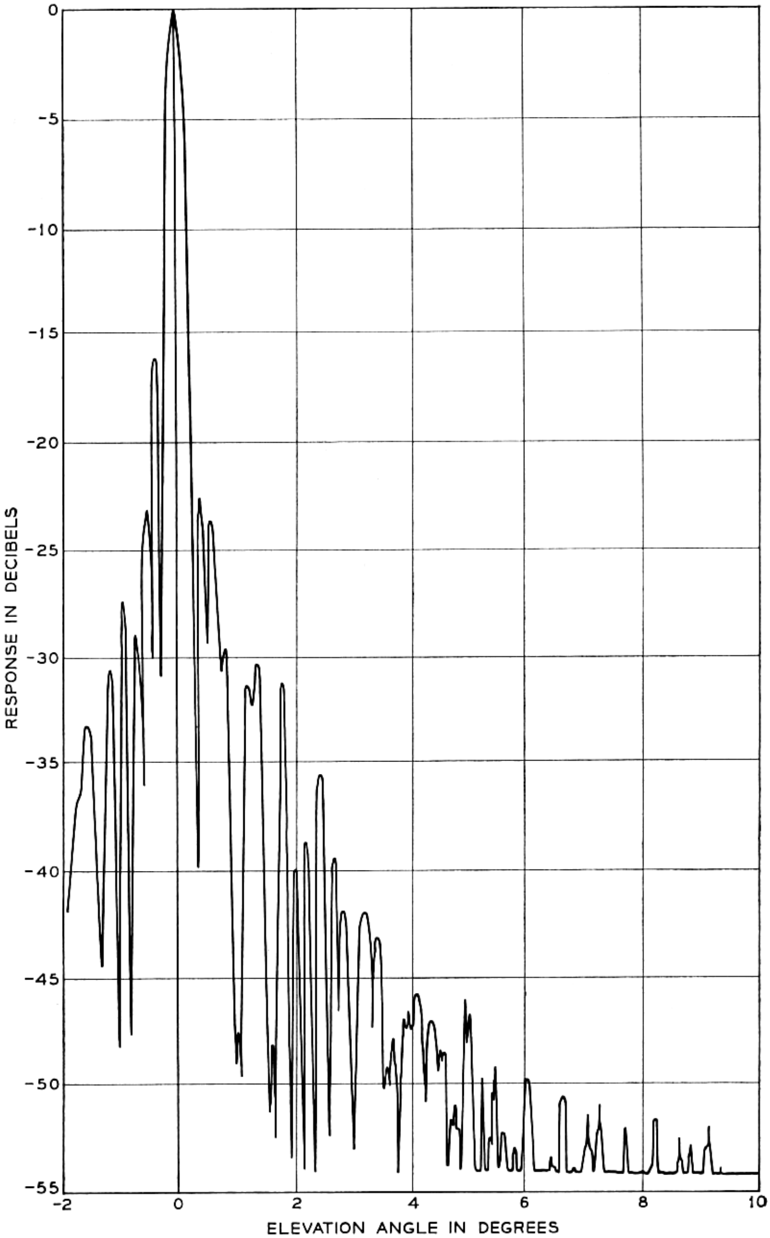

Fig. 6 — Antenna directivity in vertical plane.

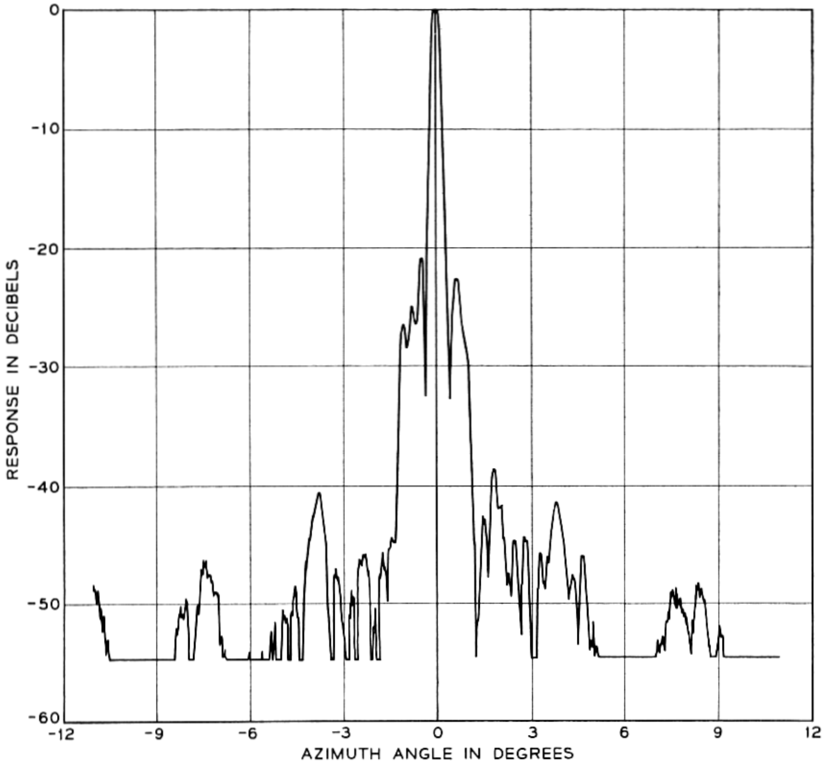

Fig. 7 — Antenna directivity in horizontal plane.

5. Estimated knife-edge diffraction basic transmission loss* (Median *scatter* loss estimated as 198 db and hence not controlling.) = 168 db
6. Receiving antenna gain (see note on Table I) = +54 db
7. Estimated signal power at antenna output on basis of knife-edge diffraction = −50 dbm

5.2 *Cornish–Andover Path*

1. Transmitter power = +37 dbm
2. Waveguide and filter loss = 2 db

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* Defined in Ref. 4, "Basic Transmission Loss (L_b). The basic transmission loss (sometimes called path loss) of a radio circuit is the transmission loss expected between ideal, loss-free, isotropic, transmitting and receiving antennae at the same locations as the actual transmitting and receiving antennae."

3. Path antenna directivity gain.* Experience on similar scatter paths indicates that the effective antenna gains on such paths are substantially less than the free-space gains of 54 db and 43 db for the two antennas. This reduction, which is usually referred to as the antenna-to-medium coupling loss, is estimated to be 11 db for the larger antenna and 3 db for the smaller antenna. The path antenna directivity gain is therefore = 83 db
4. Estimated median basic transmission loss (scatter propagation) during November = 220 db
5. Estimated received signal power at antenna output on basis of scatter propagation = −102 dbm

The transmitter power at a standard TD-2 station[3] is +27 dbm, and the waveguide and filter losses total about 3.5 db. A horn-reflector antenna of 10-foot aperture and gain of approximately 40 db at 4200 mc is also standard equipment. The transmitted wave is linearly polarized. Thus the effective radiated power at Cornish was about 15 db greater than that of a normal TD-2 transmitter.

VI. EXPERIMENTAL RESULTS

6.1 *West Paris–Andover*

As noted above, the predominant mode of transmission over this path was expected to be by diffraction rather than by scatter, and hence a comparatively steady signal was expected.

The principal tests over this path may be divided into two parts, (*i*) "fine grain" elevation runs at the azimuth angle corresponding to maximum signal when "on-beam," and (*ii*) "fine grain" azimuth scans at various fixed elevation angles. Certain runs, each of about one hour in duration, were made at various fixed elevations, all on the azimuth bearing of maximum received signal, to establish the fact that the signal was steady in each case.

The maximum received signal on this path ranged from about −75 dbm to −80 dbm during the various days of the tests. The expected signal as computed above, based on knife-edge diffraction, was −50

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* "Path Antenna Directivity Gain (G_p). The path antennae directivity gain is equal to the increase in the transmission loss when lossless, isotropic antennae are used at the same locations as the actual antennae." Transmission loss $L = L_b - G_p$. See Ref. 4.

dbm, indicating that the intervening hill was considerably more effective than an ideal knife edge in attenuating the signal. On the basis of the received signal levels the basic transmission loss, as defined above, was about 193 db for the West Paris–Andover path. Since this was fairly constant during the period of any single test, the variations in received signal power as the direction of the beam of the Andover antenna was changed reflected changes in the path antenna directivity gain.

In view of the fact that the basic purpose of this study is the evaluation of three specific sites from the standpoint of frequency sharing between satellite communication systems and ground microwave systems, the results are plotted in terms of actual received interfering power at the site in question.

Figs. 8 and 9 show fine structure plots of vertical scans during clear weather and during a heavy rain, respectively. Fig. 10 presents a smooth curve of the envelope of the peaks of the interference up to an elevation of 50 degrees.

Figs. 11 and 12 are fine grain azimuth scans at fixed elevations of zero and +2 degrees, relative to that of maximum signal, i.e., 1.573 degrees above the horizontal. Fig. 13 is a similar scan with the antenna elevated 8.573 degrees above the horizontal.

Finally, Figs. 14 and 15 present 360-degree azimuth scans at fixed

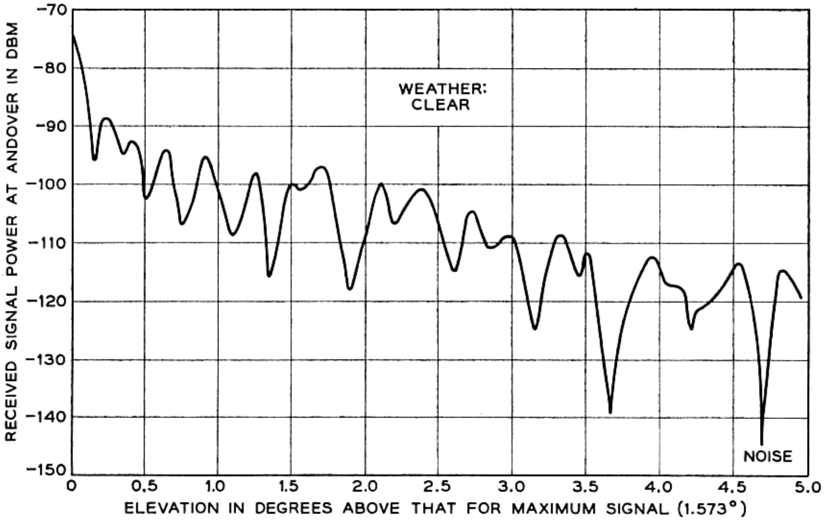

Fig. 8 — Elevation scan, West Paris transmitter activated (vertical scan showing fine structure). Signal is steady at any elevation of antenna.

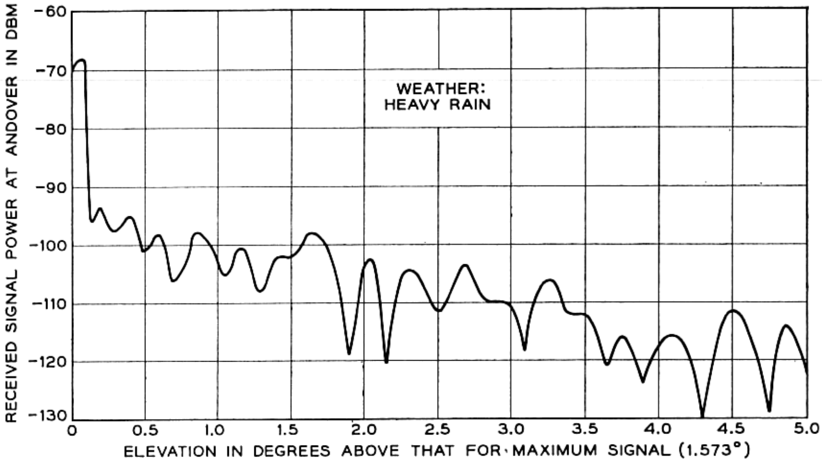

Fig. 9 — Elevation scan, West Paris transmitter activated (vertical scan showing fine structure). Signal is steady at any elevation of antenna.

elevations. In these figures the maximum signal values in sectors of various widths are plotted. It will be noted on Fig. 14 that the signal, when the antenna was directed at about 180 degrees from the direction of West Paris, was only about 10 db below the signal received when pointed directly at West Paris. A similar reflection down 14 db was noted when the Cornish transmitter was activated and the Andover antenna rotated through 360 degrees of azimuth at an elevation angle of 2.43 degrees. The source of the reflections is as yet unidentified.

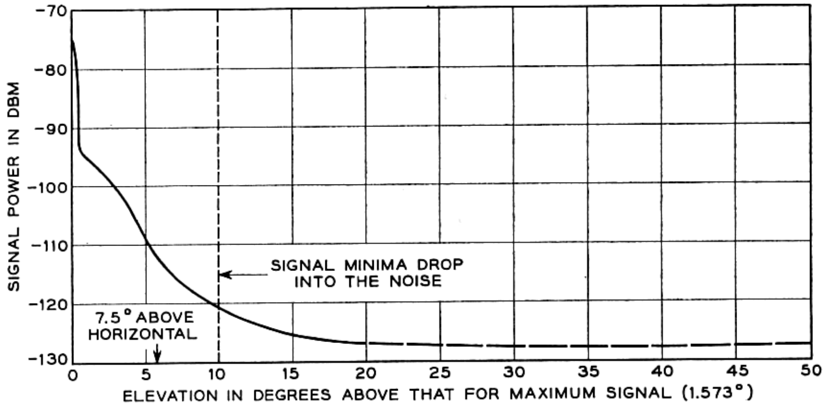

Fig. 10 — Elevation scan, West Paris transmitter activated (envelope of peaks of maximum signal).

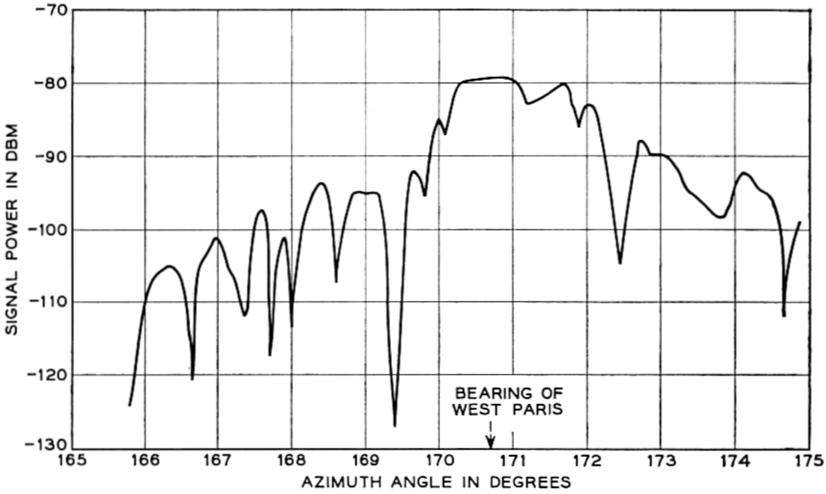

Fig. 11 — Azimuth scan, West Paris transmitter activated (receiving antenna elevated for maximum signal, i.e., 1.573° above the horizontal).

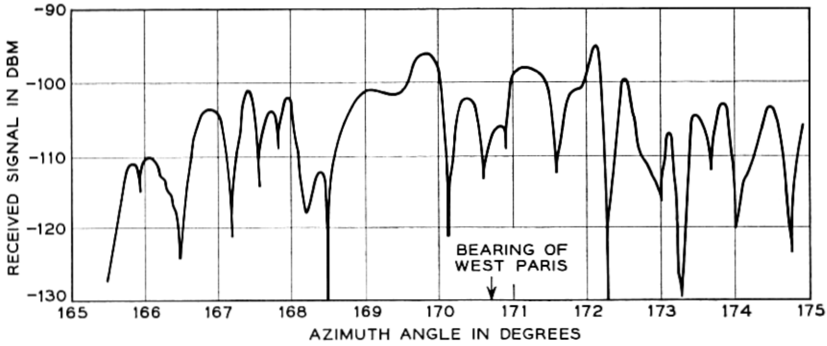

Fig. 12 — Azimuth scan, West Paris transmitter activated (receiving antenna elevated 2° above that for maximum signal, i.e., 3.573° above the horizontal).

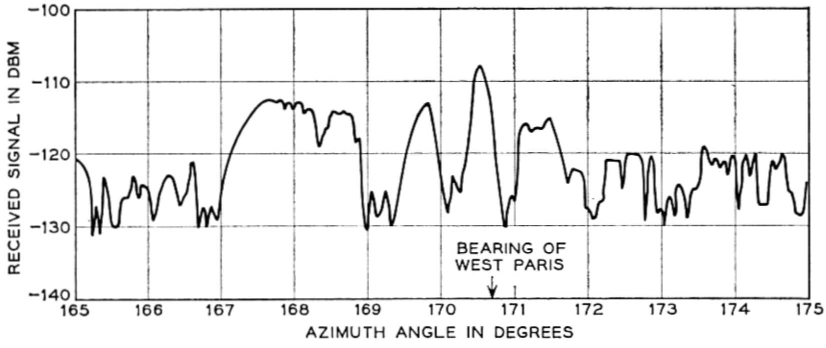

Fig. 13 — Azimuth scan, West Paris transmitter activated (receiving antenna elevated 7° above that for maximum signal, i.e., 8.573° above the horizontal).

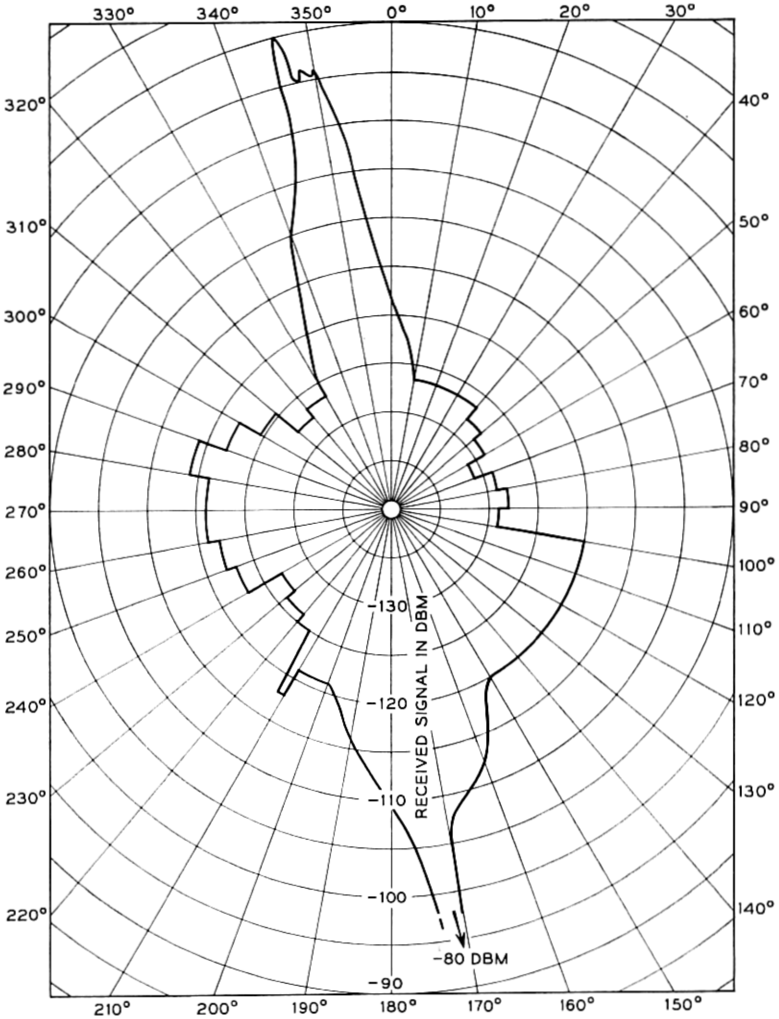

Fig. 14 — Azimuth interference profile, West Paris transmitter activated (receiving antenna elevated for maximum signal when "on-beam," i.e., 1.573° above the horizontal).

6.2 *Cornish–Andover, Maine*

As mentioned above, examination of the profile of the path indicates that propagation by scatter would be controlling, with an expected median basic transmission loss of 220 db between isotropic antennas for the time of year the measurements were made.

In addition to the elevation and azimuth scans such as were also made on the West Paris–Andover path, runs totaling 107 hours were made with the Andover antenna elevated in angle sufficiently to bring the median signal down close to the level of the noise in order that periods of possible signal enhancement could be accurately observed. The azimuth angle at all times was that for maximum signal when "on-beam," i.e., 184.92 degrees.

When on the coordinates of maximum interference, the signal was steady within a db, and measured about −108 dbm at the input of the maser, as compared with the expected value of −102 dbm. Thus the basic transmission loss of the path at this time was 226 db based on an estimated path antenna directivity gain of 83 db. Elevating the receiving antenna less than a degree altered the character of the signal so that it varied continually about ±10 db. Typical portions of the strip chart traces are shown for several antenna elevations on Fig. 16.

Fig. 17 shows the results of an elevation run giving median values of

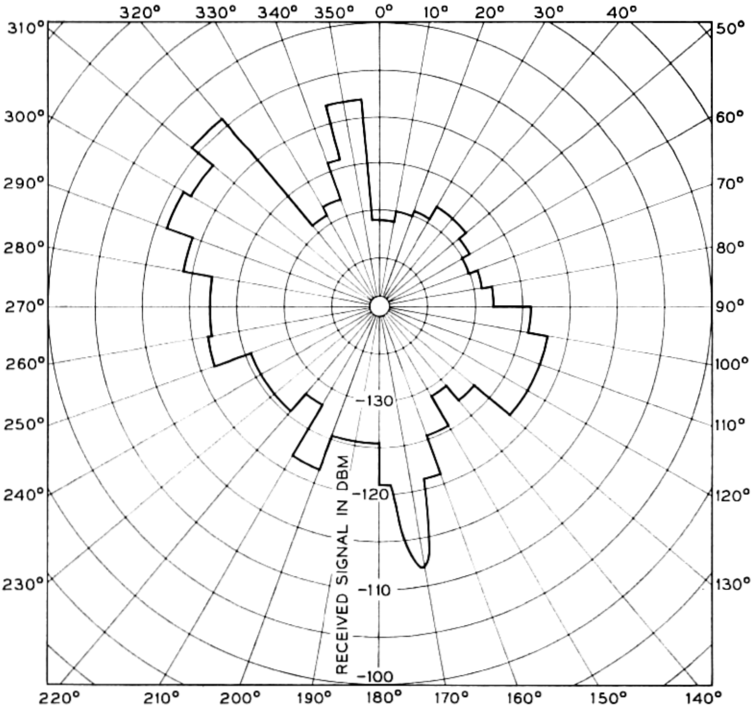

Fig. 15 — Azimuth interference profile, West Paris transmitter activated (receiving antenna elevated 7.5° above the horizontal).

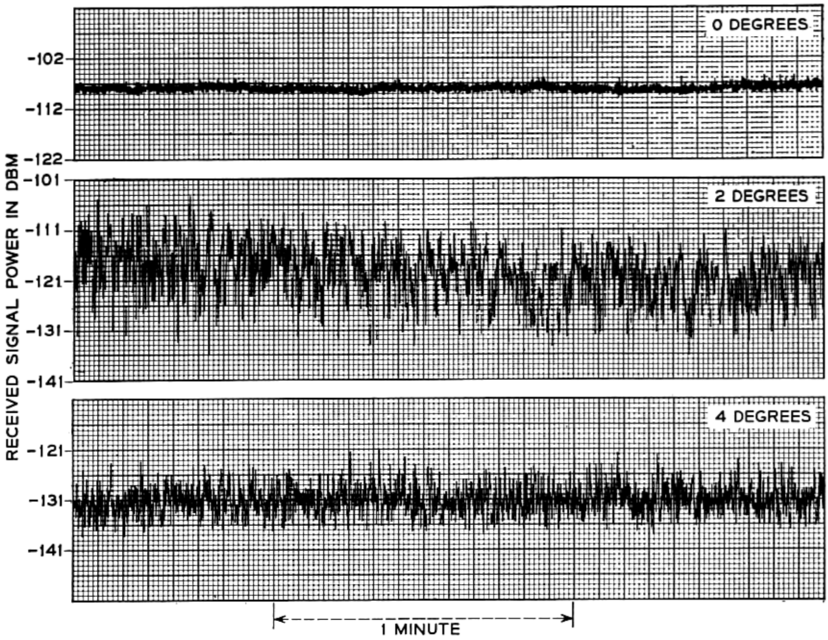

Fig. 16 — Received signal from Cornish for various antenna elevations at Andover (elevation angles are in degrees above that for maximum signal).

interference at intervals of 0.2 degree in elevation. The variation in signal strength was so great that it was impossible to reset the antenna elevation to a particular angle and obtain the same interference level to within the order of ±5 db. A reproduction of a portion of the strip chart from which the results on Fig. 17 were obtained is shown on Fig. 18. Here the rate of elevation scan is 0.043 degree per second. Also shown on Fig. 18 for comparison is an elevation scan made at Andover with the West Paris transmitter activated.

An azimuth scan with the antenna beam elevated 7.5 degrees above the horizontal with the Cornish transmitter activated showed that the interference power was below the noise, i.e., -141 dbm, for all angles except in the direction of Cornish. Here the interference power reached a maximum of -132 dbm.

Fig. 19 shows a running plot of hourly median received signal power at Andover extending over a period of nine days, the actual measuring time totaling 107 hours. Furthermore, since the main interest was in signal enhancement, several different elevation angles were used during the period. Thus the changes in average hourly median from day to day reflect to a considerable extent changes in path antenna directivity gain.

Signal enhancements in which the median power rose 7 db or more for brief periods were individually examined, and the median value at the time of maximum rise relative to the normal median signal level at the time was tabulated. The duration of each enhancement at a level

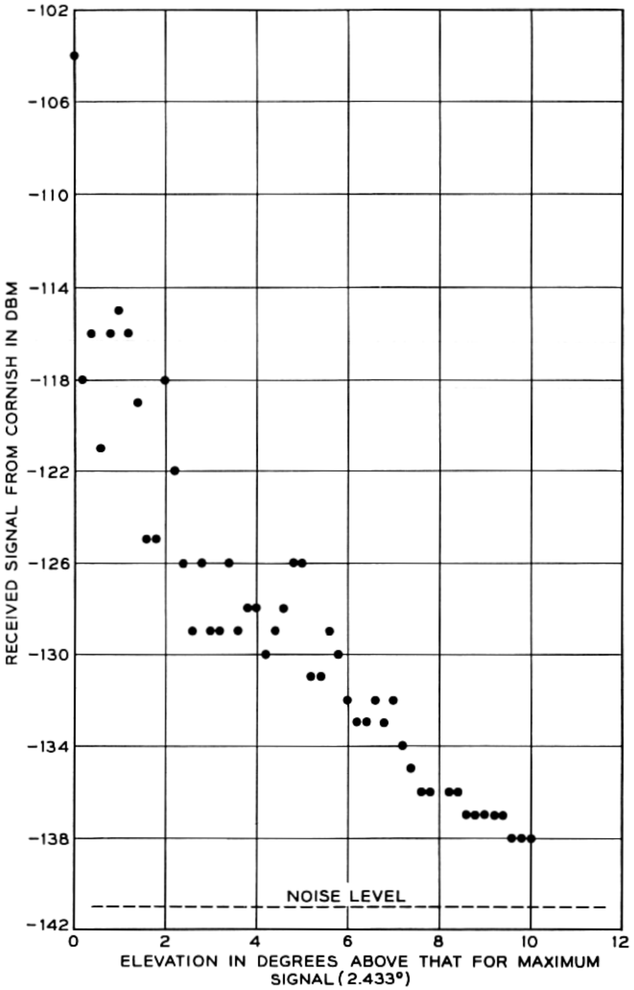

Fig. 17 — Elevation scan, Cornish transmitter activated (Andover antenna directed toward Cornish; data from Fig. 18).

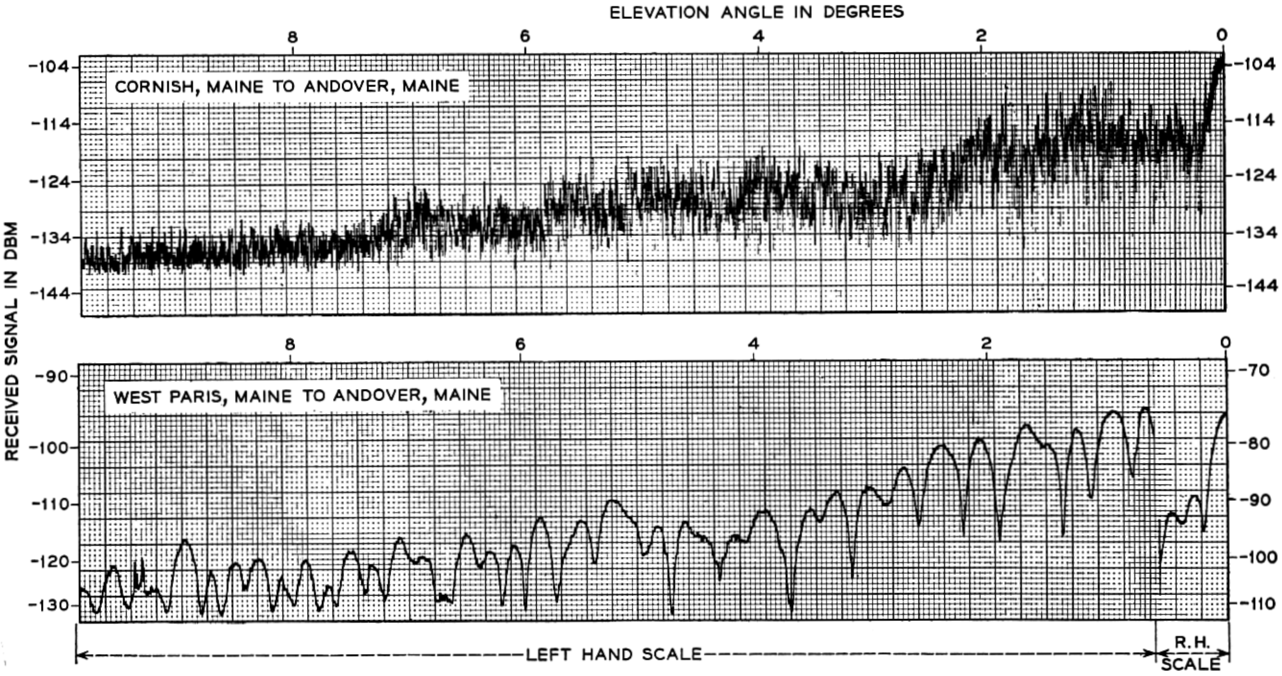

Fig. 18 — Elevation scans (elevation angles are in degrees above that for maximum signal in each case; azimuth angles are fixed at value giving maximum signal at reference elevation in each case; elevation scan rate is 0.043° per second).

PERIOD	ON-BEAM SIGNAL
11-6-62—11-7-62	-109 DBM
11-8-62	-108 DBM
11-10-62	-104 DBM
11-13-62	-108 DBM
11-14-62	—

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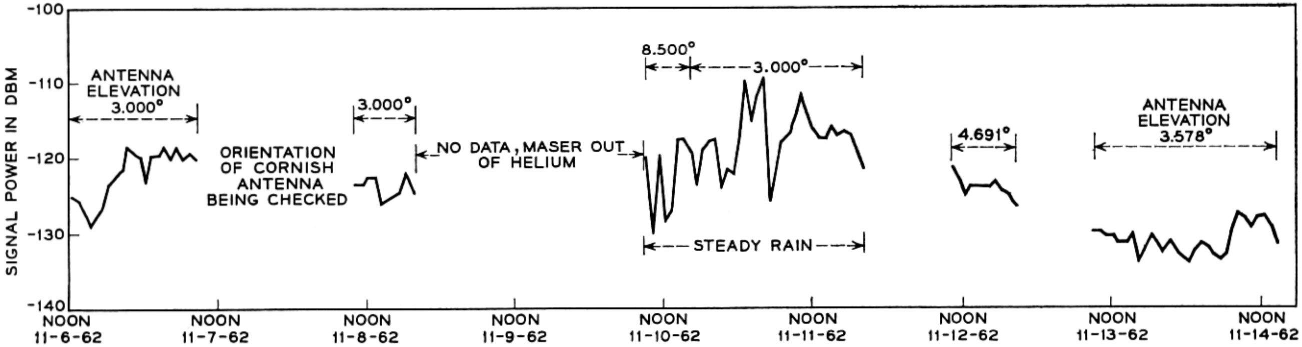

Fig. 19 — Hourly median received signal at Andover from Cornish (elevation angles are referred to that for maximum received signal, i.e., 2.433° above the horizontal).

halfway (in db) from the normal median to the peak median value was also recorded.

The short-term, e.g., five seconds, median varies normally about ±3 db in any brief period such as an hour, and such normally expected increases associated with these variations were not classified as enhancements. Three typical periods that were classed as enhancements are shown on the strip chart reproductions on Fig. 20. Here the chart speed is one small division per second. In the top example on this figure the average median is taken as -121 dbm, and the median at the peak as -106 dbm, and the enhancement is thus 15 db. The enhancement in the middle example is also 15 db, and for the bottom is 20 db.

A total of 56 enhancements thus defined occurred in the 107-hour period. Fig. 21 shows a plot of the cumulative percentage of the total

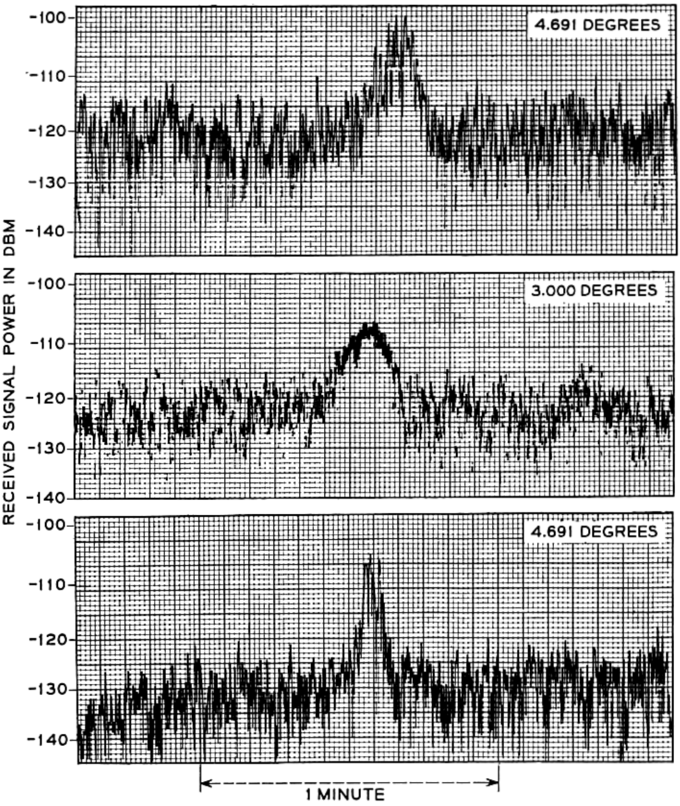

Fig. 20 — Typical periods of signal enhancements — Cornish-Andover path (elevation angles are in degrees above that for maximum signal).

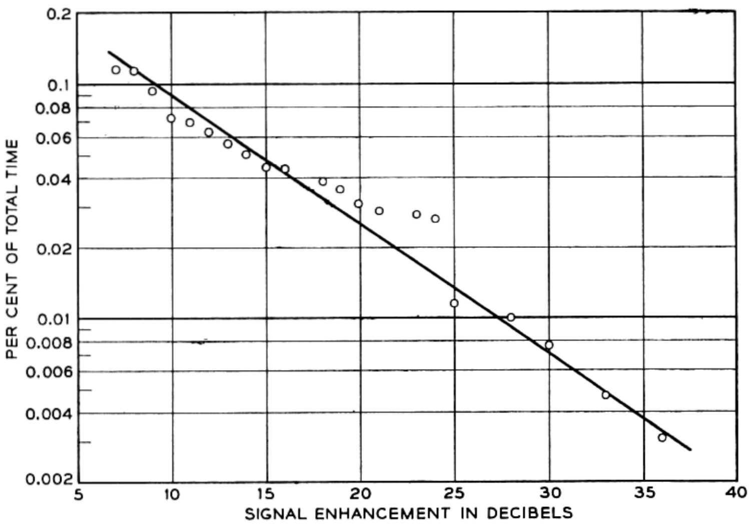

Fig. 21 — Probability of signal enhancements — Cornish-Andover path (cumulative percentage of time the signal strength was enhanced any given amount above the median, normal variations in median excluded; duration of observations 107 hours).

period of 107 hours the signal was enhanced, as defined above, any given amount or more above the median. Thus 0.01 per cent of the 107 hours the signal was enhanced 27 db or more above the median signal value.

Fig. 22 shows the distribution of the duration of signal enhancements.

VII. INTERPRETATION OF RESULTS AND CONCLUSIONS

7.1 *Cornish–Andover Path*

Recommendation No. 356* of the Xth Plenary Assembly of the C.C.I.R. held in 1963 provides that the mean value of interference from radio relay systems into an earth station receiver in any hour should not exceed 1000 picowatts, psophometrically weighted. On the basis of four exposures into the earth station receiver, the message channel interference per exposure is 250 picowatts or 18 dba at reference level.

The signal-to-interference ratio at baseband may be related to the ratio of the desired carrier to the interfering carrier by the Receiver Transfer Characteristic as defined in Recommendation No. 356. The

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* This will appear in the forthcoming publications of the Xth Plenary Assembly, Geneva, 1963.

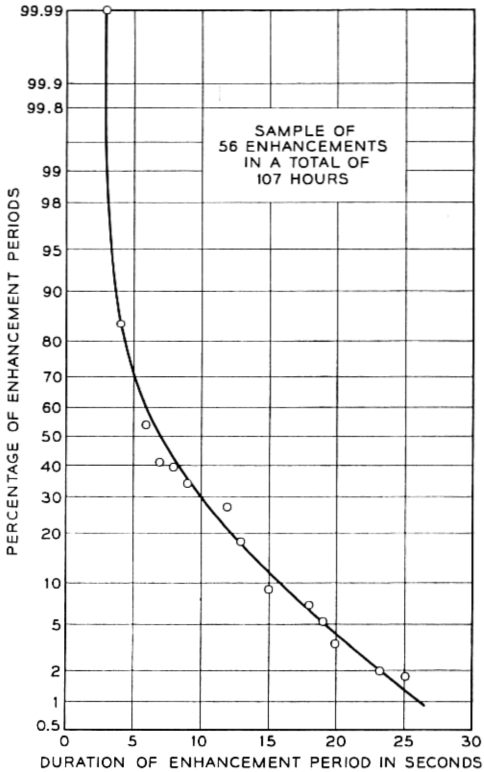

Fig. 22 — Duration of signal enhancements — Cornish-Andover path (percentage of enhancement periods having durations equal to or greater than values shown on abscissa; sample of 56 enhancements in a total of 107 hours).

magnitude of the Receiver Transfer Characteristic depends upon the frequency separation of the two carriers, the characteristics of the modulation, and the radio receivers themselves. Fig. 3 of Ref. 2 shows computed values of this relationship for a possible satellite system, a TD-2 system and a TH system.[5] Here the signal is Gaussian noise having the same power per channel as an average talker, and the interference is expressed in dba at a zero-db transmission level point, or reference level. Thus we find that the mean value of the ratio of the desired carrier to the interfering carrier should be 25 db or greater in order that the baseband noise not exceed 18 dba at reference level. A reasonable value for the received carrier power at the earth station receiver from the satellite is about −98 dbm. The interfering carrier should then be −123 dbm or less.

A signal power of about −128 dbm was observed on the average when the Andover antenna was directed at the Cornish transmitter and elevated 7.5 degrees above the horizontal. Since the power into the transmitting antenna was +35 dbm, the transmission loss is 163 db. Because of higher power and antenna gain, the effective radiated power of the Cornish test transmitter was about 15 db greater than that of a standard TD-2 transmitter. Therefore it may be concluded that a TD-2 transmitter could be operated at Cornish, Maine, with its antenna directed toward the earth station, and the mean interference during the period of measurement would have been 20 db below the permissible value recommended by the C.C.I.R.

Recommendation No. 356 also provides that the message channel interference into an earth station receiver should not exceed 80,000 picowatts, psophometrically weighted, or 43 dba at reference level, for more than 0.02 per cent of any month. On the basis of four interferences per satellite ground station, the probability of occurrence per exposure should not exceed 0.005 per cent.

Reference to Fig. 21 shows that enhancements of 33 db were observed during the test period with a probability of 0.005 per cent. This leads to an expected interference value of −110 dbm, or a ratio of desired to interfering carrier power of 12 db, at the antenna output of the satellite ground receiver. This corresponds to 31 dba, or 5000 picowatts, a value well within the above objective developed from the C.C.I.R. recommendation.

The earth station transmitter at Andover operates in the 6-kmc common carrier band, and therefore it could potentially interfere with a common carrier receiver such as the TH microwave system operating in this band. While no companion interference measurements were made in this frequency range, it is quite practical to estimate with adequate accuracy the interference from Andover that might fall into a TH receiver that might be located at West Paris or at Cornish.

Recommendation No. 357 of the Xth Plenary Assembly of the C.C.I.R. provides that the interference from an earth station transmitter into a radio relay system should not exceed in any hour 1000 picowatts, psophometrically weighted. Again allowing four interferences per relay route from such a source, the interference per station becomes 18 dba at reference level. Fig. 3 of Ref. 2 shows that for this value of interference from the earth station transmitter, the mean value of carrier-to-interference ratio at the converter of the TH receiver should not be less than 58 db, providing the earth station transmitter frequencies are interleaved between the TH frequencies.

Since the normal received carrier power of the TH receiver is −27 dbm, the interfering carrier must be −85 dbm or less. Although the measurements were made at 4170 mc, the estimated system loss is less than one db different at 6000 mc. Thus the transmission loss with the earth station antenna elevated 7.5° is about 163 db, as before. Therefore, the power into the earth station antenna at Andover could be as great as 48 dbw or 63,000 watts without exceeding the mean interference recommendation.

Recommendation No. 357 also provides that the interference into a relay system should not exceed 50,000 picowatts psophometrically weighted one minute mean power for more than 0.01 per cent of any month. On the basis of four exposures, this reduces to 50,000 picowatts for not more than 0.0025 per cent of any month.

The latter permissible power recommendation is 23 db greater than that for the per-exposure objective for a mean power of 250 picowatts as developed above. Fig. 21 shows that signal enhancements of 38 db were observed for 0.0025 per cent of the observational period. This implies that for these specific sites the 0.01 per cent recommendation is 15 db more restrictive on earth station power than the mean interference recommendation. This leads to a maximum transmitter power of 33 dbw or 2000 watts.

If the antenna at Cornish were not beamed directly at Andover, the maximum transmitter power at the latter site could be raised by the antenna directivity loss thus obtained. For the 10-foot horn-reflector antenna, this amounts to over 40 db for 10 degrees of angle.[6]

Furthermore, with a nonstationary satellite the probability of the earth station antenna being oriented at the interfered-with radio relay receiver, as assumed above, is quite low. This will reduce substantially the probability of the interference reaching 50,000 picowatts, and in turn will lead to a maximum transmitter power considerably greater than 2000 watts.

7.2 *West Paris–Andover Path*

The separation between the West Paris test transmitter and the Andover station was only 23.5 miles, and the median received signal with the antenna at the latter site elevated 7.5 degrees above the horizontal was about −112 dbm. With a standard TD-2 transmitting arrangement the power would have been about one db less or −113 dbm. This lacks 10 db of meeting the objective of −123 dbm developed above from the C.C.I.R. recommendation for mean interference in any hour.

This additional transmission loss could be provided by about 2 degrees of antenna discrimination[6] at West Paris.

A TH receiver operating at West Paris potentially could suffer interference from an earth station transmitter operating in the 6-kmc common carrier band. The basic transmission loss in this band is estimated to be within about one db, as in the 4-kmc band. Using the objective of −85 dbm developed above, and with the West Paris antenna 2 degrees off beam, the permissible power at Andover, as far as interference at West Paris is concerned, could be about 31 dbw.

No long-term data were obtained on this path from which one might predict the probability of occurrence of short-duration signal enhancements. However, it is quite possible that these might limit the maximum tolerable power at Andover to a lower value than that derived on the basis of tolerable mean interference.

VIII. ACKNOWLEDGMENTS

The writer wishes to acknowledge his appreciation of the efforts of the Eastern Area of the Long Lines Department of the American Telephone and Telegraph Company in setting up the test transmitters at Cornish and West Paris. He is also indebted to D. K. White of Bell Telephone Laboratories who was responsible for conducting the tests, collecting the data and assisting in the analysis of it; also to A. L. Durkee of Bell Telephone Laboratories for his estimates of the basic transmission loss of the two paths and to J. N. Hines for his directivity patterns of the Andover antenna.[7]

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7. For a detailed description of the Andover, Maine, earth station receiver with its antenna, the reader is referred to the Telstar issue of the B.S.T.J., **42,** July, 1963, which appeared after the present paper was submitted.