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EXPERIMENTS WITH UNDERGROUND ULTRA-HIGH-FREQUENCY ANTENNA FOR AIRPLANE LANDING BEAM

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ABSTRACT

Experiments are described on the electrical properties of an ultra-high-frequency transmitting antenna operating very near to and below the ground surface. The work was done with the purpose of locating the landing beam in the center of an airport in order to secure a steeper approach path and to provide for landing service for different wind directions. The effect of the proximity of the ground to the transmitting antenna upon the low-angle distribution of energy in the radiated field and upon the polarization of the field is described. An approximate mathematical analysis is given of the mechanism of setting up a landing path when the transmitting antenna is below the ground surface.

CONTENTS

I. INTRODUCTION

In the course of experiments with the radio landing beam [1] an investigation was made during 1933–34 on the operation of an ultra-high-frequency transmitting antenna very near to and below the ground surface. The work was done with the purpose of locating the landing-beam antenna in the center of a landing field. In this location the approach path becomes steeper for a given point of contact of the landing airplane with the airport surface and thereby permits full utilization of long runways without requiring a very flat approach to the airport. A further advantage of this location is that landing-beam service may be provided for all directions of approach to the airport to meet varying wind conditions. The investigation led to what appears to be a practicable solution of locating the landing-beam antenna in the center of an airport. In addition, a number of interesting phenomena on the effects of the proximity of the ground upon the transmitted wave were observed and are reported in this paper.

[1] H. Diamond and F. W. Dunmore, *A Radiobeacon and receiving system for blind landing of aircraft*. BS J. Research **5**, 897–931 (1930) RP238. Proc. Inst. Radio Engrs. **19**, 585–626 (1931). H. Diamond, *Performance tests of radio systems of landing aids*. BS J. Research **11**, 463–490 (1933) RP602. Proc. Inst. Radio Engrs. **22**, 120–121 (1934).

II. INCREASED STEEPNESS OF APPROACH

That a steeper approach path is obtainable by locating the transmitting antenna at the center of the field is clearly evident from figure 1. Graph *A* is the theoretical landing path with the landing-beam transmitter located at the far edge of the field and the sensitivity of the airplane receiver adjusted so that the point of contact of the landing airplane with the airport surface is at a point 1,000 ft on the approach side of the center of the field. Graph *B* shows the theoretical landing path corresponding to the same point of contact, but with the transmitter at the center of the field. The length of airport runway in this illustration is assumed 5,000 ft, and the height of the airplane receiving antenna 10 ft. It is of interest to note that the obstacles in the approach would prevent the possibility of following path *A*, the airplane clearing the edge of the airport by only 10 ft (the difference between the height of the landing path at that point (20 ft) and the height of the receiving antenna above the bottom of the landing gear). In case of path *B*, the steepness of approach is more normal and the airplane clears the edge of the field by 53 ft.

Not only does the center-of-field location provide a steeper approach path for a given point of contact, but also it affords considerable flexibility for varying the steepness of approach without appreciable change in the point of contact. Thus the clearance at the approach end of the field may be doubled by moving the point of contact only 250 ft toward the center of the field. With the transmitter located at the far edge of the field, this clearance would require moving the point of contact by 2,000 ft, that is, to within 1,500 ft of the far edge of the field, thereby seriously reducing the length of runway available for coming to a stop.

III. TESTS WITH TRANSMITTING ANTENNA AT SMALL DISTANCES ABOVE THE GROUND SURFACE

Because of its location in the center of an airport, the choice of the transmitting antenna to be employed was necessarily restricted to the simplest possible type. Accordingly, a horizontal half-wave transmitting antenna was adopted and was used throughout the tests.

The use of a simple half-wave antenna in place of the directive antenna array previously employed for setting up a landing path led to a consideration of whether the transmitter power and receiver sensitivity employed were sufficient. Also, while optical theory showed that the slope of the landing path would be the same for both types of antennas, it was desired to determine the effect on the path of placing the transmitting antenna close to the ground surface. Tests were accordingly made to investigate these features.

The transmitter utilized two 500-w tubes in push-pull, operating at a frequency of 90,800 kc (3.3 m), and the half-wave antenna was fed from it by a short two-wire parallel-conductor transmission line. The transmitter was completely shielded and the transmission line properly terminated so that the radiation was confined to the antenna proper. The receiving equipment consisted of a detector and a two-stage audio amplifier fed by a parallel-conductor transmission line from a half-wave receiving antenna. The output of the receiver was rectified and applied to the landing beam indicator (a d-c microammeter). The receiver sensitivity corresponding to half-scale ("on

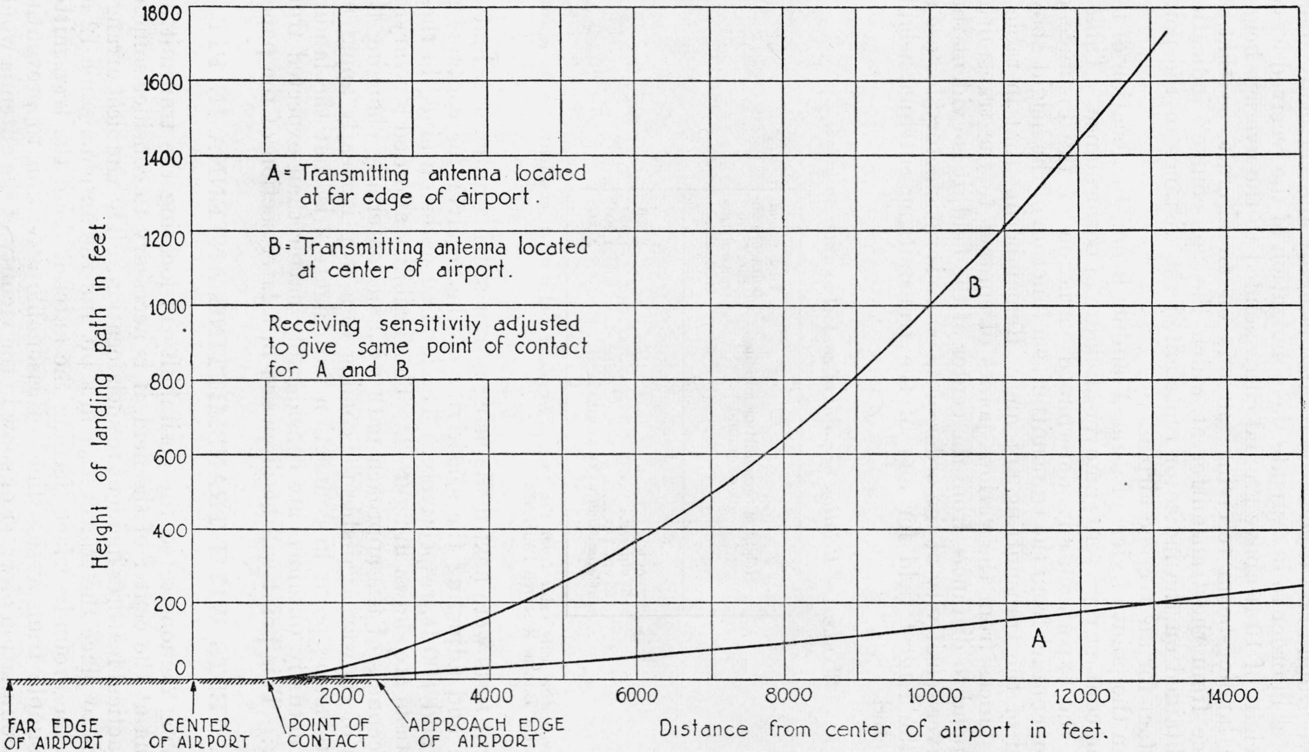

Figure 1.—*Approach paths corresponding to edge-of-field and center-of-field landing-beam locations.*

course") deflection of this indicator was approximately 5,000 μv. The antenna was mounted on a portable support so that its center was 10 ft above ground and it could be rotated laterally and vertically about its center in order to investigate the polarization of the received wave. The height of 10 ft above ground corresponded to the average height of the landing-beam receiving antenna on an aircraft, so that the distance from the transmitter at which the "on-course" indication was obtained on the indicator represented the distance of the point of contact for an average airplane.

From the point of view of using a landing beam, the location of the point of contact represents an over-all figure of performance. Table 1 shows the experimentally determined variation of the distance of point of contact from the transmitter as a function of the height above ground of the transmitting antenna. Remembering that in table 1 the distances from the various points of contact to the transmitter correspond to distances from the center of the field, it is evident that a receiver sensitivity of the order of 5,000 μv is satisfactory for use at even the largest field for any of the transmitting-antenna heights considered.

TABLE 1.—*Relation of point of contact to antenna height*

Height of transmitting antenna above ground	Distance of point of contact from transmitting antenna [1]
	ft
28 cm	1,300
51 cm	1,550
89 cm	1,800
165 (one-half wave length)	2,000

[1] For evaluating this value from the transmitter power and receiver sensitivity, see the equation on page 476 of Bureau Research Paper 602.

Flight tests were next made using a transmitting-antenna height of 30 cm and adjusting the sensitivity of the receiver for contacts at 1,300 and 800 ft, respectively. The landing paths obtained in these flight tests are shown in figure 2. The flexibility afforded for varying the steepness of the approach path without materially changing the length of runway available for coming to a stop is clearly apparent. An interesting point in connection with figure 2 is that the landing paths actually obtained are considerably flatter than expected from theory. This point will be discussed in a later section of the paper.

IV. TESTS WITH TRANSMITTING ANTENNA IN PIT

Having demonstrated the desirability of locating the transmitting antenna at the center of the field, it is necessary to consider some of the practical features incident to such location. The simplest arrangement is to place the transmitter in a pit and the antenna some 12 in. above the ground surface, feeding the antenna from the transmitter by a simple transmission line. Reasonable attention to preventing the accumulation of water or snow in the vicinity of the antenna would be sufficient to safeguard its electrical operation. However, the presence of such an antenna in the center of the airport presents some

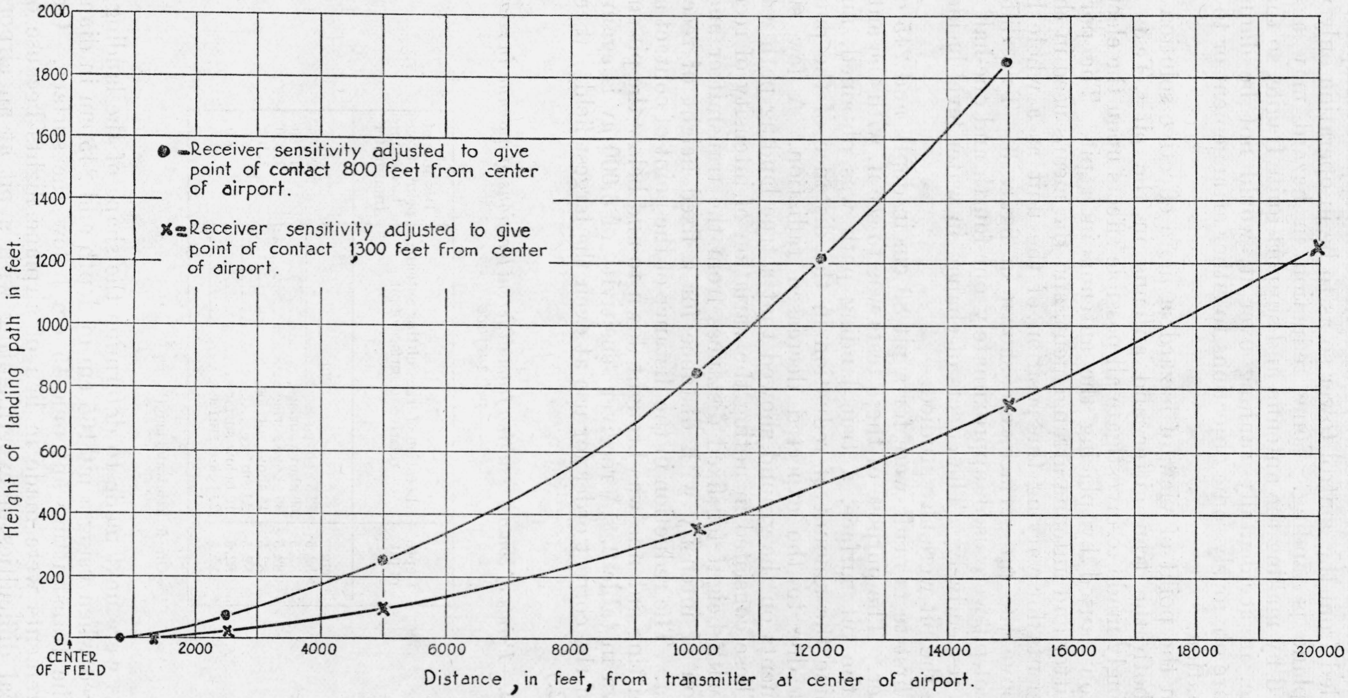

FIGURE 2.—*Typical approach paths possible with landing beam located at center of airport.*

hazard. It is likely that this hazard might be reduced to a negligible degree by making the half-wave antenna and support collapsible and controlled from the control tower so as to be in operation only while an airplane is landing. Some reduction in hazard may also be obtained by making the antenna and support quite fragile, so that an airplane, in accidentally running over it, would not be damaged. There are obviously some objections to either arrangement or to their combination.

From the point of view of hazard, a more effective solution is to place both the transmitter and antenna in the pit. Tests were accordingly made to investigate all possible effects upon the electrical operation caused by placing the antenna in a pit. The portable transmitter and antenna arrangement, and the means used in the pit experiments for varying the position of the unit as a whole below and above the pit surface, are shown in figure 3. Two different depths of pit were used, approximately one-fourth and one-half wave length, respectively. The effects of change in water level inside and outside the pit were also studied.

The first tests made were for a pit 80 cm in depth and 245 cm in diameter. The purpose of these tests was to see if, with the antenna below the pit surface, a true landing path was obtained, and to determine the amount of reduction in the distance of the point of contact due to the expected decreased radiation. A few simple experiments on the ground showed that a true landing path was set up. These consisted in noting the variation of intensity of received signal with height for fixed distances from the transmitter and the variation of intensity with distance for a fixed height of receiving antenna. The reduction in the distance of the point of contact as the transmitting antenna was brought down to and below the pit surface is shown in table 2. A receiver sensitivity of 5,000 μv is again seen to be of the correct order for use at even the largest field. (See figs. 1 and 2.)

TABLE 2.—*Points of contact resulting from different locations of antenna in relation to pit surface*

Depth of pit	Location of transmitting antenna relative to surface of pit	Distance of point of contact from transmitter
cm	cm	ft
[a] 82.5	82.5 above surface	2,000
82.5	60 above surface	1,750
82.5	30 above surface	1,200
82.5	15 above surface	1,100
82.5	At surface	950
82.5	10 below surface	900
82.5	20 below surface	900

[a] One-fourth wave length.

Tests were next made to determine the shape of the landing path produced when using a pit 165 cm in depth and 245 cm in diameter, with the transmitting antenna 45 cm below the surface. Ground measurements were made in lieu of airplane flights because of the practical difficulties of experimenting with a pit at an airport. A special receiving set was used with self-contained batteries and receiving antenna to permit hoisting up and down a pole. Figure 4

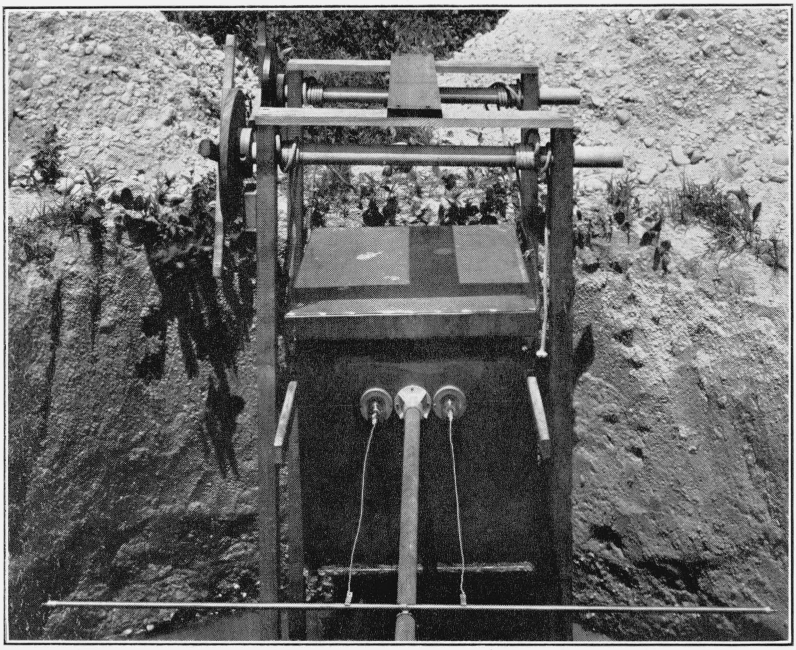

FIGURE 3.—*Experimental transmitting equipment used in the pit tests.*

shows the variation of the intensity of received signal with height for two distances from the transmitter, 65 and 190 ft, respectively. The two graphs are plotted to adjusted ordinate scales so that they overlap, forming a single smooth curve. Figure 5 shows the variation of the intensity of received signal with distance from the transmitter at a fixed height for the receiving antenna. This latter graph was derived from data taken as follows. The receiver was adjusted for an arbitrary volume output at 50 ft from the transmitter and carried away from the transmitter until the signal intensity was halved. The volume output was then adjusted to its original value and the procedure

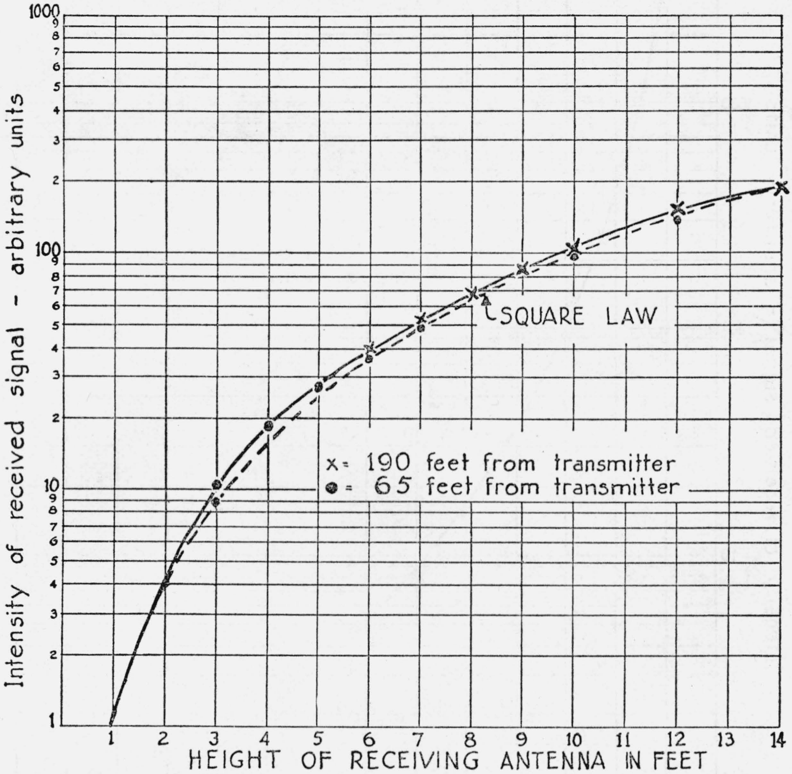

FIGURE 4.—*Vertical distribution of intensity of received signal in field radiated from transmitting antenna in pit.*

repeated again and again, the distance from the transmitter being recorded corresponding to each adjustment of volume. A value of 8 was arbitrarily chosen for the signal intensity at the farthest point measured, 310 ft.

From figures 4 and 5 it is possible to compute the landing path corresponding to a given signal intensity. Thus assume that at 50 ft from the transmitter, the output volume indicator deflects to one-half scale at a height of 1 ft. At 100 ft from the transmitter, the received signal at 1-ft height is one-tenth of that at 50-ft distance (see fig. 5). To return to the original received signal, it is necessary to raise the receiving antenna to 3.2 ft (see fig. 4). This is a second point on the landing path. The complete landing path, derived in this way, is shown in figure 6. There is of course a family of such paths, the steepness depending entirely on the intensity of the line considered. Corresponding to a height of 10 ft at distances of 800 and 1,300 ft from the transmitter, the landing paths would be somewhat flatter than

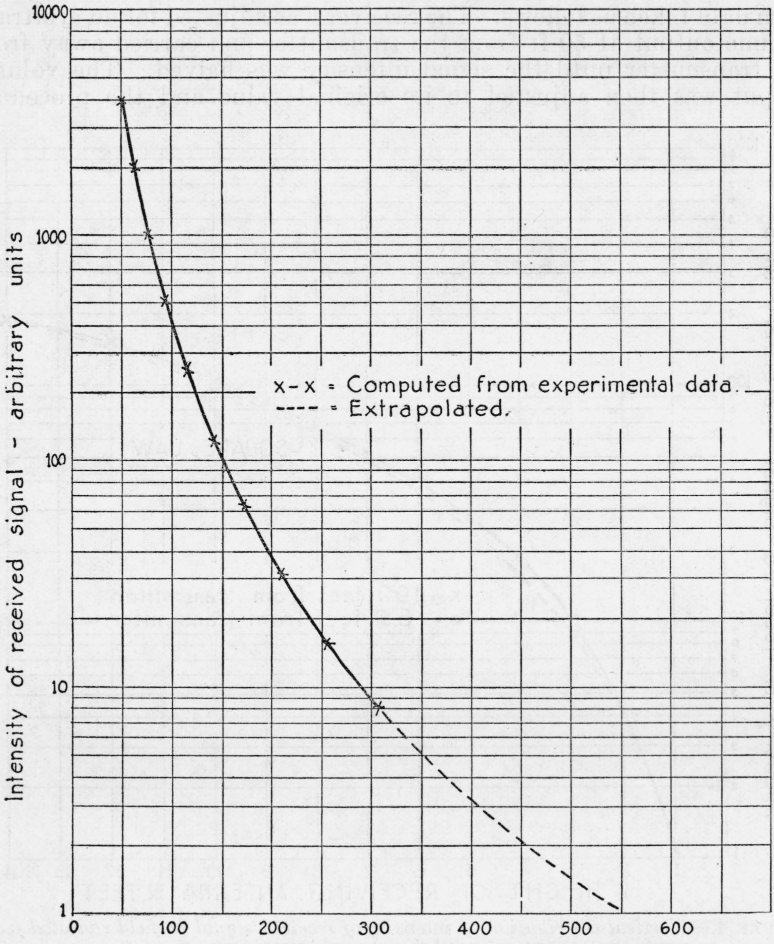

FIGURE 5.—*Variation of the intensity of received signal with distance from the pit transmitting antenna, corresponding to a constant height of the receiving antenna.*

those shown in figure 2 (for the transmitting antenna 30 cm above ground).

V. STUDY OF SHAPE OF LANDING PATHS

It is of interest to note the effect of the proximity of the ground to the transmitting antenna upon the shape of the lines of constant received signal forming the landing paths. As will be shown later in this section, the theoretical equation of the landing path may be stated as

$$y=y_0(r/r_0)^2, \tag{1}$$

where

y_0=the height of the receiving antenna above the bottom of the landing gear,

r_0=the distance of the point of contact from the transmitter,

r=distance from the transmitter,

y=corresponding height of the landing path.

Experimentally, this equation was checked closely when using directive transmitting antenna arrays with their centers located from three-fourths to one wave length above ground.[2] However, with a half-wave transmitting antenna close to and below the ground surface, the landing paths were found to be considerably flatter. Empirical equations of the form of equation 1, but with different exponents,

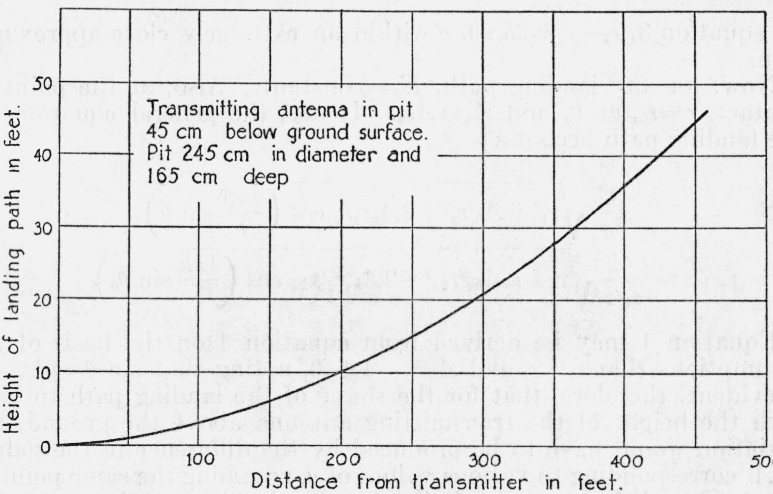

FIGURE 6.—*Shape of a landing path computed from the data of figures 4 and 5.*

were determined to fit these landing paths. For the antenna 30 cm above ground (see fig. 2), the exponent was found to be 1.85 instead of 2, while for the antenna in the pit 45 cm below the ground surface (see fig. 6) the exponent was found to be 1.75. There would appear to be a steady transition in the shape of the path as the antenna is brought down to and below the ground surface. As a check on the trend of this transition, a further test was made with the transmitting antenna 15 cm above the ground surface. For this case, the shape of the path was found to be very nearly the same as for the antenna in the pit. The difference in the shape of the paths under the different test conditions is possibly caused by the fact that when the antenna is near the ground, the wave incident on the ground is no longer plane, so that equation 1, which is based on the assumption of plane-wave ground reflection, does not hold.

The derivation of equation 1, showing that other assumptions involved do not contribute to the apparent departure from the plane-

[2] See footnote 1, p. 1.

wave theory, follows: Given an antenna h units above the ground and its image at similar distance below the ground. For unit antenna current, the electric field set up at a point P (at a height y above ground, at a distance r from the point on the ground surface just below the antenna, and making an angle θ with the ground) is

$$E_P=C\left\{\frac{1}{r_2}\cos\omega\left(t-\frac{r_2}{V}\right)+\frac{A_h}{r_1}\cos\omega\left(t-\frac{r_1}{V}\right)\right\}, \tag{2}$$

where A_h is the complex reflection coefficient for horizontally polarized waves, and r_2 and r_1 are the distances between the point P and the antenna and its image, respectively. The amplitude of E_P may be written as equation 3, remembering that $\omega/V=2\pi/\lambda$

$$E_P=\frac{C}{r_1r_2}\sqrt{r_1^2+A_h^2r_2^2+2A_hr_1r_2\cos\frac{2\pi}{\lambda}(r_1-r_2)} \tag{3}$$

In equation 3, $r_1-r_2=2h\sin\theta$ within an extremely close approximation.

Now, for any landing path, E_P=constant. Also, at the point of contact, $r=r_0$, $\theta=\theta_0$ and $A_h=A_{h0}$. Hence, the general equation for the landing path becomes

$$\frac{C}{r_1r_2}\sqrt{r_1^2+A_h^2r_2^2+2A_hr_1r_2\cos\left(\frac{4\pi h}{\lambda}\sin\theta\right)}$$
$$=\frac{C}{r_{1_0}r_{2_0}}\sqrt{r_{1_0}^2+A_{h_0}^2r_{2_0}^2+2A_{h_0}r_{1_0}r_{2_0}\cos\left(\frac{4\pi h}{\lambda}\sin\theta_0\right)} \tag{4}$$

Equation 1 may be derived from equation 4 on the basis of the assumptions that $r_1=r_2$ and $A_h=-1+j0$, noting that $\sin\theta=y/r$. It is evident, therefore, that for the shape of the landing path to vary with the height of the transmitting antenna above the ground, the variation would have to be produced by the difference in the values of A_h corresponding to various values of y, assuming the same point of contact but different transmitting-antenna heights. A large number of computations, corresponding to possible practical values of h, y_0, r_0, and the electrical ground constants, showed that this is not the case. It would, therefore, appear that the variation must be caused by the lack of planeness of the radiated wave.

VI. THEORY UNDERLYING OPERATION OF LANDING-BEAM ANTENNA IN PIT

The fact that a landing path is set up with the transmitting antenna located inside the pit presents a study in the optical behavior of the ultra-high-frequency radiations. In an attempt to arrive at a theoretical analysis of the phenomena involved, two approaches present themselves. The first is that the rays penetrate the sides of the pit and emerge at the earth's surface. The vertical distribution of energy obtained may then be assigned to the fact that rays at the lower angles have the longer optical paths and hence the greater attenuation. There is quite strong evidence, however, that this is not the actual case. Firstly, an experiment was made in which the walls of the pit were lined with a copper shield. This resulted in negligible change in attenuation of the transmitted wave. At a distance of 190 ft. from the transmitter, the intensity of the received signal and its variation with height were very nearly the same with and without the shield. Furthermore, an examination of the angles involved shows that even were the rays transmitted through the walls of the pit, they would reach the ground surface at such angles as to require total internal reflection; there could thus be no rays emerging at the ground surface.

The next likely explanation of the phenomena involved is that the rays are diffracted around the rim of the pit, the intensity of radiation dropping off as a function of the angular deviation below the marginal rays just clearing the rim. The experimental evidence pointed to this theory as a plausible one. A marked change in the water content in the surrounding ground and also shielding the walls of the pit, introduced no appreciable change in either the intensity of received signal or its vertical distribution. However, the fact that the shape of a line of constant received signal was so very nearly the same as that for the case of the transmitting antenna above ground required that ground reflection of the diffracted rays enter into the picture. We are indebted to Dr. Chester Snow of the National Bureau of Standards for assistance in working out an approximate mathematical analysis of this problem, which serves to give a clear idea of the phenomena involved.

Referring to figure 7, the transmitting antenna is taken perpendicular to the plane of the paper. The marginal rays 1 and 2 of a right section of the wave emerging through the surface of the pit make angles with the ground surface equal respectively to ϕ_0 and $\pi-\phi_0$. Consider the receiving point P at a distance r from the transmitting antenna and at an angle θ above the horizontal. By Huyghens' principle, each element of the wave front, P' (at an angle ϕ with the horizontal), becomes a new source and radiates energy in all directions. Part of this energy reaches the point P directly along the path R, while part reaches it by reflection from the ground along the path $P'P_3P$. The latter appears to come from the virtual image of P' located at P_1, directly below P' by a distance,

$$2h=2a(\sin\phi-\sin\phi_0) \tag{5}$$

It is possible to assume an image under the general point P', even though the surface of the reflecting plane is cut away from below it, since, for the angles of θ involved, the actual reflecting point P_3 always falls beyond the rim of the pit. The intensity at P due to the two rays from P' may then be set up in terms of the various distances and angles indicated on figure 7, and it may be summed for all the elementary points on the wave front between the limits of the marginal rays, as indicated in the expression

$$E_P=\frac{A}{r}\int^{-\phi_0}\left\{1+\cos\phi\right\}\left\{\sin\omega\left[t-\frac{a+R}{V}\right]-\sin\omega\left[t-\frac{a+R'}{V}\right]\right\}d\phi, \tag{6}$$

where $(1+\cos\phi)$ is the Stokes' obliquity factor taking into account that the new wavelet at P' tends to be propagated with maximum effect in the direction of propagation of the original wave front at this point. Equation 6 involves the assumption that $\alpha=\phi$, since θ, being always less than 3 degrees, is small compared to ϕ. In

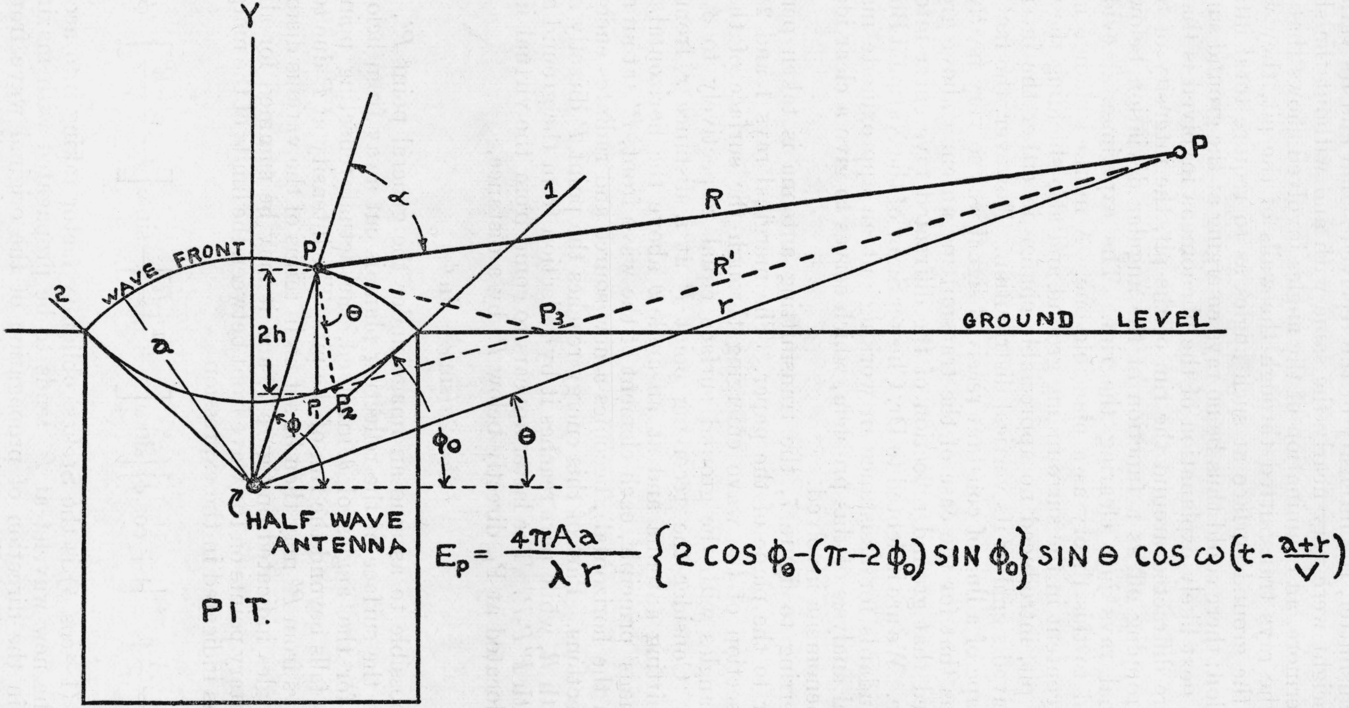

FIGURE 7.—*Mechanism of setting up a landing path with the transmitting antenna in a pit.*

equation (6,) $a+R/V$ is the phase retardation with respect to the phase at the antenna of the wave reaching P along the path R, and $a+R'/V$ is the phase retardation of the wave reaching P via $P'P_3P=R'$. The negative sign is taken before this term to indicate a negative image. Placing

$$R=r-\frac{R'-R}{2} \text{ and}$$

$$R'=r+\frac{R'-R}{2}$$

we may write from equation 5 and from the fact that $R'=R+P_1P_2=R+2h\sin\theta$ approximately

$$\left.\begin{aligned} R&=r-a.\sin\theta(\sin\phi-\sin\phi_0) \\ R'&=r+a.\sin\theta(\sin\phi-\sin\phi_0)\end{aligned}\right\} \tag{7}$$

substituting equation 7 in equation 6, we have

$$E_P=\frac{A}{r}\int_{\phi_0}^{\pi-\phi_0}\left\{1+\cos\phi\right\}\left\{\sin\omega\left(t-\frac{a+r}{V}+\frac{a\sin\theta(\sin\phi-\sin\phi_0)}{V}\right)\right.$$

$$\left.-\sin\omega\left(t-\frac{a+r}{V}-\frac{a\sin\theta(\sin\phi-\sin\phi_0)}{V}\right)\right\}d\phi \tag{8}$$

Simplifying

$$E_P=\frac{2A}{r}\cdot\cos\omega\left(t-\frac{a+r}{V}\right)\int_{\phi_0}^{\pi-\phi_0}\left\{1+\cos.\phi\right\}\left\{\sin\left[\frac{\omega a}{V}\sin\theta\,(\sin\phi\right.\right.$$

$$\left.\left.-\sin\phi_0)\right]\right\}d\phi \tag{9}$$

But since θ is small, $\sin\left[\frac{\omega a}{V}\sin\theta(\sin\theta-\sin\phi_0)\right]=\frac{\omega a}{V}\sin\theta\left(\sin\phi-\sin\phi_0\right)$

Also $\omega a/V=2\pi a/\lambda$

Therefore

$$E_p=\frac{4\pi Aa}{\lambda r}\cdot\cos\omega\left(t-\frac{a+r}{V}\right)\cdot\sin\theta\cdot$$

$$\int_{\phi_0}^{\pi-\phi_0}(1+\cos\phi)\,(\sin\phi-\sin\phi_0)d\phi \tag{10}$$

Integrating

$$E_p=\frac{4\pi Aa}{\lambda r}\cdot\left\{2\cos\phi_0-(\pi-2\phi_0)\sin\phi_0\cdot\right.$$

$$\sin\theta\cos\omega\left(t-\frac{a+r}{V}\right) \tag{11}$$

Equation 11 gives the field intensity at the point P in terms of the angle of elevation θ, the dimensions of the pit, and the wave length in air. For a pit of given dimensions and with the antenna in a given position, equation 11 resolves into

$$E_p = C \sin \theta \cos 2\pi f\left(t - \frac{a+r}{V}\right) \tag{12}$$

The latter equation indicates that the intensity at the point P is a sine function of the angle of elevation of the point P. Since for small angles, $\sin \theta = \theta$, the vertical distribution of intensity is seen to be a linear function of the height. In our experiments, we obtained a square law function. (See the dotted curve in fig. 4.) However, the receiver used was of the triple-detection type of which the law of relation between output and input was probably close to a square law, so that there is fair agreement between the theory and the experimental data.

Referring to equation 11, the first group of factors indicates that for a given antenna location in the pit, the intensity P increases with the opening of the pit (i. e., with its diameter) and decreases with an increase in the wave length used. The portion of equation 11 in braces shows that for a given pit diameter, the intensity at P is a function of the angle of the marginal ray; i. e., of the depth of the antenna in the pit. A study of this term discloses that the intensity is large for small angles of ϕ_0 and decreases as ϕ_0 is increased, becoming zero for $\phi_0 = \pi/2$. The factor $\sin \theta$ in equation 11 gives the relation of the intensity with the angle of elevation of the receiving point, while the remaining cosine function indicates the phase of the resultant field at the receiving point.

From the foregoing analysis, it becomes apparent why the path of a line of constant field intensity is of very nearly the same shape with the transmitting antenna in the pit as for the antenna a short distance above the ground surface. The wave front emerging from the pit is practically equivalent to a physical antenna above the ground surface, so that the phenomena of interference between a direct and reflected wave may occur. From the trend of change of path shape with proximity of the antenna to the ground (discussed in section V), the equivalent height of the experimental combination used to set up the landing path of figure 6 was approximately 15 cm.

VII. POLARIZATION OF THE RECEIVED WAVE

A study of the polarization of the electric field corresponding to different positions of the transmitting antenna above the ground surface and above and below the pit surface revealed further evidence of the effect of the ground proximity. It was found that the ratio of vertically to horizontally polarized electric-field component radiated from the horizontal antenna at various azimuth angles on either side of the normal to the length of the antenna was much greater than expected as the antenna was brought close to the ground surface. For the receiving antenna at a distance of 100 m and at a height of 3 m the ordinary theory requires that the ratio be very small because of the very small angles of elevation involved.

Figure 8 shows the data obtained for the transmitting antenna at various heights above the ground surface. Each set of curves on this figure corresponds to a fixed position of the transmitting antenna and shows the relative amplitudes of the horizontally and vertically polarized electric field components as a function of angle (in the horizontal plane) on either side of the normal to the transmitting antenna. The magnitude of the vertically polarized electric field and the rapid increase in the ratio of vertical to horizontal field component as the transmitting antenna is brought closer to the ground are far beyond what would be expected from the plane-wave theory.

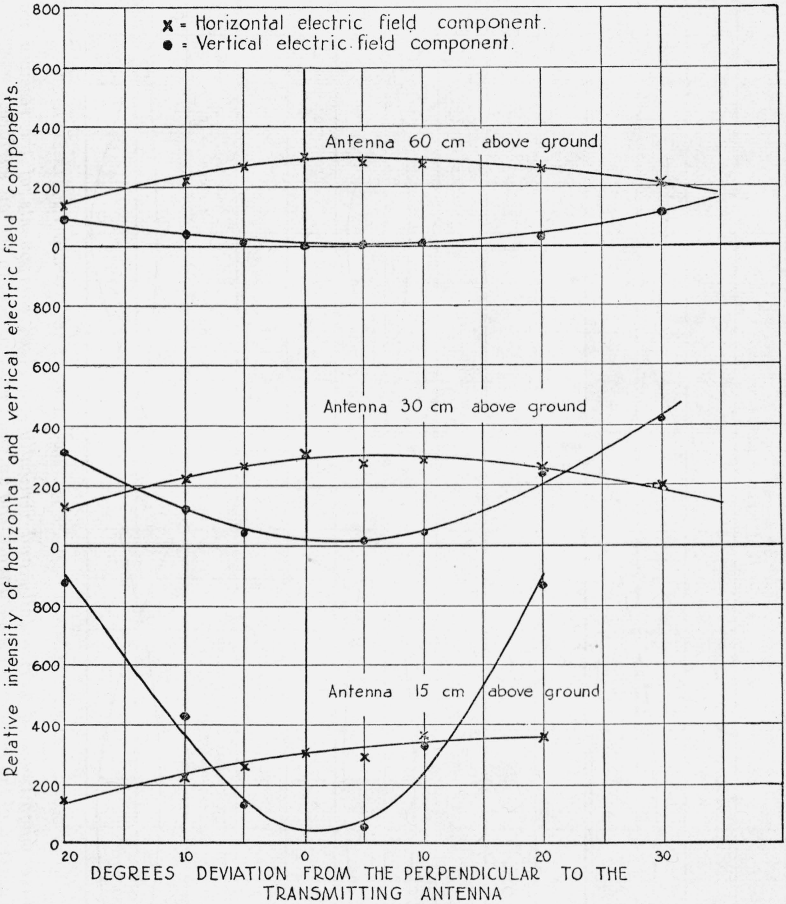

FIGURE 8. *Relative magnitudes of horizontally and vertically polarized components of the received wave as a function of height of transmitting antenna above the ground surface.*

Figure 9 shows similar data for the transmitting antenna at various positions with respect to the surface of a pit approximately one-fourth wave length in depth (80 cm). A study of figure 9 in comparison with figure 8 brings out the following points:

1. For equivalent heights above the pit surface and above actual ground surface, the relative amount of vertically polarized component is considerably lower for the former.

2. The relative amount of vertically polarized component for departures from the normal of ±15° is negligible until the antenna approaches within 60 cm of either the pit or the ground surface.

3. In the case of the experiments with the pit having a depth of one-fourth wave length, the relative amount of vertical component

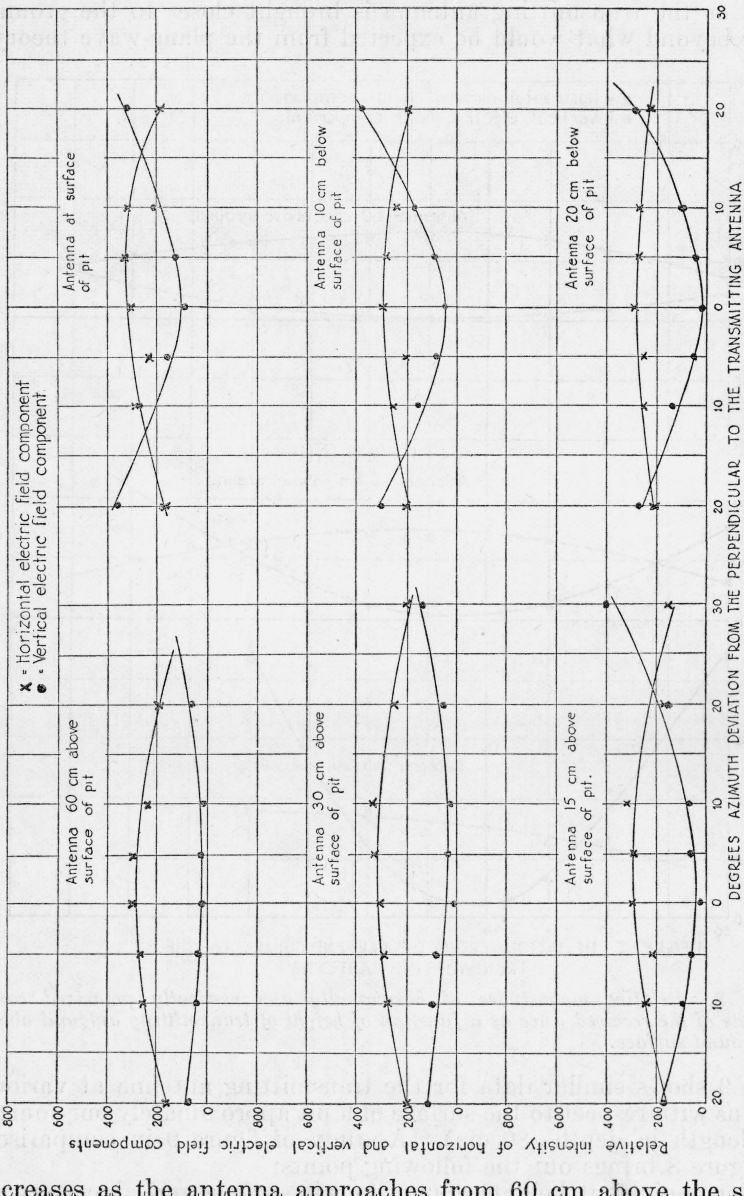

FIGURE 9. *Relative magnitudes of horizontally and vertically polarized components of the received wave as a function of the position of the transmitting antenna with respect to the pit surface.*

increases as the antenna approaches from 60 cm above the surface to the surface and then would appear to decrease gradually as the antenna is brought to 20 cm below the surface.

There was a twofold reason for our interest in the presence of an appreciable vertical component in the radiated field. Firstly, such a component results in a tilt of the plane of polarization of the total electric field, so that tilting of the airplane receiving antenna on either side of its normal horizontal position would result in different readings of the landing path "course" indicator. Secondly, since the vertical component is not useful it represents an actual waste of energy. The first reason does not become important until the ratio of vertical to horizontal component becomes greater than unity for angular departures of less than $\pm 10°$ from the normal direction to the transmitting antenna. A little study will show that this is the case particularly since, in normal use of the landing beam, the transmitting antenna would be oriented at all times perpendicularly to the existing wind direction.

The next test was made to see if the depth of the water level inside or outside the pit would affect the ratio of vertical and horizontal electric-field components. Any variation in this ratio would indicate a transfer of a portion of the total available energy from one component to the other and would therefore result in a change in the landing path, as followed with a receiving set of fixed sensitivity fed from an antenna responsive only to the horizontal component. A series of measurements were made for various conditions of water level inside the pit and in the ground surrounding the pit. To extend the data secured, two depths of pit were used, approximately one-fourth and one-half wave length. The rise and fall of the water level in the surrounding ground was observed to have negligible effect upon the relative amount of vertical and horizontal electric field components. On the other hand, changing the water level and hence the reflecting surface inside the pit was found to have a marked effect upon the relative values of these components.

The results obtained from this series of measurements are correlated in figure 10. The abscissas represent distance in fractions of a wave length between the transmitting antenna and the surface of the water in the pit (or the bottom of the pit, if dry). The ordinates represent the total width in degrees of the sector, substantially at right angles to the length of the transmitting antenna, in which the vertical component is less than the horizontal. This may be termed the effective useful sector of the landing beam. Graph *A* is for the transmitting antenna at the surface of the pit, while graph *B* is for the antenna 20 cm below the pit surface. All of the data obtained for the antenna in these two positions corresponding to both depths of pit used are plotted in figure 10. The graphs show a definite minimum width of useful sector for a height of antenna above the reflecting surface equal to one-fourth wave length and a trend to a maximum width for a height of one-half wave length. This is in agreement with what is normally expected for the case of a transmitting antenna above ground.

Unlike the case for a transmitting antenna above ground, the relative amount of vertical component in the radiated field is very much greater. This is probably attributable to the effect of the proximity of the ground to the high-voltage ends of the transmitting antenna, which may result in the production of a vertical current. There is some experimental basis for believing this to be the case. In some of the tests made, it was observed that varying the position of the antenna below the pit surface and at the same time keeping the effective reflecting surface at a constant distance below the antenna did not result in the same relative amount of vertical component.

The difference in the net proximity effect of the sides of the pit for the various antenna positions may be offered as an explanation of this phenomenon. This effect is indicated by the graphs of figure 10, graph *A* for the antenna at the pit surface showing, on the average, a greater width of useful sector than graph *B*, which corresponds to the antenna at 20 cm below the pit surface.

From the practical point of view, insofar as use of the landing beam transmitting antenna in a pit is concerned, it is possible to provide for an unchanging ratio of the two components by waterproofing the pit. This will result in an unvarying amount of energy in the horizontal electric field (for a given transmitter power) and hence in a fixed landing path.

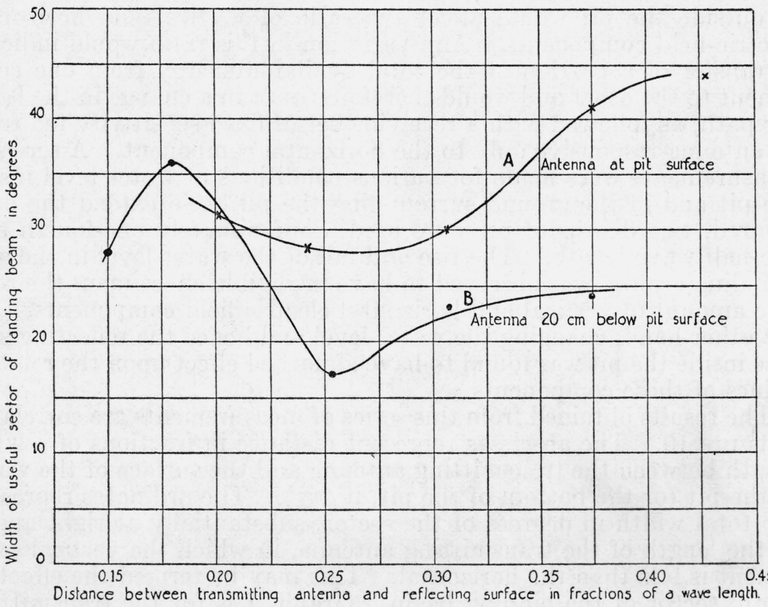

FIGURE 10. *Effect of distance between transmitting antenna and reflecting surface at bottom of pit upon relative magnitudes of horizontal-and vertical-field components.*

Ordinates denote the width of sector, normal to the transmitting antenna, wherein the horizontal component is greater than the vertical.

VIII. CONCLUSIONS

As a result of the various experiments outlined, the following conclusions may be drawn.

A very material increase in the flexibility of use of the landing beam, particularly in providing a suitably steep approach path to large airports, may be obtained through employing a half-wave transmitting antenna located at the center of the airport. The antenna may be a small fraction of a wave length above the ground surface or in a pit below the ground surface. In either case the proximity of the ground to the horizontal transmitting antenna introduces interesting effects upon the electric field radiated.

As the transmitting antenna is brought closer to the ground surface, the shape of a line of constant field intensity in the radiated field (for angles of elevation less than 3 degrees) departs from a parabola, becoming somewhat flatter. The effect appears to be the same for the antenna in a pit as when it is just above the ground surface. This arises from the phenomena involved in the radiation of an electric field from the transmitting antenna located in the pit. The wave front emerging from the pit operates as a large number of new sources which produce direct radiation to the receiving point and also indirect radiation by way of reflection from the ground surface. The two sets of radiation produce an interference pattern very similar to that produced by a transmitting antenna a short distance above ground.

The proximity of the ground to the transmitting antenna also increases the relative amount of vertically polarized electric field in the emitted wave. This effect may be limited through use of the pit. The depth of the pit should be of the order of one-half wave length, corresponding to which the width of useful sector of the landing beam is a maximum. The pit should be waterproofed so that water cannot enter it from the surrounding ground, and thereby change its effective depth. The proximity effect may be further limited by keeping the walls of the pit away from the ends of the transmitting antenna; the minimum cross-sectional dimension should be at least three-fourths of a wave length.

The walls and bottom of the pit may be lined with shielding material in order to render constant the radiation losses to the surrounding ground. The roof of the pit, required for the protection of landing airplanes, must be of a nonconducting material of low dielectric constant to permit of free emergence of the radiated wave.

WASHINGTON, April 7, 1937.