Experiments with Directivity Steering for Fading Reduction *

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Short-wave fading is largely due to phase interference between multiple path signals of varying path length. Fortunately, stable angular differences usually exist between these paths at the point of reception. It is therefore desirable to employ antenna directivity which is "steerable" and sufficiently sharp to accept only one of the several paths in order to reduce this fading.

This paper describes experiments made with a "steerable" directive antenna during reception of transoceanic short-wave signals. The results demonstrate that sharp angular discrimination is a basically sound method of combating fading which is due to phase interference.

INTRODUCTION

RAPID fading in radio communication has been recognized for some time as being due to the interaction of distinct components having different transmission times. The possibility that these components might arrive from slightly different directions was suggested by various observed facts, among which was the behavior of sharply directive antennas.

It has been noticed in the past that fading was affected by the directivity of the receiving antenna. An example is given in the oscillograph records of Fig. 1 showing observations made by the authors some years ago at Cliffwood, New Jersey. These illustrate a condition of less fading on a large "inverted vee" [1] antenna than on a small non-directional antenna, using telegraph signals received from station GBK in England. Beating the signal with a local oscillator provided the audio frequency which was recorded. The directive antenna output was recorded on the upper trace while the lower strip recorded the output of the substantially non-directive, comparison antenna.

Such observations as these suggest the possibility of controlling and reducing fading by a systematic use of sharp directivity. The present paper reports some experiments in which changes in fading are correlated with changes in the directive pattern of a rhombic antenna [1] made by mechanically changing its shape.

It may be reasoned that, where the total differences in the path

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[1] E. Bruce, "Developments in Short-Wave Directive Antennas," *Proc. I. R. E.*, Vol. 19, pp. 1406–1433, August, 1931; *Bell Sys. Tech. Jour.*, October, 1931.

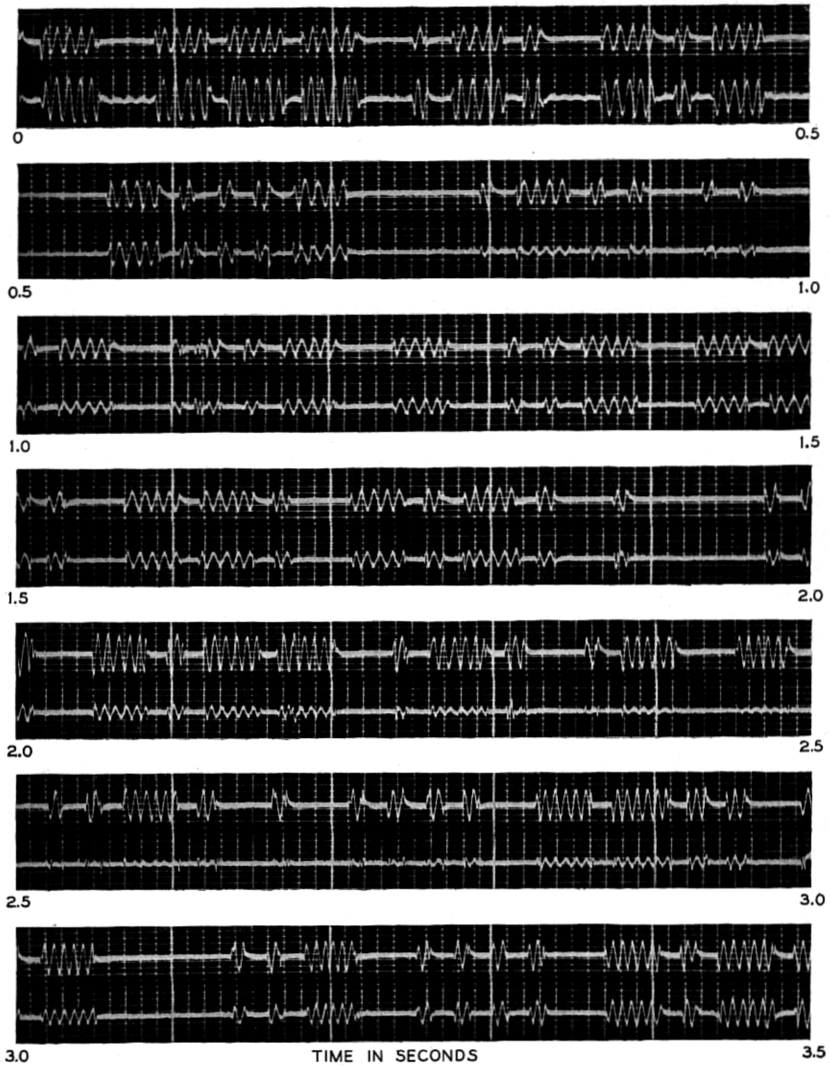

Fig. 1—Oscillographic record of carrier fading reduction. The upper trace is proportional to the output of a large "inverted vee" antenna, and the lower trace to the output of a half-wave vertical antenna when receiving station GBK on 16.6 meters. Taken at Cliffwood, N. J., November 16, 1927, 4:00 P.M., E. S. T.

lengths are small, variations can result only in the carrier and side bands fading in and out together or in other words "general" fading. In such cases, there either may or may not be appreciable angular separation between the multiple waves at the point of reception. However, there is little question that, where multiple waves cause a "selective" fade over a speech band which is, of course, a very small percentage of the carrier frequency, a material path length difference must exist. Where this is the case, it is difficult to conceive of wave routes which do not possess appreciable angular separation between them at the place of reception. The truth of this latter point is of vital importance in this discussion.

The hope of success in fading reduction through directivity rests on the possibility of a continuous, stable angular separation between the interfering waves during times when fading is really troublesome. Fortunately this possibility is reasonably existent; therefore it should be possible to reject all but one of the interfering paths, by means of sharp directivity, with a consequent reduction in selective fading.

Description of Equipment

Tests have shown [2] that a greater degree of angular spread between the multiple waves exists in the incident vertical plane than in the horizontal plane. It might be expected, then, that such a scheme as that illustrated in Fig. 2 would be worth trying. Here the steep edge of a moderately sharp directional characteristic is moved just far enough into the wave cluster, assumed directively stable, to accept the first wave. Obviously it is possible to approach the wave cluster from the bottom as illustrated or we may approach the cluster from above.

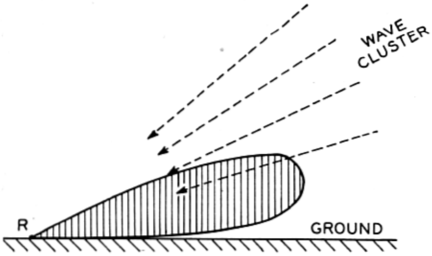

Fig. 2—Edge system for achieving fading reduction with moderate antenna directivity.

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[2] H. T. Friis, C. B. Feldman, and W. M. Sharpless, "The Determination of the Direction of Arrival of Short Radio Waves," *Proc. I. R. E.*, Vol. 22, pp. 47–78, January, 1934.

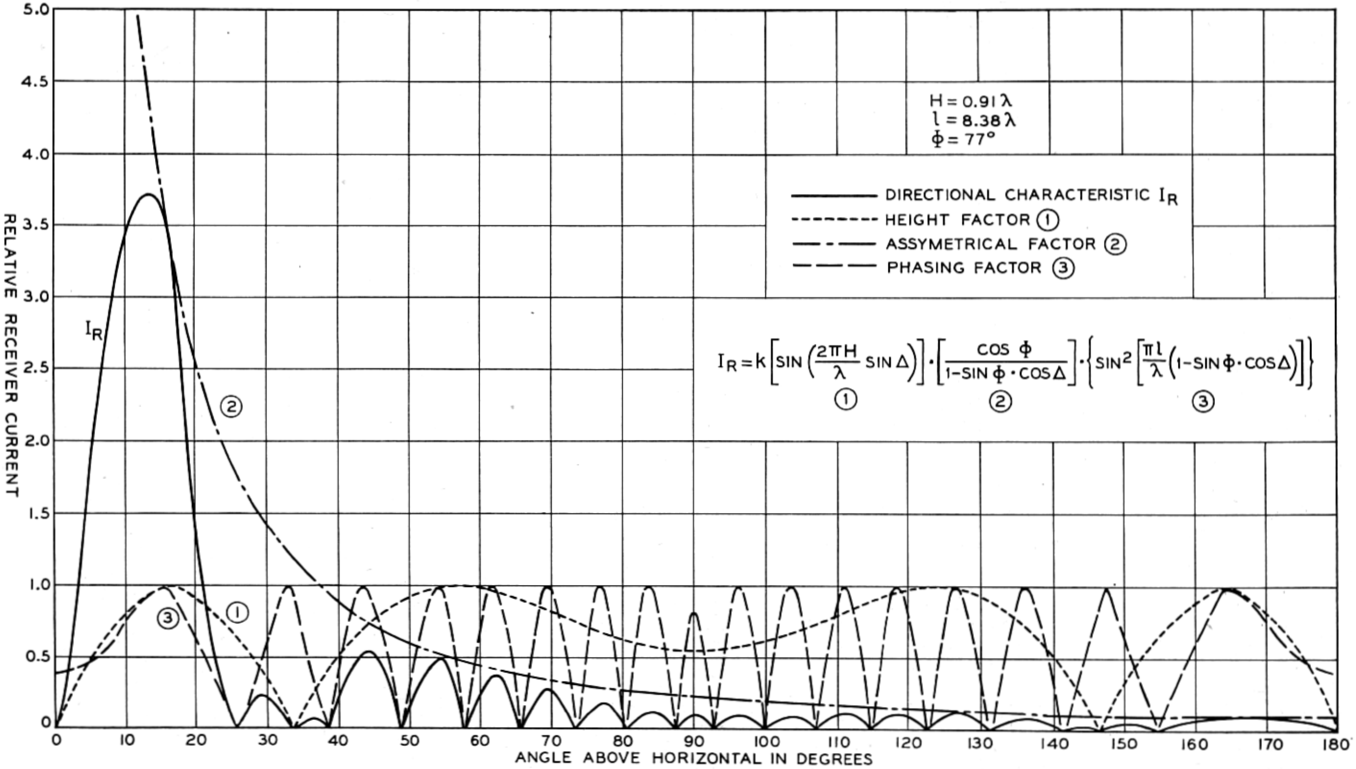

Fig. 3—Receiver current diagram of incident plane directivity for one adjustment of a steerable rhombic antenna. The factors in the equation are plotted separately.

A primary essential in this scheme is that no minor ears of the directive diagram be of appreciable size.

Using this scheme, it is not necessary to discriminate completely against the adjacent waves for practical benefit. A discrimination of ten decibels between two adjacent waves of equal amplitude will make improbable a fade deeper than 5.7 decibels from their sum. Fading of this depth would be relatively unimportant for ordinary speech transmission.

An edge wave may at times be much smaller in amplitude than the adjacent waves. The scheme under discussion may be usefully operative even in this situation since the very smallness of the edge wave means that it cannot be seriously harmful. When signals are weak, the edge of the directive diagram should be advanced until a large amplitude wave is encountered. Some fading of small depth would then exist.

It was stated above that the antenna system used should have no minor ears of appreciable size. At the same time, the edge position of the major loop must be continuously adjustable. A simple method of meeting these requirements is that of mechanically moving the elements of a "long-wire" antenna in space so as to alter the manner of its exposure to the space waves.

Figure 3 is a rectangular plot of the incident plane directive diagram of a large horizontal rhombic antenna when used for GBW on 20.78 meters. The essential antenna dimensions are indicated on that figure as well as the equation for the directive diagram.

Each bracketed quantity in the directive equation of Fig. 3 is separately plotted on that figure together with the final resulting product. Factor 3, known as the "phasing" factor, exerts the greatest influence on the shape of the major lobe. This factor contains only the variables of length l and the angle ϕ, defined as half of the side interior angle. The length cannot be made easily variable but the angle ϕ can be readily adjusted. When an adjustment in ϕ is available for this antenna, Fig. 4 gives the directions of the major lobe maxima, and the first nulls, above the horizontal for a series of wave-lengths. It is evident that a useful degree of steering is provided without limiting the desirable variable wave-length features of the antenna. In all cases, the minor ears remain small.

In Fig. 5 is shown a remote controlled power-winch system for altering the interior angles. This experimental system in slightly modified form was in operation at Holmdel, New Jersey, for some time, without any antenna breakages. This was primarily possible because the angles of flexing were very small and copper-clad steel wire was

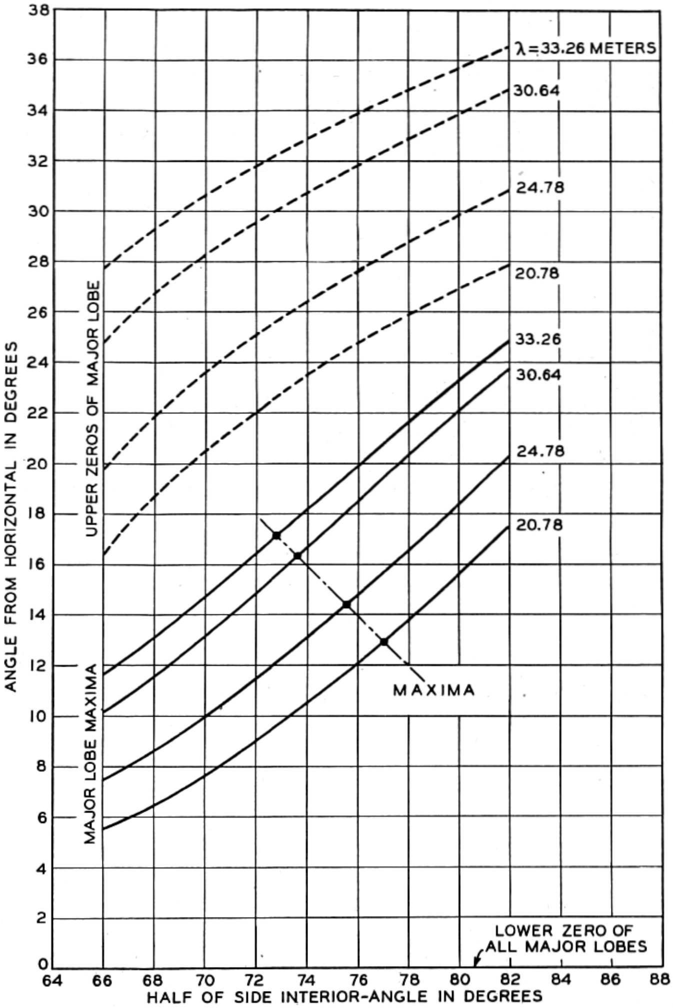

Fig. 4—Steerability, at several wave-lengths, of the horizontal rhombic antenna used for the fading reduction studies. The antenna element lengths were 184 meters and their height 19 meters.

employed in the antenna. The power-winch was equipped with automatic safety stops at the extreme positions, also with a potentiometer which was coupled to the winch to permit the use of a voltmeter as an antenna position indicator. This position indicator was located at the operator's position. By using counterweights, the required size of the winch motor is reduced.

The adopted system for observing selective fading required a fre-

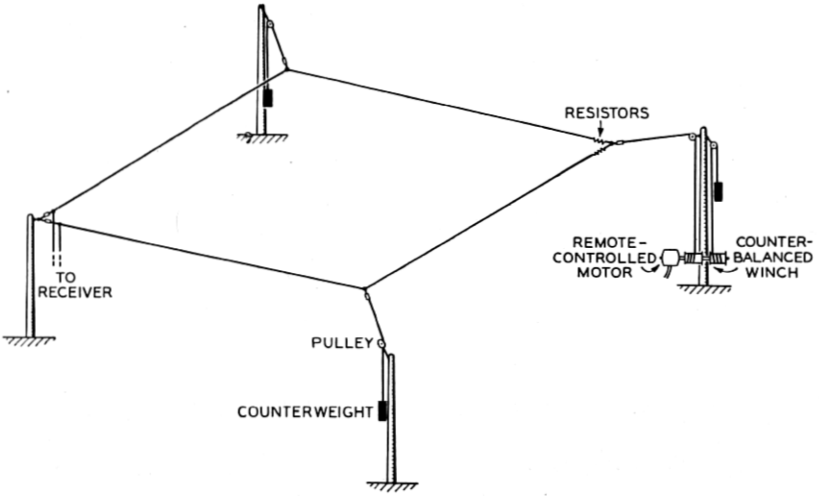

Fig. 5—Mechanical layout of the steerable horizontal rhombic antenna.

quency wobbled carrier from the transmitting station. By beating this frequency-wobbled carrier with a local fixed frequency, a wobbled audio note was obtained after detection. This audio output was impressed on the horizontal plates of a cathode ray tube, after being amplified by an audio amplifier. This produced a horizontal spot deflection on the tube screen which was directly proportional to the field strength of the signal. The vertical plates had a locally adjusted sweep circuit voltage impressed on them to produce vertical spot deflections. The sweep frequency was synchronized with the wobble rate so that the extreme upper and lower deflections occurred at the same instant as the respective upper and lower frequencies of the wobble. Figure 6 indicates the cathode ray picture of a signal without selective fading while that of Fig. 7 shows a severe case of selective fading. It is apparent that general fading was revealed by the horizontal collapse of the rectangle of Fig. 6.

It is an interesting fact that upon the first appearance of the cathode ray figure, with the wobble rates employed, it is a horizontal line moving up and down, but after a few seconds, the traced solid figure stands out clearly, due to the persistence of vision.

One of the surprising results of experience with this system was that, at times of severe fading, eight or ten depressions were occasionally seen within a sweep of a few hundred cycles.

For comparison purposes, there were two complete outfits, as described, with their cathode ray tubes mounted side by side. One outfit

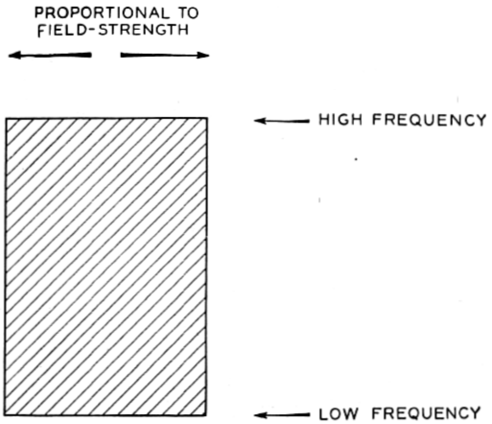

Fig. 6—Cathode ray oscillograph figure for no selective fading when observed with wobbled carrier.

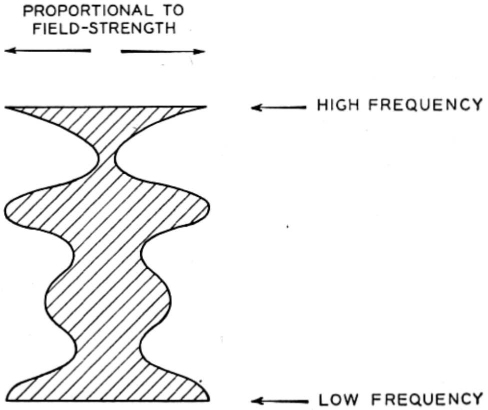

Fig. 7—Cathode ray oscillograph figure for severe selective fading when observed with wobbled carrier.

operated on a simple antenna system, as a standard of comparison, while the second was connected to the adjustable directive antenna. Fig. 10 is a photograph of this apparatus.

Other tests also going on at Holmdel, N. J., were concerned with the measurement of the comparative delay times and the respective angles of the various paths of the waves.[2] To permit this, the British Post Office transmitter sent pulses of very short duration. At the receiving point, a single transmitted pulse frequently appeared as several spaced pulses when a sweep circuit was employed. The spacing enabled the measurement of the relative time delays. It was found to be the apparently invariable fact that the earlier arriving pulses are the lower in angle with the horizontal and are relatively stable in direction. These tests suggested that a somewhat similar scheme of observations would be useful to the present work since, if pulses were similarly employed, one would actually see the effect on each individual path of steering the antenna.

Accordingly, cathode ray equipment was constructed employing a circular sweep system, in place of the usual linear sweep, thus making the entire time interval always in view. Figure 8 illustrates how the pulses sometimes appeared during this sweep. Since the pulses were always vertical, their definition was lost if permitted to slide down into

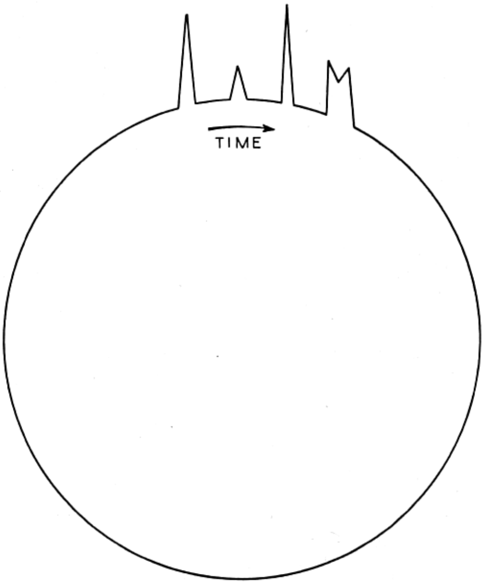

Fig. 8—Cathode ray oscillograph pulse figures when using the circular sweep circuit. The circumference is traversed by the spot in twenty milliseconds.

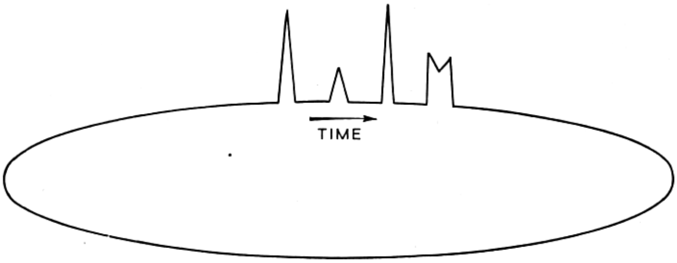

Fig. 9—Cathode ray oscillograph pulse figures when using the elliptical sweep circuit.

the "3 o'clock" or "9 o'clock" positions of the circle. This possibility was considerably reduced by employing the ellipse in Fig. 9 instead of the circle. For general observation purposes the ellipse was used but for more accurate time delay measurements the circle was employed.

The British Post Office station transmitted pulses at intervals of 0.02 second. In order to synchronize with them, an oscillator variable about 50 cycles was used to keep the pulse position stationary. A split-phase circuit feeding the four cathode ray plates produced the circular or elliptical sweep. This equipment is also shown in Fig. 10.

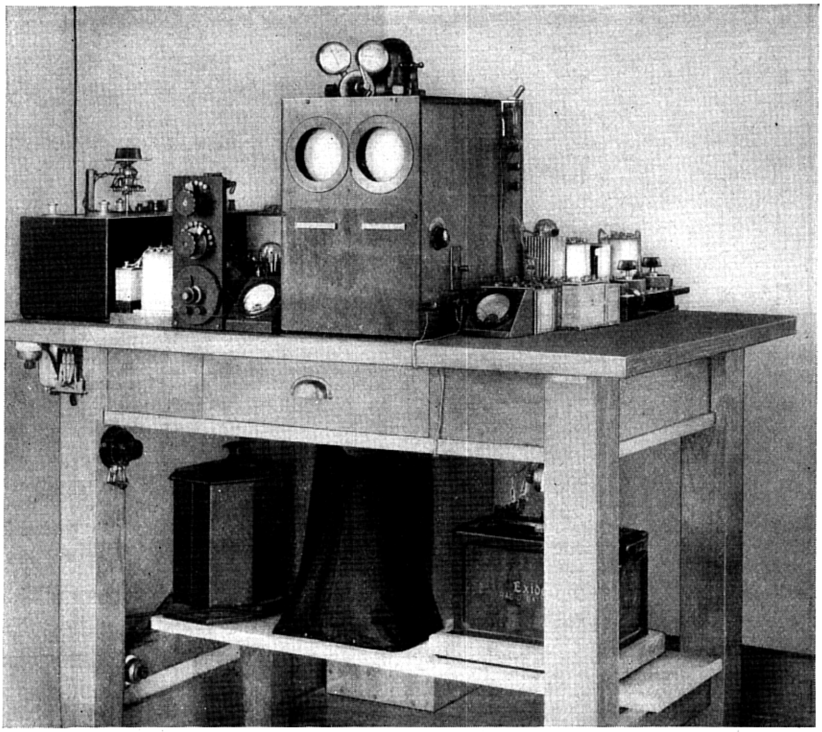

Fig. 10—Cathode ray oscillographs, their amplifiers, and the sweep circuit installation. The meter in the center of the table is the antenna position indicator.

Some studies of general carrier fading were made with a pair of magnetic counters actuated by trigger gas tubes. These fading counters were operated together with automatic recorders so as to maintain the same integrated average signal output. Since, in the recorder integration, ten-second intervals elapsed between gain readjustments, the fading counters operated to record all quick faces, during these intervals, which fell below the average output level by any prescribed amount. A photograph of this equipment is shown in Fig. 11.

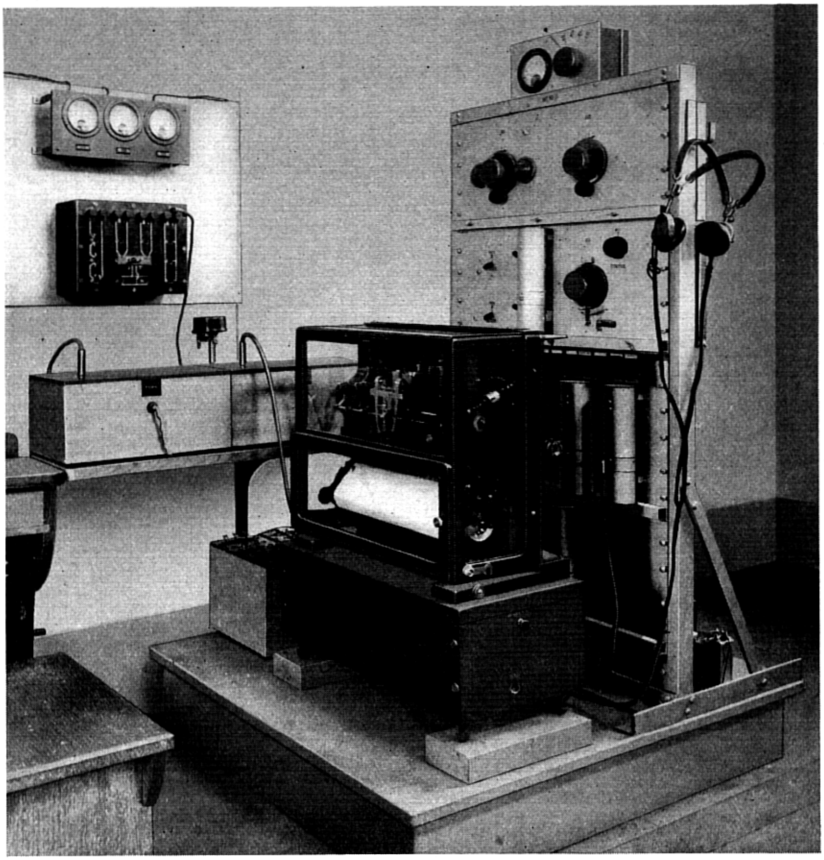

Fig. 11—Field strength recorder and fading counters used for fading reduction studies.

RESULTS

Cathode ray tube observations of selective and also general fading were made on the British Post Office stations GBW and GBU using wobbled carrier. Whenever possible, these observations were made at half-hourly intervals. For record purposes, arbitrary numbers ranging from 0 to 4 were adopted. Zero meant very little fading (five per minute or less) and the most severe cases were represented by 4. These figures were recorded separately for the standard antenna and for the rhombus. The difference between the numbers assigned to each antenna gave an indication of the fading reduction accomplished.

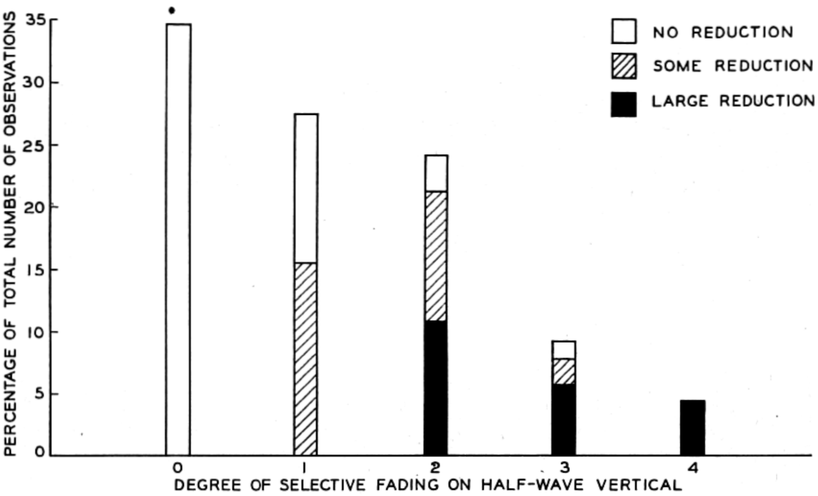

Fig. 12—Selective fading severity and its reduction at the best positions of the rhombic antenna. Stations GBU and GBW, March and April, 1933.

Figure 12 is a summary of results of these half-hourly observations made during the working hours of March and April, 1933. Disregarding the fact that portions of that figure are shaded, the total lengths of the vertical bars represent percentage of the total number of observations plotted against the degree of the selective type of fading, observed on the comparison antenna, as indicated on the abscissas.

During each of the above observation intervals, the rhombus was steered over its available range to determine the best position for reduction in selective fading. Each of the vertical bars in Fig. 12 is subdivided by shading into the various degrees of fading reduction obtainable at the best position of the adjustable rhombus. The solid sections represent large selective fading reductions, the cross-hatched sections are fair reductions, while the unshaded portions indicate that the reductions were not of appreciable magnitude.

Analyzing Fig. 12, the results show that 51 per cent of the readings gave no reduction in selective fading; however, for 35 per cent of the readings there was practically no selective fading to be reduced. On the other hand, if one disregards the rather mild and therefore relatively harmless fading cases, graded 0, 1, and 2, rhombic fading reductions were possible 89 per cent of the remaining time, so that when selective fading on the comparison antenna was really troublesome, it is important to note that an appreciable rhombic selective fading reduction was nearly always accomplished. By deliberately steering the rhombus to a disadvantageous angle, it was possible four per cent of the time to make the selective fading worse on the rhombic antenna than on the comparison antenna, but no case has been observed where, at an ordinary rhombic antenna setting, the selective fading was not at least equal to or less than that on the comparison antenna.

While the cathode ray tube figures indicated some degree of general fading, where all frequencies fade together, it was evident that this type of fading is of far less importance than the selective type of fading, in fact it was rarely noticeable except when the selective fading was almost absent.

Figure 13 is a photograph of permanent wobble records of selective fading as recorded by the string oscillograph previously mentioned. The center string was actuated by the signals from the half-wave vertical comparison antenna while the rhombus signal was fed to the upper string. The third string was not utilized. The frequency wobble can be seen on close examination and as each small timing division is 0.01 second, the audio frequency is recorded. The record has been marked at the wobbled frequency extremities.

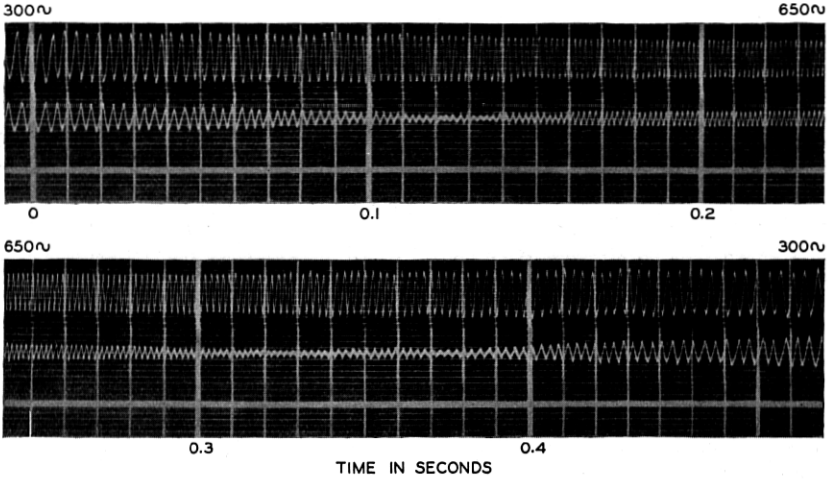

Fig. 13—Oscillographic record of selective fading reduction. The upper trace is proportional to the output of the rhombic antenna, when the angle ϕ equalled 69 degrees, and the center trace is proportional to the output of the half-wave vertical antenna. The lower string was idle. Wobbled carrier from station GBU, April 19, 1933, 4:00 P.M., E. S. T.

Figures 14, 15, and 16 are sketches of three interesting series of pulse patterns observed on the rhombic and comparison antennas. The three groups reading from left to right show the effects on the individual pulses of the steering of the rhombus, as indicated by the angle ϕ. The steering achieved at these angles can be seen by referring again

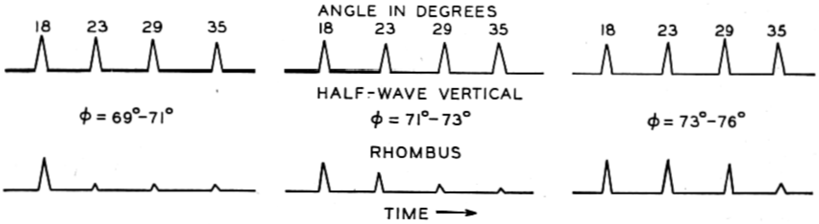

Fig. 14—Pulse pattern changes with steering, March 8 and 9, 1933. Station GCS on 33.26 meters.

to Fig. 4. Marked over the individual pulses are the arrival angles above the horizontal, measured through the cooperation of co-workers.

Figure 14 is of a test, at thirty-three meters, during a period when a wide angular spread of the cluster prevailed. Four narrow pulses of similar magnitude appear on the half-wave antenna. The progressive effect of suppressing the higher angle waves by steering the rhombus is shown. Very appreciable selective fading reductions are possible under such conditions.

Figure 15 is a sketch of twenty-meter observations during a period when selective fading reductions were achieved at the lower angle antenna settings. The broad, flat tops of the pulses are incidentally an interesting contrast to those in Fig. 14. These are possibly due to an increased horizontal spread of wave angles.

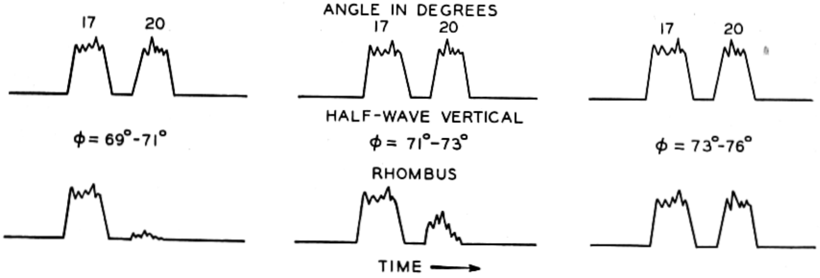

Fig. 15—Pulse pattern changes with steering, April 8, 1933, 2:00 P.M., E. S. T. Station GBW on 20.78 meters.

Figure 16 is of a case where it was possible deliberately to make the fading on the rhombus worse than that on the comparison antenna. Since the later pulse had a higher amplitude than the earlier one, rhombic steering by equalizing the relative amplitudes, as shown in the left-hand figure, made the selective fading very bad indeed. The opportunities for producing a result of this nature are rather rare, in fact in our previously mentioned wobble studies it was possible to make

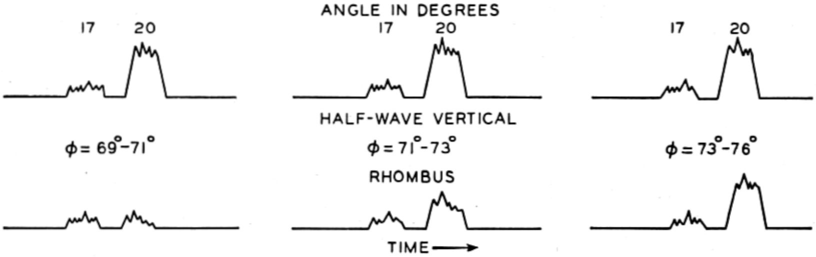

Fig. 16—Pulse pattern changes with steering, April 8, 1933, 2:40 P.M., E. S. T. Station GBW on 20.78 meters.

the selective fading worse only four per cent of the total time of observations.

Occasionally, and in particular on twenty meters, only slight selective fading was observed. When pulse transmissions were available during these times, only one major pulse could be seen. Really bad fading invariably occurs when multiple pulses, which are widely spaced in time, are observed.

It may be evident, from the previous discussions in this paper, that the change in antenna output, with steering, is closely related to the number and spread of the waves arriving and to the selective fading improvements obtainable. Figure 17 shows three cases of results secured by reading relative gain changes, as shown by automatic recorders.

Case 1 is typical of a closely spaced wave cluster arriving at an average angle of about ten degrees above the horizontal. Case 2 can be explained as due to a narrow wave cluster at eleven degrees plus another of less amplitude at eight degrees. We would ordinarily expect annoying selective fading in such an event. Should we deal with many closely spaced waves having a large angular spread, very little gain change would be evident while steering the rhombic antenna, but selective fading improvements over the comparison antenna might still be possible.

Curve 3 is of considerable interest in that it served as one of the experimental checks of the theoretical directive pattern calculations. The change in gain with steering is so well defined that probably only one wave-direction existed. This belief was supported by an absence of noticeable fading. Independent measurements, made by an average angle measuring installation[2] consisting of two horizontal dipoles at different heights which determines the average angle by the ratio of the respective outputs, gave the arrival angle at from eighteen to nineteen degrees above the horizontal. Figure 4 indicates that a ϕ-angle

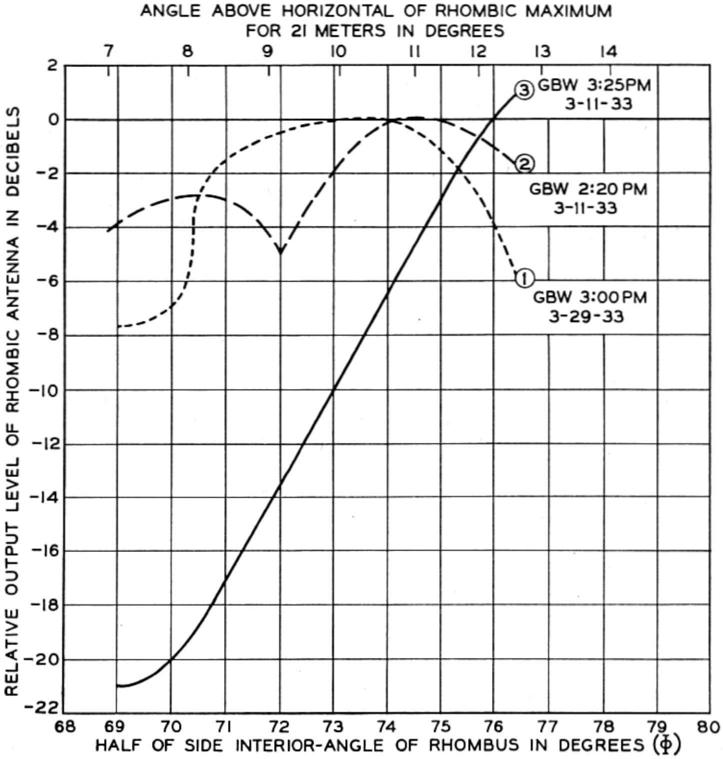

Fig. 17—Horizontal rhombic antenna output changes with steering as shown by automatic field strength recorders. Corrections for changes in signal level with time, as obtained from a half-wave vertical antenna, have been applied.

of about 68 degrees would place a null at this angle. While the range of steering of the rhombic antenna in use did not permit an adjustment to less than about sixty-nine degrees, the trend of the curve leaves little doubt as to the correctness of our null point calculation.

As might have been expected, the previously described fading counters for studying general carrier fading showed that reductions were usually obtained at the directivity positions which also gave the least selective fading. This type of apparatus is incapable of determining whether general fading or selective fading conditions are affecting the amplitude of the fixed carrier frequency.

Conclusion

It is believed that the results, discussed in this paper, demonstrate that sharp angular discrimination is a basically sound method of combating selective fading.