DEVELOPMENT OF A VHF DIRECTIONAL LOCALIZER PARTS I AND II

PART I
PRELIMINARY TESTS

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PART II
THE MONITOR

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TECHNICAL DEVELOPMENT REPORT No 183

Prepared for
The Air Navigation Development Board
Under
Project 9 1
By
CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT AND
EVALUATION CENTER
INDIANAPOLIS INDIANA

May 1954

U S DEPARTMENT OF COMMERCE
Sinclair Weeks, Secretary

CIVIL AERONAUTICS ADMINISTRATION
F B Lee, Administrator
D M Stuart, Director, Technical Development and Evaluation Center

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PART I

PRELIMINARY TESTS

FOREWORD

The Air Navigation Development Board (ANDB) was established by the Departments of Defense and Commerce in 1948 to carry out a unified development program aimed at meeting the stated operational requirements of the common military/civil air navigation and traffic control system This project, sponsored and financed by the ANDB is a part of that program The ANDB is located within the administrative framework of the Civil Aeronautics Administration for housekeeping purposes only Persons desiring to communicate with ANDB should address the Executive Secretary, Air Navigation Development Board, Civil Aeronautics Administration, W-9, Washington 25, D C

SUMMARY

Progress is outlined in the development of a localizer having greater freedom from siting effects Without sacrificing any operational characteristics, it has been found possible to build at a given site a localizer which will produce a substantially straighter course than the present conventional eight-loop localizer produces Three alternative directional arrays for accomplishing the purpose are described together with the means for feeding and monitoring these antennas

INTRODUCTION

The development of a very-high-frequency (VHF) directional localizer was initiated at the Technical Development and Evaluation Center of the Civil Aeronautics Administration in September 1947 With the establishment of the Air Navigation Development Board in 1948, the project was given additional support under their sponsorship The objective of the project was to develop an improved localizer which would concentrate most of the radiated energy in a narrow sector of azimuth along the runway center line This was to be done without necessitating any changes in aircraft receiving equipment and without requiring any departure from piloting techniques normally employed when using the instrument landing system (ILS)

The main reason for the development was to improve the conventional localizers which are essentially nondirective in the azimuthal distribution of total energy radiation [1,2,3] Perhaps the chief concern of the field engineer installing a conventional localizer is in properly catering to the site sensitiveness of the facility Reflections from natural and man-made objects surrounding the site produce scalloping and course bending of readily calculable periods Charts and formulae exist which relate such a period to the perpendicular distance of the reflecting object from the localizer course [4] This often allows the source of particularly offending reflections to be identified, but it is seldom practical to remove the object In some cases, the reflection amplitudes are sufficiently large to affect seriously the "flyability" of the localizer course

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[1] Sidney Pickles, "Army Air Forces' Portable Instrument Landing System," Electrical Communications, Vol 22, No 4, 1945

[2] Peter Caporale, "The CAA Instrument Landing System," Electronics, February and March 1945

[3] R A Hampshire and B V Thompson, "ILS-2 Instrument Landing Equipment," Electrical Communications, Vol 27, No 2, June 1950

[4] Charles S Franklin, "Instrument Landing Tables," ARL Memorandum Report No 172, Aircraft Radio Laboratory, Wright Field, Dayton, Ohio, June 15, 1944

In such cases it is necessary either to choose another site, a procedure which has definite limitations if a particular runway is to be served by ILS, or it is necessary to modify the antenna patterns of the localizer in such a way that less signal is radiated in the direction of the reflecting objects If the troublesome objects are located behind the localizer, much good can be done with simple back screens of various types At least one standard type of localizer has been constructed in quantity with a built-in ratio of front-to-back radiation [5] To modify the localizer antenna patterns, the use of large screens made of wire has received much attention, particularly by Pickles [6]

Undoubtedly, the case with which it is most difficult to deal is that of large reflecting objects located in front of the localizer and at only a small angle from the course Unfortunately, such cases are not rare They sometimes take the form of a row of hangars near the approach end of the runway and, to make matters worse, often have large surfaces parallel to the runway, in which case extreme directivity in the localizer would be desirable

The foremost thought in this project was the achievement of a localizer design, not unduly complicated, which would produce a flyable course at almost any site that might be encountered

Another reason for the development of the directional localizer was to improve the behavior of automatic approach equipment It is well understood that precision and stability in automatic approach are compromised by the necessity of reducing undesired responses to course bending [7,8,9,10] A substantial improvement in the quality of localizer courses would allow the adoption of values for the automatic approach control parameters and would mean smoother and more accurate performance Recognition of this fact is evident in the current efforts of the Radio Technical Commission for Aeronautics (RTCA), Special Committee 18 on Automatic Flight Control, to arrive at a set of tolerances for the characteristics of ILS ground facilities, including localizer course bends

DESIGN OF A LOCALIZER ANTENNA

In the design of a localizer antenna, there are a number of requirements which are imposed by the nature of the service and by the characteristics of related air navigation components Among these are the following

1. The operating frequency is in the range 108 to 112 Mc, which give a wavelength of about nine feet
2. The polarization must be horizontal with a high degree of purity
3. The vertical dimension of the antenna should be small, preferably less than one wavelength
4. The stability of the radiation patterns must be high, with minimum effects from the weather
5. The construction should be such that installation is simple and maintenance is relatively inexpensive

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[5] "Handbook of Maintenance Instructions for Radio Set AN/CRN-10," U S Army Air Force Technical Order AN16-30 CRN 10-3.

[6] Sidney Pickles, "Use of Screens for Reduction of Localizer Siting Requirements," Technical Memorandum No 96, Federal Telecommunication Laboratories, Inc , October 1946

[7] Francis L Moseley and Chester B. Watts, Jr , "Automatic Radio Flight Control," Proceedings of the National Electronics Conference, October 1946

[8] Paul A Noxon, "Flight Path Control," Aeronautical Engineering Review, August 1948

[9] Chester B Watts, Jr , and Logan E Setzer, "Some Recent Developments in Radio-Controlled Flight and Landing," CAA Technical Development Report No 118, July 1950

[10] David L Markusen, "Flight Path Control," Proceedings of the National Electronics Conference, Vol VI, September 1950

It is horizontal directivity which is required in the directional localizer, and this cannot be obtained without a correspondingly large horizontal aperture However, the limitation on the vertical dimension appears to rule out some otherwise attractive antenna types such as the wire-curtain lens described by Kock,[11] as well as paraboloid reflectors of usual proportions.[12]

THE PARABOLIC ANTENNA

In view of the various requirements, it was decided to try what may be termed a parabolic strip antenna which is illustrated in Fig 1 The reflector, otherwise known as a parabola, has the form of a narrow strip of a parabolic cylinder and physically looks like a curved metal fence Since the strip width, designated as height h, is relatively small (approximately one wavelength), the source of radiation must be placed close to the reflector in order to avoid having an excessive amount of radiation escaping over the top This results in a configuration which has the source deeply buried in the parabola, that is, the depth d of the reflector is substantially greater than the focal length f Even so, for large values of aperture a, the distance from the source to the end portions of the reflector is also large, with the result that some diffraction over the reflector is inevitable

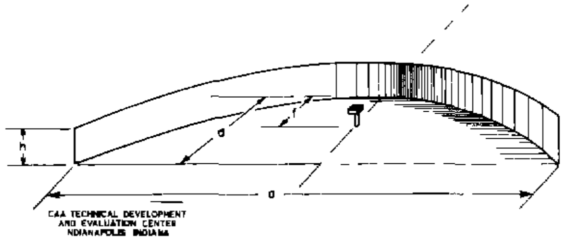

Fig 1 Parabolic Strip Antenna

The arrangement appeared to offer promise with regard to stability, simplicity of construction, and cost of maintenance The problem was to find the optimum values for height, aperture, and focal length and to determine the nature of the source which would best illuminate the reflector Unfortunately, no applicable theory was available which did not involve intolerable approximations, therefore the problem had to be attacked by empirical methods

MEASURING FIELD PATTERNS

It was necessary to arrange means to observe and to record the azimuth field distribution of experimental antennas Because of the appreciable phase error which is due to proximity and which is present with large-aperture arrays, it was usually impractical to make pattern measurements on the ground except in a narrow sector directly in front of the antenna In order to be able to carry the field meter around an unobstructed circle of sufficient radius to yield the true pattern, it was necessary to make test flights Accurate measurements of ground antenna patterns are difficult to obtain while in flight, the primary difficulty being to avoid the introduction of large spurious signal variations due to changes in attitude of the airplane The use of the conventional V-type receiving antenna for field strength measurements was found unsatisfactory in this respect. However, a number of satisfactory patterns were obtained when the V-type antenna was used and when the plane was flown in a circle of 20-mile radius around the localizer. The effect of making the radius so large was to spread out the ground pattern so that it could be easily distinguished from the spurious variations due to attitude changes Thus it was possible to eliminate by the process of averaging out the spurious changes and to obtain an acceptable pattern of the experimental antenna. The method is undesirable because of the excessive time and flying required to obtain one pattern

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[11] Winston E Kock, "Metal-Lens Antennas," Proceedings of the Institute of Radio Engineers, Vol 34, pp. 828-836, November 1946

[12] H T Friis and W D Lewis, "Radar Antennas," The Bell System Technical Journal, Vol. 26, No. 2, April 1947.

A much better antenna for measuring field strength was found to be a quarter-wave antenna trailing on a piece of RG-58/U transmission line about 150 feet behind the airplane The antenna was actually the extension of the inner conductor of the transmission line, and a one-quarter wavelength section of braid was folded back over the line to form a trap to reduce the amount of coupling to the outside of the line A drag cone was attached to keep the trailing cable stretched out in a reasonably straight line behind the airplane The arrangement was successful electrically but was quite a nuisance mechanically

The receiving antenna finally adopted was a half-wave dipole mounted on an 18-inch pedestal over the pilot's compartment of the Douglas DC-3 airplane The dipole was parallel to the longitudinal axis of the airplane With this antenna, it was possible to obtain satisfactory patterns when flying in a circle having a six-mile radius at an altitude that was usually 1,000 feet above the ground

A Type BC-733-D localizer receiver was modified for use as a field-strength meter by disabling the automatic gain control, applying fixed bias, and coupling the diode second detector to a Microsen direct-current (d-c) amplifier and an Esterline-Angus recorder The circuitry was arranged so that the full-scale indication on the recorder always corresponded to about 50 volts across the total diode load This resulted in an almost linear deflection of the recorder pen with changes in the receiver input level, and the pattern could then be conveniently obtained from the chart without reference to a calibration curve

PARABOLA DEVELOPMENT

In the development of the parabolic localizer antenna, various reflector shapes and feed arrangements were tried both at full scale and at tenth scale on the 1,000-Mc model antenna range A typical setup of a model parabolic strip antenna is shown in Fig 2A The signals from the model were received by a horn, shown in Fig 2B, located about 150 feet from the turntable

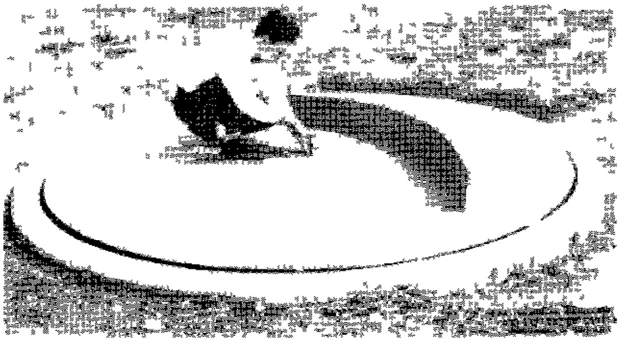


Fig 2A Model Parabolic Antenna on Turntable

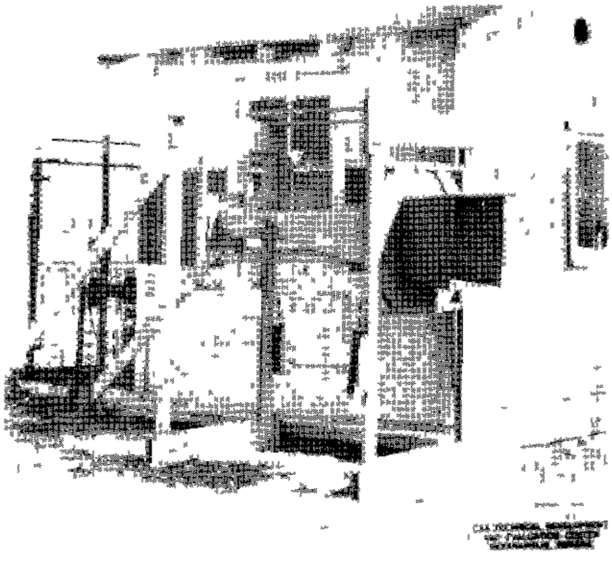


Fig 2B Model Antenna Range Receiving Horn

A full-scale parabola was built at the north end of the north-south runway at the Indianapolis airport This site is characterized by a telegraph line and by railroad tracks running almost perpendicular to the runway center line about 75 feet north of the parabola location The parabola construction utilized wooden poles with horizontal copper wires vertically spaced three inches apart The focal length was 13 5 feet The original aperture of 113 feet was later reduced to 80 feet The height, which was originally 24 feet, was cut to 16 feet and then to 9 feet

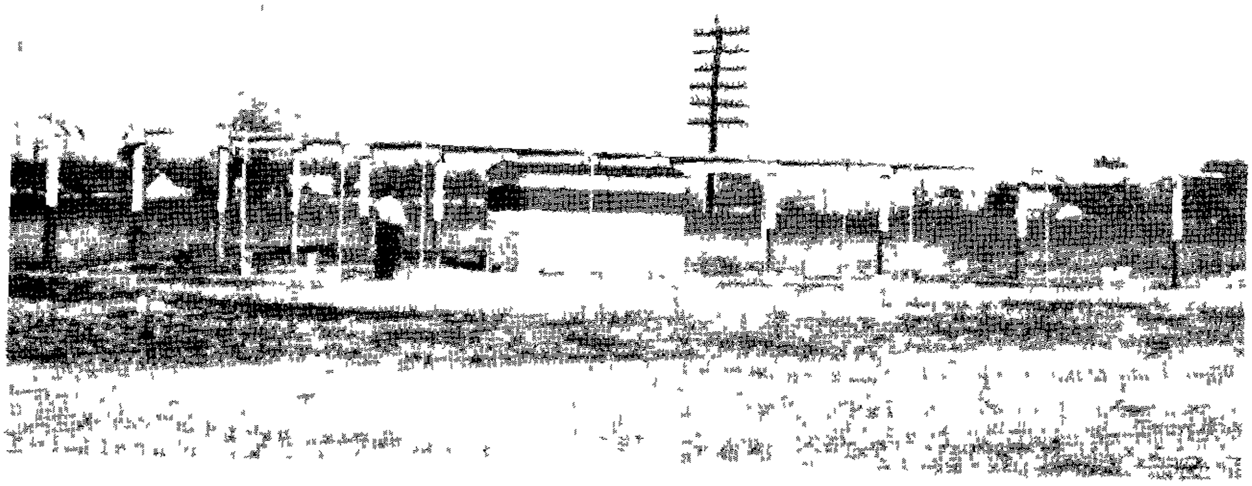


Fig 3A North Parabola Test Site Showing Telegraph Lines

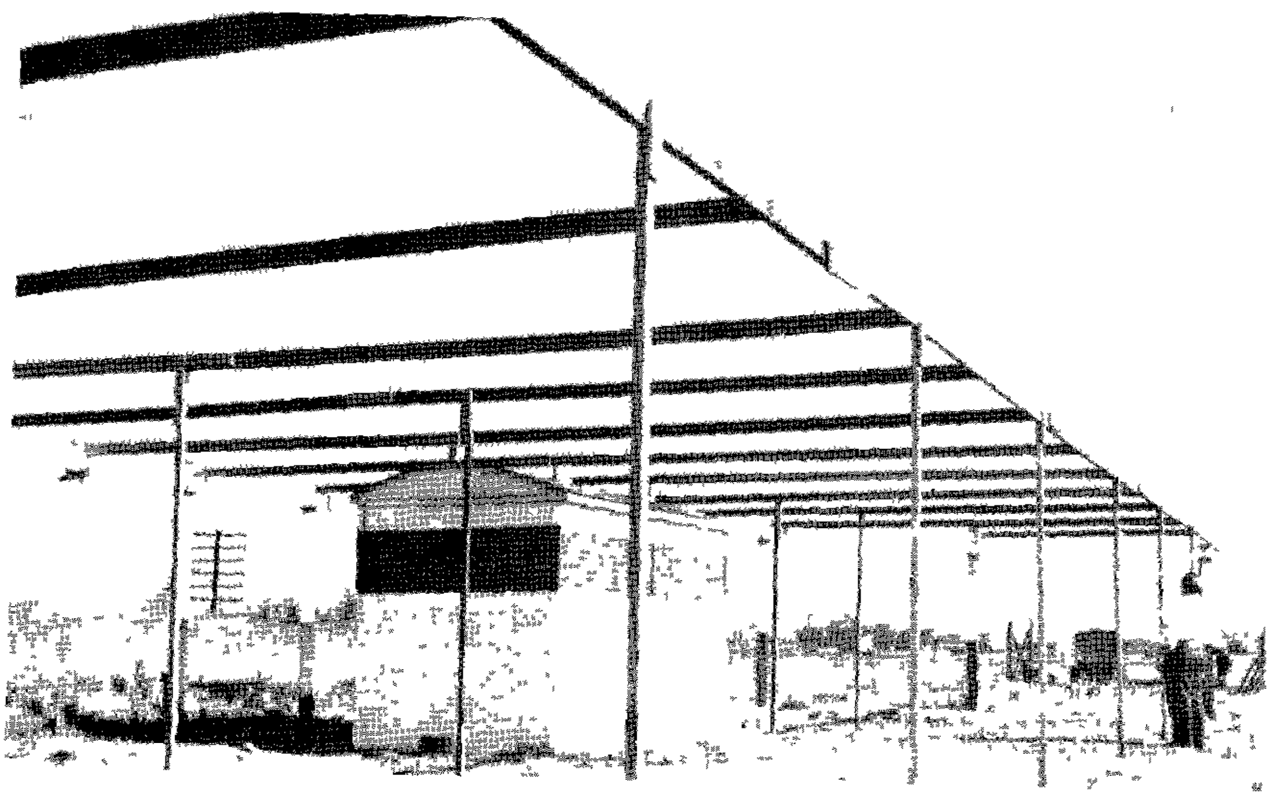


Fig 3B North Parabola With Full Top Screen

At the west end of the east-west runway, another full-scale parabola was built with an aperture of 80 feet, a height of 12 feet, and a focal length of 18 feet. The height was later cut to 7 feet. Both parabolas were tried at the lower heights with a metal screen wholly or partially covering the top. Fig. 3A is a view of the site showing the telegraph line behind the parabola installation, and Fig. 3B is a closeup view of the parabola at a height of 9 feet, with a full top screen.

Various types of radiator elements were investigated as possible energy sources for illuminating the parabola These types included dipole, V-type, and loop antennas used both singly and in phased pairs and also included slotted vertical cylinders of various diameters

It was found to be very important to have a feed arrangement supplying illumination which decreased toward the ends of the parabola Without optimum energy distribution, the minor lobe amplitudes of the field patterns were excessive Feed arrangements which utilized phased pairs of loops were best in this respect Although slotted cylinders which appeared to have proper amplitude distribution of energy were found, they made relatively poor sources for the parabola because of their phase characteristics

The best over-all results were obtained with the 13 5-foot focal length parabola used in combination with phased pairs of loops From the standpoint of antenna patterns, it appeared that the higher the parabola the greater the effectiveness It was necessary to reach a compromise between height and performance The performance of the uncovered parabola at a 16-foot height was about equal to that of the covered one at a 9-foot height It deteriorated only slightly when the cover was trimmed back to form a rim one-quarter wavelength in width Because of the relatively simple and rugged construction which this form permitted, this compromise was adopted as the final arrangement

After determination of the feed system and the form of the parabola, detailed drawings and specifications were prepared for a light metal prefabricated parabolic antenna which would be suitable for transporting by aircraft and for setting up with minimum effort Two such antennas were procured on contract one was to be tested at TDEC, the other was to be supplied to the Department of the Air Force The parabolas were delivered by the contractor in September 1951 Fig 4 shows one of the portable parabolas assembled at the Indianapolis Airport

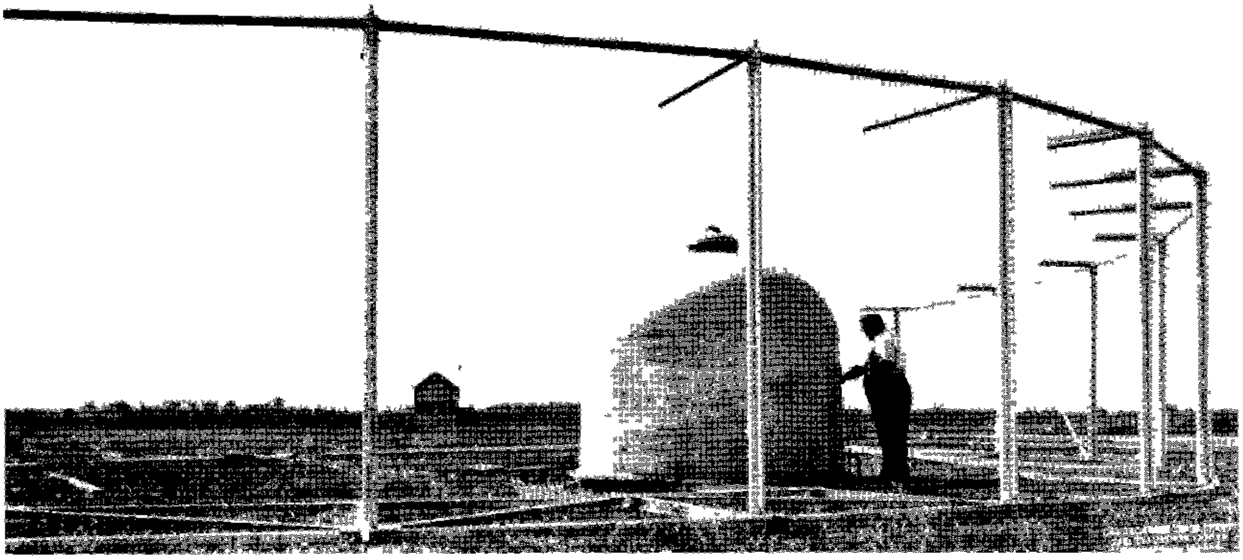


Fig 4 Portable Parabola Assembled for Test at North Localizer Site

The principle dimensions of the antenna are given in Fig 5A The illuminator system consists of four horizontal-loop radiators located at the corners of a 30-inch square and centered on the focal point of the parabola The loops are mounted on pedestals approximately one-half wavelength above ground. Fig 5B shows a schematic diagram of the transmission-line network used to energize the loops Loops designated as A and C are polarized clockwise, B and D are polarized counterclockwise

The operation of the feed system may be explained briefly by referring to Fig 6A The energy for loops A and C, for example, is fed partly at junction x and partly at junction y of the bridge The energy fed at junction x produces inphase excitation of the loops while energy fed at junction y produces antiphase excitation The corresponding radiation patterns are shown in Fig 6B The tie line L has a length which brings the component patterns into phase in the direction of the reflector and results in a total pattern which resembles a cardioid

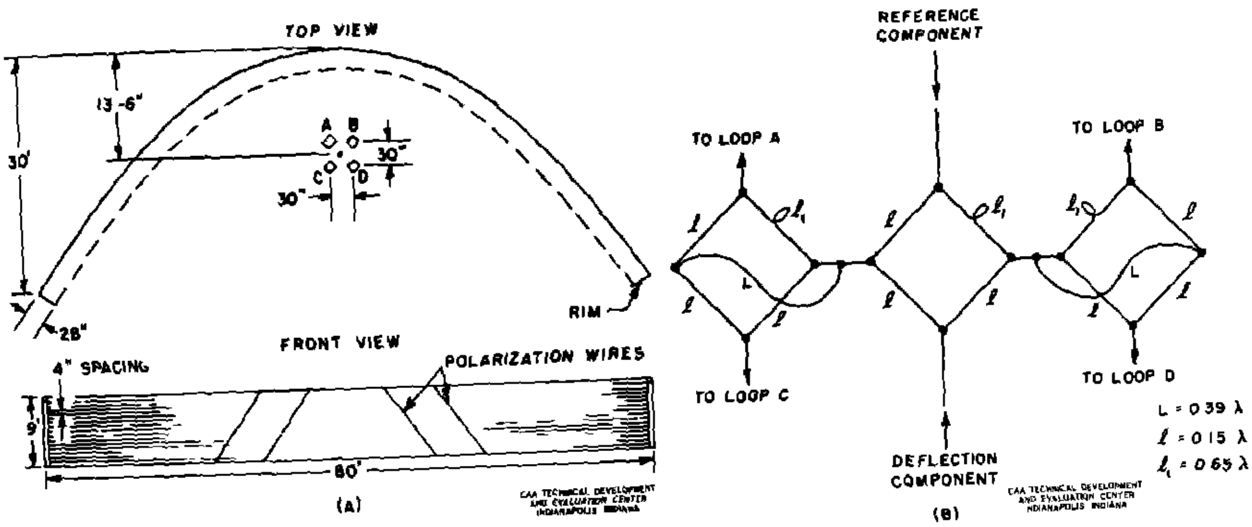


Fig. 5 Parabola Feed System

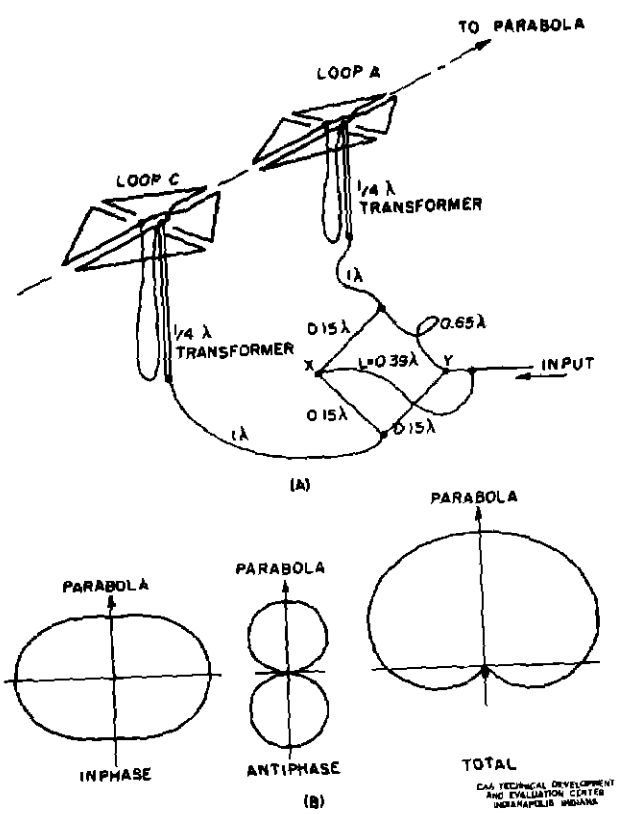


Fig. 6 Composition of Feed Pattern

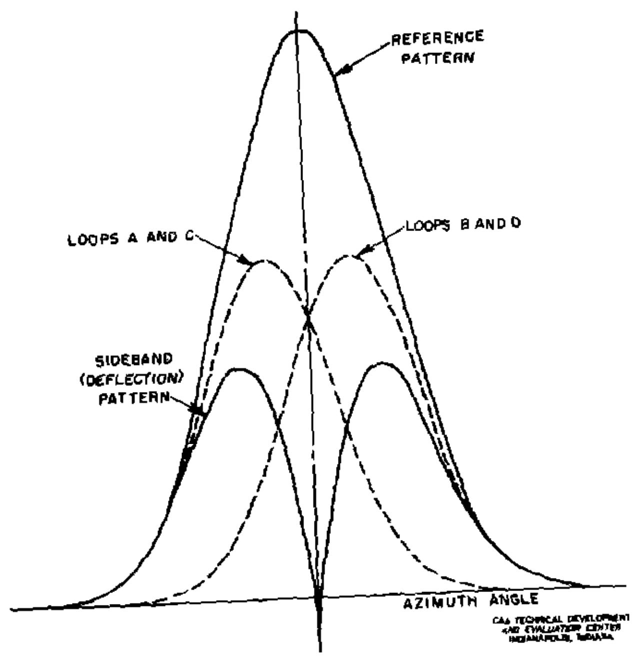


Fig 7 Composition of Parabola Patterns

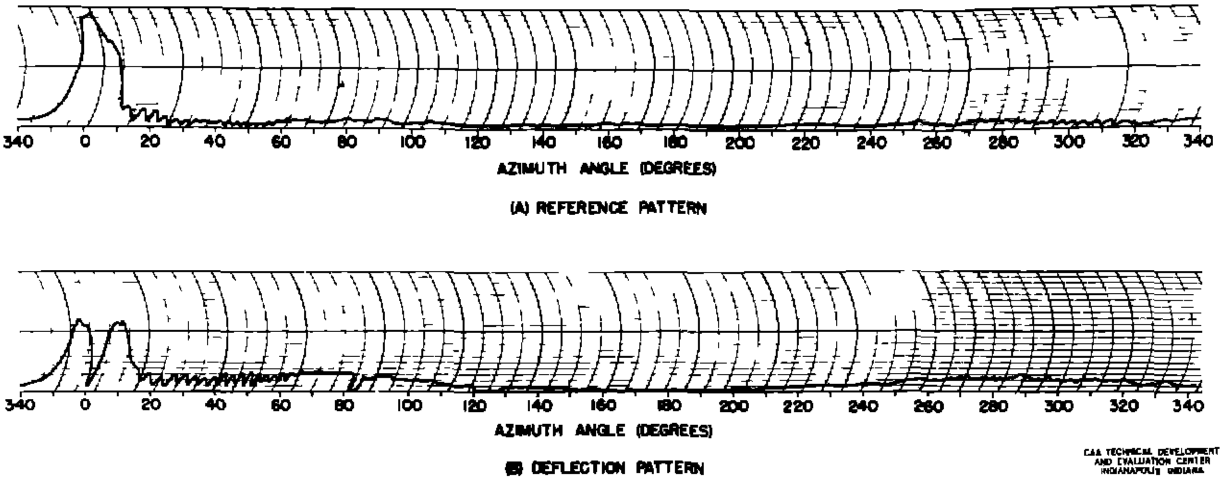


Fig 8 Typical Measured Field Patterns for the Portable Parabola

Thus, the illumination of the parabola tapers toward the ends, a condition which is necessary for low minor lobe level, and relatively little energy is radiated directly from the mouth of the parabola.

Since loops A and C are not located on the axis of the parabola, the reflected beam lies to one side of the center line, as indicated in Fig 7 Likewise, loops B and D produce a reflected beam, the maximum intensity of which lies on the other side of the center line It is the function of the center bridge of the feed network, Fig 5B, to permit simultaneous inphase and antiphase excitation of the left and right beams Inphase excitation of these patterns results in the reference or carrier pattern, while antiphase excitation produces the deflection or sideband pattern Both resultant patterns are shown in Fig 7.

Measured field patterns of the portable parabola are reproduced in Fig. 8 These were obtained with the modified BC-733-D linear field meter at a radius of six miles and at an altitude of 1,000 feet above ground. The effects of the telegraph wires at the rear of the antenna are visible in these patterns as well-defined ripples in regions of optimum reflection angles These patterns were obtained at a carrier frequency of 109.1 Mc, although there was no significant change in pattern shape over the band 108 to 110 Mc

In order to produce a tone localizer course, the feed lines are connected to suitably modulated sources of reference signal E_r and of deflection signal E_d of the usual form

$$E_r = A_r \left\{ 1 + m(\sin \alpha t + \sin \beta t) \right\} \sin \mu t \qquad (1)$$

$$E_d = A_d (\sin \alpha t - \sin \beta t) \sin(\mu t + \phi) \qquad (2)$$

where

A_r = reference-signal amplitude factor

A_d = deflection-signal amplitude factor

ϕ = radio-frequency phase angle

m = modulation index = 0 20, approximately

α = first-tone angular velocity = $2\pi 90$, radians per second

β = second-tone angular velocity = $2\pi 150$, radians per second

μ = carrier angular velocity = 2π (carrier frequency)

A localizer course is produced when the signals are detected by any standard localizer receiver It is customary to adjust the radio-frequency (r-f) phase angle ϕ to minimize the angular width of the course After this is done, the amplitude ratio A_d/A_r is adjusted to bring the course width to the standard value of 5° Fig 9 is a reproduction of a typical recording of course deviation indicator (CDI) current obtained during flights across the main beam of the antenna at a radius of six miles Within the main beam, the recording shows a smooth crossover Outside of the main beam, the CDI moves in an apparently random fashion because of the minor lobes of the radiation pattern Many false courses exist, but the energy level is low in comparison with the energy in the main course Since the false courses have low energy, they are easily suppressed by means of an auxiliary clearance array which will be discussed later

Ranking equal in importance with freedom from bends, an attribute of a good localizer course is absence of attitude effect. A localizer which has no attitude effect will produce an on-course indication at an azimuth angle which does not depend in any way upon the heading, bank, or pitch angles of the airplane It would be ideal if the CDI would respond only to changes in the azimuth angle. The presence of any appreciable attitude effect is a source of confusion and annoyance to the pilot and a cause for poor performance of automatic approach equipment

Attitude effect differs from course bending in that it is not generally considered to be a function of the site, rather, it is a characteristic of the localizer station itself. The effect is produced by radiation of a vertically polarized component of the deflection signal E_d Such a signal may originate as leakage radiation from the transmitter, modulator, or transmission lines, or it may be radiated by the antenna system The effect may be simply explained by reference to Fig 10 This diagram shows space relations only and does not indicate phase or time. Let us suppose the airplane is equipped with a pure plane-polarized horizontal receiving antenna and is flying on-course By definition then, the horizontally polarized component of deflection signal E_d is zero Only reference signal E_r is present by intention. However, when attitude effect exists, there is a vertically polarized component of deflection signal E_d as indicated If the axis of the airplane is horizontal, as indicated by line a to a′, the vertical signal is rejected and the CDI is centered, but, if the pilot banks the airplane, line b to b′, then some of the vertical signal is received and the CDI is deflected erroneously.

This oversimplified explanation cannot be expected to be in very close agreement with observed magnitudes of attitude effect, because the airborne antenna does not behave as a pure plane-polarized receiving system. Furthermore, the magnitude of the CDI deflection depends upon the relative time phase of the received E_r and E_d signals, and the time phase in turn depends upon the characteristics of the receiving system, upon the propagation effects, and upon the phase originating at the localizer station For this reason it is difficult, if not impossible, to make ground measurements which will allow quantitative prediction of the magnitude of attitude effect which will be observed in a given airplane A simple procedure, such as observing the magnitude of the course shift with the tilt of a receiving dipole, is of little value For example, if the vertically polarized deflection signal E_d happens to be in time phase quadrature with the horizontally polarized signal, the tilted dipole test shows zero attitude effect, nevertheless, severe attitude effect may be observed in the airplane This is because the airplane receiving antenna may shift the phase of the vertical signals with respect to the horizontal ones

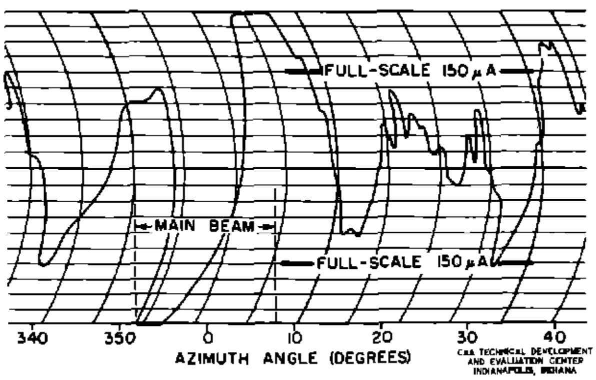


Fig 9 CDI Current in Region of Main Beam of Parabola

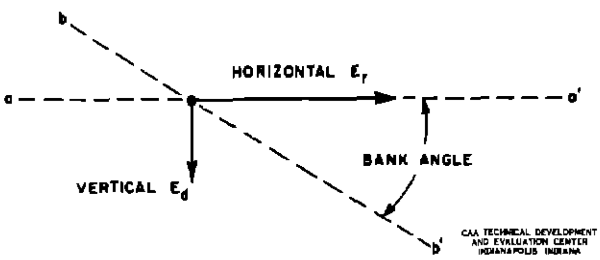


Fig. 10 Attitude Effect

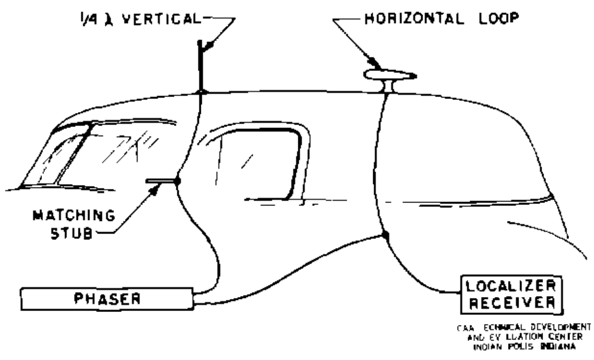


Fig 11 Measurement of Vertical Component

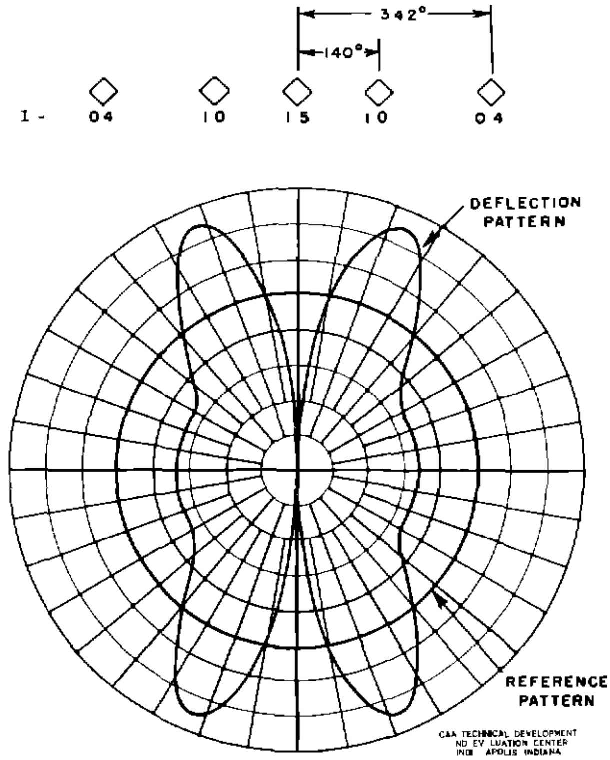


Fig 12 Calculated Patterns of Clearance Array

During the course of the development of the parabolic localizer antenna, it was found that very much attitude effect was present and that production of the vertically polarized deflection signal appeared to be inherent in the parabola Furthermore, the phase of the vertical signal was almost in quadrature with the horizontal signal with the result that the tilted dipole test showed little effect The magnitude of the effect in the airplane was approximately 30 microamperes, or one-fifth scale on the CDI, for a 30° angle of bank

In order to be able to measure the magnitude of vertical radiation of a deflection signal without regard to its phase, the arrangement shown schematically in Fig 11 was employed Through use of separate receiving antennas for horizontally and vertically polarized signals, it was possible to adjust the relative phase to obtain a maximum CDI deflection due to the spurious vertical signal. This deflection could then be taken as a true measure of the magnitude of the vertical signal

When the foregoing method for indicating the magnitude was used, the vertical signal from the parabolic antenna was cancelled by the addition of four inclined wires acting as polarization converters These wires are shown in Fig 5A With the wires in place, the attitude effect in the airplane was reduced to an unmeasurable value.

THE CLEARANCE ARRAY

One of the requirements in the development of the directional localizer was that the system should need no change in existent piloting techniques used with ILS This means that (1) there must be no false courses, (2) full-scale clearance (150 microamperes CDI deflection) must be maintained to the sides, and (3) there must be a back course It appears that these conditions cannot be satisfactorily achieved with the directional array alone.

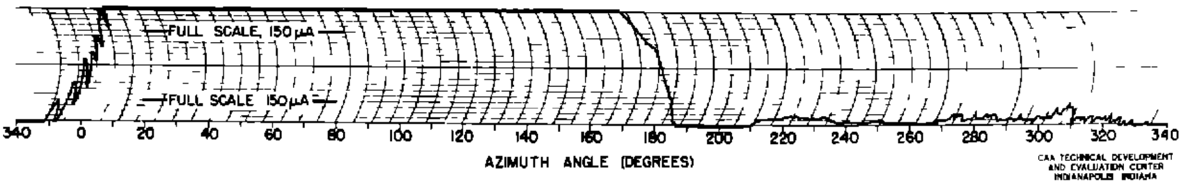


Fig 13 Recording of CDI Current, 6-Mile Radius, Clearance Array Alone At North Localizer Site

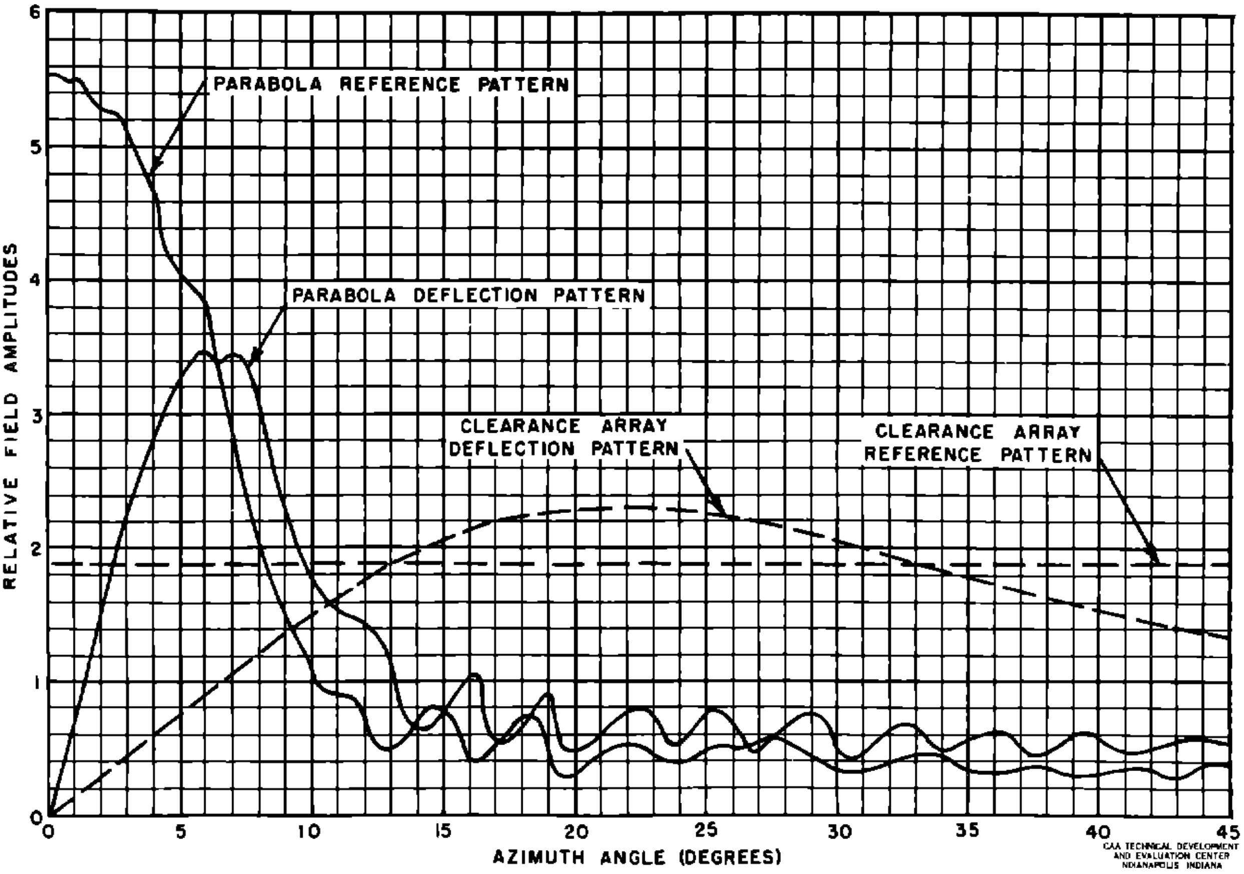


Fig 14 Showing Relations Between Parabola and Clearance-Array Patterns

Early in the development of the parabolic directional antenna, attempts were made to obtain clearance with an auxiliary three-loop array operating on a common carrier frequency The performance of such an arrangement was found to be critically dependent on the relative positions of the two arrays and was generally unsatisfactory because of interference effects

During experiments with the parabola utilizing a two-loop feed, it was found that clearance could be obtained with the directional array alone by phasing the reference and deflection signals properly The effect may be explained as follows the main beams of the deflection and reference patterns were formed primarily by energy which was reflected from the parabola The remaining part of each pattern, outside of the main beams, was formed primarily with energy which diffracted over and around the parabola. Because of this condition, the relative phase of the two patterns was not constant with azimuth but shifted about 90° across the transition into or out of the sector of the main beams Thus, phasing for maximum side clearance resulted in a very broad course or no course at all However, a compromise phase could be found which preserved the course and at the same time gave clearance

This arrangement was tried in an experimental parabolic-antenna installation at Wold-Chamberlain Airport, Minneapolis, Minnesota, during the winter of 1949-50 The method was discarded because (1) course width and clearance were critically dependent on the relative phases of deflection and reference signals to the extent that a special phase monitor had to be installed and (2) since the compromise phase condition in the main beams resulted in a wider course, it was necessary to increase the amplitude of the deflection signal to obtain standard course width. This, in turn, increased the amplitude of deflection signal striking reflecting objects and tended to defeat the objective of the directional localizer

The use of a clearance array operating on a separate carrier frequency was first tested in connection with this project in July 1950 It was found that the difference between the two carrier frequencies is not critical, but they should be high enough to avoid interference with 90-cycle per second (cps), 150-cps, and voice frequencies and yet permit both carrier frequencies to lie within the passband of a receiver tuned to the channel A figure of 8 kilocycles (kc) was adopted as a suitable value for the difference frequency The location of the clearance array is also noncritical and should be chosen primarily from the standpoint of ease in monitoring

The construction, installation, and tuning procedure for a clearance array follows the standard practices associated with a conventional localizer However, the course need not be as sharp as that of the conventional array Only sufficient sharpness is required to develop full-scale CDI deflection at the edges of the sector occupied by the main beams of the directional array Tests on a three-loop clearance array showed insufficient sharpness, but a five-loop array proved to be entirely adequate for use with the directional antennas described in this report The calculated field pattern and the loop spacings for the five-loop clearance array are shown in Fig 12

At the Indianapolis north parabola site, the five-loop clearance array was installed at a point on the center line about 375 feet in front of the mouth of the parabola A typical recording of the CDI current at a six-mile radius, with the clearance array operating alone, is reproduced in Fig 13 It will be noted that severe scalloping, caused by reflections from the telegraph lines in the rear, is present in the region of the front course

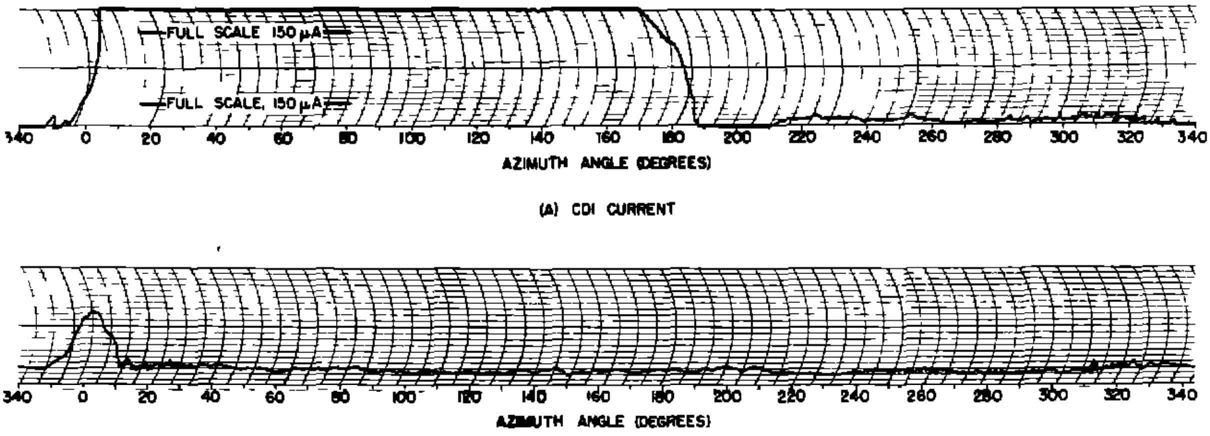
When the clearance array is operated in conjunction with the parabolic directional array, its power level is adjusted to a value sufficient to override safely the minor lobes in the directional patterns, so that full-scale clearance is obtained at the sides This then results in a clearance-array field strength which is approximately one-third that of the main beam of the directional array This situation is illustrated in Fig 14, which shows the field patterns of both arrays based on a common scale

With both arrays in operation, it is apparent that when the airplane is on or near the front course the receiver responds primarily to the signals of the directional array which is designed solely to produce a high quality course When the airplane is outside of the main beam, the receiver responds primarily to the signals of the clearance array However, in each case the discrimination against the lower-level signal is much greater than would at first be suspected from a consideration of the curves of Fig. 14 This is due to the phenomenon called "capture effect," which will be discussed later in some detail.

A recording was made of the CDI current at a six-mile radius at a time when the parabolic directional and clearance arrays were operating simultaneously as a complete localizer. This recording is reproduced in Fig 15A It will be noted in Fig 9 that the smooth main-course crossover due to the parabola was preserved, while the remainder of the record followed the clearance recording of Fig 13 The total field recording, Fig 15B, shows the ratio of parabola field strength to that of the clearance array

CAPTURE EFFECT

Two benefits have accrued as a result of placing the clearance array on a separate carrier frequency First, there is no problem of r-f interference between the arrays, so that the location of the clearance array with relation to that of the directional array is noncritical Second, the discrimination against the weaker signal is increased by capture effect This is more important than the first benefit, because the clearance array with its inherently non-directive distribution of energy would be expected to produce poor quality courses at a poor



(A) CDI CURRENT

(B) TOTAL FIELD STRENGTH

CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

Fig. 15 Recordings for Simultaneous Operation of Parabola and Clearance Arrays

site. Of course, the poor quality front course of the clearance array tends to be suppressed by the higher field strength of the directional array, but this suppression ratio receives a further substantial increase by the effect of capture

The capture effect is a phenomenon existing in the detection of two amplitude-modulated signals of different levels and different carrier frequencies Let us suppose the signals are represented by two vectors of magnitudes X and Y, Fig 16, so that the total signal at any instant is given by

$$e = X \cos \mu t + Y \cos (\mu + p) t \quad (3)$$

in which $\mu/2\pi$ is the carrier frequency of one signal and $p/2\pi$ is the beat frequency, which is relatively small but supersonic Equation (3) can be rewritten

$$e = E \cos (\mu t + \psi), \quad (4)$$

where

$$\psi = \arc\tan \frac{Y \sin pt}{X + Y \cos pt} \quad (5)$$

and

$$E = [X^2 + Y^2 + 2XY \cos pt]^{1/2} \quad (6)$$

The function E (t) is called the beat envelope, and an example of its form is shown plotted in Fig 16 for the particular value of the ratio $Y/X = 0.5$. The amplitudes X and Y are not constant but are modulated by different audio signals at rates which are slow compared with the beat frequency For example

$$X = A (1 + a \sin \alpha t) \quad (7)$$

and

$$Y = B (1 + b \sin \beta t) \quad (8)$$

where

A = carrier amplitude of first signal

B = carrier amplitude of second signal

a = modulation index of first signal

b = modulation index of second signal

α = angular velocity of first-signal modulation

β = angular velocity of second-signal modulation

This results in a slow variation of the form of the beat envelope A perfectly linear envelope detector will faithfully reproduce this form, including the audio-frequency variations The problem then is to calculate the actual amplitudes of the $\alpha/2\pi$ and the $\beta/2\pi$ signals present in the detector output Presumably, this could be done by harmonic analysis of Equation (6)

The general solution of the problem becomes extremely involved. Binomial expansion of Equation (6) results in a complicated series containing many frequencies If we assume the depths of modulation of both signals to be equal, then

$$a = b = 2n \tag{9}$$

Calculating the ratio r of $\beta/2\pi$ amplitude to $\alpha/2\pi$ amplitude, ignoring all other frequencies, and letting

$$\frac{B}{A} = \rho \tag{10}$$

we obtain from the first term of the expansion

$$r = \rho^2, \tag{11}$$

for the first plus the second terms,

$$r = \rho^2 \left[\frac{1 + 3n^2 + \rho^2(2 + 3n^2)}{2 + 3n^2 + \rho^2(1 + 3n^2)}\right], \tag{12}$$

for the first plus second plus third terms,

$$r = \rho^2 \left[\frac{2 + 40n^2 + 17n^4 + \rho^2(9 + 36n^2 + 44n^4) + \rho^4(4 + 20n^2 + 15n^4)}{4 + 20n^2 + 15n^4 + \rho^2(9 + 36n^2 + 44n^4) + \rho^4(2 + 40n^2 + 17n^4)}\right] \tag{13}$$

and continuing indefinitely From this it can be deduced that, for the special case where n and are both small,

$$r = \frac{1}{2}\rho^2, \text{ for } n \ll 1, \rho \ll 1 \tag{14}$$

In the application of capture effect to the directional localizer, we might tolerate the limitation on modulation depth, but the signal ratio takes many values, including unity. In such a situation there is no simple formula for capture effect

Butterworth has presented for this case a solution based on elliptic integrals [13] Butterworth's work has been verified (except for numerical errors) by Aiken in another treatment of a similar situation [14] Data obtained by Butterworth is given in Table I with numerical errors corrected.

[13] S Butterworth, "Note on the Apparent Demodulation of a Weak Station by a Stronger One," The Wireless Engineer and Experimental Wireless, Vol. VI, No 74, November 1929

[14] Charles B Aiken, "Theory of the Detection of Two Modulated Waves by a Linear Rectifier," Proceedings of the Institute of Radio Engineers, Vol 21, No. 4, pp 601-629, April 1933

ρ	r
0.1	0.0050
0.2	0.0202
0.3	0.0466
0.4	0.0852
0.5	0.138
0.6	0.210
0.7	0.306
0.8	0.437
0.9	0.630
1.0	1.000

Table I

Relationship of ρ and r

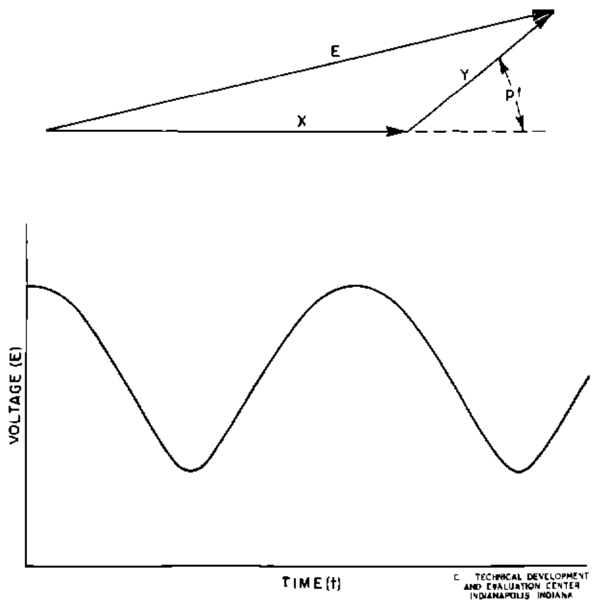


Fig. 16 On Capture Effect

It should be pointed out that if a square-law detector is employed, the capture effect is expressed simply by Equation (11). Since the capture effect is a function of the detector characteristic, we can expect very much variation between receivers. Measured capture-effect curves obtained in the laboratory for two typical localizer receivers are shown in Fig. 17.

TRANSMITTER AND MODULATION EQUIPMENT

Transmitters for directional-localizer use are conventional, except that two are required, and some care must be taken to insure a stable beat frequency. A sufficiently stabilized beat frequency can be readily obtained by the use of a pair of properly ground crystals in a common oven. For example, for the operating channel 109.1 Mc the crystal frequencies used were 6061.333 kc and 6060.888 kc. When multiplied by 18, these values gave carrier frequencies equally spaced 4,000 cps above and below the nominal center frequency of the channel. A separate exciter unit was constructed containing the dual-crystal oven, the two oscillator circuits, and an identification code wheel with a 1,020-cps oscillator. The dual-crystal oven is illustrated in Fig. 18.

A block diagram of the arrangement of transmitters and modulating equipment is given in Fig. 19. The Type TUQ transmitters have an unmodulated output of about 50 watts. These transmitters include provision for voice modulation.

Directional-localizer tests were conducted with both electronic sideband generators and mechanical modulators for producing 90 and 150 cps. Since one of the important parameters of a directional localizer is the ratio of the radiated field strengths produced by the directional and clearance arrays, it is very desirable to be able to adjust the total field from one array. If mechanical modulation is used, this adjustment can be accomplished simply by variation of the transmitter-output coupling. However, with electronic modulation, a power change requires many adjustments. For this reason mechanical modulators are preferred. In these tests there were used two military Type MRN-1 mechanical modulators which had been modified to accomodate inputs and outputs to RG-8/U transmission line at both input and output. In the region of the transition into or out of the main beam, the signal amplitudes from the directional and clearance arrays are comparable. If the relative phases of the two sets of 90- and 150-cps tones are such that they will cause cancellation, a low clearance dip is observed in this region. It is important to prevent this occurence by tying the phases together so that the tones are additive. This was done by a mechanical coupling between the modulators. Similar precautions should be observed in connection with the voice and 1,020-cps identification modulations At the terminals of the modulator output bridge, this arrangement provides about 17 watts of reference signal and 0 7 watt of deflection signal These figures are for the usual condition of 20 per cent modulation of each tone in the reference signal The reason for the relatively low output compared with the unmodulated capability of the Type TUQ transmitter is the downward nature which is characteristic of the modulation of mechanical modulators

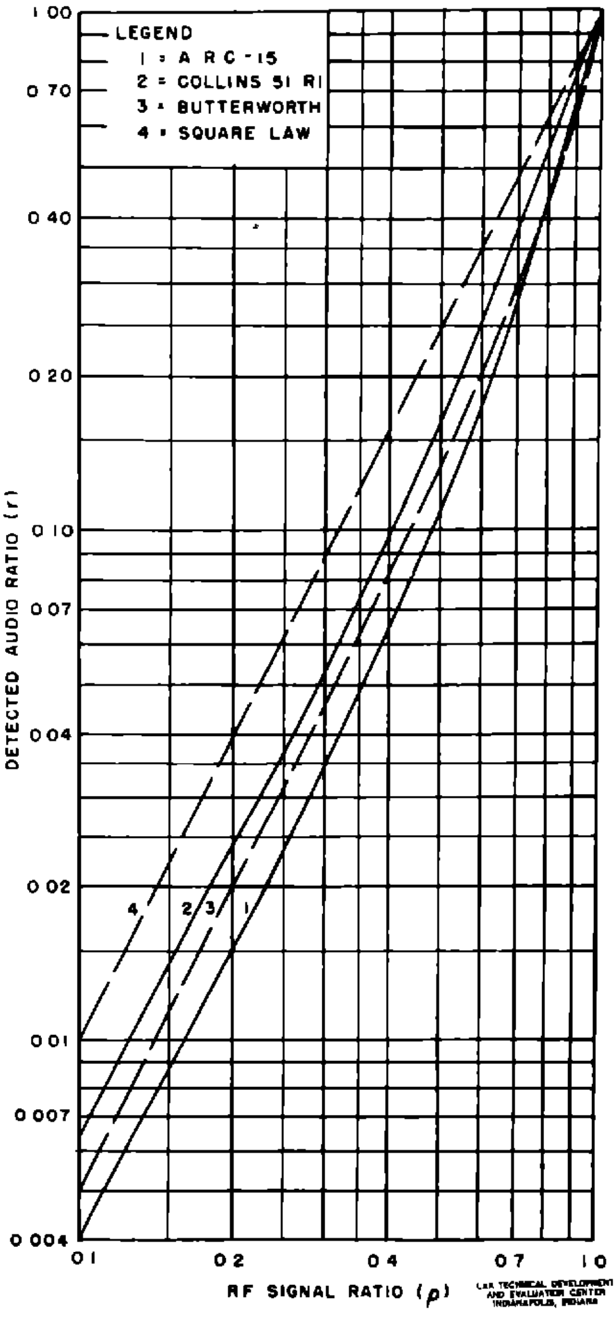


Fig. 17 Measured Capture Effect Using Typical Localizer Receivers

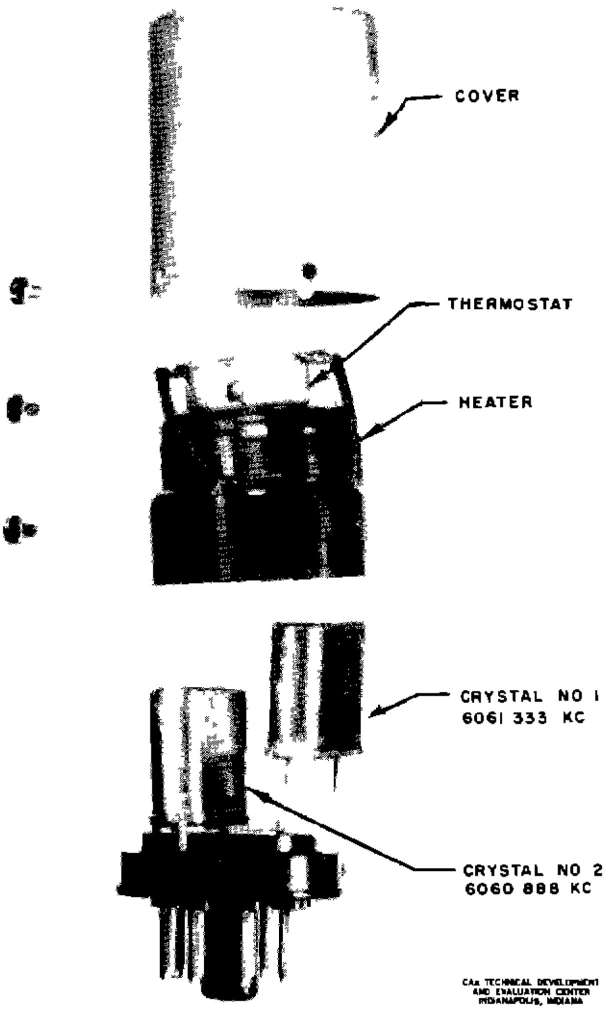


Fig. 18 Dual-Crystal Oven

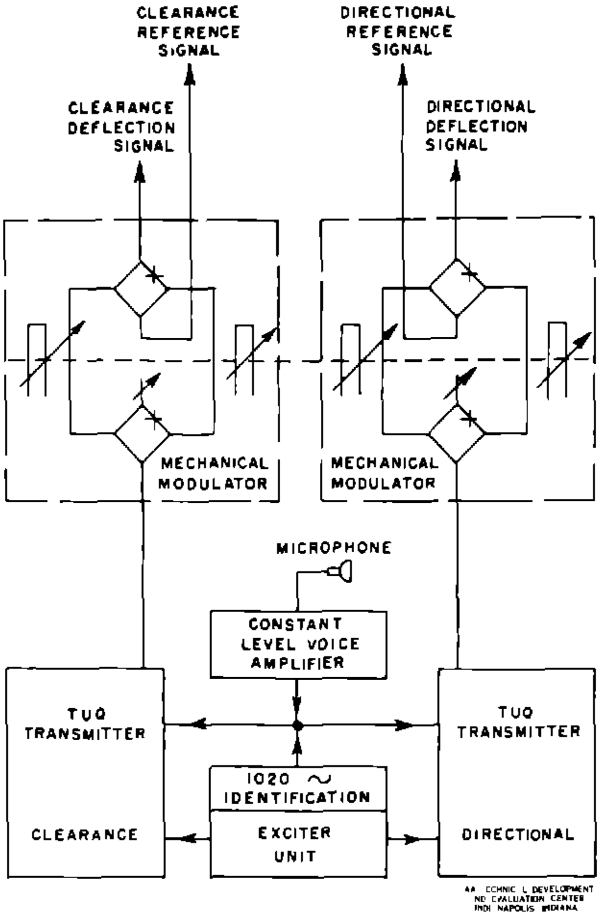


Fig 19 Block Diagram, Transmitter and Modulation Equipment

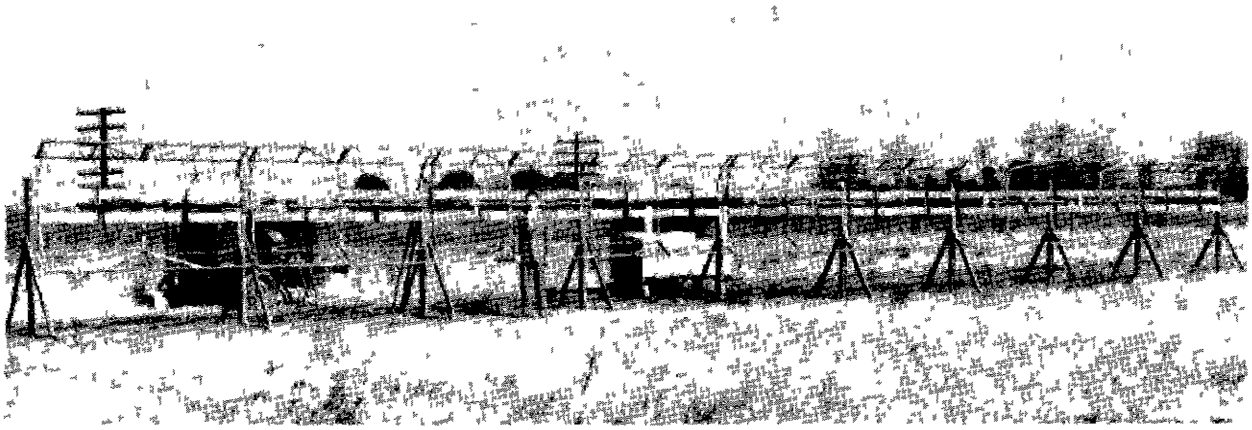


Fig 20 Alford Linear Dipole Array Assembled for Test at North Localizer Site

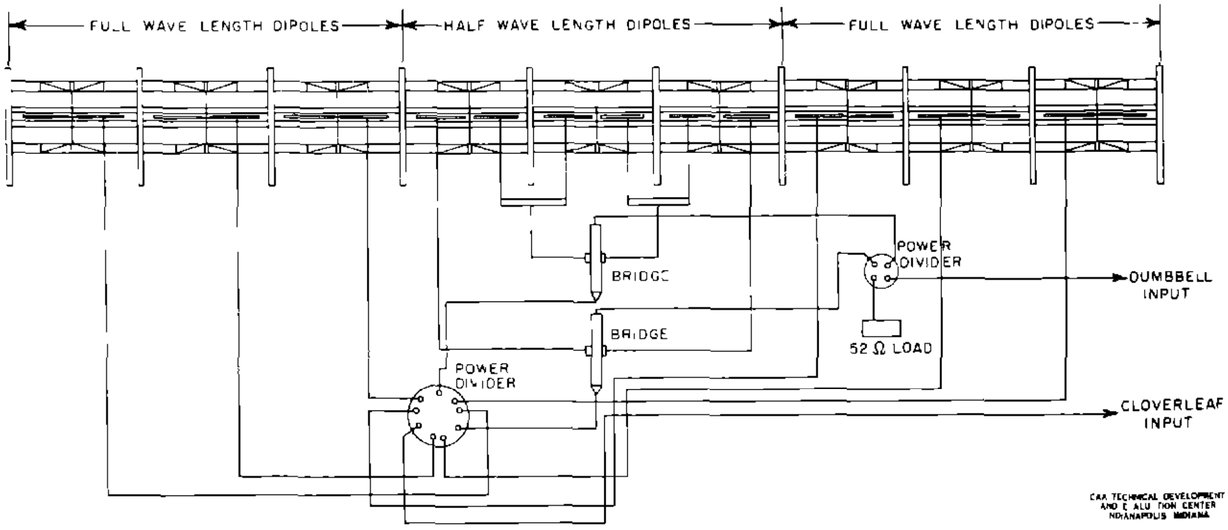


Fig 21 Feed System for Alford Linear Dipole Array

The voice and identification levels are adjusted to modulate each transmitter approximately 50 and 5 per cent, respectively. Some cross modulation of voice and identification sidebands with the 90- and 150-cps tones necessarily occurs in the mechanical modulators. However, with 20 per cent tone modulation, the cross-modulation products are not large and the voice and identification quality is very good

A LINEAR ARRAY OF DIPOLES

At an ANDB-sponsored meeting held at TDEC in July 1950, it was decided that a linear-dipole array designed for directional-localizer service should be tested and compared with the parabolic antenna at Indianapolis A linear array having an aperture of about 40 feet had previously been supplied by Andrew Alford to the Aircraft Radio Laboratory at Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. In order to increase the aperture to a value at least as great as that of the parabola, TDEC purchased additional elements and feeding network from Alford. The complete antenna was assembled at the Indianapolis north localizer site in November 1950, and it is shown in Fig 20. The aperture of the array is 88 feet, and the feed network is housed in the wooden box at the center rear. Fig. 21 shows schematically the feeding arrangement.

In contrast to the parabola development, it was possible for the designer of the linear-dipole array to calculate readily the radiation patterns of the antenna and to expect reasonable agreement with measurements. This was, in fact, the case. Measured reference-and deflection-array patterns obtained in the usual way at a six-mile radius are shown in Fig 22. It will be noted that the deflection pattern is much superior to that of the parabola, Fig 8, with regard to the level of minor lobes. However, the reference pattern is broader. When the array was energized as a localizer, the CDI recording reproduced in Fig 23 was obtained. A test for attitude effect showed none measurable in the airplane The vertical component measured on the ground was extremely small.

When the combination of the linear array and the clearance array was operated, some difficulty was experienced with clearance in the transition region. This difficulty was attributed to the relatively wide reference pattern of the linear array, which situation tended to prevent the clearance array from capturing the receiver. A recording of CDI current for the linear array operated with the same clearance array that was used with the parabola is shown in Fig. 24A, which indicates the regions of marginal clearance on each side of the course. The relative level of the clearance array is shown by the total-field-strength recording, Fig. 24B.

It should be pointed out that by the addition of one or more bridges in the feed network, it would have been possible to feed a reference signal into a greater number of the elements. This would have resulted in a sharper reference pattern.

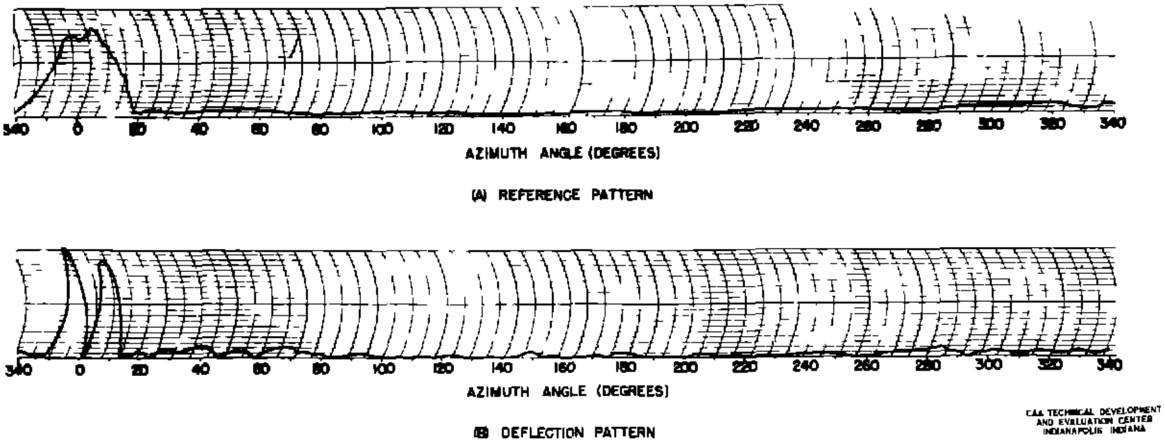


Fig. 22 Measured Field Patterns for Alford Linear-Dipole Array

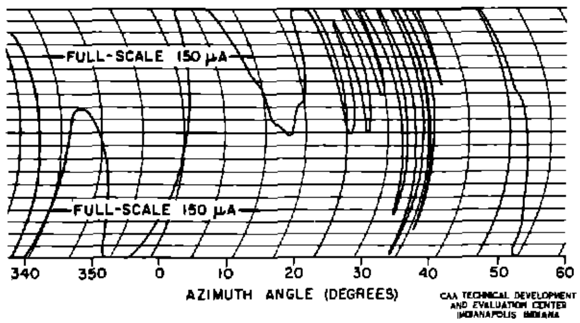


Fig. 23 CDI Current in Region of Main Beam, Linear Array Alone

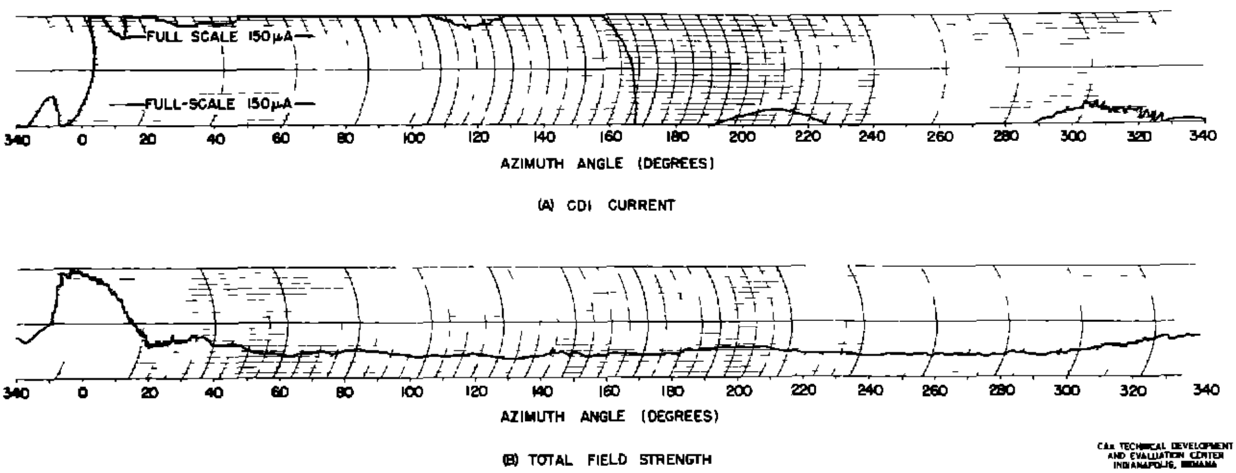


Fig 24 Recordings for Simultaneous Operation of Linear and Clearance Arrays

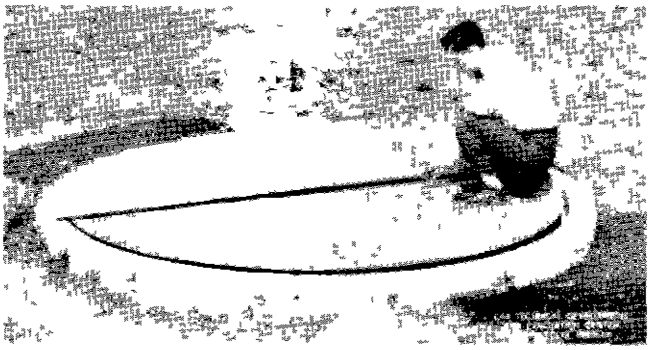


Fig 25 Model Slotted-Waveguide Array on Turntable

In addition to its ability to produce high quality radiation patterns, the linear array has the particular military advantages of being broadband and relatively portable

THE SLOTTED-WAVEGUIDE ARRAY

In order to retain the advantages of a linear array and at the same time to obtain a simple feed system, it was decided early in 1951 to investigate the possibilities of a slotted-waveguide array The first step was to construct and test 1/10-scale models utilizing the two types of feed arrangement described in a previous report [15] The end-feed arrangement was preferred to the center-feed because of the possibility that a low minor-lobe level would be obtained in both reference and deflection patterns

A model of an end-fed slotted-waveguide array, placed on the turntable for pattern measurements, is shown in Fig 25 The model was constructed of 4- by 8-inch aluminum heating duct Although comparatively crude, the model performed sufficiently well to encourage construction of a full-scale antenna

Fabrication of the full-scale waveguide was carried out on contract by Tarpenning-LaFollette Company, Indianapolis, Indiana, utilizing techniques normally employed in the construction of large air-conditioning ducts The material used was galvanized sheet iron, and

[15] Chester B Watts, Jr , "Some Considerations of Wide Aperture Localizer Antennas," CAA Technical Development Report No 155, January 1952

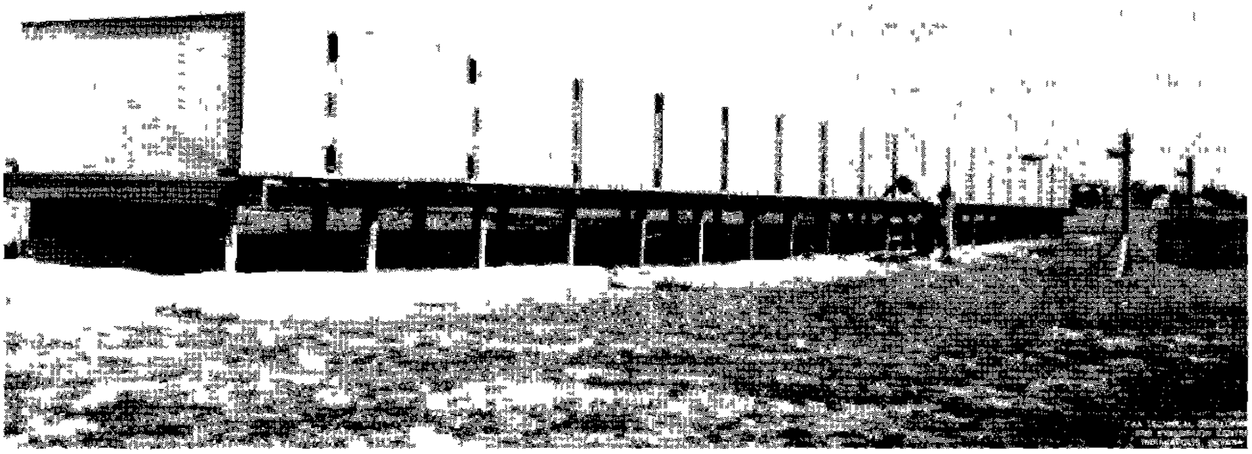


Fig 26 Slotted-Waveguide Array at North Localizer Site

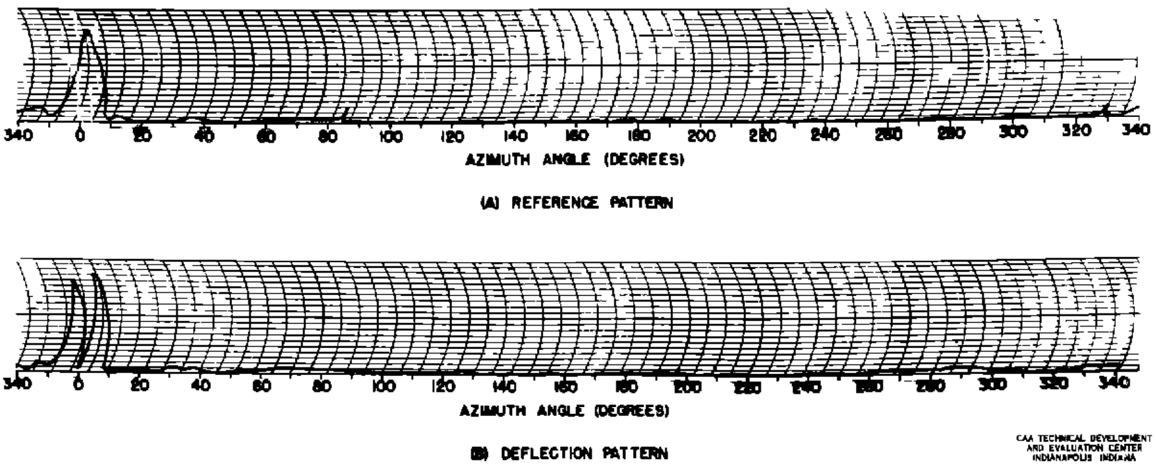


Fig. 27 Measured Field Patterns for Full-Scale Slotted Waveguide at North Localizer Site

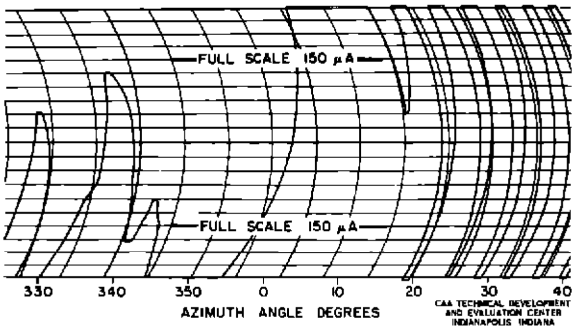


Fig. 28 CDI Current in Region of Main Beam,
Slotted-Waveguide Array Alone

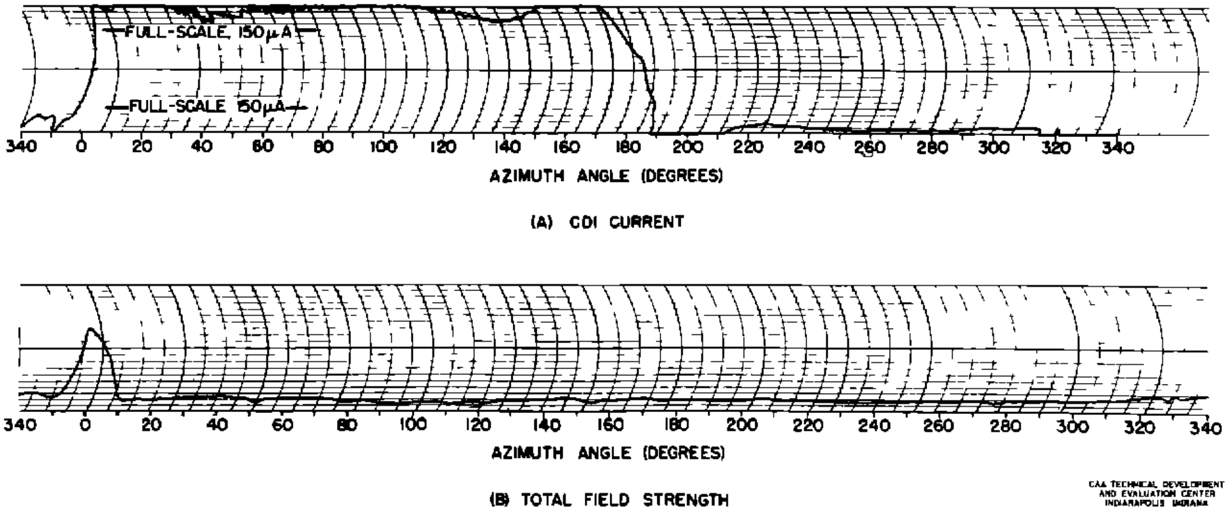


Fig. 29 Recordings for Simultaneous Operation of Slotted-Waveguide and Clearance Arrays

the dimensions were 3 1/2 by 7 by 105 feet The assembly operation was completed in one week, utilizing approximately 90 man-hours of labor The feed probes were constructed and installed later by TDEC personnel There are 18 probe-fed slots spaced slightly less than 0 5 guide wavelength or about 0 7 free-space wavelength apart.[16] A view of the completed array is shown in Fig 26

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[16] J E. Eaton, L J Eyges, and G G Macfarlane, "Linear-Array Antennas and Feeds," Chapter 9, pp 299-301, Microwave Antenna Theory and Design, edited by Samuel Silver, published by McGraw-Hill, 1949

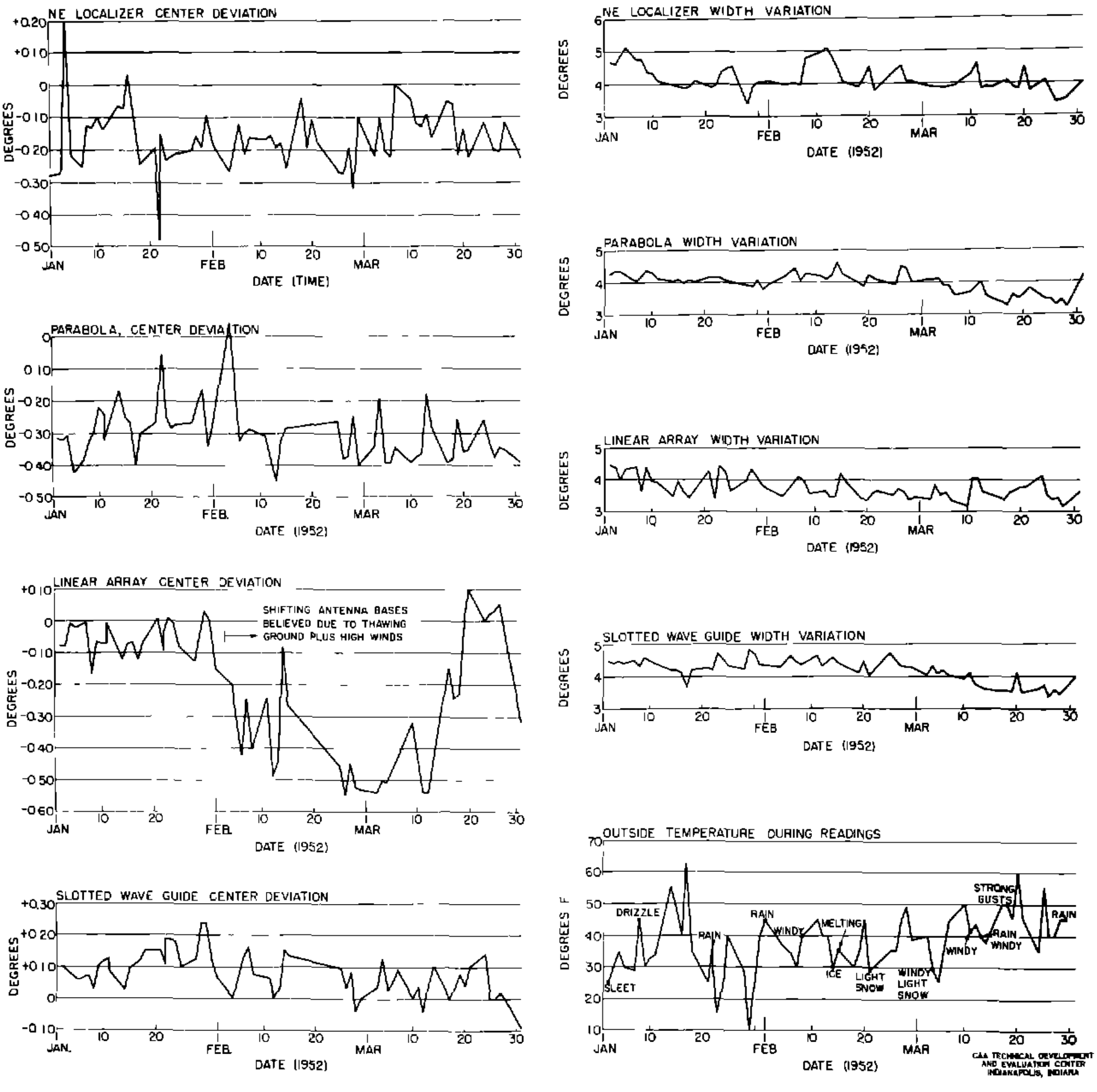

Fig 30 Results of Instrument-Truck Measurements of Course Position and Width During Months of January, February, and March 1952

Typical reference and deflection patterns for the slotted-waveguide array are shown in Fig 27 A recording was made of the CDI current when in the region of the main beam and while the waveguide array was operating alone This recording is reproduced in Fig 28 Like the linear-dipole array, the waveguide array showed no measurable attitude effect in the airplane, while ground measurements showed that a negligibly small vertical component of radiation was present

Operation of the combination of the slotted waveguide with the clearance array resulted in the recordings of Fig 29 It is noteworthy in this case that the clearance array is operated at a considerably lower level with respect to the main beam This is possible because of the low side-lobe amplitude of the waveguide patterns and because of the more nearly optimum relation between the beam widths of the waveguide reference and deflection patterns.

The slotted-waveguide array in its present form is not an inherently broadband antenna It can only be operated over a range of approximately 1 0 Mc without significant deterioration of pattern shape Larger frequency changes require either a corresponding change in basic dimensions or the introduction of loading devices

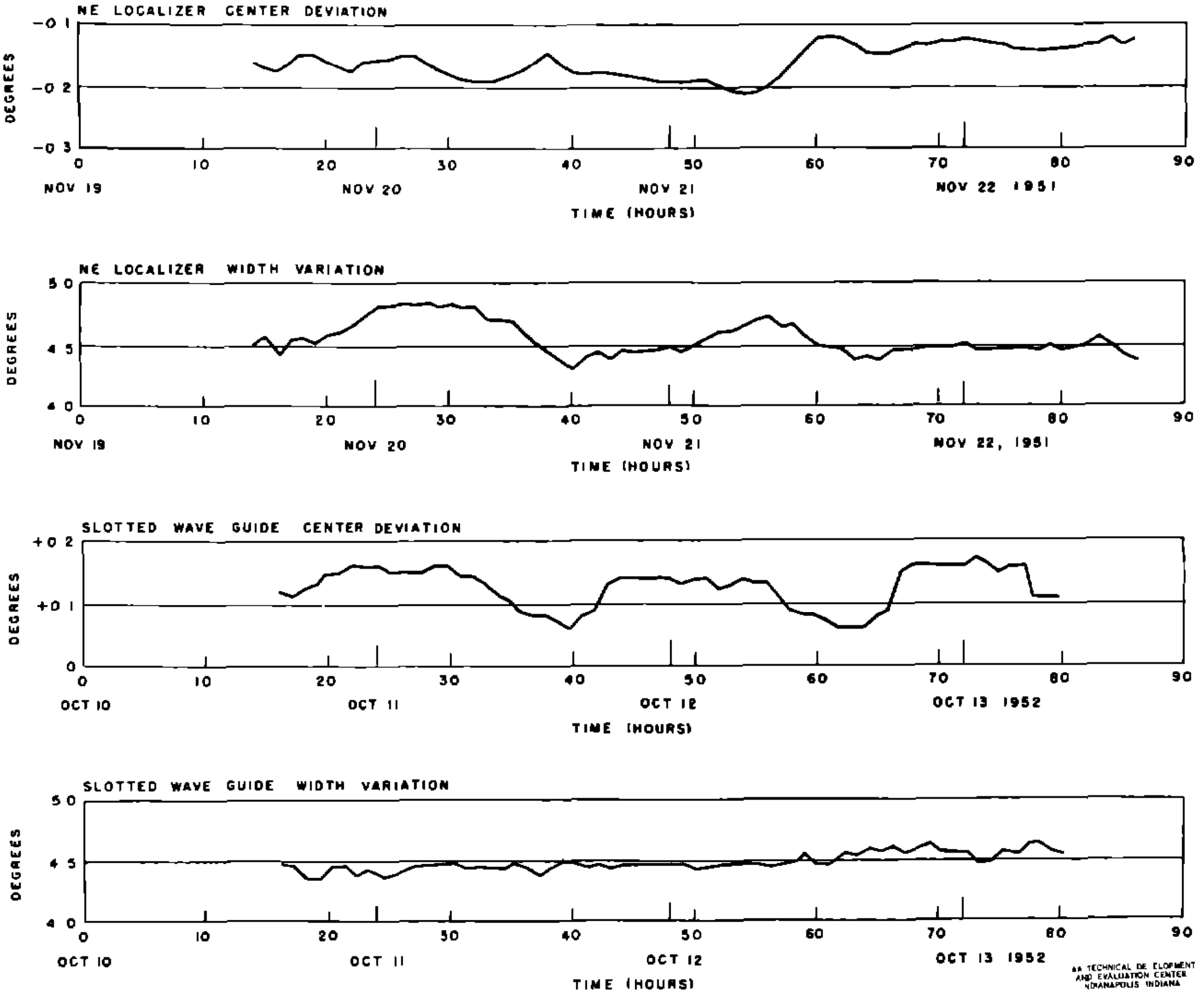

Fig. 31 Results of Measurements of Course Width and Position Obtained Under Conditions of Continuous Operation With Fixed Receiver Monitor

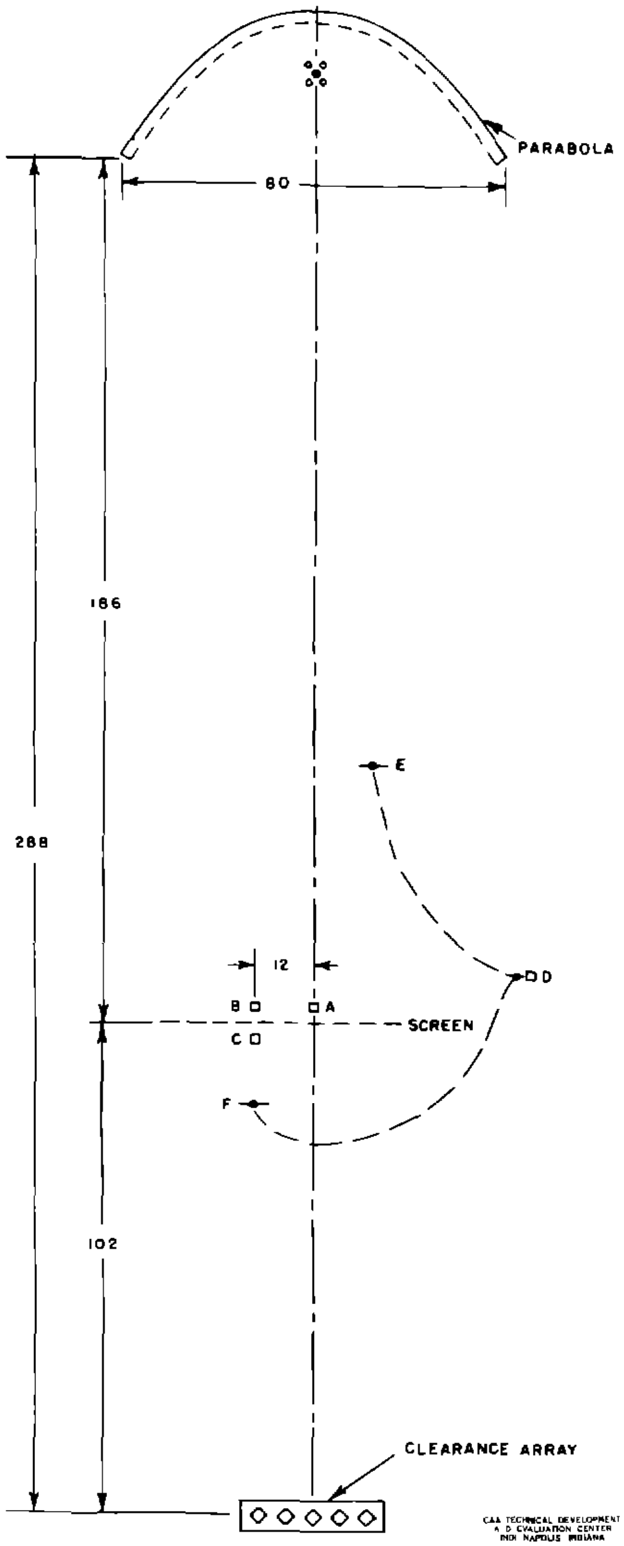

Fig 32 Layout of Antennas and Monitoring Pickups With Parabolic System

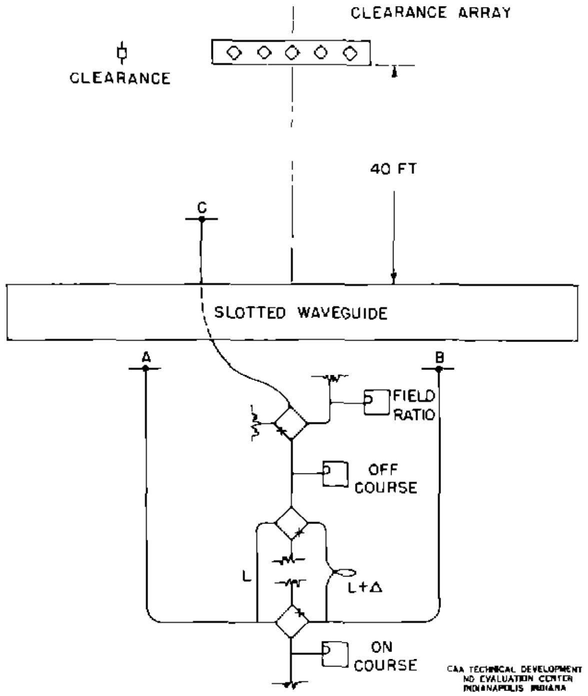

Fig 33 Layout of Antennas and Monitoring Pickups With Slotted-Waveguide System

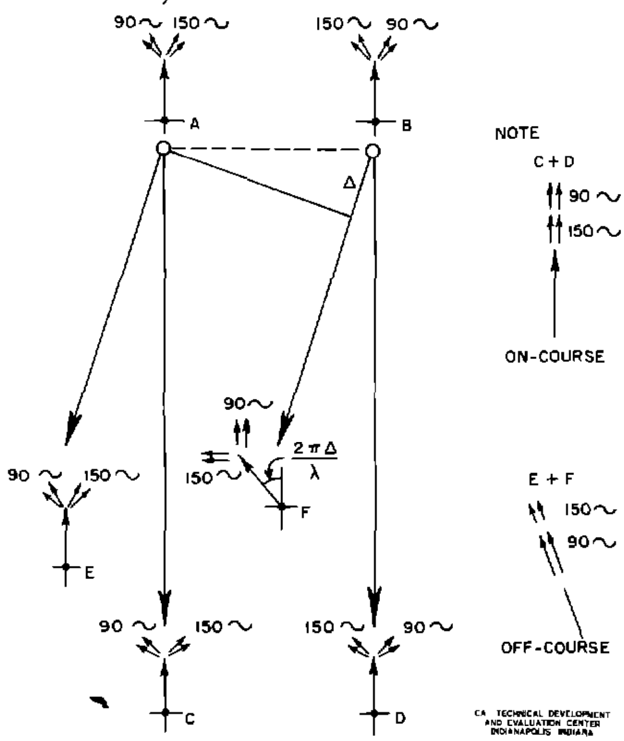

Fig 34 Vector Addition of Voltages in the Aperture-Field Monitoring System

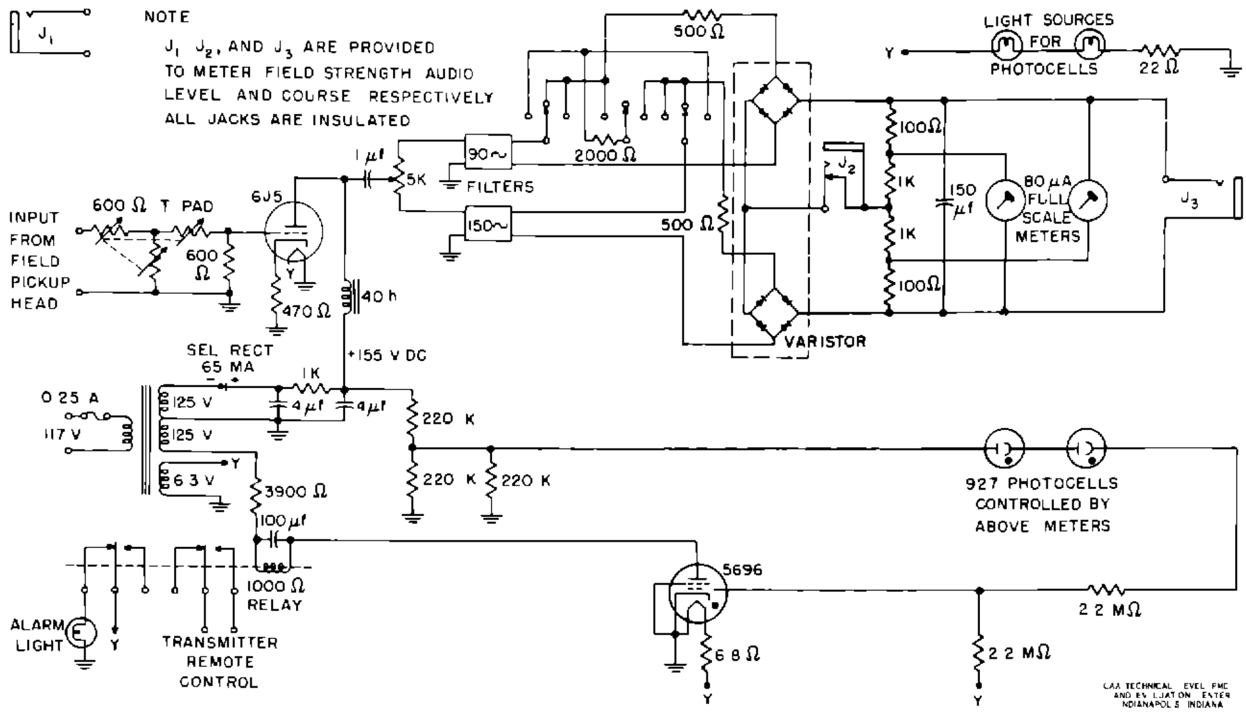

Fig 35 Schematic Diagram of Monitoring Unit

STABILITY TESTS

During January, February, and March of 1952, almost daily measurements of course position and width were made on the three directional arrays at the north locali er site and on the commissioned northeast localizer These measurements were made in each case with a standard receiver carried in the instrument truck at the far end of the runway approximately 6,000 feet from the localizer, and the results are given in Fig. 30 The over-all system stability is indicated by data of this type Variations may be produced either by modulation equipment, by antennas, or by receiving equipment Ordinarily, it is rather difficult to separate the various contributions to the over-all system error, particularly if they are comparable in magnitude The same receiving equipment was used throughout to obtain the data presented in Fig 30 The modulation equipment was common to all arrays except the commissioned northeast localizer Any errors contributed by the common equipment should produce a corresponding correlation among the various total error curves, if the error of the common equipment can be considered fixed over the period of time taken to complete a series of observations This period was usually about one-half hour in length Inspection of the data of Fig 30 reveals some correlation, particularly between the error curves of the parabola and the slotted waveguide Unfortunately, as noted in the data, difficulty was experienced with shifting of the supports for the linear array, so that most of the results for February and March were of poor quality

Additional stability tests which were made employed a continuously operating receiver and recorder located in a shelter at the far end of the runway Three receiving antennas were utilized, one antenna was on the center line, while the other two were located on either side of center By means of a clockwork mechanism, the receiver input was periodically switched to each antenna in succession. Thus a semicontinuous record of both center deviation and course width was obtained Information obtained by this means, for both the slotted-waveguide directional array and the northeast commissioned localizer, is plotted in Fig 31

In the winter of 1951-52, weather at Indianapolis was not severe enough to constitute a thorough test of stability under snow and icing conditions Under the prevailing conditions it can only be concluded that any one of the three directional arrays, when properly maintained, had a stability which was comparable to that of the other components of the system

MONITORING EQUIPMENT

Although the development of monitoring equipment for a new facility is customarily left until the last, it is no less important to successful continuous operation Unless there is thoroughly accurate and dependable monitoring, the facility user is without confidence and the maintenance personnel lack a yardstick with which to measure performance

It must be admitted that there is no such thing as perfect monitoring that is, the positive detection of every conceivable combination of malfunctions is practically impossible This is especially true when one considers the rather unlikely simultaneous occurrence of compensating errors However, a good monitor will detect all of the likely malfunctions and a very large number of the unlikely ones in addition These include failure within the monitoring system itself, which means that the monitoring circuitry must be as inherently fail-safe in nature as possible

The problem of monitoring a directional localizer is not particularly different from that which exists with the conventional localizer, with two exceptions (1) the large aperture of the directional array introduces a much larger proximity-phase effect, and (2) the existence of two more or less separate antenna arrays in the directional localizer calls for a means of monitoring the ratio of their radiated fields

A general plan for monitoring the directional localizer was chosen One set of monitoring equipment was constructed and tested to a limited extent Fig 32 shows the layout of monitoring heads which has been used with the parabolic system It could also be used with the linear array or slotted waveguide A standard monitoring head, designated as A, is used for detecting the parabola on-course signal Similarly, B represents a standard head used for detecting change in course width Both heads are located in a region between the two transmitting arrays where the radiation fields are approximately equal A small screen is provided to make heads A and B primarily responsive to parabola signals Only a small screen is required, because capture effect is operative in the monitor as well as in the airborne receiver Monitoring head C is used to detect the clearance signal It is placed on the opposite side of the screen so that it is not responsive to parabola signals The on-course position of the clearance array is not directly monitored Monitoring head D was modified to provide transmission-line input instead of using the usual antenna rods Dipole antennas E and F are placed in strong parabola and clearance fields, respectively While E picks up a parabola signal modulated predominantly with 150 cps, F picks up a clearance signal modulated predominantly with 90 cps Both signals are carried by transmission lines to the input of head D With proper positioning of antennas E and F, the output of head D will show equal quantities of 90 and 150 cps Any change in ratio of radiated fields will then be shown by inequality of the 90- and 150-cps signals in D

Probably the major deficiency in the monitoring system just described results from proximity-phase error While head B functions fairly well as a relative indicator to show change from an established condition, it gives no absolute measure of course width or phase If head B is used for phasing with the layout shown, the phase will be in error by an angle of approximately 25° The system can be phased correctly, however, by using a compensating section of transmission line which is then removed for normal operation

In order to completely side-step the proximity-phase problem, a quite different monitoring arrangement was adopted for the slotted-waveguide array Rather than attempt to monitor the field pattern at a distance, it was decided to use the aperture fields on the basis that the aperture and distance fields have a well-known and unique relationship to each other Fig 33 shows the layout of monitoring pickups for a slotted-waveguide array This layout utilizes the principle of aperture-field monitoring Dipole antennas A and B are located about 15 feet in front of, and approximately midway between, the center and ends of the slotted waveguide The energy picked up by the two dipoles is fed by transmission line through a double-bridge network to the on-course and off-course detector heads These detector heads are of the standard type and are modified for transmission-line input In addition, the off-course monitor signal is fed through a third bridge to the field-ratio detector head The off-course clearance signal is picked up by dipole C and fed through the third bridge and thence to the field-ratio detector head Dipole C is positioned in such a manner that, with normal radiated fields, the field-ratio detector shows equal quantities of 90- and 150-cps signal

The addition of vector voltages in the double-bridge network to produce on-course and off-course indications may be explained by reference to Fig. 34 Each of the dipoles A and B is primarily responsive to fields from the three or four slots which are closest to it The resultant fields at the dipoles are represented by vectors at points a and b A distant observer on the center line would see the original fields without relative phase shift, as shown at points c and d As shown, the sum of c and d is a carrier with inphase, 90- and 150-cps sidebands of equal amplitude (otherwise known as on-course signal) For this reason, as seen again in Fig 33, the signals from dipoles A and B are added without relative phase shift and are fed to the on-course detector A distant observer off the center line would see the original fields with a relative phase shift $2\pi\Delta/2$ due to the path difference Δ as shown at points e and f, in Fig 34 The sum of the fields at e and f is a carrier with inphase, 90-and 150-cps sidebands of unequal amplitude (off-course signal) As indicated in Fig 33, the signals from dipoles A and B are added with relative phase shift produced by transmission line of length Δ and are fed to the off-course detector The aperture-field monitoring system can be used to adjust the relative phase of reference and deflection signals without compensation for proximity

The circuitry of the monitoring system has been made as nearly fail-safe as possible Fig 35 is a schematic drawing of one channel which can serve interchangeably for on-course, off-course, or clearance indications, or for field ratio

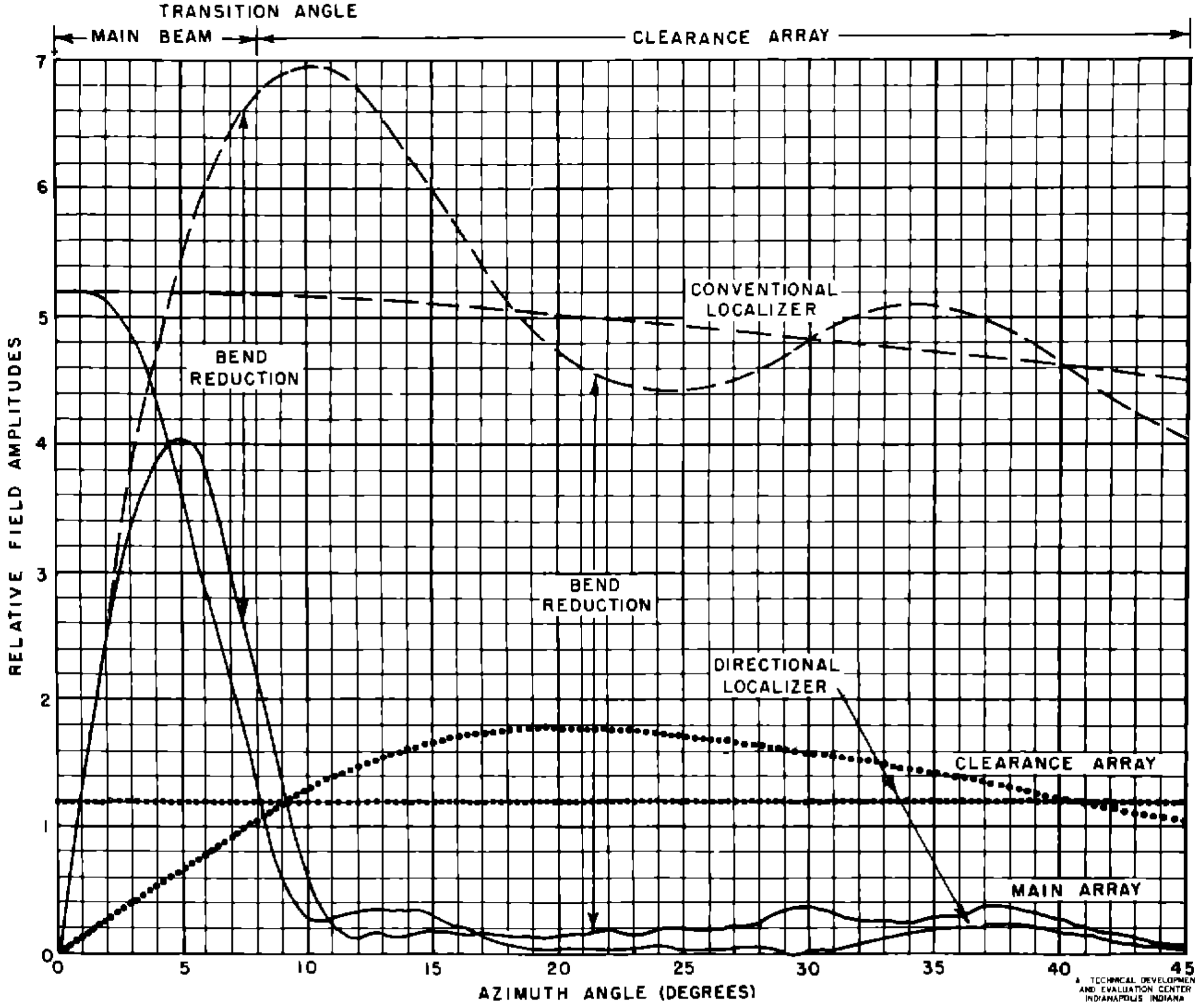

Fig. 36 Evaluation of Specific Bend Reductions Expected With Directional Localizer Compared With a Standard 8-Loop Localizer

DISCUSSION AND RESULTS

The project has evolved three directional-localizer designs which have as their principal components (1) a directional-antenna array, (2) a clearance-antenna array, (3) transmitter and modulation equipment for the directional array, (4) transmitter and modulation equipment for the clearance array, and (5) a monitoring system for both arrays It is apparent that the directional localizer is essentially equivalent to two conventional localizers installed at a common site If a directional localizer were to be installed at a site which has an existing conventional-localizer station, the existing station might provide the clearance array, the transmitter, the modulation equipment, and part of the monitoring system

The performance improvement to be expected can be estimated in some specific cases by reference to Fig 36 In it are plotted typical sets of field patterns for directional and conventional localizers To permit comparison, the carrier or reference patterns are shown with the same on-course amplitudes and the deflection or sideband patterns are plotted with equal initial slopes This amounts to specifying that both systems have the same course width or sensitivity If the site has a well-defined reflecting object at some particular azimuth from the localizer causing course bends, the amplitude of the course bends will be directly proportional to the deflection sideband field radiated toward the object Thus the amount of bend reduction provided in this case by the directional localizer is given by the ratio of the conventional to the directional deflection fields for the particular azimuth angle in question This is indicated in Fig 36 It is usually proper to ignore the effect of bends in the front course of the clearance array because of the large suppression ratio provided by capture effect

Experimental verification of this theory has been obtained in two cases at Indianapolis by creating course bends with an artificial reflecting object consisting of several horizontal wires 400 feet long stretched between 90-foot poles The wires were oriented parallel to the runway and about 3,000 feet from the localizer The two azimuth angles chosen were 7 6° and 14 0° The arrangement produced bends just off the approach end of the runway Bend amplitudes were found to be approximately in agreement with the theory indicated upon comparison of the directional array with the clearance array operating alone

While some localizer sites encountered in practice are characterized by well-defined reflecting objects, more often there are many smaller reflections, any one of which is not very serious in itself The combined effect, however, is to give the localizer course an apparently random roughness which may be just as objectionable as sinusoidal bends

An accurate estimate of the performance improvement to be expected from the directional localizer is, in general, difficult to make because of the very large number of variables involved. Nevertheless, there is good reason to believe that at most sites the improvement is substantial and in some cases may even be spectacular Only by actual installation and use of the directional localizer at a considerable number of sites which are known to be poor can its value be determined

CONCLUSIONS

A directional localizer, based on any one of the three designs described in this report, is capable of producing substantially straighter courses than the present conventional eight-loop localizer In general, the sharper the directional patterns the greater is the improvement to be expected On the basis of practical experience to date as well as of theoretical considerations, it is believed that an optimum aperture for a directional localizer is about 200 feet This figure provides a pattern sharpness which is about the maximum that can be used without sacrifice of linearity of the CDI deflection with azimuth Extension of the existing localizer antennas to a 200-foot aperture appears to be impractical in the case of either the parabola or the linear array of dipoles However, it would be a relatively simple matter to extend the slotted-waveguide array to a 200-foot aperture Therefore, the slotted-waveguide array appears to be the most suitable for obtaining the ultimate performance.

A secondary advantage which would appear to result with the use of a larger aperture is greater freedom from the usual transient course movements due to the disturbances of the localizer radiation field by ground vehicles and by taxiing or low-flying aircraft This advantage would be expected because pattern formation begins at a greater distance from the antenna

It should be noted that the methods described in this report result in directive patterns usually associated with microwave antennas and thus achieve relative freedom from reflection effects at the same time that the present investment in 110-Mc airborne receivers is protected

DEVELOPMENT OF A VHF DIRECTIONAL LOCALIZER

PART II

THE MONITOR

SUMMARY

This report describes a monitor developed at the CAA Technical Development and Evaluation Center to accommodate the monitoring requirements of the directional localizer These requirements are unique when contrasted with those of the conventional eight-loop localizer A second goal was to develop a monitoring system which would be as nearly fail-safe as possible with regard to component failure in the monitor itself

The monitor provides an alarm whenever the transmissions of the localizer ground equipment vary by more than a predetermined amount or whenever the monitor itself fails Its use insures that the localizer is functioning properly, as indicated by the radiated field near the facility

INTRODUCTION

To produce the desired radio-frequency and space-modulation patterns for precision guidance of aircraft to the center line of an airport runway, the directional localizer uses an antenna system comprised of two arrays These two arrays are designated the directional array and the suppressor array The directional array in the system for which this monitor was designed consisted of a 100-foot waveguide feeding 18 slots which produce a beam 5° wide down the center line of the runway The suppressor array consisted of five loops. These loops produce a field that suppresses the minor lobes of the directional array and also provides a back course and clearance around the remainder of the 360° of azimuth not covered by the directional system

The monitor must continually check the radiations from both of these arrays and must provide an alarm whenever these radiations deviate from normal by a prescribed amount Specifically, deviation limits as established by the Air Navigation Development Board[1] are as follows

"1 Shift of the on-course line of either the course or suppressor localizer of more than one-third of a degree from the center line of the runway,

2 Reduction of power output of either the course or suppressor localizer to less than 50 per cent of normal,

3 Change in course sensitivity of either the course or suppressor localizer of more than 20 per cent,

4 Deviation of ratio of carrier field strength on-course of the course localizer to the suppressor localizer outside the limits of (3 5 ± 0.5) to 1 "

The alarm itself consists of a signal to an auxiliary piece of equipment known as the automatic-transfer unit which, upon receiving an alarm signal, immediately switches the antenna arrays to a standby transmitter and a standby modulation unit Simultaneously, an alarm signal is sent to the control tower in order to give both visual and aural notice that a transfer has taken place If after the changeover takes place the alarm persists for five seconds, the 90- and 150-cps-modulation components are removed from the transmissions and, when possible, the carrier is left on to provide communications and identification

It is a further requirement of the monitor that, when power returns after a power failure, the monitor shall be prevented from giving an alarm until after the station and the monitor equipment have had approximately one minute in which to warm up

THEORY OF OPERATION

The monitor system can be considered to be composed of five separate systems

1 Directional-course and course-sensitivity system

2 Suppressor course-width system.

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[1] "Component Characteristics, Transition Program VHF Directional Localizer," by the Air Navigation Development Board, May 25, 1951.

3 Field-ratio system
4 Field-strength and audio system
5 Time-delay system

A detailed discussion of each of these systems follows

Directional-Course and Course-Width System

The directional array poses the most difficult monitoring problem because it has a much larger aperture than conventional localizers have If simple on-course and off-course field detectors were used, as is the case with a standard eight-loop localizer, they would have to be located about 1100 feet in front of the array for the same proximity error This distance would make siting requirements most difficult at many airports

The most desirable position for the monitor antennas should be the approach end of the instrument runway and approximately one mile from the transmitting-antenna arrays, a place where the proximity error would be negligible However, tests have demonstrated that reflections from taxiing and flying aircraft in the vicinity would make it necessary to use an inordinately long time delay in the alarm circuits Such a delay is impractical Therefore, a system has been developed for monitoring the directional antenna near its aperture Fig 37 is a view of the localizer installation, and Fig 38 shows the location of the monitor antennas Fig 39 shows the interconnections of the monitor antennas

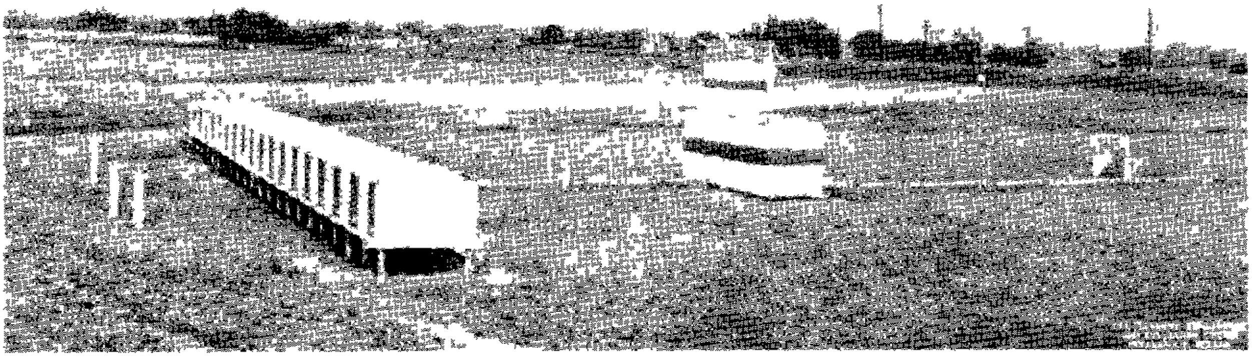

Fig 37 Localizer Installation

As seen in Fig 40, if at a given instant of time the carrier signal fed to the slots on the left side is as shown in the vector diagram (a) and if the sideband signal fed to the slots on the left side is as shown in diagram (b), then the resultant energy fed to the slots on the left side will be as shown in diagram (c) If at the same instant of time the carrier signal fed to the slots on the right side is as shown in diagram (d) and if the sideband signal fed to the slots on the right side is as shown in diagram (e), then the resultant energy fed to the slots on the right side is as shown in diagram (f)

Again as seen in Fig 39, the dipoles and their connecting lines L_1 and L_2 to bridge A are equivalent, so that the signals are added together in bridge A to give a resultant which is fed to detector C See diagram (h), Fig 40 The output of detector C will have equal 90- and 150-cps audio components of the normal on-course signal which is analyzed in a unit to be described later

If a course shift is caused by a drop in the 90-cps modulation percentage, for example, the vectors would appear as shown in Fig 40, diagrams (a_1), (b_1), and (c_1) for carrier, sideband, and resultant energy fed to the left slots Carrier, sideband, and resultant energy fed to the right slots would be as shown in diagrams (d_1), (e_1), and (f_1) The energy feeding the detector C from the bridge A would appear as shown in diagram (h_1), and the 90- and 150-cps audio output of the detectors would no longer be equal Therefore, the system described would be able to detect a shift in the localizer course from its normal position A large reflecting object placed in front of the waveguide but at some distance away from the monitor dipoles could deflect the course without affecting the monitors The monitors however are not intended to monitor other than equipment operation Tests covering the effects of reflecting objects are described later in this report

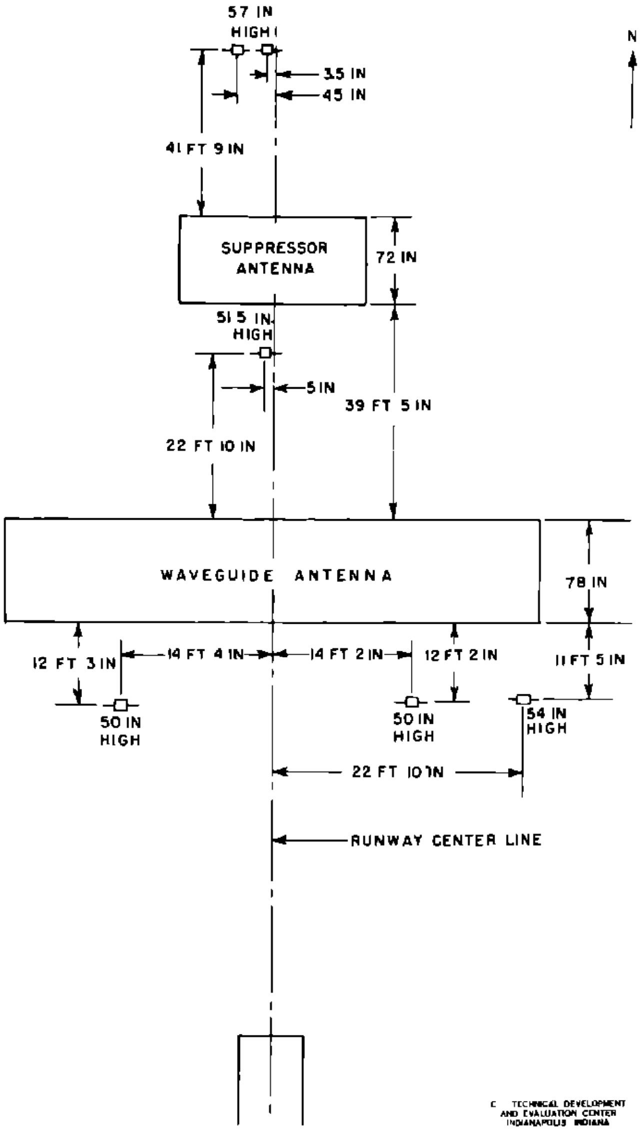

Fig 38 Location of Monitor Antennas

The directional off-course or course-sensitivity monitoring function will now be discussed The same two dipoles are connected to bridge B, Fig 39, and L_4 is made longer than L_3, which means that the signals from the right side of the waveguide are delayed in-phase before combining in bridge B with the signals from the left side. With a normally operating localizer, the effect of this phase delay on the vectors is as follows Carrier and sidebands from the left dipole are as shown in Fig. 40, diagram (c_2) Carrier and side-bands from the right dipole are delayed by $\Delta°$ as shown in diagram (g_2)

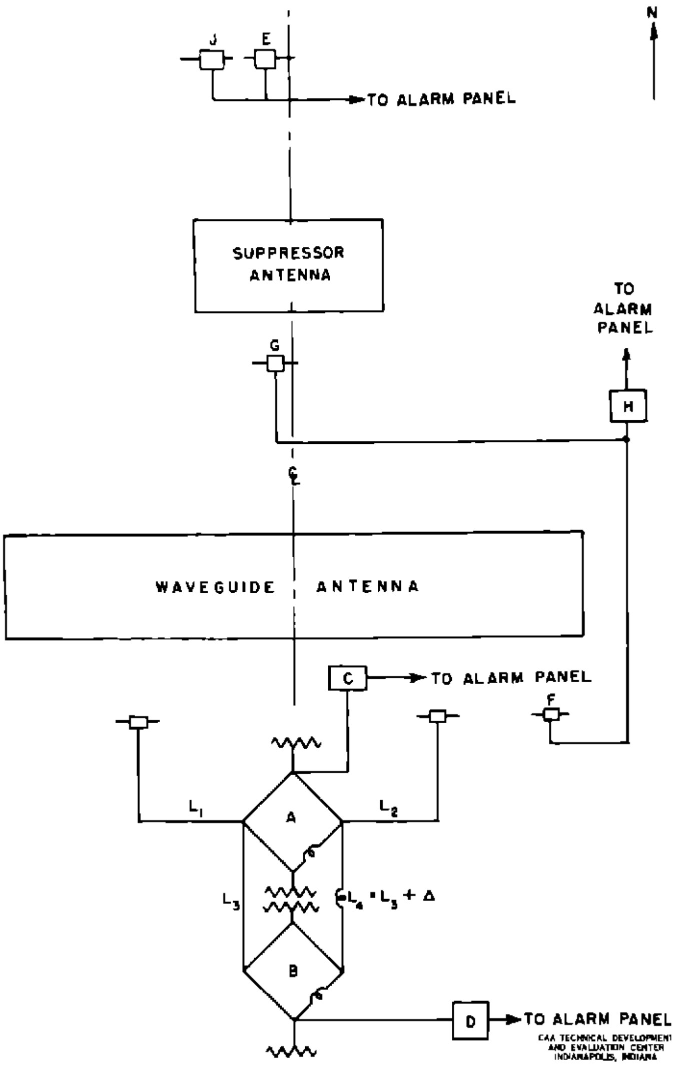

Fig. 39 Monitor-Antenna Interconnection

After addition in bridge B, the energy appears as shown in diagram (h_2) where $\frac{E_{150}}{E_{90}}$ = 1 67, the 4 5-db difference used in this system. When rectified in detector D, the 150-cps audio component will be larger than the 90-cps component. Thus the difference in length Δ between lines 3 and 4 causes detector D to simulate an off-course detector, and the magnitude of Δ determines how far off course

A decrease in the magnitude of the sidebands fed to the waveguide would produce a broader course. The carrier and sidebands fed to the left slots are shown in diagrams (a_3) and (b_3), and the resultant is shown in diagram (c_3). The carrier and sidebands fed to the right slots are shown in (d_3) and (e_3), and the resultant is shown in (f_3) The phase of the energy from the right dipole shifted by Δ°, as shown in diagram (g_3), and the resultant in bridge B appears as shown in diagram (h_3), where

$\frac{E_{150}}{E_{90}} < 1.67$. The off-course detector D detects a change in the 90/150 ratio and therefore measures course sensitivity

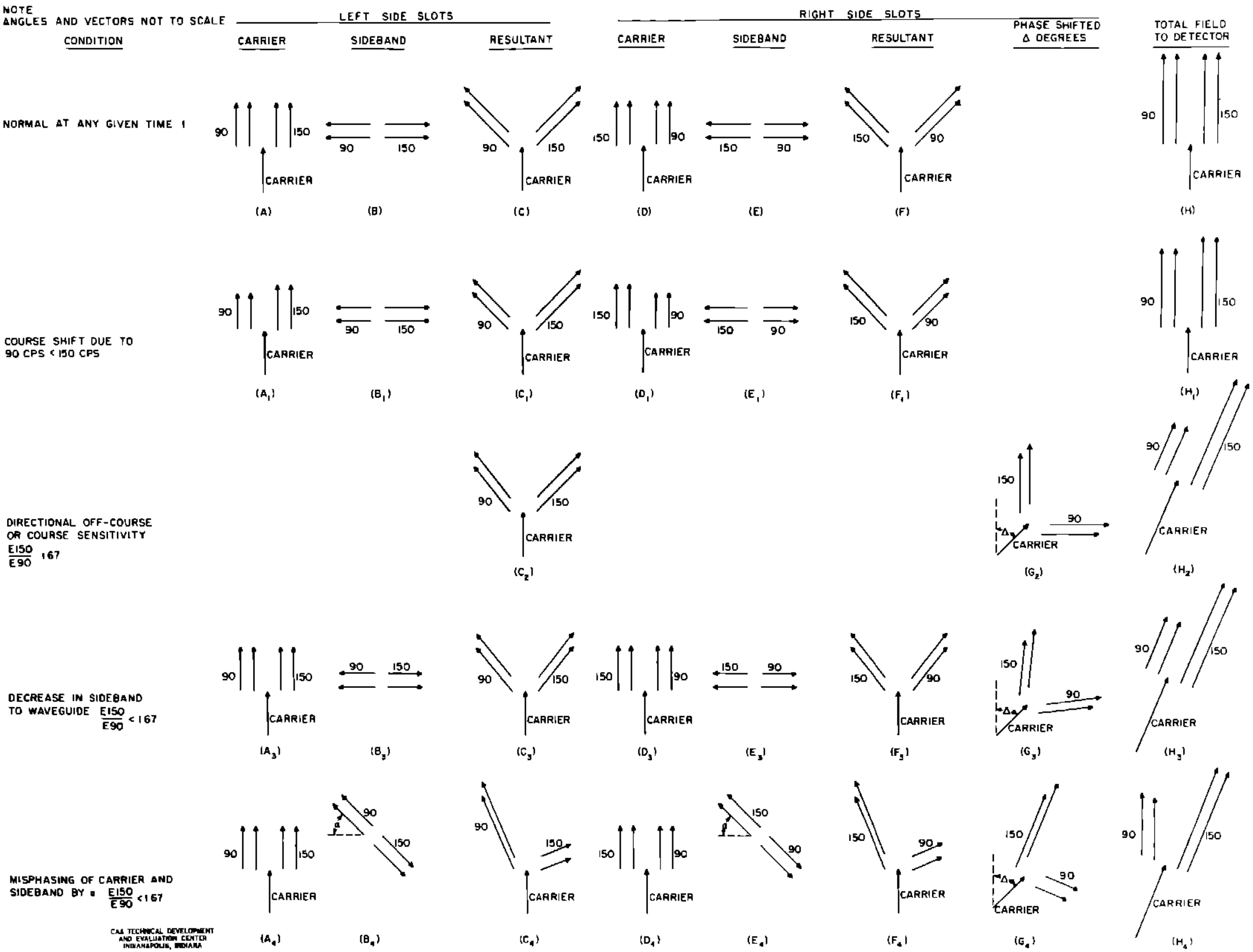

Fig 40 Vector Diagrams of Carrier and Sideband Signals

It can also be shown that the off-course detector D can be used to establish proper phasing between carrier and sidebands fed to the waveguide antenna For example, if sidebands are misphased by an angle α, then the carrier and sidebands fed to the left slots are as shown in diagrams (a_4) and (b_4) and the resultant is as shown in (c_4) Carrier and sidebands fed to the right slots are as shown in diagrams (d_4) and (e_4), with the resultant as shown in diagram (f_4) The phase of the right-slot energy shifted through $\Delta°$ is shown in diagram (g_4), and the resultant in bridge B is shown in diagram (h_4), where $\frac{E_{150}}{E_{90}} < 1\ 67$ Thus, the off-course detector D is sensitive to phasing between carrier and sidebands

Consideration will now be given in detail to the detectors C and D These are modified Type CA-653 field-detector units,[2] in addition to the voice-rejecting 90- and 150-cps filters By the addition of a pick-up loop close to the tuning inductance and by the equipping of this loop with an RG 8/U cable connector, the units were modified for an RG 8/U cable input instead of for the dipole input normally used with these units The cathode-biasing system on the 6SF5 amplifier was changed from a 1000-ohm resistor with a 10-microfarad by-pass capacitor to a 330-ohm resistor with no by-pass capacitor This change was made to prevent the loss in gain which occurred at low temperatures (-10°C) at which the by-pass capacitor decreased in capacity An automatic gain control was incorporated into these units to provide constant 90- to 150-cps output with fixed modulation percentage when the r-f input level changed This modification was necessary to prevent a premature alarm in case the r-f power output of the transmitter decreased but still remained within the 50 per cent limit This decrease in r-f power is discussed further in connection with the alarm circuitry The automatic gain control consists of a microammeter movement with a vane attached to the moving element The movement of the vane changes the capacity between two plates which are connected across the tuned circuit at the input of the detector unit The moving coil is connected electrically in series with the diode load and therefore moves in accordance with the rectified r-f field current If the rectified field current tends to rise, the vane moves to increase the capacity between the plates and to detune the circuit and thus reduce the rectified field current It was necessary to suppress the zero-current position of the meter movement a great amount in order to flatten the gain-control characteristics The total amount of rectified field current available ranges from about 200 to 700 microamperes, while the meter movement exerts its full range of control with a current change of about 10 microamperes Therefore, the amount of current change necessary in the meter to cause a capacity change is a very small percentage of the total current in the circuit, and the control characteristic is very flat over a range of at least 4 to 1 in the field intensity or of 16 to 1 in transmitter power

The output of the modified Type CA-653 field-detector units is set at 5 volts, which is developed across a 600-ohm load This output is lower than that which is often used with these field detectors, but it is more than enough to drive the alarm panels and it gives less distortion than higher outputs

The monitor alarm rack, shown in Fig 41, is located in the transmitter building and is operated by the output of the field detectors through a 600-ohm line Fig 42 is a schematic diagram of one of the alarm panels, and Fig 43 shows a rear view of one panel Two panels are fed from the detectors C and D, Fig 39 As indicated in Fig 42, the 600-ohm line is terminated in a 600-ohm potentiometer which also serves as a gain control A thermistor circuit follows the gain control and is used to compensate the amplifier gain for temperatures from -10° to +60° C A 6J5 tube is used for gain, and it matches into standard receiver-type 90- to 150-cps filters The outputs of the filters are fed through a three-position switch which enables a common monitor alarm-panel design to serve as either an on-course monitor or an off-course monitor on either side of the course This switch is connected to a receiver-type Varistor with a resistive load across sections of which meters M_1 and M_2 are connected

A null in signal at any place in the monitor circuits for a normal on-course localizer was not considered to be fail-safe, inasmuch as many components could fail and give a null in signal while the actual localizer departed from normal operation Therefore, a design was developed which required that there be signal at all times in all parts of the monitor, even when the localizer was operating exactly as prescribed If the meters M_1 and M_2 were both connected across the total Varistor load and were not tapped down by 100 ohms as they actually are, it can be seen that with equal 90- and 150-cps signals being fed to the Varistor

[2] "Modification of Type CA-653 Field Detector to Provide VOR Voice Rejection," Electronics Establishment Branch Instruction Letters, CAA Office of Federal Airways, October 3, 1951

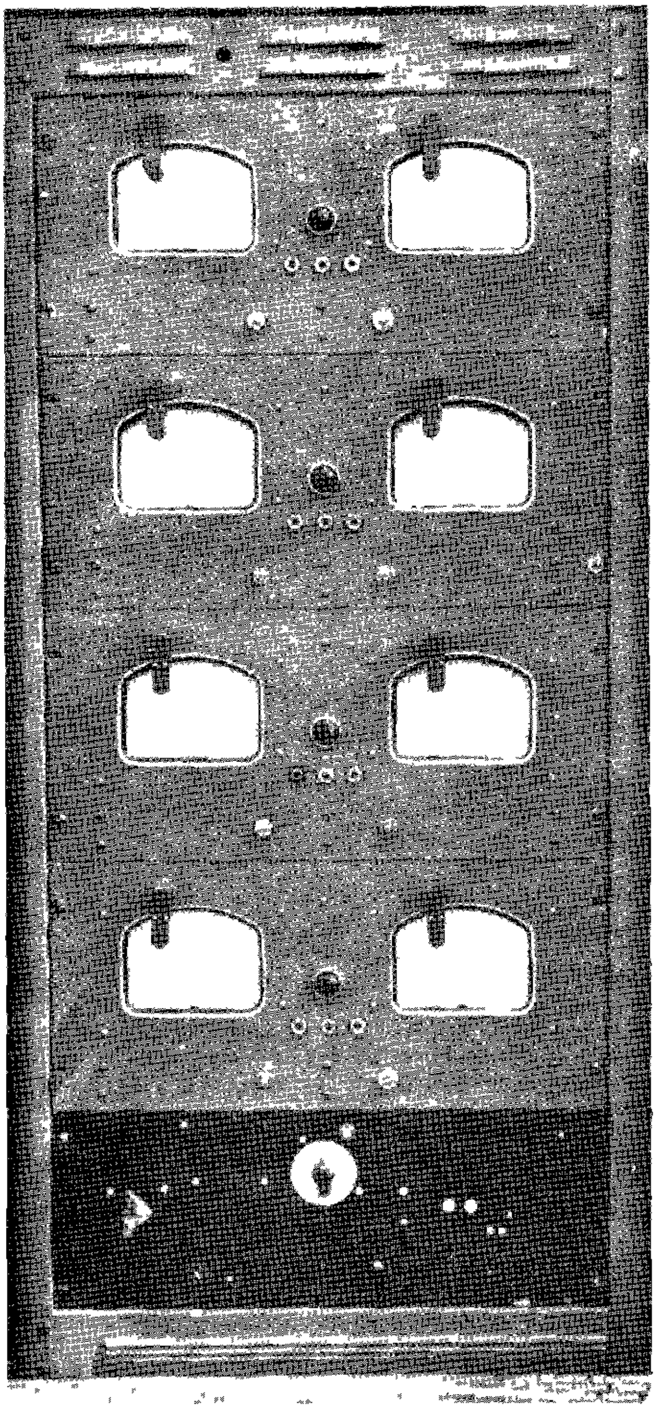

Fig. 41 Monitor-Rack Assembly

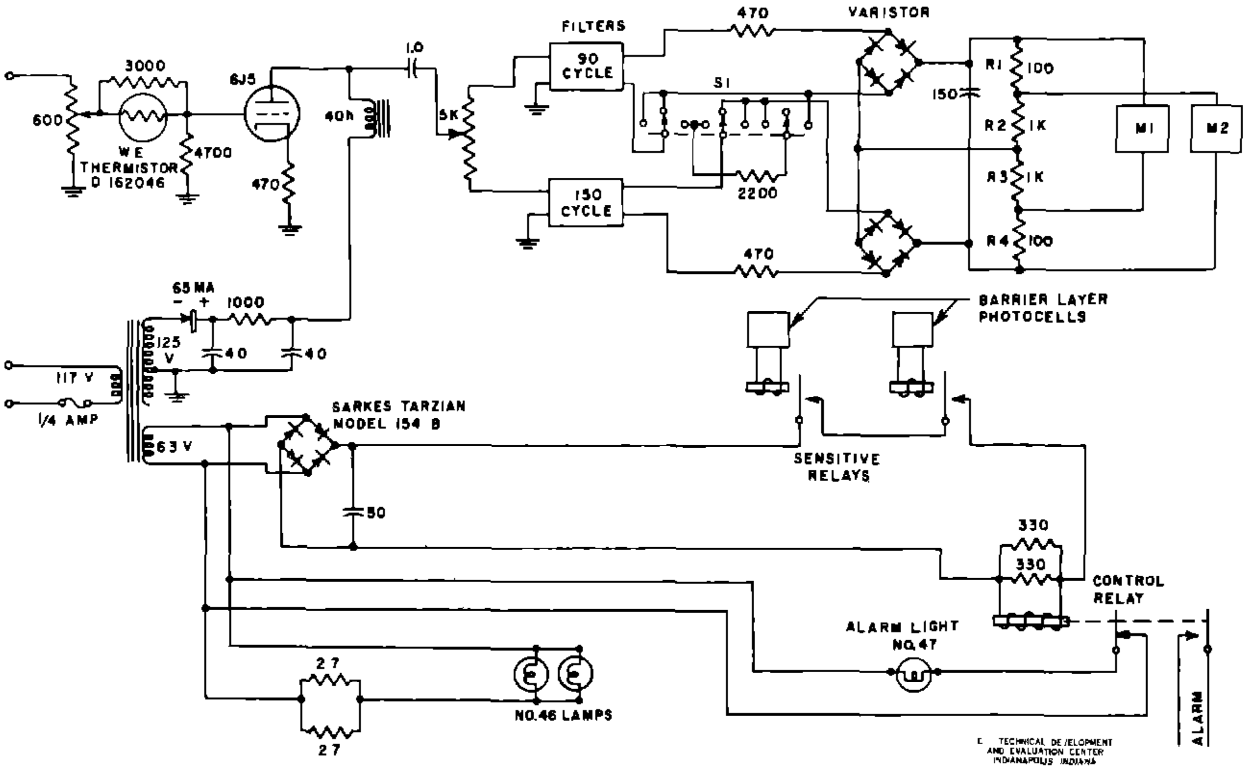

Fig. 42 Schematic Diagram of Alarm Panel

there would be no deflection of the meters because the rectified 90- and 150-cps signals would cancel each other If each meter were now tapped down 100 ohms from the ends of the Varistor load as shown in Fig 42, each meter would read up-scale because, in the case of meter M_1, the voltage across R_1 and R_2 would be larger than the voltage across R_3 and, in the case of meter M_2, the voltage across R_3 and R_4 would exceed the voltage across R_2

If because of a fault in the localizer the 90-cps signal should decrease, the reading of meter M_1 would decrease and the reading of meter M_2 would increase because the voltage across R_1 and R_2 would decrease For similar reasons, a decrease in 150-cps signal will cause meter M_1 to increase and meter M_2 to decrease in reading Therefore either one meter or the other will decrease in reading if the course shifts, and it is this decrease which actuates the desired alarm

It should be noted that if both the 90- and the 150-cps signals decrease in the same proportion yet not enough to give an alarm on a normal localizer course, the monitor will become more sensitive to course shift and the alarm might occur at 1/6°, for example, instead of 1/3° A decrease in power output of the transmitter could cause a decrease in the 90- and 150-cps signals except for the automatic-gain controls included in the field-detector units These automatic-gain controls therefore prevent premature alarms caused by any factor which reduces field strength.

An alarm indication on the meters actuates a relay in the following manner The meter scales and the back covers are drilled through at 30 per cent of full scale A flag is attached to the meter pointer as shown in Fig 44 and will cover the hole in the meter scale when the current through the meter falls to 30 per cent of full scale A stop is placed in the meter so that the pointer cannot move below the 30 per cent full-scale reading Even when the current is zero, the flag will still cover the hole A source of light is produced by a lamp bulb placed in front of the meter and directed through the hole in the meter The lamp is operated at reduced voltage, and the manufacturer anticipates a life of not less than one year A barrier-layer-type photocell is placed behind the meter and is illuminated by the bulb except when the flag intercepts the beam of light. Therefore, the photocell receives light until an alarm occurs, at which time the meter reading drops low enough to cut off the light The photocell is of the self-generating type, that is, it requires no external source of power other

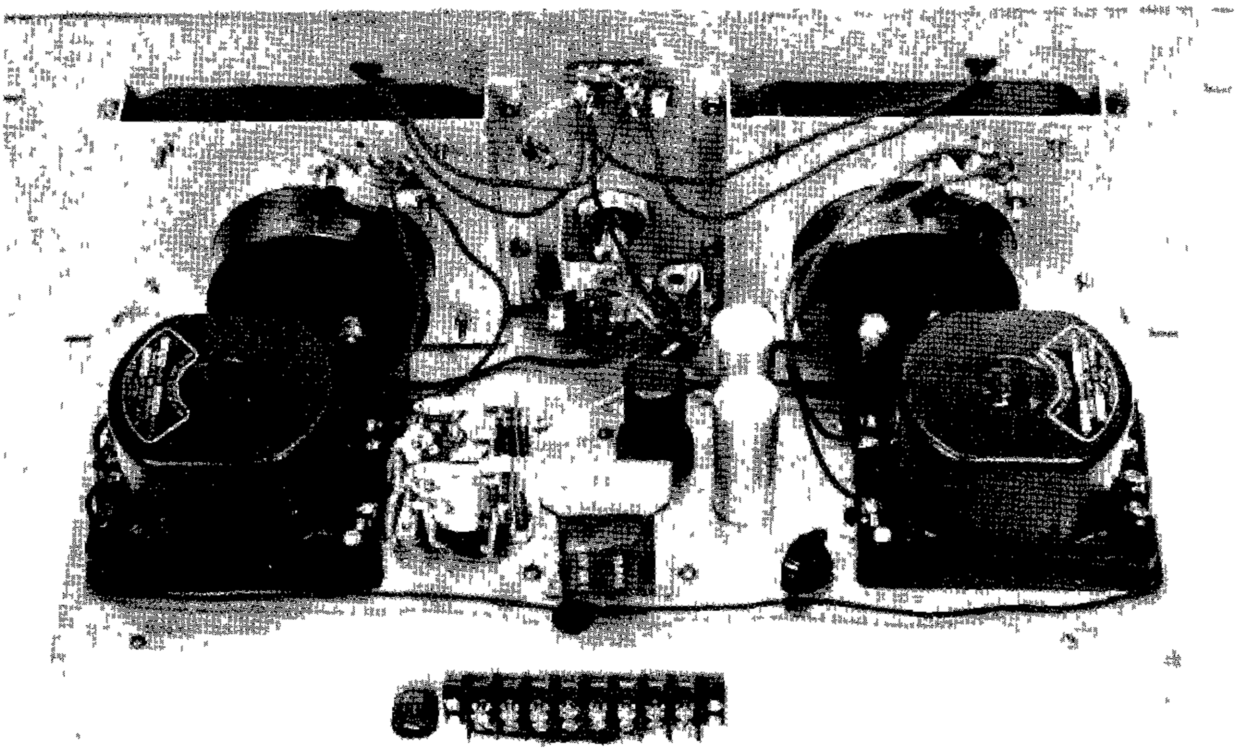

Fig 43 Rear View of Alarm Panel

than the light energy which strikes it. The photocells operate sensitive relays with normally open contacts, and the sensitive relays in turn operate a power relay with normally open contacts in the alarm circuit.

The foregoing description applies also to the off-course or course-sensitivity monitor, except that the 90- and 150-cps signals coming out of the filters are equalized by switch S_1 by inserting 4.5 db of attenuation in the larger signal before applying it to the Varistor

The normal operation of the monitor (no alarm) requires that (1) there is a signal in the amplifiers, (2) there is rectified current in the meters, (3) light is reaching both photo-cells, (4) both sensitive relays are energized, (5) contacts in the sensitive relays are closed against the opposing pull of spring tension, (6) the power relay is energized, and (7) the contacts of the power relay are closed against spring tension Open or short circuits in the tubes, meters, lamps, photocells, or relay coils will cause an alarm, as will localizer transmission failures This type of circuitry represents a higher degree of fail-safeness in the monitor alarm circuits than has been available in previous monitors

Since the condition of fail-safeness is always a matter of degree, the following definition has been adopted in this work A monitor is not fail-safe if it can fail without giving an alarm during a period of normal localizer transmission

Suppressor Course-Sensitivity System

In reference again to Fig 39, field detector E is located at a point 4.5 db off the back course of the suppressor antenna array The 4.5-db point provides operation of the monitor alarm circuit for an0 89-db change in course sensitivity. This is the same limit of 0 89 db used for the on-course monitor, and it allows the use of identical monitor equipments Detector unit E is identical to the modified Type CA-653 detector described previously, except that it is fed by its own dipole in the usual manner. It is not modified for RG 8/U cable input. The output of this field detector is connected to an alarm panel and its switch is thrown to the off-course position, corresponding to the direction of the displacement of the field detector off-course This alarm panel is identical to those already described, and the output of this panel becomes the suppressor course-sensitivity alarm

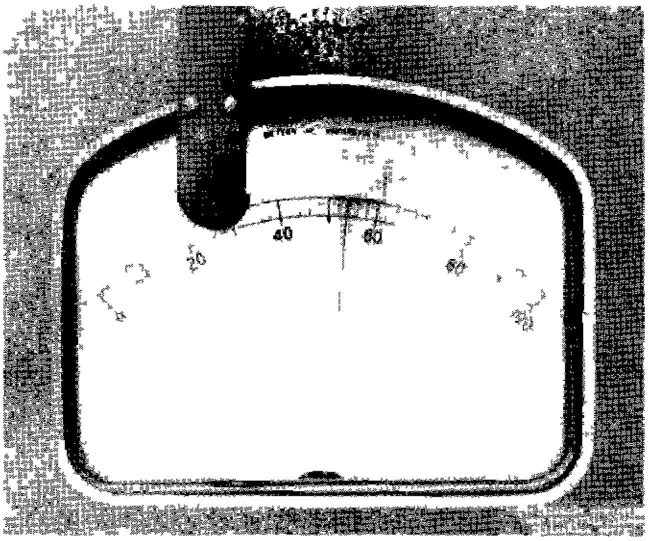

Fig 44 Alarm Meter

Field-Ratio System

The field-ratio monitor requires two dipoles, F and G See Fig 39 Dipole F is placed on the 150-cps side of the directional antenna, and dipole G is placed on the 90-cps side of the suppressor antenna These dipoles are so located that they each receive the same field intensity from their respective antenna arrays, furthermore, during normal localizer transmissions, the 90-cps signal induced in one unit is equal to the 150-cps signal induced in the other The r-f outputs of these two dipoles are fed to detector H through a T-connection Detector H is identical to detectors C and D It is connected through a 600-ohm line to an alarm panel identical to those previously described, and its switch is set for on-course signals

If the suppressor field strength should decrease, then output from dipole G will decrease the 90-cps signal detected will be less than the 150-cps signal, and an alarm will occur Similarly, an alarm will occur for a decrease in directional field strength, except that in this case the 150-cps signal will decrease It should be noted that if both the directional and the suppressor fields fall off in the same ratio there will be no alarm, because the automatic-gain control in detector H will provide constant 90- to 150-cps output with lowered r-f input This necessitates an additional field-strength alarm system which will be described

Field-Strength and Audio System

Field detector J, Fig 39, is used to provide the reduced field alarm It is a standard Type CA-653 detector head with the cathode-circuit modification consisting of the 6SF5 described previously and a connection to the cathode of the 6H6 diode detector to provide a d-c level which is proportional to field strength Since this detector is not provided with automatic gain control, it can be used as an r-f level indicator. The direct current is fed to a meter with photocell alarm circuits to provide an alarm should the carrier power decrease more than 50 per cent A further requirement of the monitoring system is that it shall provide an audio output to check voice and identification transmissions This same field detector provides the required audio output, and it is the only one which will do so because the other field detectors are equipped with 90- and 150-cps filters to suppress voice and identification signals [3]

The Time-Delay System

The time-delay system provides two separate time delays necessary for satisfactory operation of the monitor The starting time delay is a 60-second delay during which an alarm

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[3] These filters are necessary in the other field detectors to prevent distortion of the 90- and 150-cps components with voice modulations as high as 50 per cent

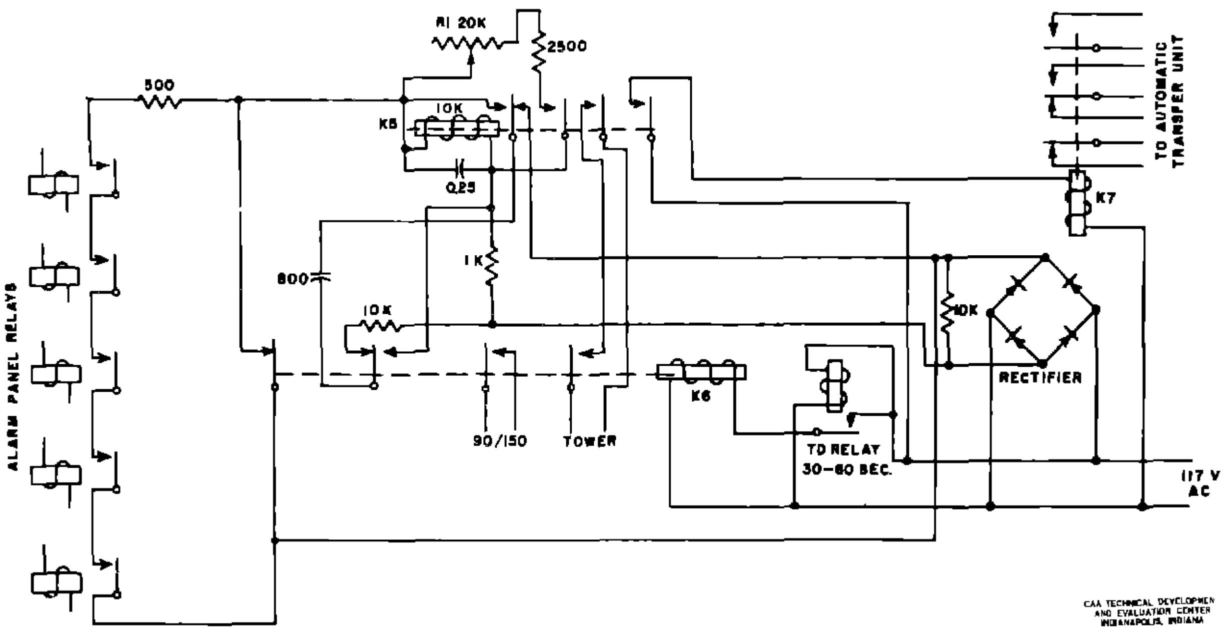

Fig 45 Schematic Diagram of Time-Delay System

cannot occur in order to allow the transmitters and the monitor to warm up when power is restored after power failure The alarm time delay makes it necessary that an alarm condition persist for five seconds before an actual alarm occurs, so that transient effects such as caused by passing aircraft will not cause an alarm when the localizer is operating normally

Fig 45 is a schematic diagram of the time-delay system The circuit requires power in all relay coils and requires closure of normally open contacts to prevent an alarm Should the motor-driven timer fail to run, the 90- and 150-cps modulation components will not be applied to the localizer and thereby will give a flag indication to the pilot. The traffic-control tower will also receive an alarm indicating, in this case, a monitor failure.

The time delay provided by capacitor C_1, in Fig. 45, is made adjustable by the variable resistor R_1 Capacitor C_2 is used to prevent relay K_5 from releasing during the time required to actuate relay K_6 Relay K_7 is provided with the necessary contacts to control the standard automatic-transfer unit

TESTS

Over-all operational tests of the monitor system were performed An instrument truck equipped with a Collins navigation receiver was used at the approach end of the runway to determine course position and course sensitivity. Adjustments which would affect course position and course sensitivity of both the directional and suppressor localizer systems and also the power ratio between them were made in the transmitting equipment The Federal Telecommunications Laboratories dual mechanical modulator lends itself particularly well to an evaluation of this type because of the ease with which modulation percentage and course sensitivity can be changed A tabulation of the test data follows
(Note These tests were made before automatic-gain controls were added to the detectors.)

Condition 1

Localizer normal with course centered and course sensitivity equal to 5°

Truck Location	Instrument-Truck Readings (μa)	Monitor Readings
Runway center line	0	60
2 5° left of center line	152	60
2.5° right of center line	147	60

Condition 2

Course shifted by decreasing percentage of 150-cps modulation until monitor alarmed

Truck Location	Instrument-Truck Readings (μa)	(degrees)
Runway center line	12 5 right	0.21
2 5° left of center line	158	-
2 5° right of center line	123	-

Monitor Readings	Left Meter	Right Meter
On-course directional	82	31 (alarm)
Off-course directional	84	36
Off-course suppressor	61	62
Field ratio	68	52

Condition 3

Course shifted by increasing percentage of 150-cps modulation until monitor alarmed

Truck Location	Instrument-Truck Readings (μa)	(degrees)
Runway center line	19 left	0.316
2.5° left of center line	139	
2 5° right of center line	160+ (off scale)	

Monitor Readings	Left Meter	Right Meter
On-course directional	31 (alarm)	88
Off-course directional	31 (alarm)	90
Off-course suppressor	62	59
Field ratio	59	72

Condition 4

Course sensitivity increased by increasing sideband power until monitor alarmed

Truck Location	Instrument-Truck Readings (μa)
Runway center line	0
2 5° left of center line	188
2.5° right of center line	184

These indicate a course sensitivity of 4 03°

Monitor Readings	Left Meter	Right Meter
On-course directional	58	59
Off-course directional	31 (alarm)	85
Off-course suppressor	61	60
Field ratio	54	66

Condition 5

Course sensitivity decreased by decreasing sideband power until monitor alarmed

Truck Location	Instrument-Truck Readings (μa)
Runway center line	1 left
2 5° left of center line	118
2 5° right of center line	118

These indicate course sensitivity of 6 35°

Monitor Readings	Left Meter	Right Meter
On-course directional	59	55
Off-course directional	89	32 (alarm)
Off-course suppressor	62	59
Field ratio	69	52

Condition 6

The suppressor-antenna carrier power was reduced until the monitor alarmed
Suppressor-antenna carrier power before reduction = 15 5 watts
Suppressor-antenna carrier power after reduction = 8.5 watts

Monitor Readings	Left Meter	Right Meter
On-course directional	58	56
Off-course directional	62	62
Off-course suppressor	32	67
Field ratio	30 (alarm)	87

Thus, the alarm occurred when the suppressor power was reduced to 55 per cent of normal

Condition 7

The directional-antenna carrier power reduced until the monitor alarmed
Directional-antenna carrier power before reduction = 37 watts
Directional-antenna carrier power after reduction = 20 watts

Monitor Readings	Left Meter	Right Meter
On-course directional	54	44
Off-course directional	81	32
Off-course suppressor	64	54
Field ratio	87	31 (alarm)

In this case the alarm occurred when the directional power was reduced to 54 per cent of normal

Another test conducted consisted of driving a large van-type truck in front of the directional antenna at varying distances from the array. The flat side of this van measured approximately 12 feet x 7 feet and, when the cab and engine compartment were included, presented a large reflecting surface On a track parallel to the long dimension of the wave-guide and 25 feet in front of it, the truck caused at the approach end of the runway a course shift of 0 25° which did not affect the monitor appreciably When the truck was driven on a track 50 feet in front of the waveguide, the course shift was 0 12° and probably represents the closest that any reflecting object should be allowed to approach the antenna. The monitor, however, is not able to detect the presence of such reflectors unless they are very close to the monitor dipoles

Another test made on the monitoring system permitted the determination of the position sensitivity of the dipoles feeding the on-course and off-course directional-array detectors One of the dipoles was moved as much as eight inches from the normal position along a line parallel to the long dimension of the waveguide, and only small indications appeared on the monitor alarm panels.

Dipoles at Normal Position	Left Meter	Right Meter
On-course monitor	61	61
Off-course monitor	61	61
One dipole displaced 8 inches		
On-course monitor	64	56
Off-course monitor	64.5	57 5

Movement of one dipole on the other axis (that is, closer to the waveguide) made a large difference in monitor readings, however.

Dipoles in Normal Position	Left Meter	Right Meter
On-course monitor	61	61
Off-course monitor	61	61
One dipole moved 1 inch closer to waveguide		
On-course monitor	67 5	52.5
Off-course monitor	71 5	50
Same dipole moved 2 inches closer to waveguide		
On-course monitor	74	45
Off-course monitor	83	41
Same dipole moved 3 inches closer to waveguide		
On-course monitor	80	39
Off-course monitor	89	34

From the immediately preceding data it can be seen that the position of the dipoles must be held within close limits in the axis perpendicular to the long dimension of the waveguide but that the position in the other axis is not very critical. These dipoles are supported by 4-inch by 4-inch posts set in concrete and have not been affected significantly by frost heaving The reason for the greater position sensitivity in the one axis is that the r-f phase relationship between the signals picked up by the two dipoles is altered and causes the monitor to indicate off-course for the same reason that the length Δ, discussed earlier in this report, simulates an off-course detector Similarly, the lines from the two dipoles must be matched as closely as possible.

An attempt was made to determine the effect of a large bird perched on the end of one of the dipoles in front of the waveguide To simulate this condition, a meter box with dimensions 6 inches by 4 1/2 inches by 3 1/2 inches was hung on the end of one of the directional-array-monitor dipoles. The presence of this box caused an alarm on both the on-course and off-course directional-monitor panels. Another test made consisted of wrapping a wet cloth about two feet square around the end of the dipoles. This loading caused the monitors to read as follows

Condition	Left Meter	Right Meter
On-course directional	46	86
Off-course directional	38	88

These readings did not give an alarm but were so close to alarm that only a small change in the transmissions would have caused an unnecessary alarm. It would seem desirable to provide some protection such as a plastic enclosure around the dipoles against birds

To aid further in the evaluation of the monitor and the localizer itself, two independent receivers were installed at the approach end of the runway, each receiver being equipped with recorders and separate antennas operating on a continuous basis to record course and course sensitivity Each receiver had three dipole antennas associated with it, one located on the runway center line and one on each side, 3/4° from the center line Clock-driven relays switched the receiver inputs sequentially to these antennas, so that the receivers produced continuous course recordings interrupted once an hour by a course-sensitivity measurement

Another aid in the monitor evaluation was the equipping of each monitor alarm panel with plug-in jacks supplying outputs proportional to the r-f level (this connection was brought back from the detector cathode in the Type CA-653 field detectors), the audio level (combined 90- and 150-cps voltages), and the localizer course These outputs were connected to a recorder through a stepping sequential switch which advanced every three minutes This system was operated continuously for more than six months, during which period there were only a few interruptions for modification of the monitor panels. The results of these recordings were compared with the results of the two receiver recordings described earlier, and the conclusion was drawn that the monitor is slightly more sensitive to localizer variations (which were very small) than were the receivers

CONCLUSIONS

As a result of the experience gained during several months of operation of this monitor in conjunction with the 100-foot slotted-waveguide directional localizer at Indianapolis in addition to special tests, it is concluded that

1 The system described adequately protects against all but the most improbable deviations from a normal transmission from both the directional and suppressor arrays.

2 The aperture method of monitoring a wide-aperture array is satisfactory and equivalent to remote-monitor pick-ups, except in the case of a large reflecting object very close to the array (less than 50 feet). On the other hand, the aperture monitor is superior to remote monitors with regard to transient disturbances from low-flying aircraft

3. The monitor is considerably more fail-safe than earlier designs

4 The automatic-gain control used in this monitor is simpler and more stable than d-c amplifier types

5. The monitor is very useful in adjusting the carrier-sideband phasing of the directional localizer

6. The simplicity of design and the fact that all four alarm panels are identical are advantages of considerable economic importance, both with regard to first cost and to maintenance.

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