# Selective Fading of Microwaves

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*The results of an extended survey of microwave propagation over two line-of-sight paths in New Jersey are described. Angle-of-arrival measurements at 1.25-cm wavelength and selective fading observations in a 450-mc frequency band centered at 3950-mc show that the severe fading can be explained in terms of multiple-path transmission. A computer of the analogue type was built to simulate the more complicated selective fading patterns.*

## INTRODUCTION

During the past few years, studies of microwave propagation have been made by the Radio Research group at the Holmdel Laboratory over two paths located in eastern New Jersey. Both of these are line-of-sight paths which might be considered to be typical links in a cross-country microwave radio relay circuit.

In conducting these studies, the usual continuous recordings of signal levels were made but the greater interest was centered in special experiments designed to reveal more of the processes which can cause fading. The most relevant information has been obtained by exploring the incident wavefronts with a narrow-beam scanning antenna (angle-of-arrival studies) and, more recently, by observing the transmission characteristics of the paths by means of a frequency-sweep technique and also by the use of very short pulses.

Some results of angle-of-arrival observations have been reported previously[1] and a companion paper describes the transmission tests conducted with very short pulses.[2] The present paper describes some of the observed mechanisms associated with fading, presents typical data obtained with the narrow-beam scanning antenna and gives examples of the frequency-sweep observations, illustrating the frequency selective

[1] W. M. Sharpless, "Measurement of the Angle of Arrival of Microwaves," *Proc. I.R.E.*, **34,** Nov. 1946, pp. 837–845. A. B. Crawford and W. M. Sharpless, "Further Observations of the Angle of Arrival of Microwaves," *Proc. I.R.E.*, **34,** Nov. 1946, pp. 845–848. H. T. Friis, "Microwave Repeater Research," *Bell System Tech. J.*, **27,** Part I, "Propagation Studies" by A. B. Crawford, Apr. 1948, pp. 183–246.

[2] O. E. DeLange, "Propagation Studies at Microwave Frequencies by Means of Very Short Pulses," *Bell System Tech. J.*, **31,** Jan. 1952, pp. 91–193.

nature of the fading. Some data derived from the continuous recordings of signal levels are presented in an appendix.

The angle-of-arrival observations were made at a frequency of 24,000 megacycles. The frequency-sweep experiment and the recordings of signal levels were made in the 3700 to 4200 megacycle frequency band as were the short pulse observations described in the companion paper.

## GENERAL DISCUSSION OF PROPAGATION PHENOMENA

The map of Fig. 1 shows the location of the experimental transmission paths. The path between Crawford Hill and Southard Hill is 17 miles long and clears the intervening terrain by 65 feet, approximately one Fresnel zone at a frequency of 4000 megacycles. The other path, between Crawford Hill and a 100-foot tower on the Murray Hill Laboratory property, is 22.8 miles long and has clearance of 280 feet. Fig. 2 shows the profiles of these two paths.

The general characteristics of over-land microwave transmission are well known and need be reviewed only briefly. During the daytime hours, when the lower atmosphere is thoroughly mixed by rising convection currents and winds, the signals are normally stable and are near

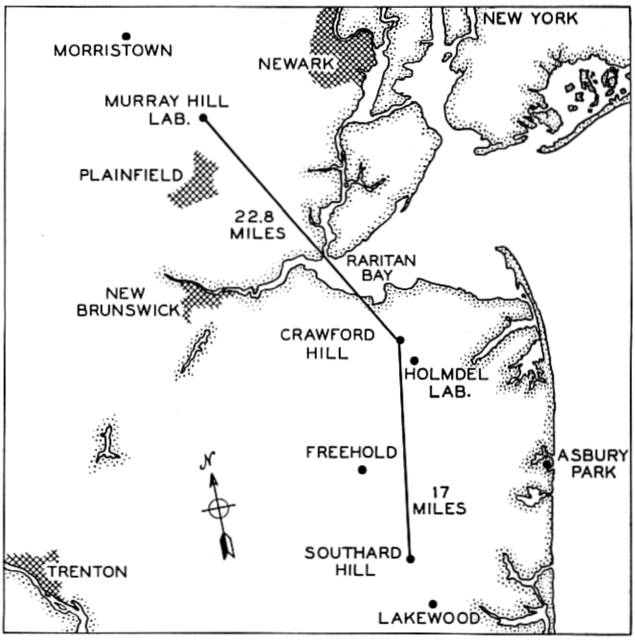



Fig. 1—Map showing location of the experimental transmission path.

the free space levels. Also during the winter months, when the humidity content of the atmosphere is low, signal variations are usually very small. However, on clear summer nights with little or no wind, non-uniform distributions of temperature and humidity can create steep dielectric constant gradients in the lower atmosphere, thus causing anomalous propagation and fading.

When fading occurred on our experimental transmission paths, an alarm circuit connected into the continuously recording equipment was arranged to operate when the signal level dropped below a predetermined value. This enabled observers to be present during severe fading periods

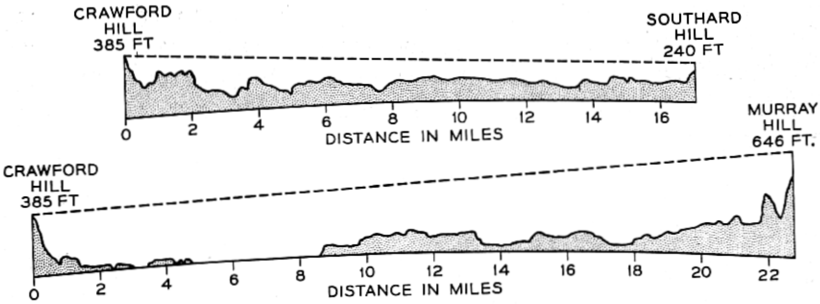



Fig. 2—Profiles of the transmission paths.

and to seek, by means of the special experiments, to determine the causes of the fading.

Although it has not been possible to provide satisfactory explanations for all of the observed fading phenomena, much of the fading (occasions when the signals are depressed to levels 15 to 20 decibels or more below the normal daytime value) can be explained qualitatively in terms of simple ray pictures. Fig. 3 is intended to illustrate some of the observed fading phenomena. The case of multiple path transmission, the most common cause of fading on either transmission path, is shown in Fig. 3(a). Two, three and sometimes more signal components are found to arrive at various angles in the vertical plane, usually above the line of sight. Wave interference among these components produces fading, the severity of which depends upon the relative amplitudes and delays of the components. At these times, different frequencies fade differently and the signals received on two vertically spaced antennas also fade differently. The use of either frequency or space diversity would be effective in this type of fading.

A relatively rare type of fading, observed only on the Murray Hill path, is believed to be caused by the mechanism illustrated in Fig. 3(b).

Here a reflecting layer is situated between the heights of the transmitter and receiver. The signal then suffers attenuation due to reflection of part of the energy from the direct path. Widely separated frequencies are affected in like fashion and the outputs of antennas spaced for diversity reception tend to be in agreement although the fine structure fading is usually different.

On neither of the experimental transmission paths is there a rgeular ground-reflected component of any consequence. Due to the roughness of the ground and the presence of vegetation, the effective reflection coefficient is of the order of 0.2 for either path. Ground reflections thus play

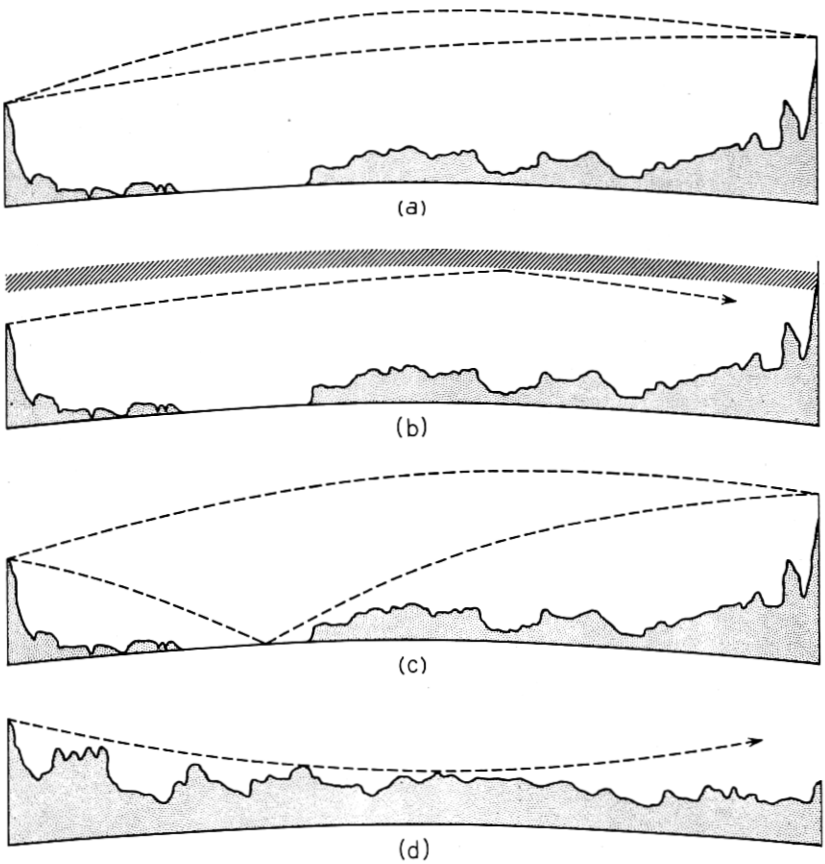



Fig. 3—Possible ray paths involved in severe fading. (a) Multiple path transmission. (b) Attenuation by reflection from an elevated layer. (c) Abnormal water reflection on the Murray Hill-Crawford Hill path. (d) Substandard conditions on the Southard Hill-Crawford Hill path.

no significant part in the fading picture with the exception of the situation illustrated in Fig. 3(c). Occasionally on the Murray Hill path, conditions of atmospheric refraction are such that a strong signal component is received by virtue of reflection from the water surface of Raritan Bay. Under normal conditions, the geometry of the path does not permit such a reflection.

Normally the dielectric constant of the atmosphere decreases with height above ground so that the ray path usually has a curvature in the same direction as the earth curvature. However, it is possible for the dielectric constant of the atmosphere to increase with height above ground (sub-standard conditions) so that the ray path has a curvature opposite that of the earth. This results in the condition illustrated in Fig. 3(d) where the limiting or tangent ray does not reach the receiver and only a weak signal is received by virtue of diffraction. Widely separated frequencies and vertically spaced antennas are affected alike as regards the average signal level but not the fine structure fading. This effect has been observed only on the Southard Hill-Crawford Hill path which has small clearance to begin with. It has been observed on several nights in late summer or early autumn after a radiation type ground fog has formed in the late evening and usually persists until the fog is dispelled by winds or by the morning sun.

There are, of course, times when the transmission conditions are considerably more complicated than those described above. Some of these apparently are due to a combination of the situations illustrated in Fig. 3 while others may be the result of an atmospheric focussing or trapping phenomenon. In addition to the various phenomena just described, which, fortunately, occur rather infrequently, there are numberous occasions when the signal varies plus and minus a few decibels relative to the free space level. It has not been possible actually to demonstrate the mechanism responsible but it seems most likely that these smaller variations are due to non-linear dielectric constant gradients which give the atmosphere the properties of a convergent or divergent lens.

An important result of the observations made to date is the conviction that the severe fades, signal excursions to levels 30 decibels or more below the free space field, were all caused by wave interference. It appears that, as the average signal level is depressed by any mechanism, it becomes more and more vulnerable to the effects of extra signal components of small amplitude that often may be present but go unnoticed when the signal is near normal levels. Thus, while the average signal level during the conditions illustrated in Figs. 3(b) and 3(d) may be no more than 15 to 20 decibels below the normal daytime level, there is usually superimposed a fine structure fading in which short duration fades to levels as much as 45 decibels below free space have been observed. For this reason it is desirable to avoid paths having small clearance over intervening terrain and also paths which have a permanent ground reflection of sufficient magnitude to depress the signal to critical levels when, due to variable atmospheric refraction, the direct and reflected components are in phase opposition.

The following sections describe the angle-of-arrival and frequency-sweep experiments on which much of the preceding discussion was based.

### ANGLE-OF-ARRIVAL OBSERVATIONS

A photograph of the Crawford Hill receiving site is shown in Fig. 4. The building housing the receiving equipment and the associated antennas are mounted on a framework which can be rotated on a concrete track, permitting investigation of the transmission characteristics of either path. The parabolic antennas on the tower are used for continuous recording of 4195 megacycle signals. The long object at the left of the

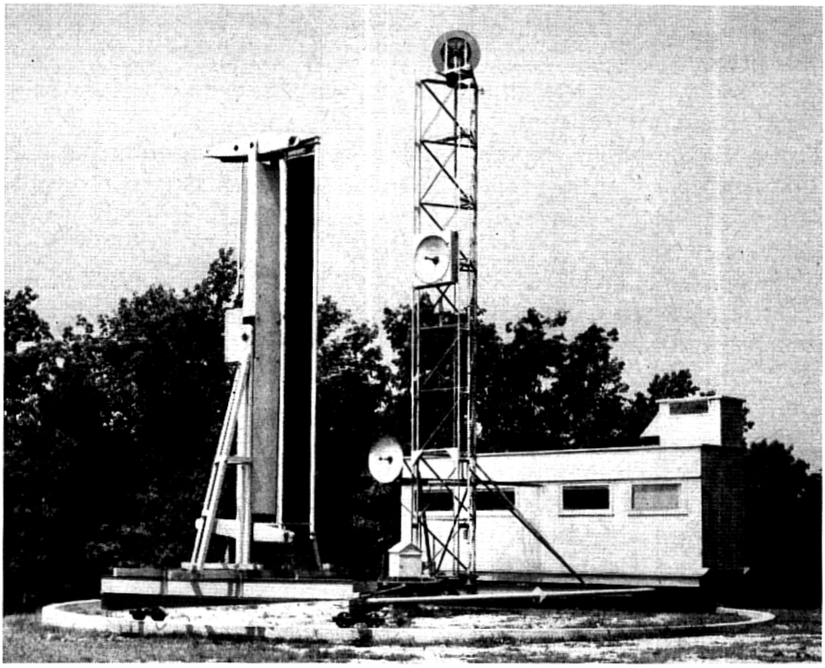


Fig. 4—The Crawford Hill receiving site.

picture is the metal-lens antenna used for making the angle-of-arrival observations. Its half-power beamwidth is 0.12 degree at the operating frequency of 24,000 mc. The focal length of the lens is 48 feet and its feed is located in the little cupola on top of the building. The feed is held fixed, while the lens is moved vertically by a motor-driven mechanism; thus the antenna beam also moves vertically. The antenna scans a total angle of two degrees in ten seconds. It is fed by a 24,000-mc radar set which is gated to receive only the pulses reflected from a corner reflector located at the distant terminal of the transmission path. The spot on the radar cathode ray tube moves vertically in synchronism with the scanning antenna, and the horizontal deflection is proportional to the amplitude of the pulse received from the corner reflector. The display thus shows amplitude of the various incoming signal components as a function of their angles of arrival.

The antenna installation on Southard Hill is shown in Fig. 5. At the left is the transmitting paraboloid for the 4195-mc continuous wave transmitter, the radar corner reflector is in the center, and on the right is the horn-reflector antenna used in the frequency-sweep experiments described below. Similar equipment is located at the Murray Hill terminus. The corner reflector is 5.5 feet on a side, and at 24,000-mc has sufficient gain to override reflections from other nearby objects, and thus becomes easily identifiable on the radar screen.

The radar oscilloscope for typical propagation conditions is shown in Fig. 6. These pictures were obtained by leaving the camera shutter open during the ten-second interval required for the antenna beam to scan through the angular range of 2°. All of these representative photographs were taken on the Murray Hill-Crawford Hill path although similar results were obtained on the Southard Hill-Crawford Hill path with the exception of Fig. 6(f). The normal daytime transmission is shown in Fig. 6(a) to consist of a single path arriving at an angle of $-0.2°$ with respect to a fixed reference angle. The horizontal lines represent intervals of 0.1°, so that changes of 0.05° can be estimated. The other pictures in Fig. 6 were all taken during fading conditions.

Figs. 6(b) and 6(c) are good examples of the multiple-path condition shown in Fig. 3(a) in which the individual components are almost equal in amplitude and well separated in angle. In Fig. 6(b) there are two components arriving at angles of 0.1° and 0.6° above the normal line-of-sight while in 6(c) there are three components with angles of 0.05°, 0.35° and 0.7° above the normal angle. The position and amplitude of the signal components may change radically in a matter of minutes, and often there is no component that can be identified as the "normal" one.

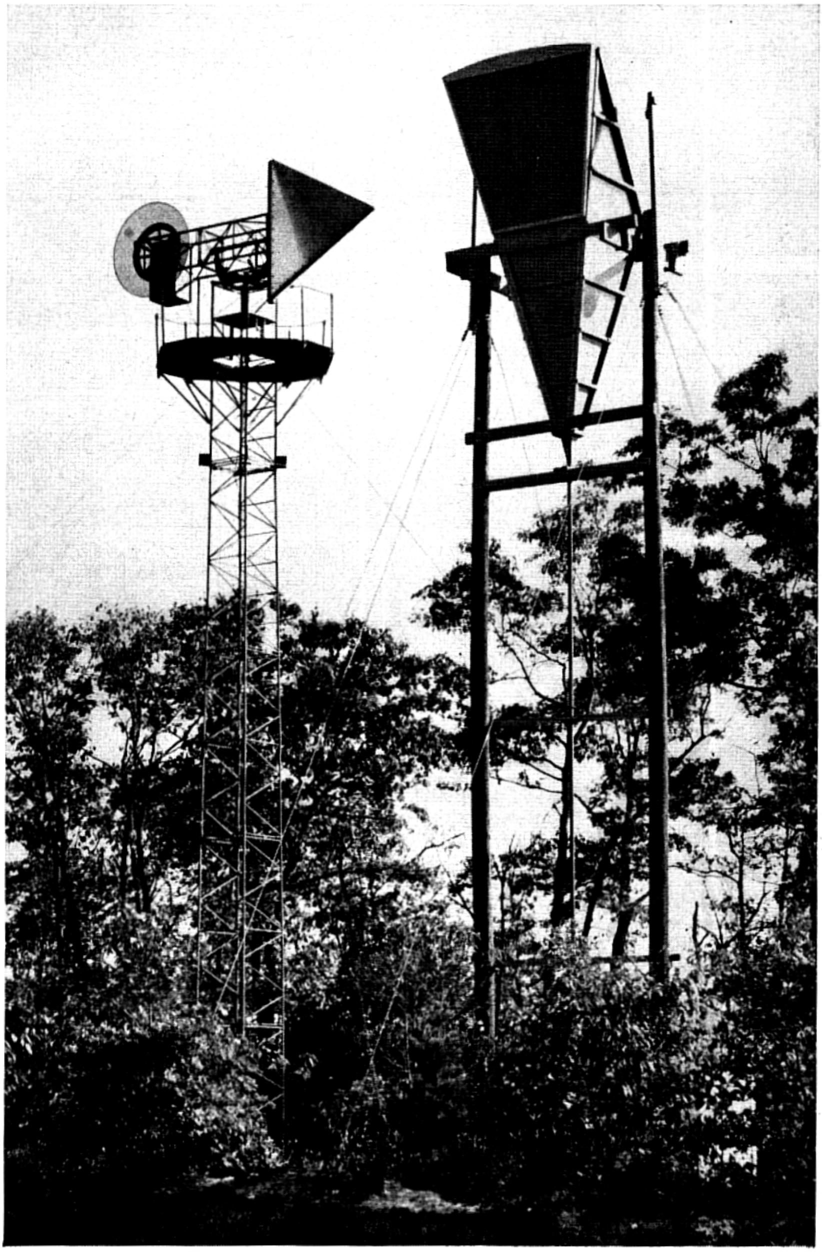


Fig. 5—The Southard Hill transmitting site.

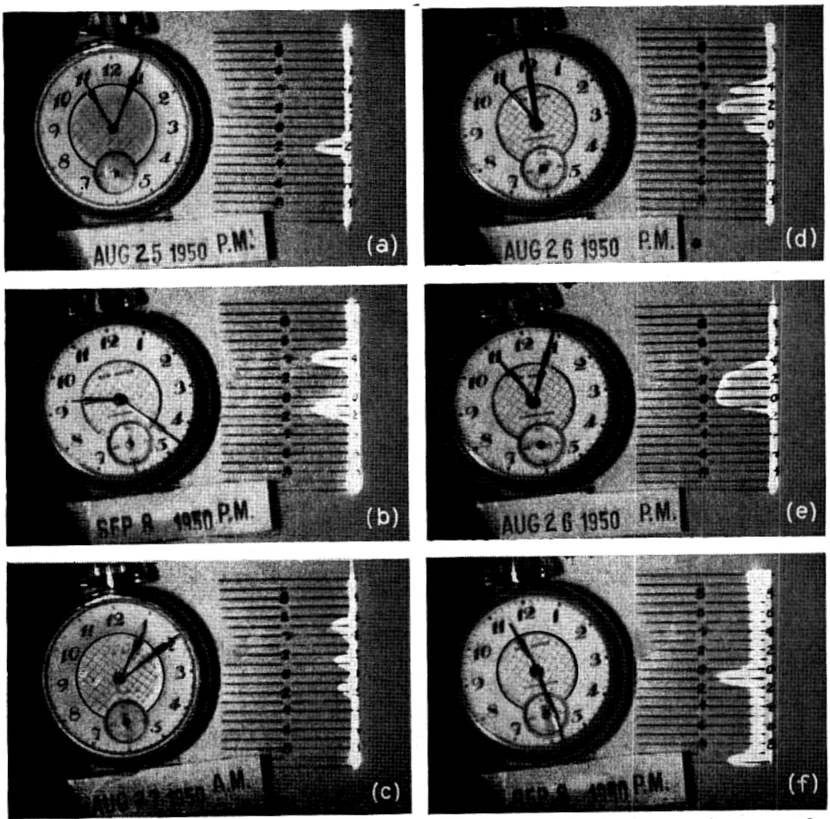



Fig. 6—Representative photographs of angle-of-arrival observations on the Murray Hill-Crawford Hill path. (a) Normal day. (b) Two elevated paths. Sept. 8, 1950; 9:23 p.m. (c) Three elevated paths. Aug. 27, 1950; 1:11 a.m. (d) Multiple paths. August 26, 1950; 11:00 p.m. (e) Wide angle "fill-in". Aug. 26, 1950; 11:04 p.m. (f) Abnormal water reflection. Sept. 8, 1950; 11:28 p.m.

During these multiple-path conditions, the recordings of the 4195-mc transmission generally show the broad maxima and sharp minima characteristic of wave interference.

Figure 6(d) shows a case in which the various paths are not completely separated while Fig. 6(e) (taken four minutes later) shows that energy is being received almost without variation over a vertical angle of 0.4°. This may represent a number of ray paths which would be separable by a narrower-beam antenna, or it may indicate a focussing or trapping phenomenon. Often when the type of transmission illustrated by 6(e) is present, the recorded 4195-mc signal may be as much as 12 to 15 decibels above the free space levels.

Fig. 6(f) illustrates the case of abnormal reflection from the water of Raritan Bay on the Murray Hill path as indicated in Fig. 3(c). Here the "normal" signal component is arriving at 0.1° above the line-of-sight while another component, almost equal in amplitude, is arriving at the very bottom of the scan, about 0.8° below the line-of-sight. It is quite probable that there have been times when this component was present but was outside the range of the scanning antenna.

The mechanisms discussed in connection with Fig. 3(b) and 3(d) cannot be demonstrated by photographs such as those just presented although the angle-of-arrival radar was instrumental in furnishing the clues to the phenomena. Due to the two-way attenuation of the radar-corner reflector technique, the signal at these times rapidly falls below the noise level of the receiver. For the same reason, it is not possible to detect the extra signal components of small amplitude which were postulated to account for the very deep fades sometimes observed under these transmission conditions.

## FREQUENCY-SWEEP OBSERVATIONS

Since most of the fading is due to interference between waves which travel over different paths of, presumably, different lengths it was realized that the fading was likely to be frequency selective. Just how selective would depend on the relative lengths of the individual transmission paths. The usual methods for determining path length differences are to use short pulses, or to sweep the frequency. Since it was likely that the path-length differences would be measured in feet rather than yards, very short pulses or a wide frequency-sweep were required. An oscillator[3] was available whose frequency could be swept over the licensed band of 500 mc between 3700 mc and 4200 mc. The frequency-sweep experiment was set up on the Murray Hill-Crawford Hill path for the summer of 1949. The following summer, the milli-microsecond pulse transmission tests described in the companion paper were conducted over the same path. As might be expected, simultaneous observations showed good agreement between the two methods.

The frequency of the transmitter, located at Murray Hill, is swept over a 450-mc band centered at 3950 mc at a 60-cycle rate. At the receiver, a similar oscillator is used for the beating oscillator except that its frequency is swept linearly through the same frequency band in one

[3] This oscillator was developed by M. E. Hines and is described in his paper published in the *Bell System Technical Journal*, Vol. 29, Oct. 1950. It uses a 416A close-spaced triode in a wave-guide cavity. The frequency is changed by means of a plunger which is capacity-coupled to the plate of the tube and which is actuated by a modified loud speaker unit.

second. Since the intermediate frequency amplifier of the receiver is only 350 kc wide, (centered at 600 kc) narrow pulses are generated each time the frequency of the transmitter crosses the frequency to which the receiver is tuned. These intermediate frequency pulses are displayed vertically on a cathode ray tube. The horizontal trace is synchronized with the one-second sweep rate of the beating oscillator.

The normal daytime frequency-sweep pattern is shown in Fig. 7(a). The vertical scale is linear in amplitude and the horizontal scale is almost linear in frequency, with frequency decreasing from left to right. Visible at the extreme left is the signal used for continuous recording. Since there is only one transmission path involved, the amplitude of the received signal is nearly constant over the 450-mc band. If another signal were present which had travelled over a path of different length, the two signals would add when the frequency is such that the path length difference is an even multiple of half-wavelengths and subtract when the path length difference is an odd multiple of half-wavelengths. Simple calculation shows that if the path length difference is one foot, the frequencies at which the signals add and subtract are separated about 500 mc. Thus the limit of resolution for the frequency-sweep experiment is a little more than one foot.

Photographs taken on a night when the angle-of-arrival radar indicated two almost equal components separated about 0.4 degrees in angle are shown in Fig. 7(b). The time interval between the two pictures is 30 seconds, during which the minimum had shifted about 150 mc. The pictures can be interpreted as simple two-path transmission with an indicated path difference of about two feet and an amplitude ratio of 0.7 to 1. On this night the minimum shifted back and forth across the frequency band—sometimes slowly and sometimes rapidly. At times the position of the minimum might remain fixed but its depth would change.

Photographs taken on a night when there were abnormal reflections from the water of Raritan Bay are shown in Fig. 7(c). There are evidently two main components with path difference of about six feet, with a small third component causing the slight decrease in amplitude of the peaks from left to right. These pictures were taken 9 minutes apart, but this type of pattern was observed over a period of about three hours on this night.

Usually the frequency sweep patterns are considerably more complicated than the ones shown so far. Fig. 7(d) shows two photographs which indicate that at least three signal components and perhaps more were present. The time interval between the two pictures was about 30 seconds.

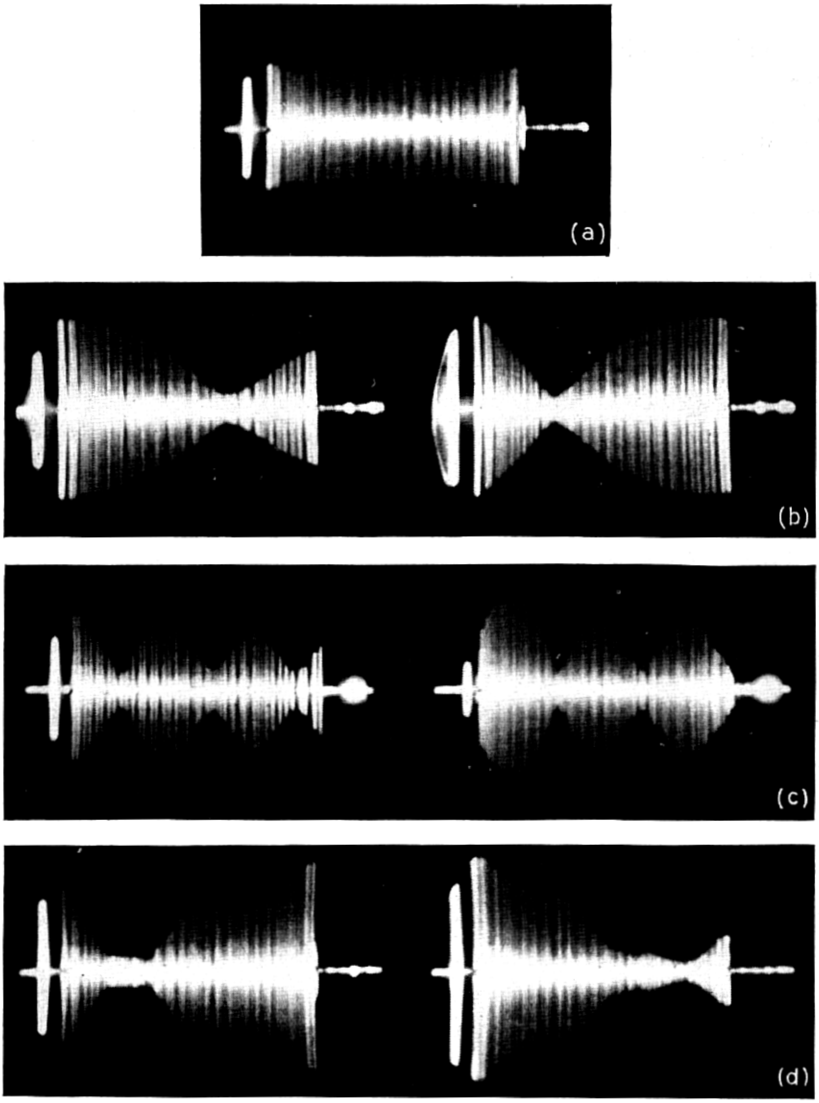



Fig. 7—Representative frequency-sweep patterns observed on the Murray Hill-Crawford Hill path. (Summer 1949.) (a) Normal day. (b) Two components with a path difference of two feet. (c) Two main components with a path difference of about six feet plus a small third component. (d) Multiple component pattern.

SYNTHESIS OF FREQUENCY-SWEEP PATTERNS

To aid in the interpretation of the complicated frequency sweep patterns, a computor of the analogue type was built. This apparatus combines four signal components, three of which are variable in delay and amplitude, and presents the result on a cathode ray tube in the same form as the actual frequency sweep patterns. Thus a particular pattern can be synthesized on the computor and the number of components, together with their path differences and relative amplitudes, read directly from the computor dials. This is accomplished by generating four 600-kc signals, three of which are phase modulated at 60 cycles per second. The total phase deviation and relative signal amplitude are variable. The four signals are then summed and displayed in vertical deflection on a cathode ray tube having a 60-cycle horizontal sweep.

The synthesis of the patterns of Figures 7(b) and 7(c) are shown in Fig. 8. The upper synthesized pattern is simply a combination of two components with relative amplitudes of 0.7 and 1 and a path difference of two feet. The lower pattern consists of the reference component with unity amplitude, a second component with an amplitude of 0.5 and a path difference of 5.7 feet, and a third component with an amplitude of 0.2 and path difference of 0.8 feet. The similarity between the actual and synthesized patterns is obvious.

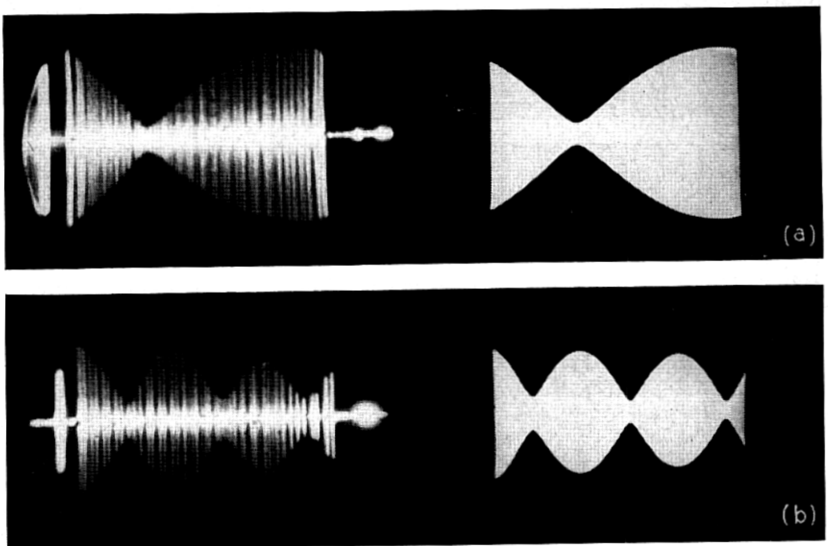



Fig. 8—Synthesis of the frequency-sweep patterns of Figs. 7(b) and 7(c).

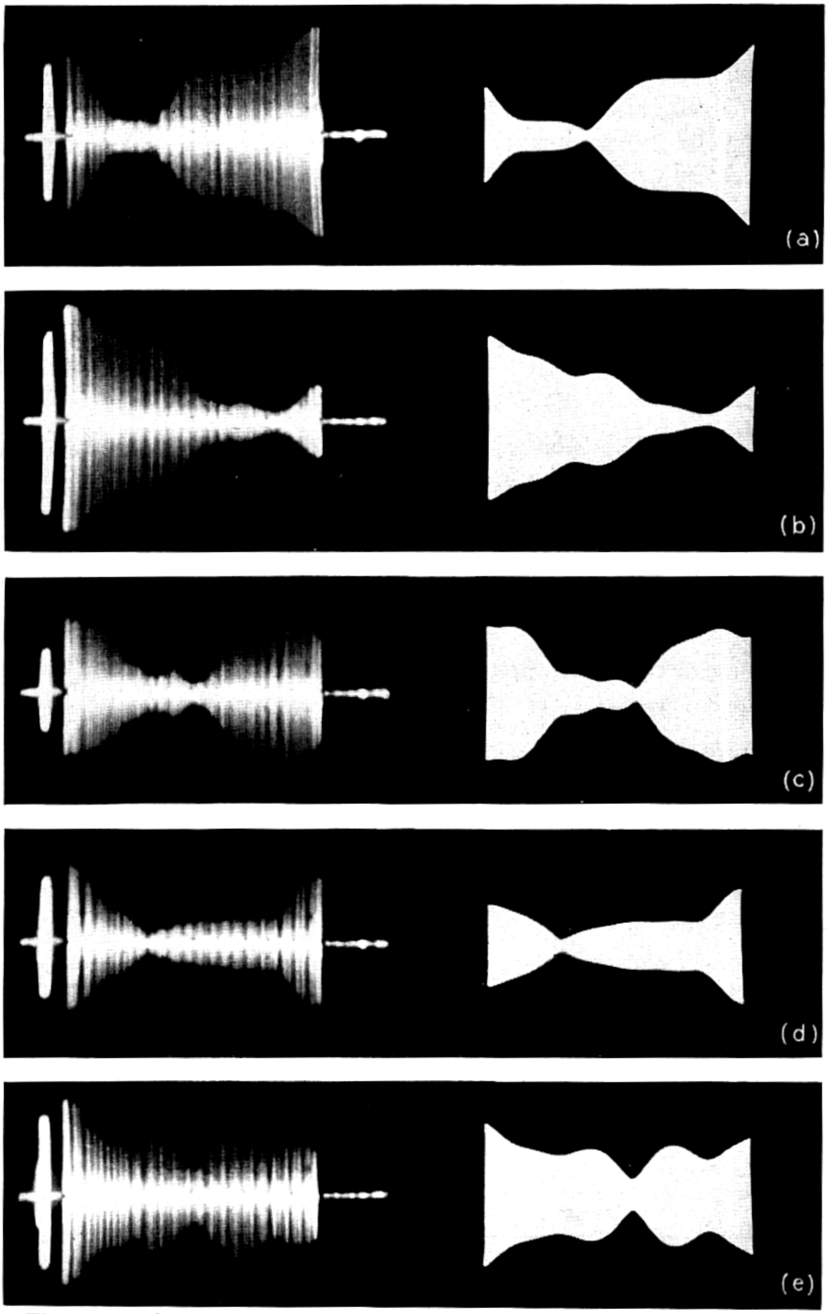



Fig. 9—Synthesis of complicated frequency-sweep patterns using four components. See Table I for values of the relative amplitudes and path differences.

Examples of attempts to synthesize some more complicated frequency sweep patterns, taken on the night of August 2, 1949, are shown in Fig. 9. Four components were required in each case, with the path differences and delays being summarized in Table I. Although the pictures all appear very different, in general major changes were required only in component No. 2 to go from one pattern from the next, as Table I shows. All the remaining components had to be very carefully trimmed in both amplitude and delay to get good synthesis (especially in the case of Fig. 9(d), but these changes were relatively small.

## CONCLUDING REMARKS

The special experiments just described have led to the conclusion, expressed earlier, that the severe fading observed on the two test paths is the result of multiple-path transmission in which several components may be involved. These components may arrive at the receiver at various angles up to three quarters of a degree above the normal daytime angle-of-arrival and, in the case of abnormal water reflection on the Murray Hill path, as much as 0.8 degree below the normal angle. The path differences among these components may vary from a fraction of a foot to about ten feet. The long-delay components are usually small in amplitude.

In all cases where observations were made during periods of exceptionally high signal levels, say 10 to 15 decibels above free space level, the frequency-sweep patterns were substantially flat, suggesting a focussing or trapping phenomenon. The frequency-sweep patterns were also flat on those nights when the signal excursions were only a few decibels above and below the normal daytime level. However, the severe fades

TABLE I

| | | Fig. 9 (a) | Fig. 9(b) | Fig. 9(c) | Fig. 9(d) | Fig. 9(e) |
|---|---|---|---|---|---|---|
| Component No. 1 (Reference) | Amplitude<br>Path diff. (ft.) | 1<br>0 | 1<br>0 | 1<br>0 | 1<br>0 | 1<br>0 |
| Component No. 2 | Amplitude<br>Path diff. (ft.) | 0.9<br>1.1 | 1.2<br>0.5 | 0.7<br>1.7 | 1.1<br>0.5 | 0.4<br>1.1 |
| Component No. 3 | Amplitude<br>Path diff. (ft.) | 0.2<br>5.2 | 0.1<br>5.7 | 0.2<br>5.6 | 0.2<br>5.7 | 0.2<br>5.7 |
| Component No. 4 | Amplitude<br>Path diff. (ft.) | 0.05<br>9.2 | 0.1<br>9.2 | 0.15<br>11.0 | 0.1<br>9.3 | 0.1<br>8.7 |
| Time | | 12:08½ AM | 12:09 AM | 12:18 AM | 12:24 AM | 12:25 AM |

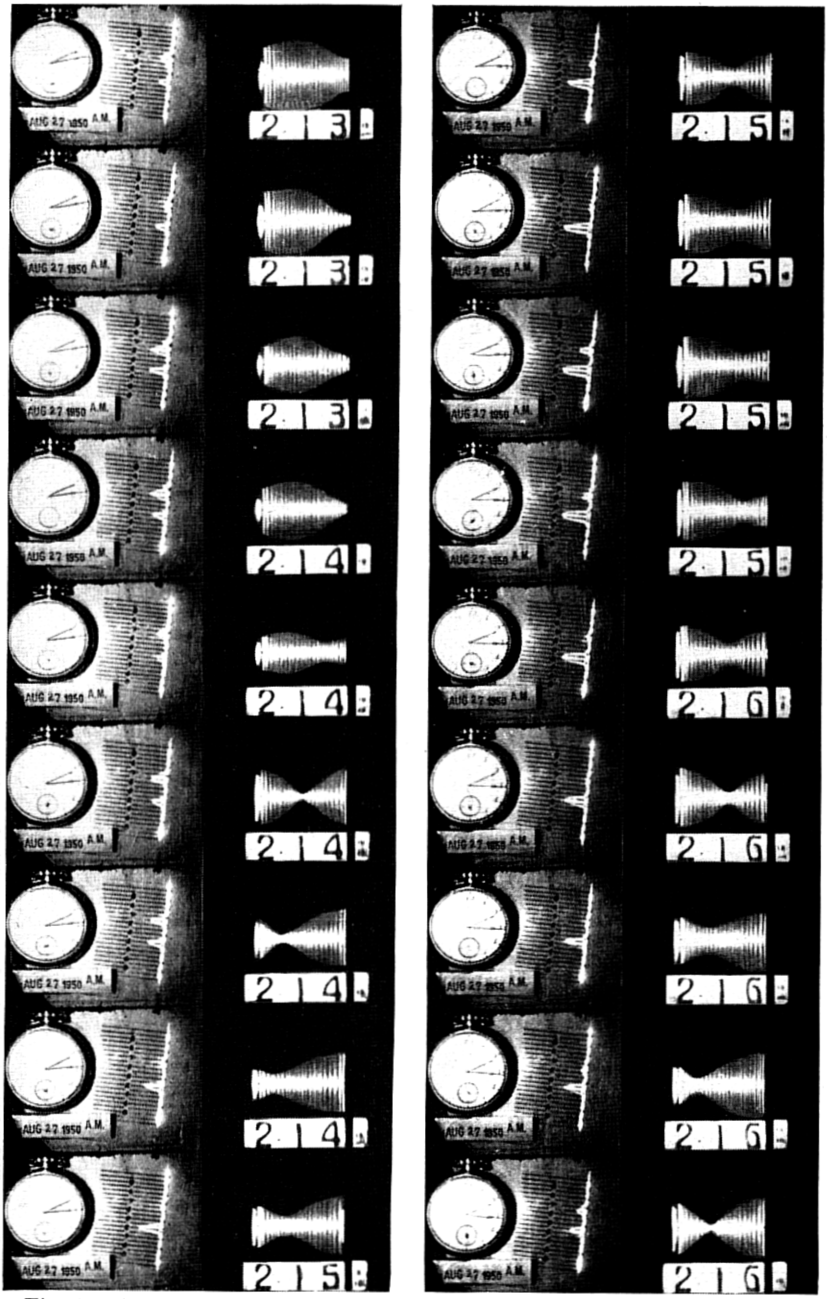
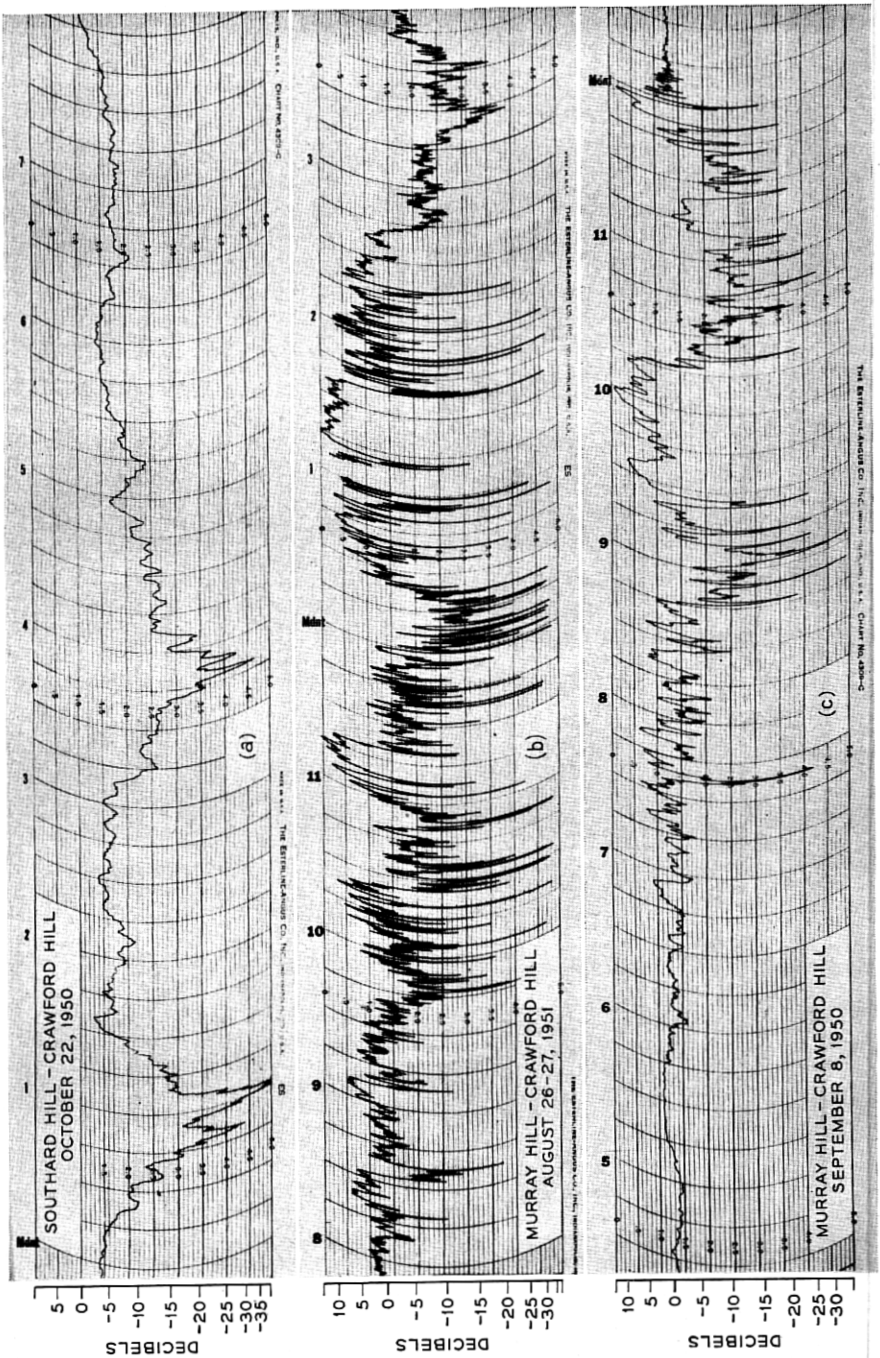



Fig. 10—A sequence of angle-of-arrival and frequency-sweep patterns taken at ten-second intervals.


SOUTHARD HILL – CRAWFORD HILL
OCTOBER 22, 1950
(a)
MURRAY HILL – CRAWFORD HILL
AUGUST 26–27, 1951
(b)
MURRAY HILL – CRAWFORD HILL
SEPTEMBER 8, 1950
(c)
DECIBELS
DECIBELS
DECIBELS

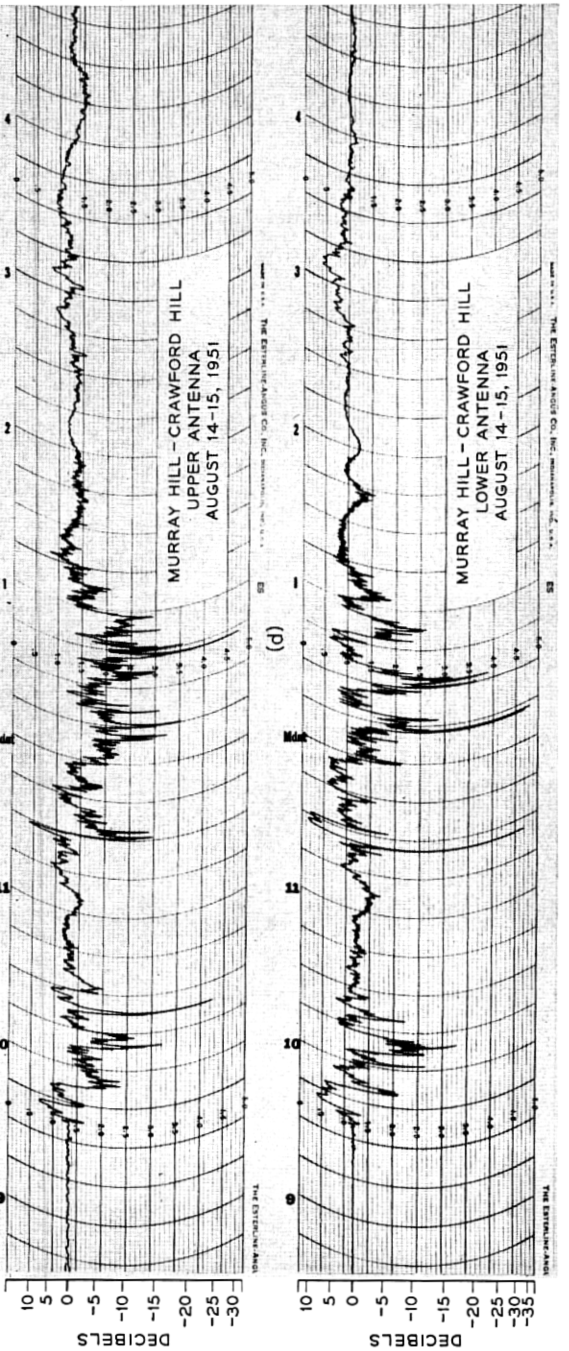
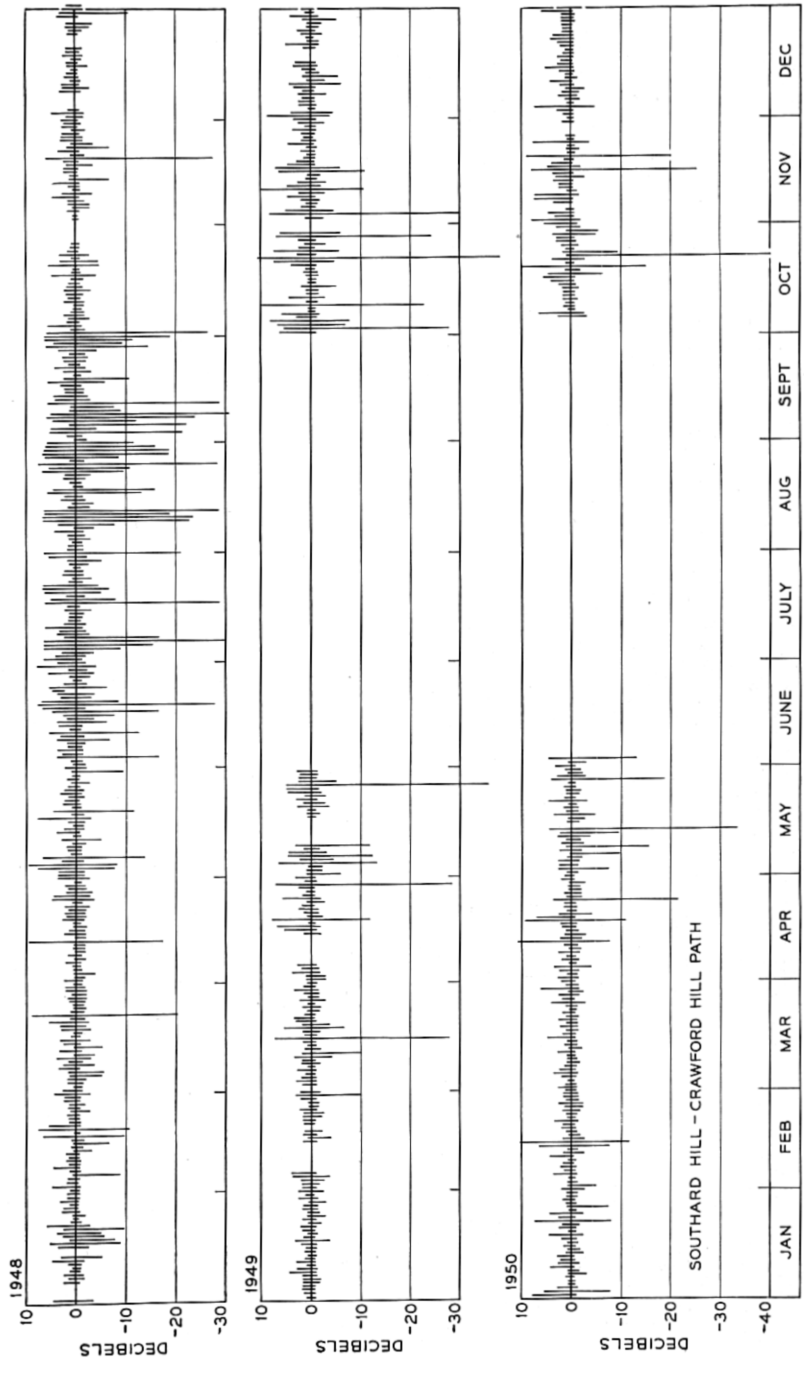



Fig. 11.—Typical recordings of 4195-mc transmission during severe fading conditions. The zero decibel line represents the normal daytime (free space) level. (a) Substandard conditions on the Southard Hill-Crawford Hill path. Night of Oct. 21–22, 1950. (b) Multiple path transmission on the Murray Hill-Crawford Hill path. Night of Aug. 26–27, 1950. (c) Multiple path transmission on a night when abnormal water reflections were present on the Murray Hill-Crawford Hill path. Night of Sept. 8–9, 1950. (d) Simultaneous recording of the outputs of two similar antennas; vertical spacing of 30 feet. Night of Aug. 14–15, 1951.


SOUTHARD HILL - CRAWFORD HILL PATH
1948
1949
1950
DECIBELS
DECIBELS
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10
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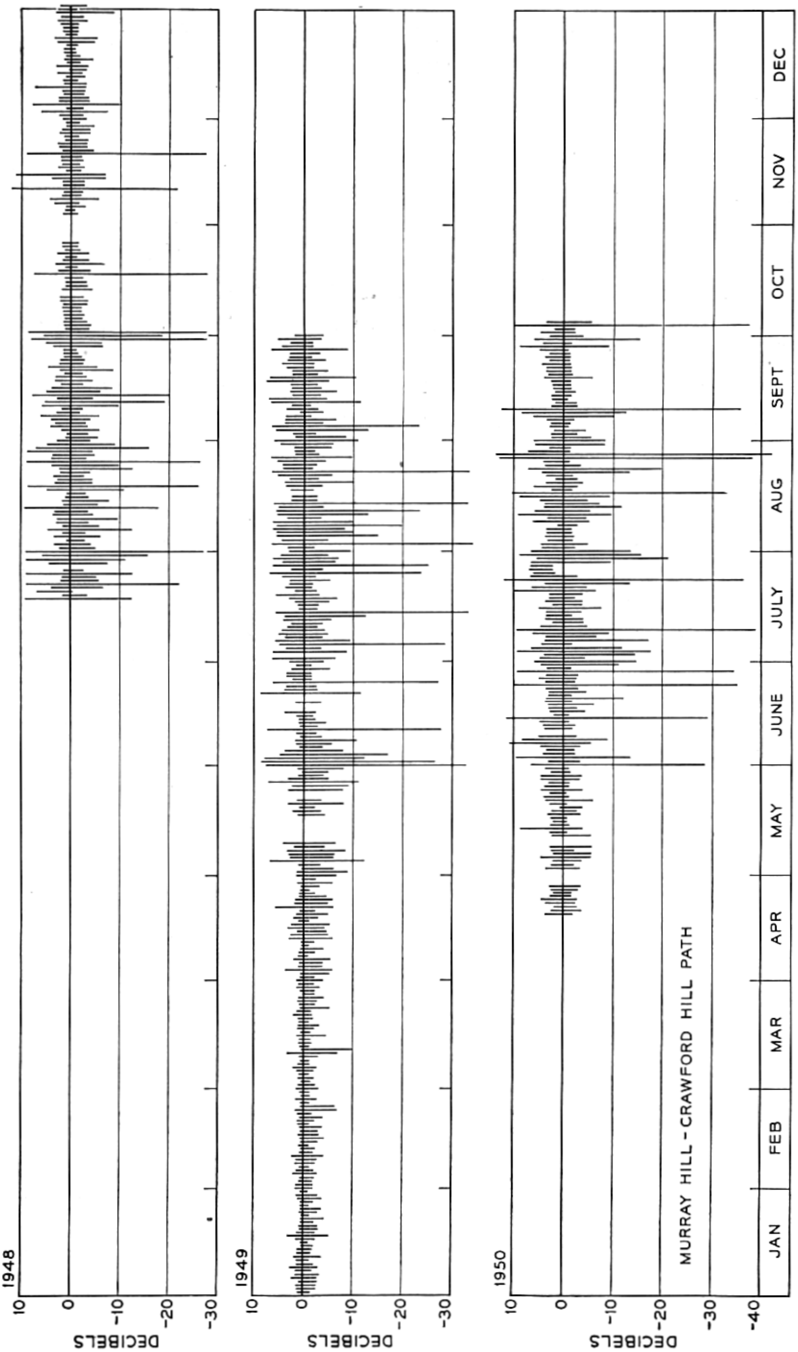


Fig. 12—Chart showing the daily fading range observed on both transmission paths for the years 1948, 1949, and 1950. The vertical lines terminate on points indicating the highest and lowest signals observed during the twenty-four hour period of noon to noon.

of short duration sometimes observed when the average signal level was depressed by the mechanisms of Figs. 3(b) or 3(d) were found to be frequency selective.

Some of the studies described in this paper were made with vertically polarized waves and some with horizontally polarized waves; at times, 45° polarization was used. In so far as it was possible to determine, the propagation characteristics of both paths were independent of the polarization used.

No meteorological soundings were made in connection with this work. Considering the rapid changes usually observed with the angle-of-arrival and frequency sweep apparatus, it is doubtful that meteorological measurements made in the usual manner would show much correlation with the radio observations except, perhaps, in a general way. The sequence of pictures in Fig. 10 is included to show how the angle-of-arrival and

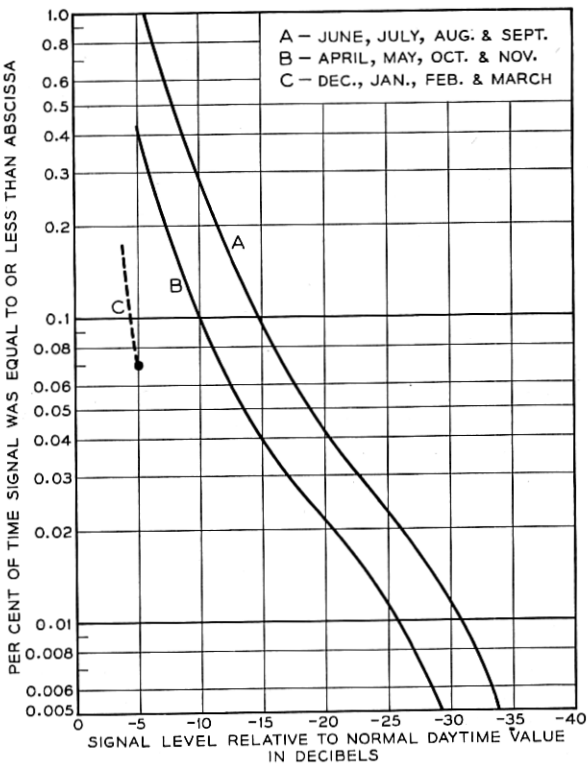


Fig. 13—Time distribution curves of the signal levels observed on the Murray Hill-Crawford Hill path. Data of 1947, 1948, 1949 and 1950.

frequency-sweep patterns change with time. These pictures were taken at 10-second intervals. On this occasion there was good correlation between the angle-of-arrival and frequency-sweep data. Such was not always the case, however, and considering the wide difference in operating frequencies, 24,000 mc and 4000 mc, instantaneous correlation should not necessarily be expected.

Although all the studies described in this paper were made on the two local paths, the results are compatible with propagation measurements made by another group in the Laboratories during a survey for the transcontinental radio relay system.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of W. M. Sharpless who, for some time, was associated with this work; also to acknowledge

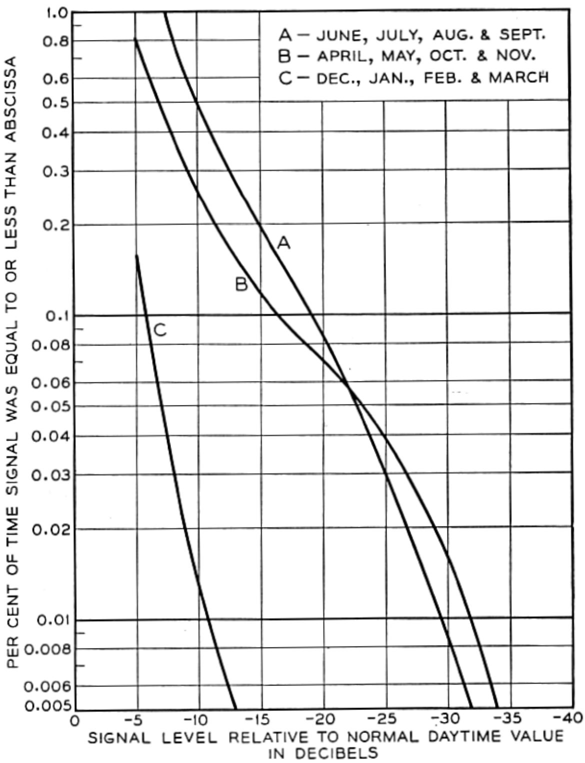

Fig. 14—Time distribution curves of the signal levels observed on the Southard Hill-Crawford Hill path. Data of 1947, 1948, 1949 and 1950.

the full time assistance of R. A. Desmond and the part time assistance of L. R. Lowry and S. E. Reed. All the work was done under the guidance of Dr. H. T. Friis.

## APPENDIX

This appendix is included to illustrate some of the characteristics of the propagation as shown by the recordings of 4195-mc signal levels. Fig. 11 is a reproduction of some typical records obtained during severe fading periods. Fig. 11(a) is an example of transmission during the substandard conditions illustrated by the ray diagram of Fig. 3(d). Fig. 11(b) is typical of multiple-path type fading in which the signal components arrive from elevated angles as shown in Fig. 3(a), while Fig. 11(c) was recorded on a night when, for a time, there were abnormal reflections from the water of Raritan Bay on the Murray Hill path, see Figs. 3(c), 6(f) and 7(c). The records of Fig. 11(d) show how the outputs of two similar antennas, spaced vertically about 30 feet, differ in regard to the deep fades of short duration.

The chart of Fig. 12 shows how the fading varies with the time of year. On this chart, the vertical lines represent the extremes in signal level observed during the twenty four hour period from noon to noon. The large signal variations are concentrated mainly in the summer months.

The time distribution of the signal levels recorded on the Murray Hill-Crawford Hill path are shown in Fig. 13. Each of the curves is for a four-month period: the period of least fading, December, January, February and March; the period of most fading, June, July, August and September; and the in-between period consisting of April, May, October and November. Data obtained in the years 1947, 1948, 1949 and 1950 are included. Fig. 14 shows similar data for the Southard Hill-Crawford Hill path. The hump in the time distribution curve for the months of April, May, October and November is due to substandard conditions, illustrated by the ray diagram of Fig. 3(d) and the typical record of Fig. 11(a), which affected transmission on this path during several nights in October, particularly in the years 1947 and 1950. When it occurred, this type of transmission usually persisted for a period of several hours.