POLARIZATION OF RADIO WAVES.

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Electromagnetic waves or radio waves are usually transmitted from a vertical antenna, which is a vertical wire of perhaps a hundred feet or more in height. To increase the capacity the wire is usually connected to a "flat top," which is a number of horizontal wires. The field radiated from a vertical wire consists of an electric field in the vertical direction and a magnetic field at right angles to the electric field.

Such a field is said to be polarized in the vertical direction. In order to receive such polarized wayes one must use a vertical receiving antenna or a vertical loop aerial, the plane of the loop being the direction of propagation of the wave. It is well known that if a loop aerial is turned at right angles about a vertical axis the signal can be made so weak it cannot be received. In this case the wave is perpendicular to the plane of the loop. If the loop is turned about a horizontal axis until the plane of the loop is horizontal the signal will be cut out because the loop is perpendicular to the plane of polarization of the wave. The plane of the coil must be parallel to the plane of polarization of the wave to receive the signal with greatest intensity. Instead of a loop aerial an antenna aerial might be used. When the antenna is in the plane of polarization and perpendicular to the direction of propagation the signal is the most intense. Thus, a vertical wire antenna will receive from a vertical transmitting antenna.

The first measurements of intensity were made by Austin (Bull. Bur. Stands. 7, 315, [1911].) The measurements were made on distant transmitting stations using relatively long waves and low frequency, such as were then used in trans-Atlantic transmission. The measurements indicated that the waves were vertically polarized. Similar results were obtained by Smith-Rose and Barfield (Roy. Soc. Proc. 107, 587 [1925]), using frequencies as high as 677 kilocycles, 443 meters wave length.

G. W. Picard (Inst. Rad. Eng. 14, 205 [1926]) was the first to investigate the shorter wave lengths. A wooden tower was built on a level flat which was free from overhead wires and trees. On this tower a linear Hertzian oscillator or antenna was mounted in a universal joint so that this aerial could be rotated into all directions. A superhetrodyne receiver was used to measure the value of the signals received in the various planes. Picard found that in the daytime, for all frequencies under one or two megacycles (300 to 150 meters wave length), the maximum signal was received with the antenna vertical. A minimum was found with the antenna horizontal. Surprising results were obtained from stations which were operated on the amateur bands of 3.5 to 4 and 7 to 8 megacycles (85 to 75 and 42.8 to 37.6 meters). These stations

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were of the antenna ground type so that the wave left the transmitter vertically polarized. The ratio of the horizontal to vertical field was at times as large as three or four to one. These measurements indicated that there was a difference between short waves and long waves. Short waves sent vertically polarized may arrive horizontally polarized. The distances from transmitter to receiver were fifty or more miles.

To try the effect of waves sent horizontally polarized a special transmitter was erected at Schenectady, N. Y., which transmitted horizontally polarized waves. These were received at Seabrook Beach, New Hampshire. At 790 kilocycles (380 meters) the received signals were predominantly vertically polarized. The average vertical to horizontal was 10:1. Similar tests were made at 3.75 megacycles (80 meters). The horizontal electric vector was found to be over twice that of the vertical vector regardless of whether the transmitter was horizontal or vertical. E. F. W. Alexanderson (Trans. Am. Inst. Elec. Eng. 45, 636 [1926]) states that he has found that short waves have their plane of polarization rotated and at times there was circular polarization. He shows a mechanical model to illustrate the circular polarization, but the details of the experiments are very meager.

The present experiments were conducted to see if there was any change of the plane of polarization near the transmitting station. The frequency selected was 30 megacycles (10 meters) and all measurements were made at distances less than 70 meters, 7 wave lengths.

The transmitter, which is diagrammed in figure 1, consisted of a loop aerial of a single turn of wire connected to the tubes so as to form a modified Colpitts circuit. Two five-watt tubes were used. The filaments were heated from a filament transformer and the plate supply



Fig. 1—The transmitter was a square single turn coil of wire. This coil was connected to the tubes as in the diagram. The tubes were mounted on the horizontal axis of the coil. When the coil was rotated the two wires connecting the coil to the tubes were twisted.

was a 500-volt transformer. With A. C. filament and plate supply the power was supplied by a single line of twisted lamp cord, which furnished A. C. at 110 volts. A. C. on the plate served for modulation so that a non-oscillating receiver could be used. Radio frequency choke coils were placed in the lines to prevent the radio current following the 60-cycle supply line. The transmitter was mounted so the coil could be rotated 180° about a horizontal axis. The tubes were mounted in a fixed position in this axis. In rotating the coil the two wires leading to the tubes twisted but were arranged to keep the relative position and area of the coil as near constant as possible. By rotating the coil the transmitted radiation was polarized in the vertical or horizontal plane at will. The receiver diagrammed in figure 2 was mounted in



Fig. 2—The receiver consisted of a coil of wire fifty centimeters square connected as in the diagram. The coil was so constructed that it could be rotated from the verticle to the horizontal position.

the same general fashion. U. V. 199 tubes were used and the filament battery was a 4.5-volt C battery and light weight B batteries were used, making the receiver portable. The receiver was mounted on a camera tripod. A single stage audio amplifier was used. A head set was used to judge the intensity. No attempt was made to estimate or measure the intensity of signals; position of maximum and minimum intensity alone were measured.

Transmitter Vertical. With the transmitter vertical the maximum position or the maximum intensity of signals were always with the receiver in vertical plane; that is, maximum intensity was received when the two coils were parallel. The intensity when the coils were at right angles was zero or near zero. There seemed to be no difference in the plane of polarization as the distance was varied from close distances to distances of about 200 feet.

Transmitter Horizontal. With the transmitter sending horizontally polarized waves, when the distance was seven feet, the maximum intensity was received when the receiver was horizontal. A minimum was noticed when receiver was vertical. This minimum was not zero, however. As the distance between transmitter and receiver was increased

maximum signals were received at positions other than the horizontal position. At certain positions the maximum was found with the receiver coil set at 45° with the transmitter. At other positions the intensity was the same regardless of the position of the receiver coil.

Receiver Placed on a Step Ladder. In general there was a difference in the plane of polarization when the receiver was on the ladder from that found at the base of the ladder. This effect was more noticeable at distances of 30 to 40 feet. The effect was not so noticeable at distances of 150 to 200 feet.

Transmitter Placed at 45° . When the plane of polarization was 45° the general effect was the same as when the transmitter was horizontal, but the positions of maximum and minimum were much sharper and easily distinguished. There was the change of position of maximum with distance and at places there was the evidence of circular polarization.

Explanation of Observations. The above observations can be explained if we can assume that the earth is a conductor and that there are currents set up in this conductor at some position below the surface. When the transmitter coil is vertical we can assume the coil to be equivalent to two linear oscillators at right angles to each other, one in the vertical position and the other in a horizontal position in the plane of the coil. This horizontal component, as well as its image in the earth, will not radiate in the direction of the receiver, and thus will have no effect on the receiver. The vertical component will radiate in the plane of the coil along the surface of the earth but will not radiate into the ground below itself and there will be no image and no interference, and the maximum will always be in the vertical. The intensity will decrease regularly with the distance.

With the transmitter at 45° we must assume that we have both a vertical and horizontal component, both of which are at right angles to the line connecting receiver and transmitter.

This horizontal component will cause an image in the earth. Both of these, the longitudinal component of the receiver and its image, will transmit horizontal waves to the receiver. The two will be out of phase and the wave from the image is through the earth traveling at a lower velocity than through the air. These will destructively interfere at points, depending on distance. These two, together with the vertical component, will cause the maximum to vary in position with distance. Maximum will be at 45° at certain points, and at other points the resultant horizontal component will be retarded a quarter wave and circular polarization will be the result.

When the transmitter was horizontal we must assume that there was from some cause, the 60 cycle leads and apparatus perhaps, a small vertical component. The general results were the same as when the transmitter was placed at 45° .

The stepladder indicated that the plane of polarization changed with height and thus the relative phase of the two waves will change. If the receiver is very close to the transmitter the intensity of the direct wave is much greater than that from the image and the effect of the image is not noticed. At distances of 200 feet the change of phase with seven feet elevation will be small and the effect will not be so pronounced as at smaller distances.

It will be noted that if the intensity of the image and transmitter is the same the intensity on the surface of the earth will be zero, provided the image is as far below the surface as the transmitter is above since they are in opposite phase. This assumes that the velocity of both waves are the same.

Transmitter on Metal Roof. The transmitter was then placed on top of the press box of the stadium. The roof is made of metal. In this manner any induced current in the roof will be located at a definite point and the radiation from this image will be transmitted through space to the receiver with the same velocity as that from the coil. With the coil in the vertical plane the maximum received signal was obtained when the receiver was vertical. This was true for all distances. When the transmitter was turned horizontal the maximum signal was still in the vertical plane and a minimum was in the horizontal This is explained by supposing that the transmitter radiated plane. a vertical component in spite of the fact that the coil was rotated to the horizontal. If there had been no vertical component and the intensity from the image was equal to the intensity from the coil itself the intensity in the horizontal should have been zero when the coil is horizontal. The image and coil are out of phase and the distance of both from the receiver are approximately the same. This is true for all except short distances. The roof is about 35 feet above the level of the ball field in the stadium.

There was no indication of rotation of the plane of polarization as was the case with the apparatus on the ground, except when the receiver was brought close to the base of the stadium. Close to the base there was in all probability a component which was transmitted through the concrete. When the transmitter was in the 45° plane the effects were substantially the same as when in the horizontal plane. The reason for this has been explained before.

Proposed Test. To test the theory further it was proposed to place the transmitter above the roof a distance equal to a wave length, then there should be maximum and minimum positions in space. Along the horizontal or at a height equal to the height of the roof and apparatus there should be a minimum signal, zero if there were no vertical component. At heights such as when the line joining receiver and transmitter makes an angle of 30° with the horizontal there should be a maximum of intensity when the receiver is horizontal.

The image is out of phase with the transmitter and the distance from receiver and oscillators differ by a half wave length, making the radiations in phase at the receiver, figure 3. With the apparatus used in the first part this would require a tower some thirty feet high. It was thought that the transmitter could perhaps be raised five meters. So a new transmitter transmitting on a wave length of five meters



Fig. 3—Diagram showing the transmitter at a height above the roof of the stadium prcss box. If the lines connecting the receiver at R, makes 30° with the horizontal there will be destructive interference at R.

was started. However, before this was finished some of the essential parts were stolen and the experiments were not tried.

Conclusion: These experiments tend to show experimentally that short electromagnetic waves are polarized the same as light waves, and that the plane of polarization rotates with the rotation of the transmitter, and that if for any reason part of the radiation is horizontally polarized the plane of rotation will vary with distance and at points circular polarization is present: that the earth acts as a conductor, and an image of the transmitter may be present at an indefinite distance below the surface, and that the ground wave seems to have a different velocity from that through space.

These experiments do not explain why short amateur waves which are vertically polarized arrive at the receiver horizontally polarized. This effect must be due to causes remote from the transmitter.

The waves used in this experiment are much shorter than those used by other experimenters.