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THEORETICAL CONSIDERATION OF AN IMPROVED GLIDE PATH ANTENNA SYSTEM

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SUMMARY

A discussion of a null-reference transmitting array for defining a glide path is given, wherein the path angle is primarily determined by a null in the vertical radiation pattern of a single antenna located at a relatively great distance above the ground. A modifier antenna is provided to control the path shape near the runway. Either straight line or curved path shapes near the bottom of the path may be produced.

The theory indicates that the path produced by this type of array would be considerably better than that of the present instrument landing system regarding stability under conditions of large snowfall, linearity of indications with deviation from the path, and ease of adjustment of the path shape near contact.

INTRODUCTION

Field experience has shown that the present instrument landing system glide path transmitting antenna array leaves something to be desired regarding the stability of the path when large amounts of snow are present. Also, with the further development of automatic landing equipment, it appears very desirable to be able to flare the path just before contact, and this proves to be cumbersome with the present antenna arrangement.

This report points out one line of attack which may be followed to improve the characteristics of the 330 Mc glide path. The basic method which is proposed involves the use of a reference pattern and a null pattern to determine the path location, rather than amplitude comparison of the patterns from two antennas.

RELATIVE EFFECTS OF LARGE AMOUNTS OF SNOW

In the case of the present ILS glide path, the upper and lower antenna patterns can be approximately represented at low angles in the vertical plane by the formulas

$$F_1 = 0.45 \sin 45\phi \tag{1}$$

$$F_2 = \sin 9\phi \tag{2}$$

where

ϕ is vertical angle, measured in degrees.

If we substitute the value 2.6 degrees for ϕ, F_1 and F_2 have the same value. This is the condition which defines the glide path angle.

The antennas which produce these vertical patterns are, at 330 Mc located at a height above ground of 21.5 feet and 4.3 feet, respectively. Assume there is a snowfall of four feet. The radiation from the lower antenna then substantially vanishes The remaining signal from the upper antenna supplies "fly-up" signal, but there is no glide path

Suppose instead there is a snowfall of two feet. Then the vertical field patterns will become approximately

$$F_1 = 0.45 \sin 45 \frac{19.5}{21.5}\phi = 0.45 \sin 40.8\phi \tag{3}$$

$$F_2 = \sin 9 \frac{2.3}{4.3}\phi = \sin 4.8\phi \tag{4}$$

It is found that the vertical angle at which F_1 and F_2 are equal is approximately 3.5 degrees. Additional points of equality, or false paths, are found near the vertical angle five degrees. No attempt has been made to calculate what happens to path shape near contact under these conditions.

The above considerations are, of course, based on a uniform increase in effective ground height, all other things being equal. In actual cases on an airport with snow-moving equipment scraping the snow into ridges and piles the results are difficult to predict, but probably no less serious.

In the case of the proposed null and reference antenna system, the upper (or null) antenna will be at a height above ground such as to produce a null at the desired path angle, while the reference antenna will be at one-half this height. At 330 Mc, these conditions result in an upper antenna height of 33 feet for a 2.6 degree path angle. The lower antenna would then be 16.5 feet above the ground. The upper antenna will be excited with 90 and 150 cps sidebands from a sideband generator or mechanical modulator of the localizer type. The lower antenna would then be fed with carrier and reference 90 and 150 cps sidebands. In such a system the path angle depends only on the height above effective ground of the upper antenna. Thus, in the case of a two foot snowfall the path angle would change from 2.6 degrees to 33/31 x 2 6 or 2 77 degrees. In the case of the four foot snowfall which would completely destroy the path of the present type system, the path angle of the null and reference antenna system would change from 2.6 degrees to 33/29 x 2.6 or 2.96 degrees. This inherently higher path stability is considered to be one of the advantages of the system.

LINEARITY OF DEVIATION INDICATIONS

In the null-reference system the field patterns for low angles in the vertical plane of the upper and lower antennas respectively can be represented by the formulas

$$F_1 = (1/2) \sin\left(\pi \frac{\phi}{\phi_o}\right) \tag{5}$$

$$F_2 = \sin\left(\frac{\pi}{2} \frac{\phi}{\phi_o}\right) \tag{6}$$

in which,

ϕ_o represents the glide path angle

The amplitude ratio was made 2 1 to simplify the following derivation, but it need not necessarily be exactly so in practice.

The upper and lower beam patterns will be the reference pattern minus and plus the null pattern, respectively.

$$B_U = F_2 - F_1 \tag{7}$$

$$B_L = F_2 + F_1 \tag{8}$$

The magnitude of F_1 does not exceed the magnitude of F_2 at any angle ϕ . Accordingly, the deviation current I, which would flow in the indicator circuit should be approximately given by the formula

$$I = \frac{B_L - B_U}{B_L + B_U} \tag{9}$$

and substituting above expressions for B_U and B_L,

$$I = \frac{F_1}{F_2} \tag{10}$$

$$= \frac{\sin\left(\pi \frac{\phi}{\phi_o}\right)}{2 \sin\left(\frac{\pi}{2} \frac{\phi}{\phi_o}\right)} = \cos\left(\frac{\pi}{2} \frac{\phi}{\phi_o}\right) \tag{11}$$

Thus, it is seen that the deviation current would approximate a cosine function, zero at the path angle, and symmetrical above and below the path. It would be reasonably linear up to deviations from path of one half the path angle, or for a 2.6 degree path, the usable linear region would be plus or minus 1 3 degrees. This represents a considerable increase in width of the linear region over that of the present ILS glide path.

MEANS FOR PRODUCING A DESIRED PATH SHAPE

Let us now assume a two-antenna null-reference antenna as described above, set up 500 feet from a runway and having a 2 1/2 degree path angle This would result in a path of hyperbolic shape, the bottom of the hyperbola being about 22 feet above the runway, directly opposite the antenna system. To keep the signals from the upper and lower antennas in phase with each other all the way down the path under these conditions, it would be necessary to displace the upper antenna 9.8 inches toward the runway There is a possibility that this displacement could be varied to provide path softening near the runway. In order to produce any path shape other than the hyperbola described previously, it will be necessary to add a modifier antenna of some sort. The modifier will be fed sideband energy from the same source which feeds the upper, or null, antenna, but the height above ground of the modifier will be approximately half that of the upper antenna. The horizontal radiation pattern of the modifier should be such that no energy is radiated parallel to the runway This means that the resultant beam patterns will be substantially unmodified, except in the region very close to the airport In directions other than parallel to the runway, however, the modifier radiation will combine with that of the upper antenna to change the vertical angle at which the sideband null, and hence the path, occurs.

To predict the horizontal field pattern of the modifier which will produce a given desired path shape, it is first necessary to find the relation between modifier amplitude and resulting path angle Recalling equation (5) in which the vertical pattern of the upper antenna is given as

$$F_1 = (1/2) \sin\left(\pi \frac{\phi}{\phi_o}\right) \qquad (5)$$

then the vertical pattern of the modifier at one-half the height is

$$F_m = M \sin\left(\frac{\pi}{2} \frac{\phi}{\phi_o}\right) \qquad (12)$$

in which,
M represents the relative modifier amplitude and will be made a function of azimuth angle In azimuths where appreciable modifier energy is radiated, the sideband null and hence the path, will no longer occur at the vertical angle ϕ_o, but rather at an angle ϕ_p, where the combined field pattern of the upper and modifier antennas shows zero energy. This "on path" condition is thus represented by the equation

$$F_1 - F_m = 0 \qquad (13)$$

Substituting the previous relationships provides the desired function which shows the modifier amplitude M necessary to produce a given path angle ϕ_p, as follows

$$(1/2) \sin\left(\pi \frac{\phi_p}{\phi_o}\right) - M \sin\left(\frac{\pi}{2} \frac{\phi_p}{\phi_o}\right) = 0 \qquad (14)$$

from which,

$$M = \frac{(1/2) \sin\left(\pi \frac{\phi_p}{\phi_o}\right)}{\sin\left(\frac{\pi}{2} \frac{\phi_p}{\phi_o}\right)} = \cos\left(\frac{\pi}{2} \frac{\phi_p}{\phi_o}\right) \qquad (15)$$

If the function of path angle ϕ_p with azimuth angle for a desired path shape is known, it is then possible to calculate the required horizontal pattern of the modifier For example, in the case of a straight line path ending at a point of contact directly opposite the trasmitter,

$$\phi_p = \phi_o \cos\theta \qquad (16)$$

in which,
θ is azimuth angle, measured from a line parallel to the runway. Substituting this function for ϕ_p in equation (15) above,

$$M = \cos\left(\frac{\pi}{2} \cos\theta\right) \qquad (17)$$

This is the required horizontal pattern of the modifier in this case and happens to be a pattern which is produced by two in-phase elements, spaced one-half wave length, in a line parallel to the runway This modifier pattern is plotted and labeled Case I in Fig. 1 The straight line path produced by this modifier is plotted and labeled Case I in Fig. 2, together with the unmodified hyperbola, shown dotted for comparison.

Suppose we consider now a more general case wherein there is a straight line path ending on the runway at a point of contact having some azimuth less than 90 degrees with respect to the antenna array. It can be shown that equation (16) above then becomes

$$\phi_p = \frac{\phi_o}{\cos(90° - \theta_c)} \cos(\theta + 90° - \theta_c)$$

$$= \phi_o \frac{\sin(\theta_c - \theta)}{\sin\theta_c} \qquad (18)$$

where,
θ_c is the azimuth of the point of contact. Substituting again in the general modifier equation (15) results in a modifier equation for this case as follows

$$M = \cos\left(\frac{\pi}{2} \frac{\sin\theta_c - \theta}{\sin\theta_c}\right) \qquad (19)$$

which is the pattern of two in-phase elements, spaced $\frac{1}{2\sin\theta_c}$ wave lengths in a line making an angle $(90° - \theta_c)$ with the runway. In particular, if the azimuth of the point of contact θ_c is taken as 45 degrees, then

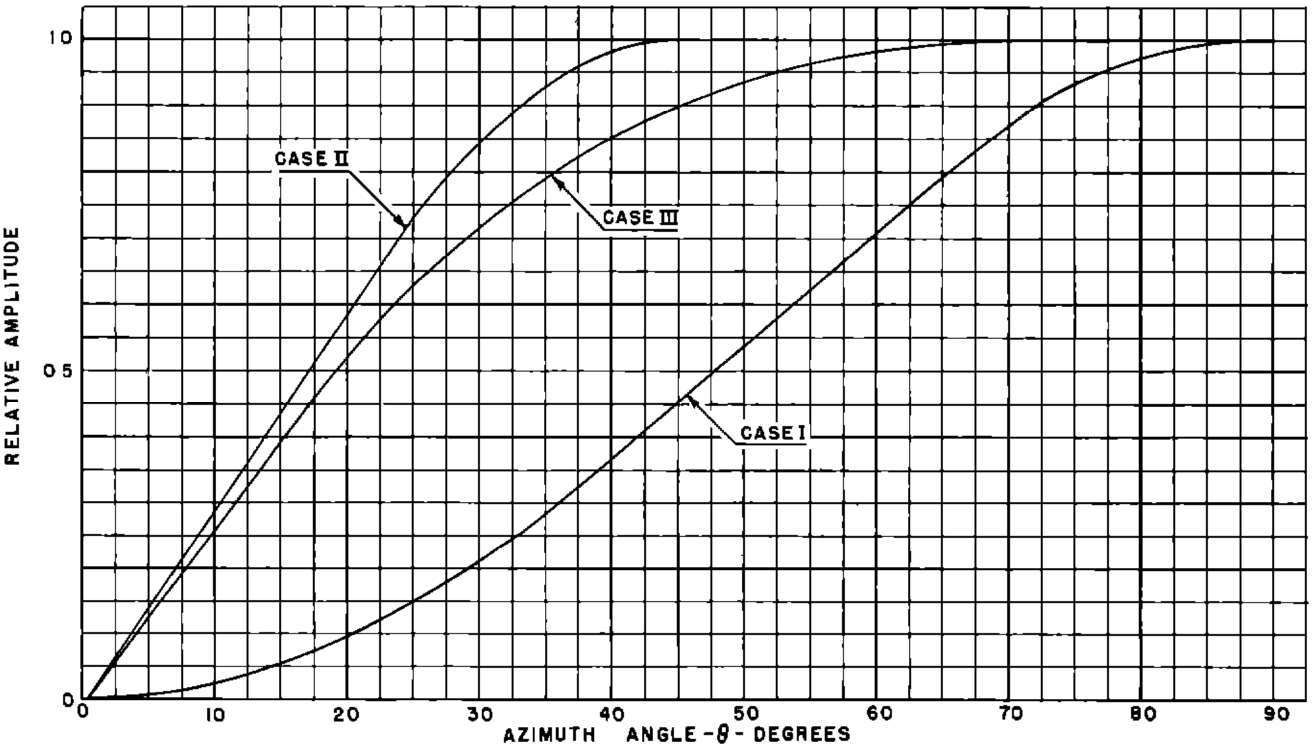

Fig. 1 Possible Modifier Patterns

$$M = \cos\ [127\ 3^\circ \sin(45^\circ - \theta)] \tag{20}$$

The modifier pattern is plotted and labeled Case II in Fig. 1. The straight line path produced by this modifier is plotted and labeled Case II in Fig 2

In the case of curved or flared paths it is a good deal simpler to start with a practical modifier pattern and determine the path shape which would result Empirically, the first choice is the pattern of two out-of-phase elements spaced one-half wave length on a line perpendicular to the runway Thus,

$$M = \sin\left(\frac{\pi}{2}\sin\theta\right) \tag{21}$$

Going backwards to determine the path shape, the first step is to obtain the path angle ϕ_p as a function of azimuth angle from the antenna θ Substituting in equation (15) results in the equation

$$\sin\left(\frac{\pi}{2}\sin\theta\right) = \cos\left(\frac{\pi}{2}\ \frac{\phi_p}{\phi_o}\right) \tag{22}$$

which will simplify to

$$\phi_p = \phi_o\ (1 - \sin\theta) \tag{23}$$

This equation should be compared with equation (16), which is the similar relation between path angle and azimuth angle for a straight path

In order to determine the actual path shape with the above modifier, it is necessary to resort to the geometry of Fig 3 In this figure the origin of coordinates is taken as the point on the runway directly opposite the antenna array. The x-axis is the runway center line, the y-axis is perpendicular to the runway, passing through the base of the antenna array, and the z-axis measures altitude above ground. The desired path equation would then be z as a function of x

The altitude z of any point p on the path at a distance x is given by the equation

$$z = \sqrt{x^2 + b^2}\tan\ \phi_p \tag{24}$$

in which,

b is the distance between the runway center line and the antenna array.

Combining equations (23) and (24)

$$z = \sqrt{x^2 + b^2}\tan\ [\phi_o(1 - \sin\theta)] \tag{25}$$

but,

$$\sin\ \theta = \frac{b}{\sqrt{x^2 + b^2}} \tag{26}$$

therefore,

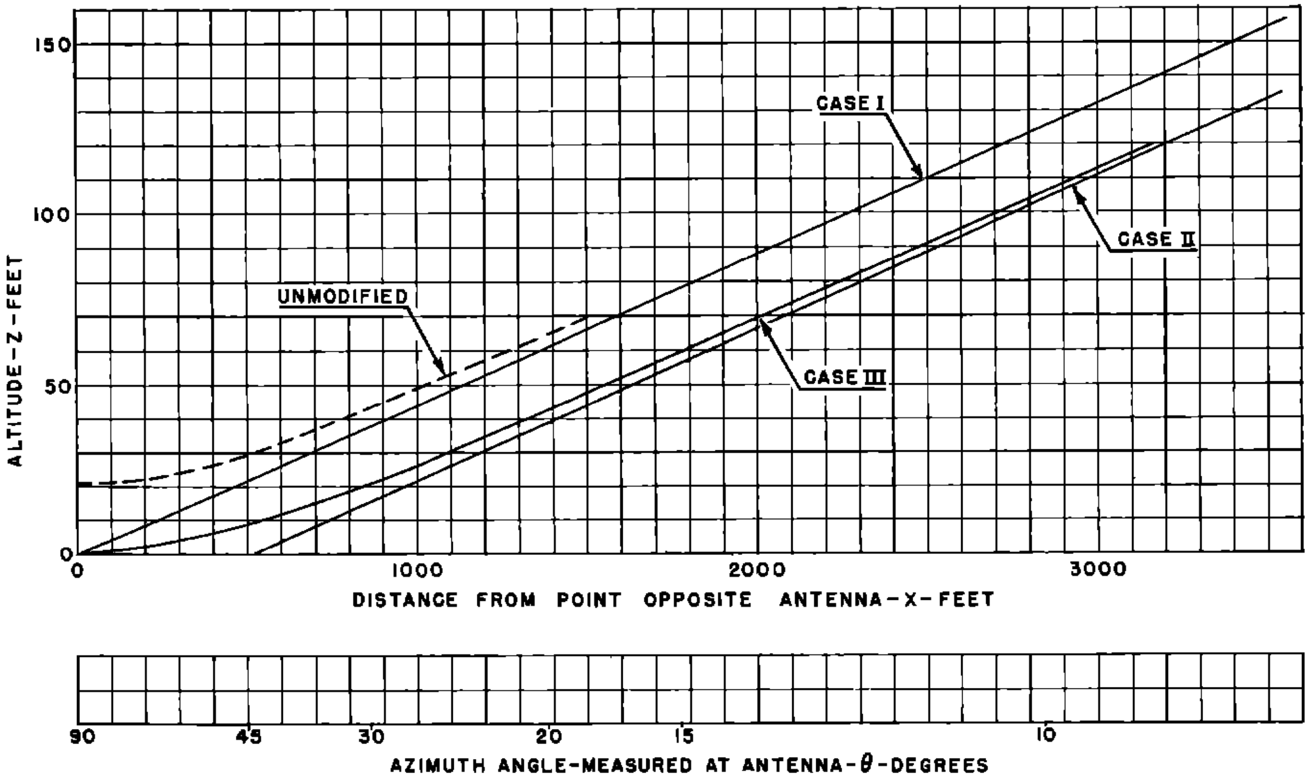

Fig. 2 Possible Path Shapes

$$z = \sqrt{x^2 + b^2}\ \tan\left[\phi_o\left(1 - \frac{b}{\sqrt{x^2 + b^2}}\right)\right] \quad (27)$$

The angle $\phi_o\left(1 - \frac{b}{\sqrt{x^2 + b^2}}\right)$ will always be quite small, in fact less than ϕ_o. Accordingly, the angle may be substituted for the tangent of the angle

$$z = \sqrt{x^2 + b^2}\ \frac{\pi\,\phi_o}{180}\left(1 - \frac{b}{\sqrt{x^2 + b^2}}\right)$$

$$= \phi_o\ \frac{\pi}{180}\ \left(\sqrt{x^2 + b^2} - b\right) \quad (28)$$

This is the equation of the path and is shown plotted and labeled Case III in Fig 2. The modifier pattern, equation (21), which would produce this path is shown plotted and labeled Case III in Fig. 1.

The path defined by equation (28) bears a striking resemblance to the unmodified hyperbolic path. It is, in fact, that same path moved vertically downwards to tangency with the runway. This fact can be demonstrated by arranging equation (28) in the normal form for a hyperbola. Substituting k for the quantity $\phi_o\,\frac{\pi}{180}$, equation (28) can be re-written as

$$\frac{(z + kb)^2}{(kb)^2} - \frac{x^2}{b^2} = 1 \quad (29)$$

A LIMITATION OF THE METHOD

There is a limitation common to all glide paths produced by radiation from an off-set transmitting antenna. The shapes of such paths are determined by the intersection of the vertical runway plane with a surface formed by the radiation pattern of the transmitting array. This latter surface is necessarily composed of straight line elements passing through the base of the transmitting array. This means, in effect, that one cannot do anything to the shape of the glide path without at the same time changing the manner in which the height of the path varies as the airplane maneuvers on the localizer to the left or right of the course. In general, the farther out from the transmitter one attempts to control the shape of the path, the worse would seem to be the effects of this limitation.

This matter can be illustrated by reference to the three cases above calculated. In Case I, where the glide path surface is a

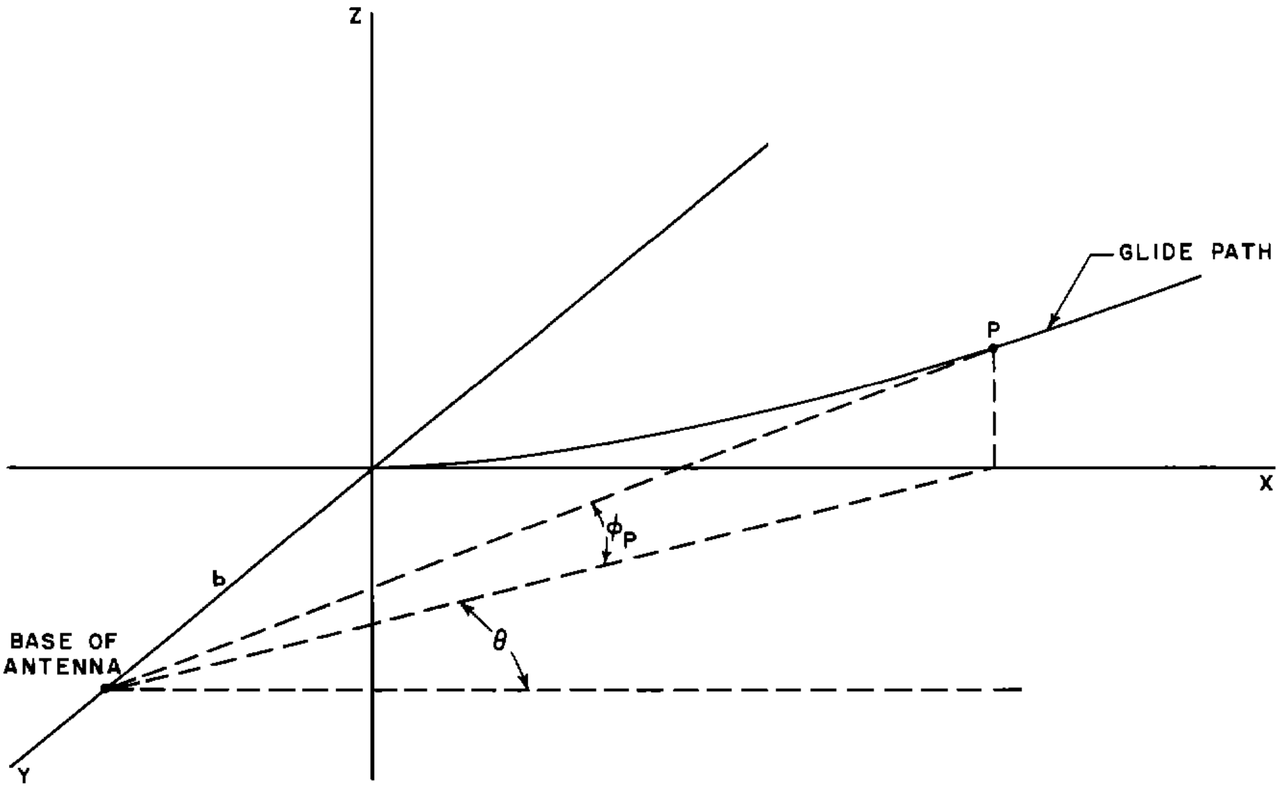

Fig. 3 Geometry of the Path Shape

plane, intersecting the ground along a line perpendicular to the runway, there is no change in path height for deviations to the left and right of the localizer. This is ideal. However, in Case II and Case III, it can be seen from Fig. 2 that if one departs from the localizer course to the extent of, for example, ten degrees azimuth angle measured from the glide path transmitter, the height of the glide path changes by about 16 percent. This amount of variation is not considered excessive. It would probably become excessive, however, if one attempted to push the point of contact out 1000 feet or more in front of the transmitter.

CONCLUSIONS

From the foregoing considerations, it appears that for the cost of seven or eight feet of extra mast height it is possible to have a glide path which contains several advantages over the present type. First, the stability of the path angle in changing weather conditions is almost certain to be superior Second, the usable linear width of the path is about twice as great Third, the method offers a relatively flexible means for adjusting the bottom of the path to have a desired flare just before contact which should prove valuable in the development of an automatic landing system.

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