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# Effect of Antenna Radiation Angles Upon HF Radio Signals Propagated Over Long Distances[1]

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Observations of a HF continuous wave radio signal which after propagating over east-west paths 6800 and 8400 kilometers in length were received on antennas having different vertical-plane radiation angles indicate that very low radiation-angle antennas may be advantageous for use in long-distance communication systems.

Much of the time, hourly median signal levels received on antennas with radiation angles less than 2 degrees exceeded those received at angles of 15 degrees by 10 decibels while signals received at angles between 2 and 5 degrees were 5 decibels greater than those received at 15 degrees.

No significant change in the fade rate of the signal received at various radiation angles was found.

A limited amount of data obtained during ionospheric storms suggests that the radio signal received on a low radiation-angle antenna is deteriorated by storm effects for a shorter time, and to a lesser degree, than is the signal received by a high radiation-angle antenna.

## 1. Introduction

In the design of antennas for use in ionospheric scatter and tropospheric communication systems, considerable attention has been given to the optimization of the radiation angle (vertical angle of radio wave radiation). In long-distance high-frequency communication circuit design, however, little attention has been paid in many cases to this parameter. In part this may be because HF radio signals seem to be receivable on almost any antenna, although not necessarily with the reliability desired in modern communication systems, and in part because the longer wavelengths of radio waves in the HF band require high antennas if low radiation angles are called for and result in greater antenna construction costs, and in part because the optimum radiation angle is more difficult to predict and more variable then for the other two examples.

Potter and Friis [1][2] in a short experiment in 1932 compared the signal strengths received on two antennas with different radiation angles for propagation paths between New Jersey and South America as well as between New Jersey and England and found that significantly stronger signals were received on the lower radiation-angle antenna for both horizontal and vertical polarizations.

Hallborg and Goldman [2] in a 1947 paper presented results of angle-of-arrival measurements made during September to December 1941 on a path between Riverhead, N.Y. and Bolinas, Calif. Measurements were made only between the hours 0900 and 2000 e.s.t., during most of which time the entire path was in the sunlight. The circuit path length was about 4000 km, a distance which is normally considered as the maximum range for 1-hop propagation. The angles of arrival reported were all greater than 5° and tended to be grouped around values appropriate for 2 and 3-hop propagation modes. It is not clear whether the equipment was capable of measuring the low angles required for a 1-hop mode. Signal intensity measurements made in 1945 over this same path were made utilizing rhombic antennas with radiation angles at 8.5 and 12.5°. A major conclusion of the results shown by this test was that a fixed-beam type of high-frequency antenna will not give maximum performance at all seasons or times of day.

Angle-of-arrival measurements were made in England by Wilkins and Kift [3] during daylight hours over the transmission path at various times between October 1952 and January 1954. Utilizing pulse signals from Negombo, Ceylon, 8700 km from the receiver at Slough, England, it was found that the strongest ray arrived predominately at angles of 7° ±2° except during the summer when signal levels were too low to record. Similar measurements on a 7200-km path between Kirkee, India, and Slough showed that the predominate angles of arrival of the strongest ray were, during winter 7½° ±2° and during summer 5° ±2°. Frequently, angles of 3 to 4° were observed on both paths; however, as the authors point out, very low angles of elevation were discriminated against by both the receiving and transmitting antennas.

Occasional oral reports tend to suggest that certain long distance HF circuits which have terminals with low radiation-angle antennas provide extraordinarily good signal reception over periods of time greatly exceeding that normally expected.

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[1] Contribution from Central Radio Propagation Laboratory, National Bureau of Standards, Boulder, Colo.

[2] Figures in brackets indicate the literature references at the end of this paper.

To provide a better understanding of the relationship between signal characteristics and antenna radiation angle a long-distance cw radio experiment was undertaken, the results of which are presented here.

## 2. Experimental Arrangement

Through the cooperation of the United States Information Agency a cw radio signal at a frequency of 20.06 Mc/s was transmitted from a Voice of America station in Munich, Germany on a 24-hour-a-day, 5-days-a-week schedule. The Munich signal was received at sites in the vicinity of Boulder, Colorado and at the National Bureau of Standards Sterling, Virginia Field Station, near Washington, D.C., on antennas having different effective heights and radiation angles. Great-circle distances from Munich to the receiving sites are: to Boulder 8400 km (5200 miles) and to Sterling 6800 km (4200 miles).

### 2.1. Transmitting Antennas

Voice of America communication commitments made it necessary to alternate transmission of the 20-Mc/s signal between two rhombic antennas which were not quite identical although both were aimed on a bearing of 295°. One rhombic antenna designated as 6E was used during the period 0000–0700 m.s.t. and the second antenna designated as 2W was used for the remainder of a 24-hour period with the exception of the period 0700–0800 m.s.t. during which time transmitter maintenance was performed and no signal was transmitted.

The bearing of Sterling from Munich is 297° and the antenna beam maximum at 295° was thus oriented nearly along the propagation path. The bearing of Boulder from Munich, however, is 316°, 21° off the main lobe direction. Fortunately, however, each of the rhombics produced strong side lobes approximately in the direction of Boulder.

Utilizing Foster's stereographic representation method for obtaining rhombic antenna patterns [4], it was calculated, at the frequency of operation, that the elevation of lobe maximum for the bearing of 295° was 10.5° for antenna 2W and 12° for antenna 6E with antenna 2W having approximately 1.1 db greater gain. In a similar manner it was found that a side lobe of antenna 2W was produced at a bearing of 317° and elevation of 16° while antenna 6E had a side lobe on a bearing of 315° elevated 12° above the horizon. The side lobe of antenna 6E provided a signal approximately 2.9 db greater than that of antenna 2W.

### 2.2. Receiving Antennas

Receiving antennas used at Boulder were half-wave horizontal dipoles with a reflector and were matched into a 50-ohm transmission line. The reflector was used to minimize the effect of signals coming in from the back side of the antenna due to reflections from nearby mountains. In all, five receiving antennas were used at Boulder and the height advantage of nearby mesas was used where possible to provide effective antenna heights ranging from 50 to 985 ft. The elevation angles of the first lobe from these antennas at the signal frequency were calculated to range from 0.7 to 15.6°. Table 1 shows the effective height and calculated radiation angle for the Boulder antennas which are designated in order of ascending height as 1B through 5B.

At the Sterling receiving site three identical half-wave dipole antennas, again matched into a 50-ohm transmission line, were installed at different heights on a 320 ft tower. Effective heights and calculated radiation angles for these antennas which are designated as 1S, 2S, and 3S are also tabulated in table 1. Antennas with radiation angles as low as those provided by antennas 4B and 5B at Boulder were not employed at Sterling because of the great tower height required.

Double conversion heterodyned receivers with mechanical filters in the second IF stage which limited the receiver bandwidth to 800 c/s were used and the AVC signal level was recorded.

Fading rate recorders were used in conjunction with the receivers during a portion of the recording period at both the Sterling and Boulder receiver locations. A discussion of the recorders is provided in ref. [5].

## 3. Experimental Results

### 3.1. Signal Strength, Munich-Boulder

Monthly median values of the signal strength in dbw (decibels above 1 watt) received on each of the five antennas at Boulder are shown in figures 1 through 4 for the months March through June of 1959. Also shown are the times during which the signal frequency exceeded the predicted value of MUF as obtained from CRPL Series D information. The median values shown here represent signal power; i.e., the noise power level, which was determined during a 5-min period each hour when the transmitter was off, has been subtracted from the median value of signal-plus-noise power measured in the same hour.

It may be observed in figures 1 to 4 that the received signal strength, at a common distance from the transmitter, is dependent in some manner upon the radiation angle of the receiving antenna but it is also evident that no single radiation angle always provides a signal of greatest amplitude. In March and April it may be seen that the antenna with the

TABLE 1.

| Boulder Antenna | Height | Radiation Angle |
|---|---|---|
| | *ft* | *deg* |
| 1B | 50 | 15.6 |
| 2B | 135 | 5.2 |
| 3B | 310 | 2.3 |
| 4B | 485 | 1.4 |
| 5B | 985 | 0.7 |
| Sterling Antenna | | |
| 1S | 50 | 15.6 |
| 2S | 150 | 4.7 |
| 3S | 312 | 2.3 |

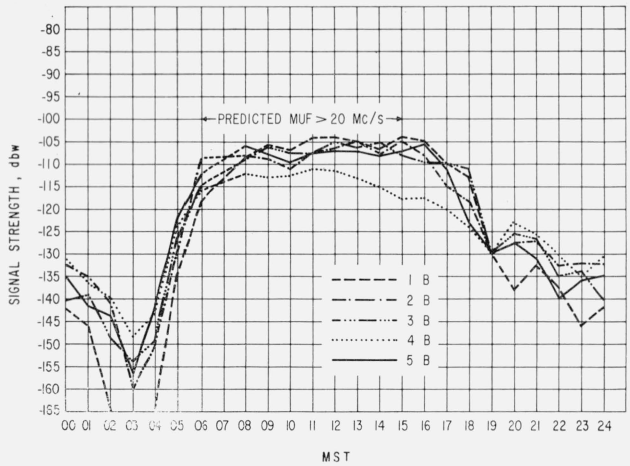


Figure 1. *Hourly median signal strength, Munich-Boulder, March 1959.*

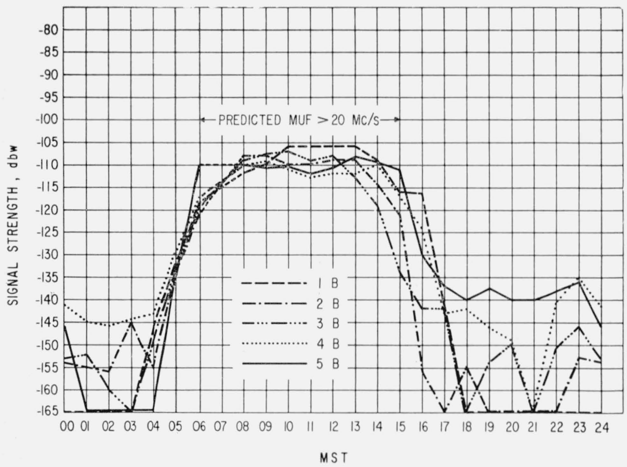


Figure 2. *Hourly median signal strength, Munich-Boulder, April 1959.*

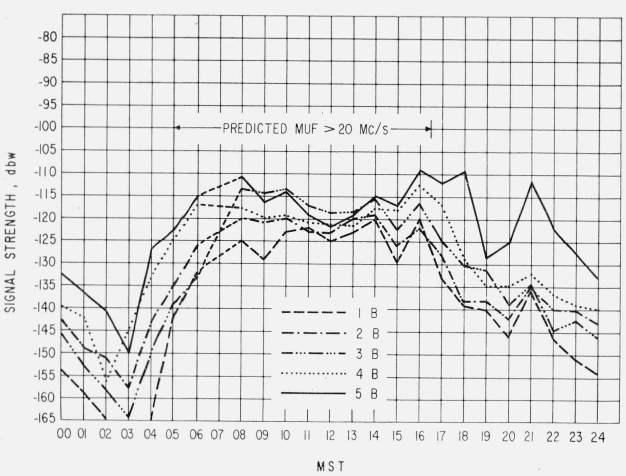


Figure 3. *Hourly median signal strength, Munich-Boulder, May 1959.*

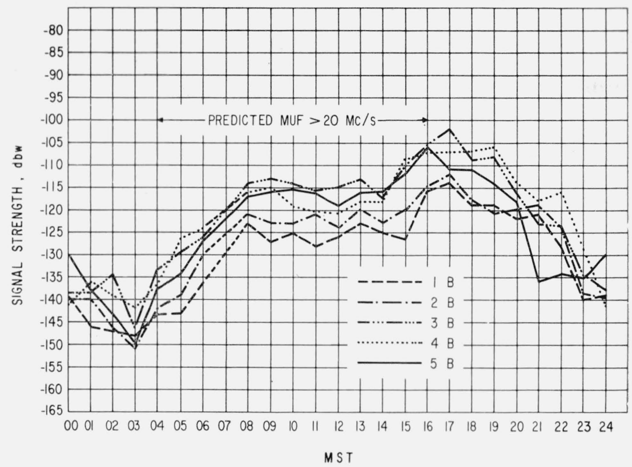


Figure 4. *Hourly median signal strength, Munich-Boulder, June 1959.*

highest radiation angle, 1B, received a signal of greater strength than the other antennas during a substantial portion of the period when the predicted value of MUF exceeded the signal frequency but that it generally produced the lowest signal level at other times of the day. In May and June this same antenna usually provided the weakest signal throughout the entire day. Another feature which may be noted is that the separation between signal levels received by the various antennas is greater in May and June than it is in the earlier two months with higher signal intensities prevailing on the lower radiation-angle antennas. These results suggest: (a) That a seasonal change in the angle of arrival of the signal on this path, progressing from higher angles toward lower angles, occurs as the ionosphere makes the transition from winter to summer conditions and (b) that angles of arrival, even under winter ionospheric conditions, in the period somewhat beyond the predicted MUF (monthly median) are substantially lower than they are during the period when the signal frequency is less than that of the predicted MUF.

To enable a better comparison of the relative merit of each antenna to be made, figures 5 and 6 are presented. These show a portion of the signal-strength time-distribution curve for each antenna during the 4-month period March through June. Figure 5 shows the results of all data, irrespective of time of day, while the curves in figure 6 were obtained by using data only from those periods of time when the predicted MUF value was less than the signal frequency. In each of the figures it is evident that the antenna with the highest of the five radiation angles, 1B, received the weakest signal for any particular percent of time. The data for antennas 2B and 3B tend to group together and show a signal level approximately 5 db higher than that of antenna 1B for a comparable percentage of time. The signal levels received on the two antennas with the lowest radiation angles, 4B and 5B, similarly tend to group together and are 10 db, or more, higher than those from antenna 1B.

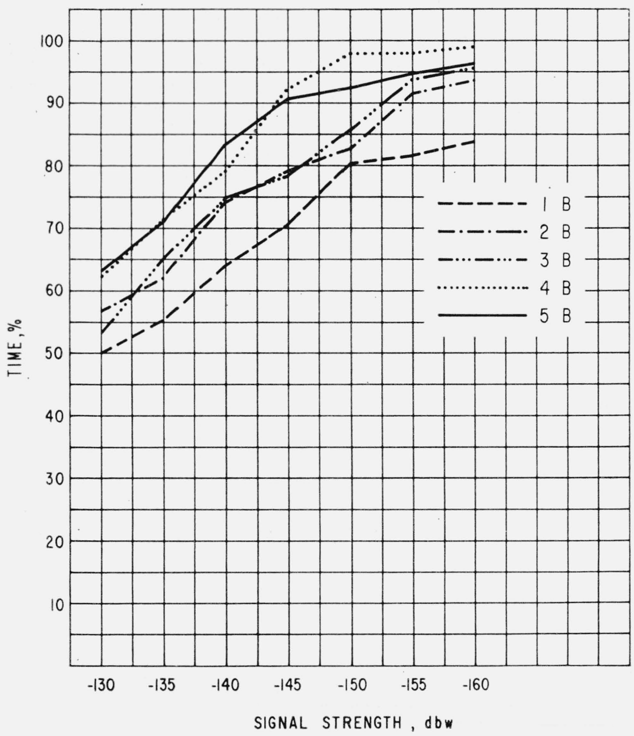


FIGURE 5. *Percent of time signal exceeds abscissa.*
Average of 4 months for all times, Munich-Boulder.

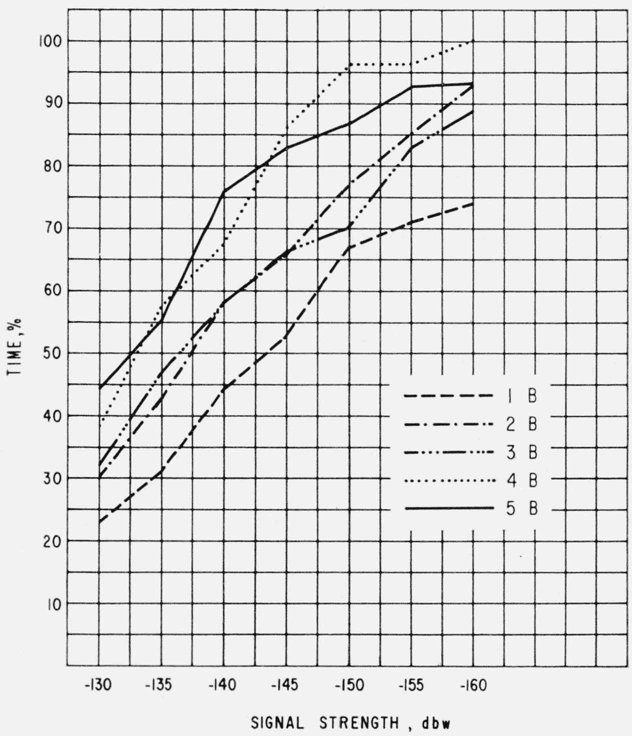


FIGURE 6. *Percent of time signal exceeds abscissa.*
Average of 4 months for those times when predicted MUF <20 Mc/s, Munich-Boulder.

The results found here suggest that over a substantial proportion of time a large amount of energy arrives at low angles, perhaps on the order of a degree or so. This fact is interesting particularly when it is noted that an optimum angle of radiation for this path, based upon a 3-hop geometrical mode and a 300-km ionospheric height, is 6°. It also may be remarked that the increase in received signal strength on the antennas with low-radiation angles occurred even though the major portion of energy from the transmitting antenna was radiated at fairly high angles of 12 to 16°.

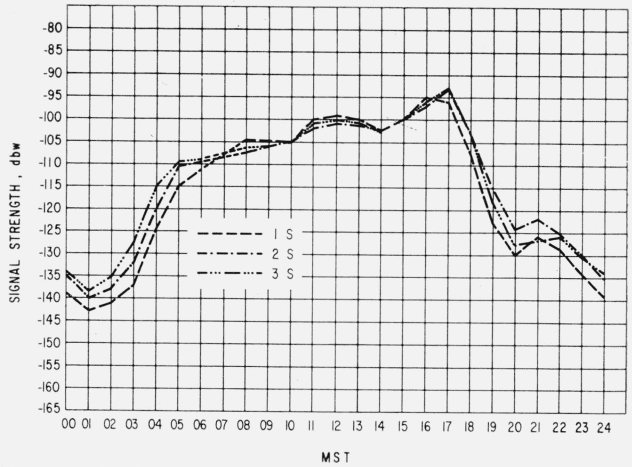


FIGURE 7. *Hourly median signal strength, Munich-Sterling, May, June, July 1959.*

### 3.2. Signal Strength, Munich-Sterling

On the shorter path between Munich and Sterling, Virginia, signal levels in dbw were recorded during a two and one-half month period from the middle of May through July 1959. The hourly median signal strength recorded on the antennas 1S, 2S, and 3S for this period are shown in figure 7.

CRPL Series D predictions for the May–July recording period indicated that normal $F$-layer propagation for the path was expected between the hours 1300 to 1800 m.s.t., approximately, and was limited to this short interval because of $F$-layer conditions at the western control point, 2000 km from the receiving terminals where low MUF values existed. In figure 7 it may be seen that the strongest signals, on all antennas, were received during this period when $F$-layer propagation could have existed.

Predictions also indicated that radio propagation over this path was expected nearly 100 percent of the time between the hours of 0400 to 1800 m.s.t. via sporadic $E$ at the western end of the path in conjunction with $F2$ or sporadic-$E$ reflections at the Munich end of the path. The sloping plateau of the median curves in figure 7 extends over a length of time corresponding approximately to that when propagation was predicted and during this time it may be observed that median signal levels on all antennas were comparable.

During the period of time when predictions indicated propagation would not be expected, 1800 to 0400 m.s.t., it was observed, except during periods of ionospheric disturbances, that signals, although considerably lower in amplitude than those received during the predicted propagation period but still well above noise level, were received nearly all the time on all three antennas. In figure 7 it may be seen that higher median signal levels were received by the two lower radiation-angle antennas during this period than were received by the high radiation-angle antenna, 1S, even though a significantly greater amount of power is transmitted at the high angle.

A comparison of the relative merit of the three Sterling antennas is provided in figure 8 where a portion of the signal-strength time-distribution curves are shown. Here, as in the case of the longer propagation path between Munich and Boulder, lower radiation-angle antennas received signals of greater strength a substantial portion of the time. More than 50 percent of the time, hourly median signal levels received at radiation angles of 2.3° were about 5 db greater than those received at an angle of 15°. An interesting result to note in comparing figures 5 and 8 is the tendency toward a 5-db difference in median signal level recorded with antennas 1S and 3S as well as 1B and 3B where each pair have corresponding radiation angles at the terminus of the 6800-km and 8400-km paths.

### 3.3. Signal Fading Rates

To ascertain whether marked differences in the fading characteristic of the received signal due to antenna height variations existed, two fading rate recorders were utilized in conjunction with certain antennas from the middle of May through July 1959. One meter was used at Boulder to record the fading of the signals received on antennas 3B and 4B, alternating from one to the other at 24-hr intervals. A second meter was used at the Sterling site alternating between the signal received on the three antennas in sequence at 24-hr intervals.

Distribution curves of the fading rate of the received signal obtained from these measurements are shown in figure 9 where it may be observed that

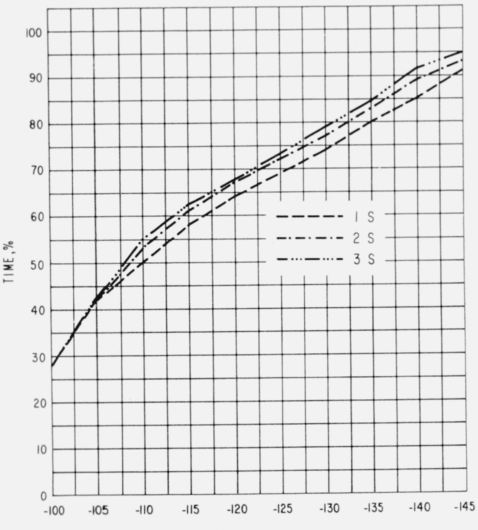


FIGURE 8. *Percent of time signal exceeds abscissa, May, June, July 1959, Munich-Sterling.*

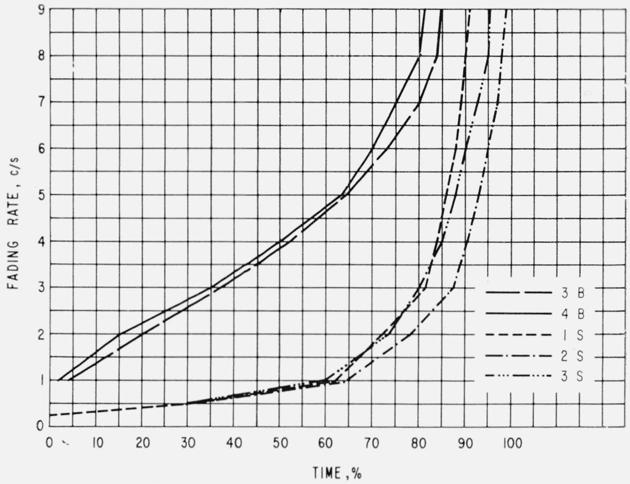


FIGURE 9. *Percent of time fading rate less than ordinate, May, June, July 1959.*

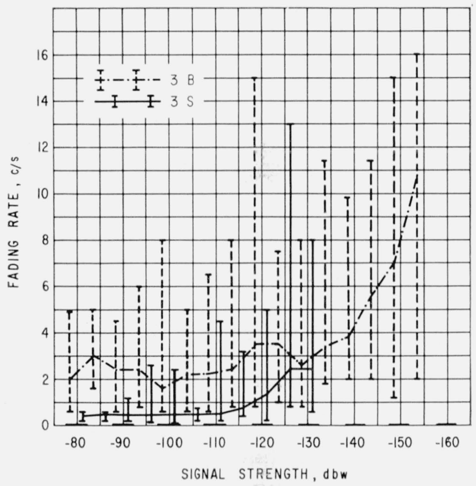


FIGURE 10. *Fade rate distribution.*

during much of the time little difference in the fading rate of signals received on antennas with different radiation angles occurs. For some 20 percent of the time, however, a difference of 1 c/s or greater in fading rates, apparently associated with antenna radiation angles, is evident.

In figure 9 it is apparent that the signals received at Boulder faded at higher rates than did those received at Sterling. This is again indicated in figure 10 where curves comparing the median value and range of fade rate as a function of signal intensity for antennas 3S and 3B, which have the same radiation angles at Sterling and Boulder respectively, are shown. The signal received at Boulder, in addition to having a higher fade rate, generally shows a greater variability of fade rate than does the Sterling signal at corresponding signal intensities.

### 3.4. Magnetic Storms

During the period of time in which the Munich signal was recorded several magnetic storms occurred which provided an opportunity to observe the signal

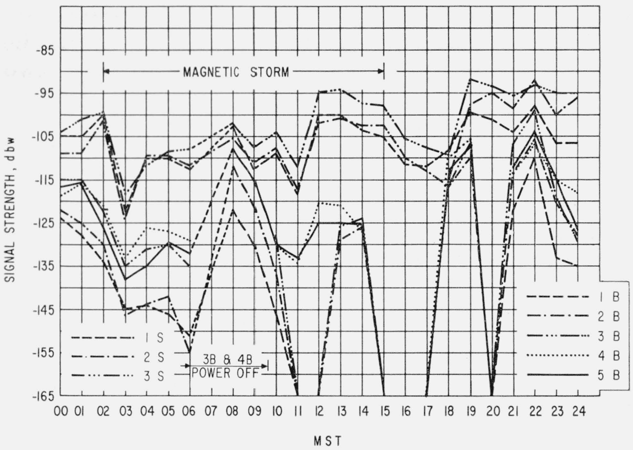


FIGURE 11. *Signal strength variation, June 11, 1959.*

characteristics in relationship to antenna radiation angles when the ionosphere was in a disturbed condition.

An outstanding example of low radiation-angle advantage is shown in figure 11 where hourly median signal intensities received on the Sterling and Boulder antennas are given for a 24-hr period on June 11, 1959 during which time a moderate intensity magnetic storm began abruptly at 0210 m.s.t. and ended shortly after 1500 m.s.t. Disturbed ionospheric conditions associated with the magnetic storm caused, at one time or another, total loss of the signal on all antennas at Boulder but a salient feature to be observed here is the differing lengths of time this occurred on the various antennas. While all antennas show a marked reduction in signal strength during the first few hours after the storm onset, with the highest radiation-angle antennas, 1B and 2B, showing the greatest signal reduction of all antennas at 0600 m.s.t., signal strengths were, by 0800 m.s.t., up to levels near the monthly median values. Following this, a decline in signal intensities occurred which resulted in the loss of signals on antennas 1B, 2B, and 3B by 1100 m.s.t. Antennas 4B and 5B did not suffer a loss of signal at this time although intensities were 15 db or more below the monthly median values. In the ensuing 9-hr period no Munich signal was evident on antenna 1B. In the same period antennas 2B and 3B did not receive any signal for a total time of 6 hr while antennas 4B and 5B did not receive a detectable signal for a total period of 4 hr. During this storm signal strengths at Sterling were, at times, as much as 25 to 30 db below the corresponding monthly median values but as may be observed in figure 11 the lowest radiation-angle antenna, 3S, received signals that were at least 5 db greater than those received on the other two Sterling antennas. Thus, during this storm, and as was generally observed during other storms, signals received on antennas with the lowest radiation angles were deteriorated the least, on both the 6800-km and 8400-km paths.

## 4. Discussion of Results

### 4.1. Diurnal and Seasonal Trends

In long-distance high-frequency radio transmission, daytime propagation by the $F2$ layer is characterized by a relatively large number of $F2$ hops. This period would have the highest angle modes and would explain why the higher angle antennas gave the strongest signals at Boulder in March and April. For sufficiently high operating frequencies there will be a time somewhat before noon over the path and again after noon, when the smallest number of geometrical $F2$ modes will prevail. Before that time in the morning and after that time in the evening waves will arrive by means of combinations of low-angle $F2$ modes with scatter or sporadic $E$, or multiple sporadic-$E$ hops plus perhaps some scattering or layer tilt mode. Frequently the arriving modes will be nongreat-circle modes. All of these modes are inherently low-angle modes and would explain the fact that the signals arriving outside the hours when the operating frequency exceeds the $F2$ path MUF are low-angle signals.

In May and June the low-angle modes received at Boulder were strongest even during the hours when the MUF exceeded the operating frequency. This phenomenon is probably explicable by the fact that the increased incidence of sporadic $E$ in May and June increased the number of possible low-angle mode combinations.

The Sterling data were obtained during a period of high incidence of sporadic $E$. In this case during the hours when the operating frequency was below the predicted $F2$ MUF all three Sterling antennas (corresponding to the lowest three at Boulder) gave approximately equal responses, as distinguished from the fact that for the same season the lower angle antennas were giving stronger responses at Boulder. As the path length increases, the number of possible low-angle modes increases hence, the greater response at the low angles at Boulder during a season when there could be low-angle daytime modes.

Since responses at angles are tied to specific modes there are some irregularities in the curves. Thus, even when the trends are toward low angles the very lowest-angle antenna does not always have the largest response, as the curves show.

It is interesting to note that the median signal-strength curves (figs. 1 to 4 and 7) do not show a discontinuity which could be identified as a true MUF failure but rather they show a relatively smooth transition from high-signal levels during the day to lower levels in the evening hours and rising again in the early morning hours. On the Munich-Sterling path it was observed that a good signal was received over a 24-hr period, on all three antennas, nearly all of the time during the recording period. A similar result at the higher antenna terminals of the Munich-Boulder path was observed on many occasions. Commonly used MUF prediction methods would not have led one to expect these results. In view of the need for greater efficiency in usage of the radio spectrum it would seem most desirable that effort be made toward extending prediction capabilities in order that well designed communication systems might make use of the signals which are received beyond the time of conventional MUF failure.

### 4.2. Strength of Low-Angle Modes

It is surprising at first glance that although the transmitting antenna had a main-lobe radiation angle which was high for both propagation paths the low-angle responses were greater so much of the day. In one instance for the Munich-Sterling path, the expected field strength at 1700 m.s.t. for a 4-hop $F2$ mode was compared to that of a 2-hop $F2$ mode. The time chosen here corresponds to that when the maximum median signal levels were obtained at Sterling (fig. 7) and when ionospheric absorption over the path was low but the $F2$ mode of propagation still possible. The 4-hop $F2$ mode is regarded as a typical high-angle mode (14° radiation angle for a 300-km layer height) and the 2-hop $F2$ a typical low-angle mode (2.5°). Using the method of Rawer [6], which includes the effects of focusing due to a curved earth and ionosphere, it was determined that the low-angle mode should be about 6 db stronger than the high-angle one if an isotropic transmitting antenna were assumed. However, in the practical case with the transmitting rhombic described in section 2 above, the directivity at a 2.5° radiation angle is lower than that at 14° by more than 10 db [7]. The low-angle mode signal would thus have been expected to be at least 3 db lower than that of the high-angle mode and yet the actual results (fig. 7) indicated that the median value of the signal received on the low-angle antenna was 3 db greater than that received on the high-angle antenna. This leads to the qualified conclusion then, that the low-angle transmission mode is more efficient than the high-angle one. The qualified in this case refers to the fact that there were not identical antennas at the two terminals.

The fact that the total received power at the low angles was so frequently comparable to or actually greater than at the high angles indicates that there may have been a larger number of these low-angle modes. The signal strengths recorded on the various antennas actually provide a comparison of the square of the sum of amplitudes of groups of modes at one range of angles with that for another range. Pulse patterns for long-distance propagation showing the presence of numerous low-angle modes appear in a paper by Silberstein [8].

### 4.3. Fading

#### a. Variation With Antenna Radiation Angle

The relationship between radiation angle and the fade rate of the received signal is not made clear from the data for, when the fade-rate distribution curves of the Sterling antennas are not coincident (fig. 9) the rate of fading of the signal received by antenna 2S, with a radiation angle intermediate between those of antennas 1S and 3S, tends to be 1 to 3 c/s lower than that found on the other two antennas. Signals with the highest fading rate were received on the antenna with the highest radiation angle. Data for the two Boulder antennas, 3B and 4B, indicate that slightly higher fading rates are found for the signals received by the antenna with the lower of the two-radiation angles. In making this latter comparison, however, it should be noted that the radiation angles of these antennas are both relatively low so that a direct comparison between fade rates at high and low angles is not available here. In general it would appear that no significant deterioration of signal quality, because of fading-rate differences due to antenna radiation angles alone, would be expected.

#### b. Differences in Fading Between Boulder and Sterling Paths

The greater degree of variability and higher fade rate found in the signals recorded at Boulder as compared with those recorded at similar radiation angles at Sterling may be attributable to the difference of the radio paths in the ionosphere. It is well known that radio signals received on paths which intercept the auroral zone are frequently characterized by rapid signal fading and doppler frequency shifts. The Munich-Boulder great-circle path traverses the region of maximum auroral activity twice whereas the Munich-Sterling path does not come much closer than 1000 km to the auroral zone. The signals arriving over the former path would then be expected to show, on the average, higher fade rates than those arriving over the latter path.

### 4.4. Behavior During a Magnetic Disturbance

An example of low radiation-angle advantage observed during an ionospheric disturbance was presented in section 3.4. Whether the results obtained here and during a few additional storms which occurred during the recording period are generally valid will require further investigation. However, the limited amount of data of this type does indicate that the length of time during which signals are depressed in strength, or lost entirely, increases as the radiation angle of the antenna increases. The time of signal intensity reduction on the various antennas may differ by as little as a few minutes up to a time of several hours.

During ionospheric disturbances great changes in the layer heights occur, the $F2$ layer often rising to heights well above the normal ones. Considerable stratification of the region also occurs. In the auroral zones, ionization capable of reflecting higher frequency radio waves than normal is produced in the $E$ region also during disturbances.

The above ionospheric changes probably all tend to provide, for the longer paths, more low-angle propagation modes. This may explain why antennas with low radiation angles suffer less signal deterioration from increased ionospheric absorption occurring as a result of the effects accompanying a magnetic storm than do those with high-angle response.

Although it is known that transmission over paths that lie, even in part, in the auroral zones are subject to a greater degree of irregularity than are transmissions over other paths, little is known, qualitatively, about auroral-zone absorption in general. The observations made during the course of this experiment when ionospheric storms occurred, while not capable of providing qualitative results, do indicate that a greater increase in the amount of absorption on the path traversing the auroral zone was produced as a result of a storm than there was on the path not passing through the auroral zone. The greater sensitivity to disturbance of the former path is evident in comparing the results at Boulder and Sterling in figure 11.

## 5. Recommendations

The data presented earlier indicates, for long-distance HF circuits, that low radiation-angle antennas appear to be advantageous. Certain factors require additional investigation, however, before categorical confirmation of the indicated trend may be asserted. As an example, it is to be noted that antennas with wide horizontal beam widths were utilized in this experiment and the results may then only be applicable when antennas with this characteristic are used if a large component of the received signal arrives on bearings differing greatly from that of the great circle path. Communication systems typically use high-gain antennas and thus have reduced horizontal beam widths. This suggests that observations of the azimuthal, as well as further vertical, direction of arrival be made with direction-finding equipment capable of measuring signals which arrive at low angles. Pulsed signal studies also would be most desirable to aid in understanding by which modes radio waves arrive at various vertical angles and how these vary diurnally and seasonally.

A factor of some importance which needs to be investigated is whether better system operation would result if low radiation-angle antennas were used for both transmitting and receiving. In view of the results found above this might be an expected result, yet it is not assured.

## 6. Summary

Observations of a HF cw radio signal which after propagating over east-west paths 6800 km and 8400 km in length were received on antennas having different vertical-plane radiation angles indicate that very low radiation-angle antennas may be advantageous for use in long-distance communication systems. Over a period of several months, wide horizontal beam width antennas with vertical radiation angles of less than 2° provided, on the average, signals nearly 10 db stronger than those received on an antenna with a radiation angle of 15° and antennas with radiation angles in the range 2 to 5° provided signals about 5 db greater than the latter antenna. For a given system threshold a substantial increase in the amount of time a circuit may be operated is provided by the use of very low radiation-angle antennas. These results were obtained even though little power was radiated at low angles from the transmitting antenna and even for paths where ray theory indicates that higher angles are required for optimum propagation.

Data indicated that little difference in the fading rate of the signal received at various radiation angles was to be expected. Higher fading rates of the signal received over the longer path were recorded and it was concluded that this was most probably caused because the radio wave path traversed the auroral zone over the longer path whereas it did not on the shorter path.

A limited amount of data obtained during the occurrence of magnetic storms suggests that radio signals are degraded a shorter period of time when received on low radiation-angle antennas than if high radiation angles are used.

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