is exactly the energy corresponding to the green line. This means that the two lines correspond to transitions between a common upper level and the two metastable states, $^1S_0$ and $^1D_2$. This common upper level must therefore lie 12.34 volts above the $^1D_2$ level. Since the ionization potential of oxygen is 13.56 volts the transition $^1D_2$-$^3P_{0,1,2}$ can be no greater than $13.56 - 12.34 = 1.22$ volts. Consequently, lines corresponding to those transitions must lie above 1μ. These are the only transitions that can result in a red auroral line and one is therefore not surprised at the non-observance of a red auroral line in the aurora or in the night sky.

Similarly, the transitions $^1S_0$-$^3P_{0,1,2}$ must lie at wave-lengths higher than 3575 A.U. and no such transitions have been observed in the Aurora, in the night sky or in laboratory experiments. This is not surprising because of the great improbability of intercombinations. It therefore seems probable that the green line is the only oxygen line in the auroral spectrum.

[1] *Nature*, **121**, p. 711, 1928.

[2] Poetker, *Phys. Rev.*, **30**, p. 812, 1927.

[3] McLennan, McLeod and Ruedy, *Phil. Mag.*, **6**, p. 558, 1928.

A VISUAL METHOD OF OBSERVING THE INFLUENCE OF ATMOSPHERIC CONDITIONS ON RADIO RECEPTION[1]

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Communicated October 1, 1928

There seems to be little doubt that radio signals may pass from one station to another by at least two different paths. The "ground wave" presumably follows the surface of the earth in much the same way that shorter waves are known to follow a wire. The "sky wave" starts obliquely upward from the sending station and reaches the observer after being bent or reflected by the Kennelly-Heaviside layer of highly ionized air. Both are subject to absorption due to the conductivity of the air, and the sky wave may have its plane of polarization rotated, or may suffer a sort of magnetic double refraction, because of the earth's magnetic field.

Changes in the ionization of the air and the height of the Heaviside layer will thus lead to changes in the amplitude, phase and polarization of the two waves, so that when both reach the receiving station together very complicated results are to be expected. That the results are in fact complicated and confusing is evidenced by the fading observed in broadcast reception and by the erratic changes in the apparent direction of the waves as indicated by a radio compass. Since it is in the region of the Heaviside layer that the aurora occurs, and since there are strong reasons for believing that electric currents in this region have an important influence on the earth's magnetic field, the study of the effect of atmospheric conditions on radio reception is of importance, not only as a step toward improvement in methods of radio communication but also as one of the very small number of methods known to us by which we may hope to find out what the conditions in the upper atmosphere really are and thus obtain a check on theories of the aurora and of terrestrial magnetism.

Since it is the sky wave that is most influenced by atmospheric conditions some method of observation that will permit the effects of the sky wave alone to be measured is much to be desired. In the methods that are ordinarily used in studying radio reception the effect observed is always that due to the resultant of the two waves. Fading records, for example, if made with a vertical antenna, show the variation from instant to instant of the vertical component of the electric field at the receiving station, and this is due partly to the ground wave and partly to the sky wave. Direction settings made by a vertical loop receiver depend upon the direction of the *resultant* magnetic field. Thus far no means of completely separating the two waves has been proposed. In fact, complete separation does not seem possible.

In the experiments described in this paper a partial separation of the ground and sky waves is effected by the use of two carefully balanced coil receivers, one coil (A) being mounted with its plane vertical and directed toward the sending station, while the other (B) is set in the vertical plane at right angles to this direction. The response of the coil A is determined by the magnetic field due to the combined action of the ground wave and the vertically polarized component of the sky wave. The coil (B) is capable of receiving a signal only in case the resultant magnetic vector has a component directed toward the sending station; and this can occur only when waves reach the receiver which are moving in a direction having a downward component, and so polarized that the magnetic vector has a component in the vertical plane. This coil, therefore, responds only to that component of the sky wave which is polarized with its electrical vector horizontal. It is not affected at all by the ground wave.

To make possible convenient visual observation the signal received by the loop A was heterodyned by coupling to the circuit of a local oscillator, and after detection and suitable amplification was brought through a transformer to one pair of plates of a cathode ray oscilloscope, so as to produce a movement of the spot in the horizontal plane. Similarly the signal from loop B, heterodyned by the same local oscillator, was brought to the other pair of plates and caused a movement of the spot in the vertical direction. The combination of the two movements resulted in a Lissajous figure on the oscilloscope screen.

Since the e.m.f. produced in the receiving circuit by the local oscillator is always greater than that due to either signal, the amplitudes of the vertical and horizontal oscillations of the oscilloscope are proportional to the amplitudes of the signals received by the two loops. And since the same local oscillator is used for heterodyning both signals, the phase difference between the vertical and horizontal oscillations is the same as that between the original signals. Thus if the signal received in A is $a \cos pt$ while that in B is $b \cos (pt + \varphi)$ the result of heterodyning with an e.m.f. $c \cos nt$ ($c > a$, and $c > b$) is to give for the circuit of loop A

$$a \cos pt + c \cos nt = (c - a)\cos nt + 2a \cos {}^1/_2(p - n)t \cos {}^1/_2(p + n)t$$

and for the circuit of loop B:

$$b \cos (pt + \varphi) + c \cos nt = (c - b)\cos nt + 2b \cos \left[\frac{1}{2}(p - n)t + \frac{\varphi}{2}\right] \cos \left[\frac{1}{2}(p + n)t + \frac{\varphi}{2}\right].$$

The complete cycle of amplitude change that is represented by the factor $\cos {}^1/_2(p - n)t$ contains two beats, so that the frequency of the beat tone after rectification by the detector tube is not ${}^1/_2(p - n)$ but $p - n$. Rectification produces no change, however, in the actual time shift between the beats from A and B, so that the phase shift *of the beat tone* is not $\varphi/2$ but φ; i.e., the same as the phase difference between the original signals.[2]

Thus the vertical and horizontal movements of the spot of light on the screen of the oscilloscope correspond both in amplitude and phase with the oscillations received by the two loops. The method would fail in the case of excessively rapid changes in the amplitude or phase of the waves. But there is no indication that such changes occur.

Thus far the method has been used chiefly with the carrier waves of a number of different broadcasting stations and gives a graphical picture of the changing phenomena that is both instructive and fascinating. It is surprising to find that modulation, unless unusually strong, is hardly noticeable and is rarely a source of disturbance.

Since the use of two loops at right angles gives only a partial separation of the ground and sky waves some caution must be used in interpreting the observed figures. Thus while there can be no vertical amplitude unless there is a sky wave, the absence of vertical amplitude does not necessarily mean that no sky wave is present, for it might be polarized with its electric vector in the vertical plane so as to produce no effect in loop B. In such cases the figure is a horizontal straight line, often changing slowly in length because of changes in the phase of the two waves.

During the day time the figure is usually a horizontal straight line of constant or very slowly changing length. As sunset approaches indications of a sky wave begin to appear. The line slowly pulsates, or tilts slowly back and forth about the horizontal. In other cases it opens up into a narrow ellipse which changes in area and inclination. On several occasions, about ten or fifteen minutes after sunset, the figure has been observed to rotate continuously—sometimes quite rapidly—in the same sense, changing at the same time from a line to an ellipse and back again. As many as twenty complete turns have been counted in a period of a few minutes. It seems not unlikely that this effect is due to the rapid rise of the Heaviside layer as darkness sets in. Due to the increasing length of path this would bring about a progressive change in phase of the sky wave, and at the same time a progressive rotation of its plane of polarization.

When a strong sky wave is present during the day time—and in the late afternoon this is not unusual—our observations thus far indicate that its modulation is much less marked than that of the ground wave. At night both waves appear to be modulated equally.

When night conditions have become established the movements of the figure are usually quite erratic. The vertical amplitude is often several times as great as the horizontal and both change rapidly. If rotation occurs it is sometimes in one direction and sometimes in the other. But although the changes are usually more rapid at night this is by no means always the case. We have observed circular polarization—indicated by a circular figure on the screen—which persisted with unchanged amplitude for as long as two minutes.

On Sept. 8, 1928, we were fortunate in being able to make visual observations during an auroral display. For several days before this date the conditions for radio reception had been unfavorable. The usual sunset phenomena were not observed and what we had come to regard as the normal night conditions were not established until quite late—if at all. On Sept. 8 observations were begun on station WEAF (New York) at 4:45 and at first indicated that conditions were still unfavorable. Only slight indications of a sky wave were observed and the changes in the oscilloscope figure were slow and not at all marked. The same conditions were found in the case of station WJZ (Bound Brook) and WGY (Schenectady) and continued with all three stations until 7:40, i.e., until more than an hour after sunset. The oscilloscope figure then began to change with great rapidity both in size and shape. During the greater part of this period of violent disturbance, which lasted until 7:48, the figure rotated counter clockwise, although the rotation was not at a uniform rate and was much confused by erratic changes. Then after a quiet period of about five minutes there was a slow clockwise rotation for over two minutes. During the evening there were several other periods of continuous rotation sometimes in one sense and sometimes in the other. At 8:45 we shifted to station WGY (Schenectady) and found that the oscilloscope figure changed so rapidly that it could hardly be observed at all. Our first thought was that something had happened to the receiving sets and we devoted some time to adjusting and testing the apparatus, finding however that everything was in order. We then shifted to other stations and found that they were now showing just as violent and erratic changes as WGY. In the course of these adjustments and changes we noticed that a brilliant auroral display was in progress. Unfortunately, we have not been able to learn the hour at which the display began. The disturbed conditions persisted for about two hours, getting less marked as the aurora became fainter. At 11:10 conditions were normal and the aurora had disappeared.

The records of the Cheltenham Magnetic Observatory indicate a magnetic storm beginning at 1:48 P.M. Sept. 8 and ending at 9:30 P.M.

We have recently built two identical short wave sets and, although systematic observations have not yet been begun, have tested the method on a sufficient number of stations on this continent and in Europe to show that it can be used successfully with short waves as well as in the broadcast band. The oscilloscope figures are similar in character and movement to those observed with longer waves but usually change more rapidly. In the case of code stations we had rather expected that the interruption of the wave would prove a source of annoyance. We find however that the figure persists from one dash or dot to the next, while the absence of modulation results in a figure that is particularly sharp and clear.

It is our intention to continue observations, especially during the sunset period, both with signals from broadcasting stations in this country and with short wave from more distant stations.

[1] The investigation of which the work described in this paper forms a part has been supported by a grant from the Heckscher Foundation for Research at Cornell University.

[2] This method of determining the phase difference between two waves by observing the phase difference between the corresponding beat tones was developed by one of the writers in 1918 at the Naval Experimental Station, New London, the main purpose then being to make possible an adaptation of "binaural" methods of direction finding to radio signals. With other devices developed during the war by members of the scientific staff the method was later patented. (U. S. Patent No. 1,510,792, "Methods and Means for Determining Phase Difference," issued to Ernest Merritt.) In the original description of the method the phase difference between the beat tones is incorrectly given as $\varphi/2$. The procedure used by the authors to make the method a visual one has been used by H. T. Friis with the signals received by two similar vertical antennae spaced about one-third of a wave-length apart, and has led to an interesting modification of the binaural method in which phase differences are observed by the eye instead of by the ear. (H. T. Friis, "Direction of Propagation and Fading of Short Waves," *Proc. Inst. Radio Engineers*, **16**, p. 658, May, 1928.)