THE MEASUREMENT OF VOR POLARIZATION ERRORS

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Technical Development Report No 202

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT AND
EVALUATION CENTER
INDIANAPOLIS, INDIANA

May 1953

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THE MEASUREMENT OF VOR POLARIZATION ERRORS

SUMMARY

This report deals with the types, the causes, and the measurement of polarization errors of VHF omnirange stations and describes the development of a method for measuring these errors on the ground Stationary and portable devices for measuring polarization errors are referred to as polariscopes The construction, use, and theory of these polariscopes are described and explained Tests made to determine the effect of the radio-frequency phase angle between the carrier and the vertically polarized component of the sideband signals are discussed There are included examples showing the confirmation by flight tests of polarization errors measured with a polariscope, and suggestions are given for further applications of this device.

INTRODUCTION

Early in the development of the very-high-frequency omnirange (VOR), tests were conducted to determine the most suitable antenna system and type of polarization It was found that a horizontally polarized antenna system was superior to vertically polarized types, and as a result the conventional five-loop antenna array was evolved [1] This array consists of five horizontal loop radiators located at the corners and at the center of a square Diagonally opposite loops are fed 180 degrees out of phase, and the electrical spacing between them is small compared to a wavelength so that a figure-of-eight field pattern results This pattern is rotated by means of a capacity goniometer which is driven by a synchronous motor at 1,800 revolutions per minute (rpm) The rotating goniometer acts as a balanced modulator, eliminating the carrier frequency and supplying sideband energy to the two pairs of loops at carrier frequency ± 30 cycles per second (cps) Since the entire field, in effect, is rotated once for each rotation of the goniometer, it is apparent that each direction in space will have a certain phase of the rotational frequency associated with it and that this phase will change degree for degree with a change in azimuth relative to the station Thus if we have a signal supplying a 30-cps voltage of reference phase, which is independent of azimuth, we can determine azimuth from the station by measuring the phase angle between the two 30-cps signals The reference signal consists of the carrier-frequency amplitude modulated by a 10-kilocycle (kc) subcarrier signal which has been frequency-modulated by a 30-cps signal The purpose of the subcarrier modulation is to provide a means of discriminating between the two 30-cps voltages in the receiver

It has been demonstrated that while the omnirange antenna radiates horizontally polarized energy the supporting pedestals radiate small amounts of vertically polarized energy Other objects such as a poor counterpoise, wires, or trees near the antenna system can produce vertically polarized radiation, however, these conditions can be remedied by proper construction and siting and will not be discussed in this report The vertically polarized energy will produce omnibearings which are in quadrature with true bearing information The vertically polarized field strength of a normal VOR station is approximately five per cent of the horizontally polarized field strength and can produce errors of from 0° to 3° in the aircraft receiver, depending upon the type of aircraft and the receiving-antenna installation

The purpose of this report is to present an explanation of polarization errors and to describe recently developed instrumentation for the measurement of such errors

SOURCES OF POLARIZATION ERRORS

Let us consider the four sideband loops of the VOR antenna See Figs 1 and 2 Energy is fed to these loops from the goniometer The currents produced in the loops are

$$I_1 = I \sin \omega t \sin \rho t \quad (1)$$

$$I_2 = I \sin \omega t \cos \rho t = I \sin \omega t \sin (\rho t + 90°) \quad (2)$$

$$I_3 = -I_1 \quad (3)$$

$$I_4 = -I_2 \quad (4)$$

where

$\frac{\omega}{2\pi}$ = carrier frequency,

$\frac{\rho}{2\pi}$ = modulation frequency (30-cps),

[1] H C Hurley, S R Anderson, and H F Keary, "The CAA VHF Omnirange," CAA Technical Development Report No 113, June 1950

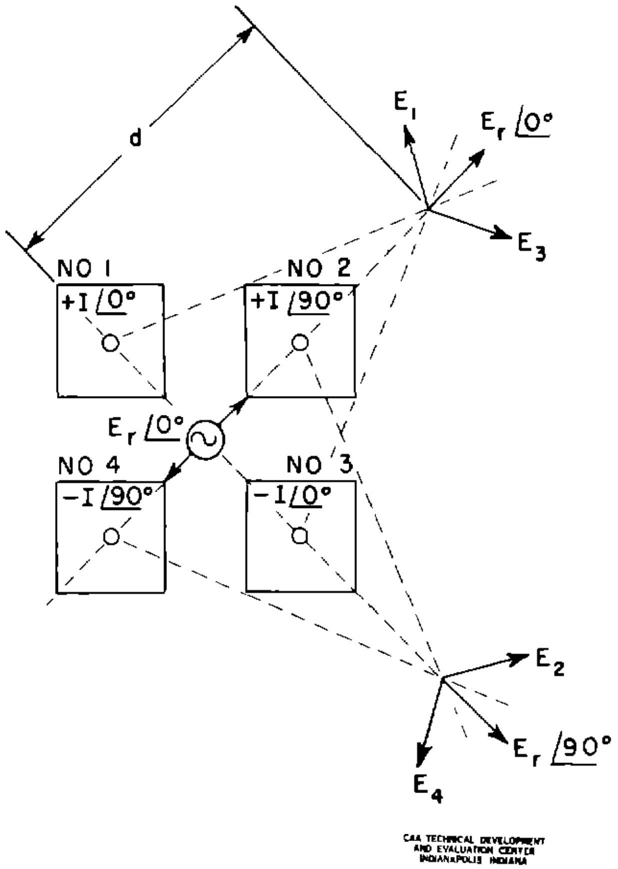

Fig 1 The Sideband Loops and Their Associated Electric Field Vectors The Phase Angles Shown Are of 30 cps

and

t = time in seconds

These currents with their associated 30-cps phase relationships are indicated in Fig 1 The horizontally polarized field patterns produced in space by these currents are indicated by the solid lines in Figs 3A and 3B Fig 3A shows the pattern produced by the currents in loops 1 and 3, and Fig 3B shows the field pattern produced by loops 2 and 4 Since the horizontal electric-field vectors at any point are perpendicular to a line through the point in question from the loops producing them, there is a cancellation of fields on a line perpendicular to one connecting the centers of a pair of loops This cancellation is almost complete when the distance d is large compared with the spacing of the loops, however, the resultant vector increases as the distance d is decreased

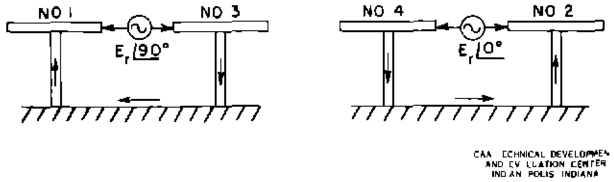

Fig 2 Current Paths Producing Vertically Polarized Radiation

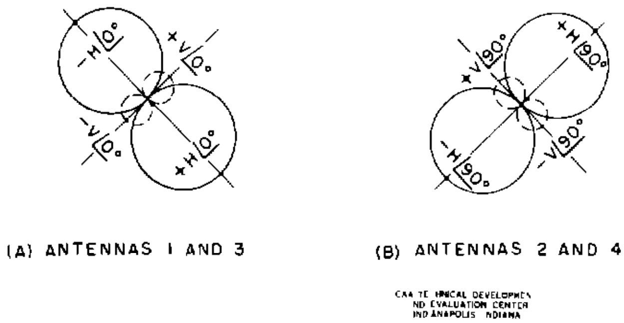

Fig 3 Vertically and Horizontally Polarized Field Patterns Produced in Space

This is shown in Fig 1, where E_1 and E_3 are vectors representing the electric fields produced by loops 1 and 3 respectively and E_r at 0° phase angle (/0°) is the resultant of E_1 and E_3 This resultant voltage may be thought of as a generator connected between antennas 2 and 4, as shown in Figs 1 and 2 It causes currents to flow through the loop pedestals and the base plate as shown in Fig 2 This flow of current results in a vertically polarized field pattern that is in phase at the 30-cps frequency but in quadrature in space with the horizontally polarized radiation which produced it, as shown in Fig 3A Similarly, loops 2 and 4 produce a vertically polarized field pattern in quadrature with their associated horizontally polarized radiation patterns Hence it can be seen that the vertically polarized radiation from the loops produces an omnibearing in quadrature with the one produced by the horizontally polarized radiation, thereby introducing errors termed polarization errors If an omnirange station radiated pure horizontally polarized energy, no polarization error would be experienced

Various attempts have been made to eliminate this source of vertically polarized radiation Replacement of the metal pedestals with nonmetallic material was of no value, since the RG-8/U cables feeding the loops acted as vertical radiators The original installation was found to be the most practical one, producing the least amount of vertically polarized radiation

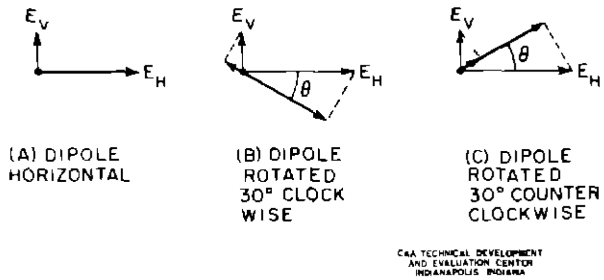

Fig 4 Components of Voltage Induced Into a Dipole Antenna by Vertically and Horizontally Polarized Radiation

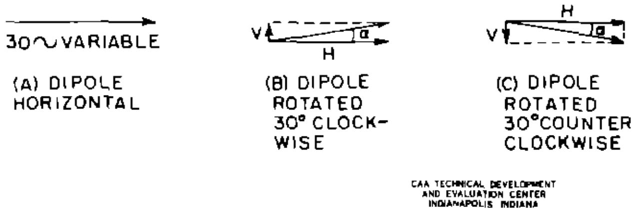

Fig 5 Attitude Error Produced by Vertically Polarized Signal Containing Bearing Information in Quadrature to the Correct Bearing Information Contained by the Horizontally Polarized Signal

A decided improvement in the polarization error of the five-loop array was experienced by placing Uskon cloth around the loop pedestals as a group [2]

If an aircraft equipped with an omnirange receiver is flown over a fixed checkpoint on the ground at a number of different headings, the indicated omnibearing may be found to vary with the heading The aircraft has only one correct omnibearing when over the ground checkpoint, and this bearing is independent of heading The change in the omnibearing with the change in heading is one form of polarization error and is referred to as push-pull error The aircraft receives the signal primarily from the horizontally polarized wave, however, as the heading is changed the amplitude and the phase of the vertically polarized signal and of the horizontally polarized signal vary and produce different omnibearing indications This is readily understood when considering the method by which the vertically polarized radiation that contains the erroneous bearing information gets into the horizontal receiving antenna mounted on the airplane If the horizontal receiving antenna were in free space without any metallic objects close by, no push-pull error would be experienced However, the vertically polarized energy induces currents in the skin or metal structure of the airplane This energy is reflected from the airplane at random polarization, the horizontal component of which is accepted by the receiving antenna Errors are thus introduced into the bearing indication The amplitude and phase of the reradiated energy is a function of the shape, material, and position of the reflecting surfaces of the aircraft. The points of reflection and the radio-frequency (r-f) currents in the skin of the aircraft change when the heading is changed, hence, the error produced by the vertically polarized radiation changes with the heading Polarization errors, in general, vary with the type of aircraft and with the location of the receiving antenna on it

Another form of polarization error occurs when an aircraft is in a banked attitude Under these conditions, the indicated omnibearing may change even though the heading of the airplane is unchanged This type of polarization error is known as an attitude error This effect may be demonstrated by guiding an airplane toward a station and rocking the wings to the left and right while holding the nose at a constant heading Attitude error may be explained by neglecting all reflection or reradiation effects due to the proximity of the airplane and by considering a dipole in free space When the receiving antenna is horizontal and perpendicular to a radial from the station, it picks up no vertically polarized radiation, and, therefore, the correct bearing to the station is indicated When the dipole is tilted to the left or right, (1) it is receptive to vertically polarized radiation as expressed by $E_v \sin \theta$ and (2) it is receptive to horizontally polarized radiation as expressed by $E_h \cos \theta$ In the first case, E_v is the field strength of the vertical wave, in the second, E_h is that of the horizontal wave, and in both cases, θ is the angle of tilt from the horizontal position Fig 4 shows these relationships for $\theta = 0°$, $-30°$, and $+30°$ Examination of Figs 4B and 4C shows that the voltage induced in the tilted dipole by the vertical wave is in phase with the voltage from the horizontal wave for counterclockwise rotation of the antenna and out of phase for clockwise rotation Hence, the phase of the voltage produced in the antenna by the vertically polarized radiation changes by 180° relative to the voltage produced by the horizontally polarized radiation It is assumed that the voltage produced by the horizontally polarized wave contains the correct bearing information previously discussed Fig 5 shows the bearings indicated by the receiver for level flight and for banks to the

[2] Ibid , p 56

Fig 6 Laboratory Polariscope Antennas

left and right It can be seen that the effect of the 180° reversal of the vertical signal causes positive error when the airplane is banked one way and negative error when banked the other way The magnitude of the error will depend upon the degree of the bank and upon the magnitude and phase of the vertically polarized energy at the receiving antenna

Both forms of polarization error may be demonstrated simultaneously when an aircraft is flown in circles at a distance over a point of known bearing from the VOR station Both push-pull and attitude errors then affect the receiver in varying degrees, depending on the position and attitude of the aircraft This is the more general case that is experienced in the normal use of omnirange navigation facilities

If the amount of vertically polarized energy from the transmitting antenna can be reduced, the observed polarization errors will be reduced proportionately

In order to study the causes and effects of the vertically polarized radiation, an accurate measuring device was required The polariscope was developed to aid in the study, measurement, and reduction of these polarization errors

THE LABORATORY POLARISCOPE

A view of the laboratory polariscope is shown in Fig 6 It consists of a horizontal dipole antenna fixed perpendicular to one end of a 12-foot aluminum channel A vertical dipole is mounted on a dolly which can be moved along the aluminum channel by a system of cables and pulleys The distance between the vertical and horizontal dipoles can be read directly on a scale which is scribed on the channel The lengths of both dipoles were cut for operation at the middle of the omnirange band, 115 megacycles (Mc) The entire assembly is supported on a wooden frame 6 1/2 feet above a metal rotatable counterpoise which forms the roof of the TDEC antenna laboratory Both dipoles were connected to RG-22/U balanced r-f cables laid in the slot of the aluminum channel The cables were brought down the end of the channel opposite the horizontal dipole and through the counterpoise into the laboratory It was necessary to keep the vertical antenna at least 5 feet from the vertical section of cables in order to minimize mutual coupling The cables were carefully prepared so that they would be of equal electrical length

The receiving and measuring equipment consisted of a Bendix ARN-14 navigational receiver installed with the course deviation indicator circuit which is connected to a microammeter which indicates zero current when centered and registers 150 microamperes (μa) left or right This is designated as a 150-0-150 microammeter The cables from the polariscope dipoles were connected to a tee fitting mounted on a balance-to-unbalance r-f transformer which in turn is mounted on the antenna receptacle of the receiver A schematic diagram of the polariscope is shown in Fig 7

Using the Laboratory Polariscope

To measure the polarization error of an omnirange station with the laboratory polariscope, only the horizontal dipole is connected to the receiver, and the counterpoise and polariscope are rotated until the horizontal dipole is perpendicular to a radial from the station The omnibearing selector is rotated until the microammeter pointer is centered on zero This determines the bearing information contained in the horizontally polarized signal from the station The omnibearing selector is then rotated five degrees each side of the on-course indication, and the microammeter readings are noted The sum of the readings divided by ten gives the sensitivity of the system in microamperes per degree

For example, if the on-course indication is found at 228° on the omnibearing selector, the selector is then rotated to 223° and the microammeter reads -97 μa, the selector is then rotated to 233° and the microammeter reads + 101 µa The sensitivity of the receiving equipment is

$$\frac{97 + 101}{10} = 19\ 8\ \mu a \text{ per degree}$$

After the sensitivity is computed, the cables from the vertical and horizontal dipoles are plugged into the tee fitting at the receiver The position of the vertical dipole is then adjusted to produce maximum deflection of the microammeter pointer This reading is recorded as Test 1

The vertical dipole cable is then removed, turned over (connections reversed), and reinserted into the tee fitting This causes the microammeter to be deflected in the opposite direction This reading is recorded as Test 2 The distance between the vertical and horizontal dipoles is recorded as an indication of the r-f phase angle between the vertically and horizontally polarized radiation from the station The microammeter readings are then converted to degrees of error by dividing the readings by the sensitivity The sensitivity should be checked every few minutes to compensate for any receiver variations

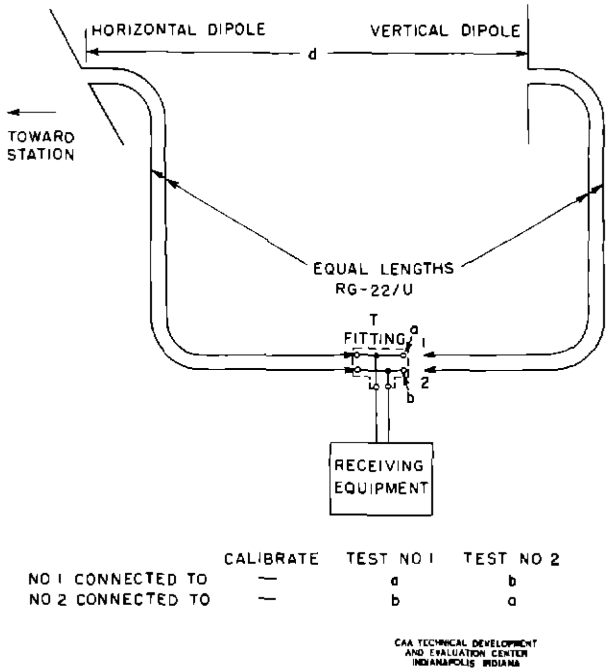

Fig 7 Sketch of Antenna Laboratory Polariscope

THE PORTABLE POLARISCOPE

In order to measure the polarization error of omnirange stations which are beyond the range of the laboratory polariscope, portable equipment capable of being quickly assembled and disassembled for portability was designed Fig 8 shows the instrument assembled at a field location and ready for use The control and measuring equipment are located in the instrument truck, as illustrated in Fig 9 The disassembled polariscope units are shown in Fig 10

The horizontal support consists of three 5-foot sections of 1 1/2-inch brass tubing The outer sections are designed for easy attachment of the dipole elements, and the RG-8/U coaxial cables are also sectionalized and carried within the brass tubing The whole assembly is supported 6 1/2 feet above the ground by means of four detachable wooden legs A wiring diagram of the polariscope is shown in Fig 11 Construction details of the dipole end of the horizontal support are shown in Fig 12

The device is equivalent to the laboratory polariscope, except that the vertical dipole cannot be moved relative to the horizontal dipole to get maximum error indication This function is accomplished by the use of a phaser made of rigid, air-dielectric, 52-ohm, adjustable coaxial line By connecting the phaser in series with the cable from the vertical dipole, it is possible to change the phase of the voltage at the receiver terminals by more than 180° The equivalent of reversing cable terminals for Test 2 is accomplished by switching 180° of additional line into the vertical dipole circuit by means of two single-pole, double-throw coaxial relays The vertical dipole is disconnected from the receiver for calibration and sensitivity checks by another coaxial relay, as shown in the wiring diagram A three-position switch S-1 marked CALIBRATE, TEST 1, TEST 2 was used to operate the relays for these switching operations

The isolation attenuators were necessary to reduce the effects of the standing waves produced by the mismatch at the receiver end of the transmission lines This mismatch was variable and unavoidable because of the changing input impedance of the receiver at various frequencies and because of the variable load produced by adjusting the phaser

Fig 13 shows an equivalent circuit of the portable polariscope The generator of 72 ohms of internal impedance is connected between points a and b and is equivalent to the vertical dipole Similarly, the generator of 72 ohms of internal impedance is connected between points e and f and is equivalent to the horizontal dipole The impedance mismatch between the generators and the transmission lines produces a 1 38 voltage

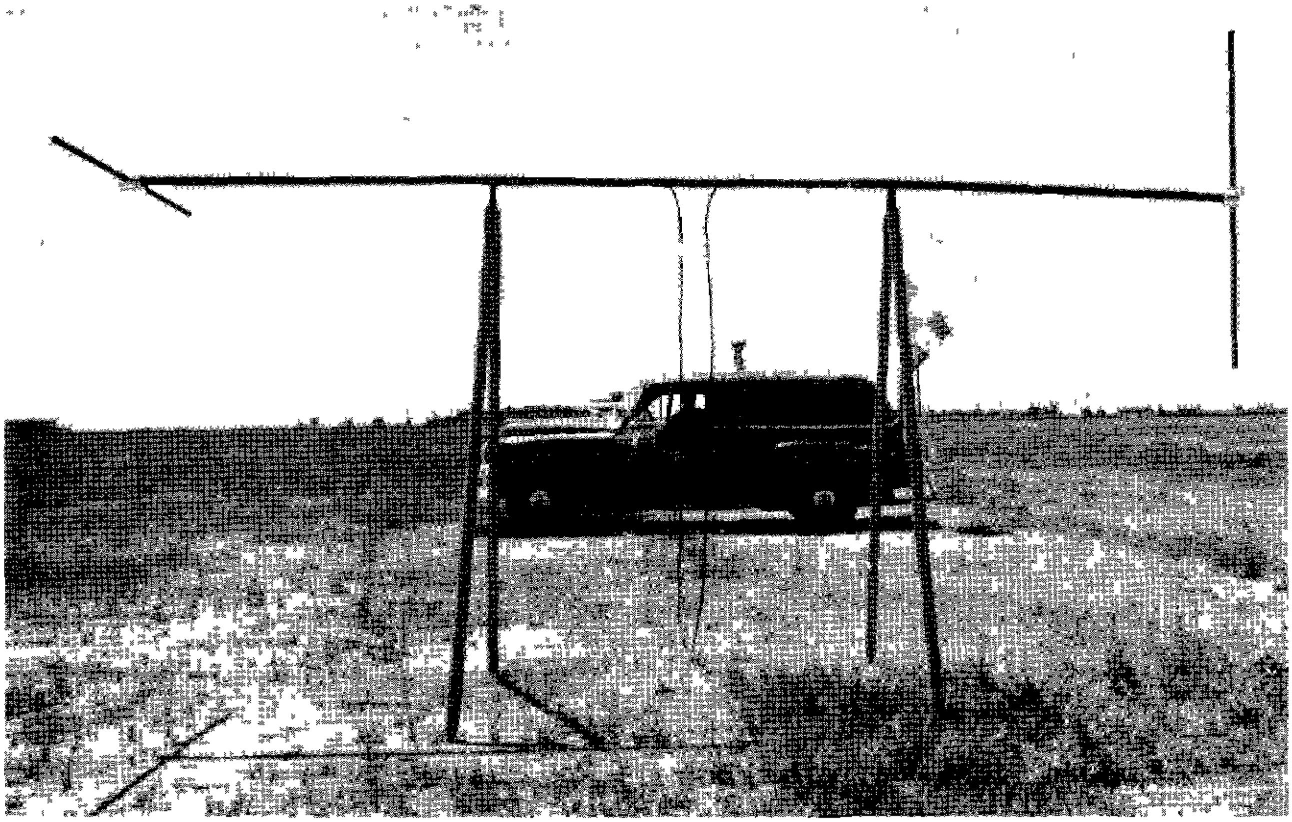

Fig 8 Portable Polariscope in Use

Fig 9 Portable Polariscope Installation in Instrument Truck

standing-wave ratio on the line This mismatch is not considered serious However, the impedance at points c and d looking from either dipole is approximately 25 ohms and may have a reactive component This would produce a serious standing wave It is necessary that the voltage produced at the receiver terminals by each dipole be proportional to the voltage induced in the dipoles by the received signals This condition must hold for all line lengths from the vertical dipole If there is a high standing-wave ratio at the phaser, the voltage at the receiver input will vary with the phaser settings By inserting the attenuators in the positions shown in Fig 13, the impedance seen by the phaser at points g and h is very close to 52 ohms, regardless of the load connected at points c and d The attenuators which were used consisted of 50 feet of RG-21A/U coaxial cable having 52 ohms characteristic impedance and an attenuation of about 15 decibels (db) per 100 feet Under these conditions, the voltage at the receiver due to the vertical dipole was found to be independent of phaser settings A similar attenuator is necessary in the horizontal-dipole feed line, so that the voltages produced at the receiver terminals

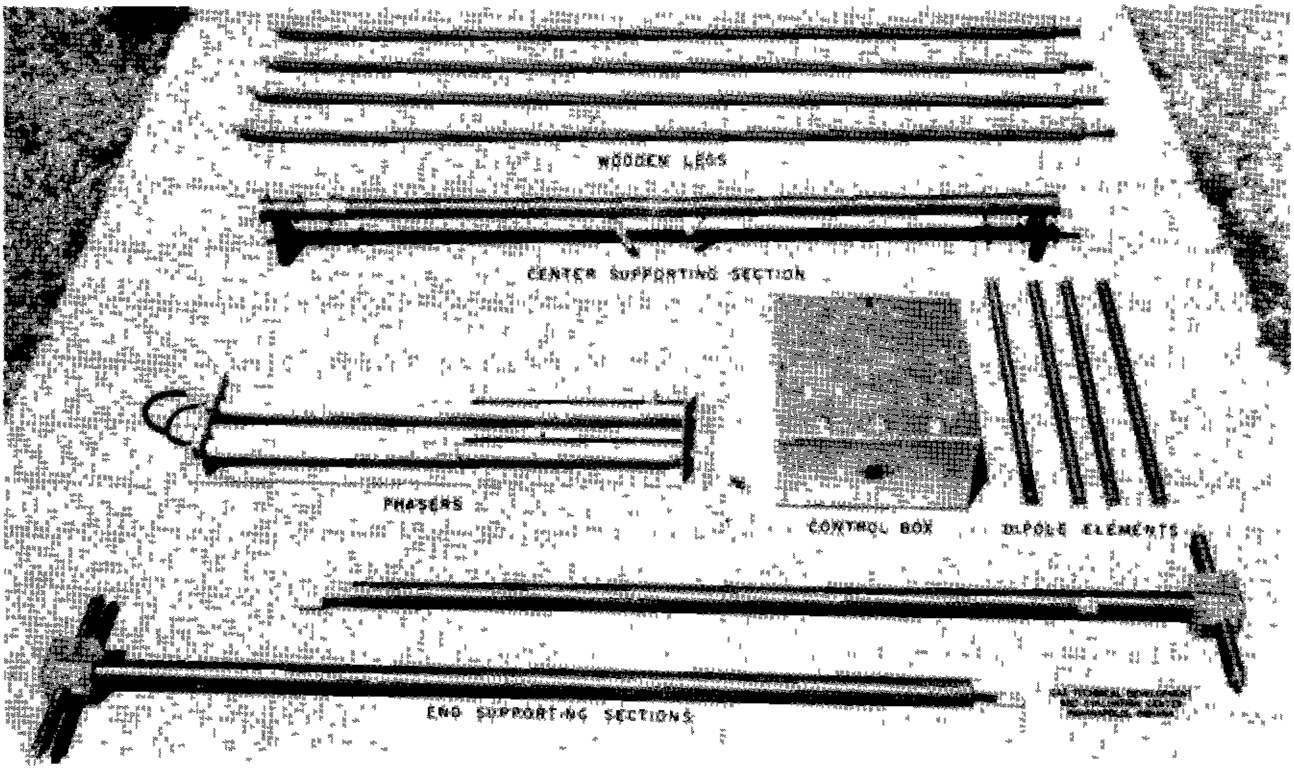

Fig 10 Portable Polariscope Components

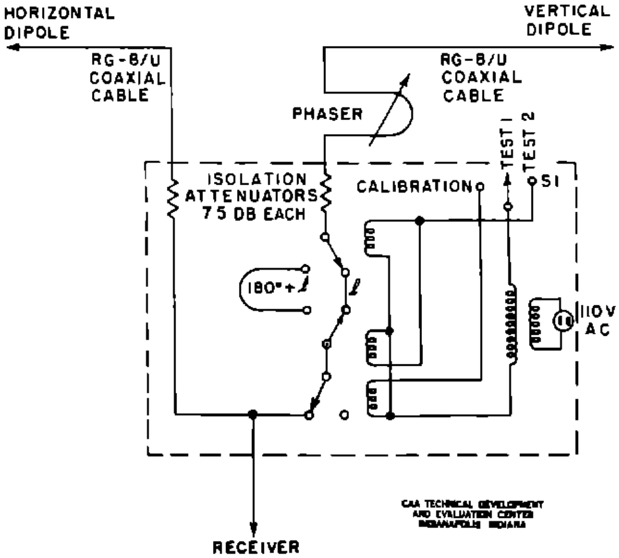

Fig 11 Wiring Diagram of Control Box

are proportional to the voltages induced in the dipole Commercial attenuators having 52-ohm input and output impedances and 6-db attenuation were tested in this application with satisfactory results Such attenuators are recommended in place of the more bulky RG-21A/U coaxial cable

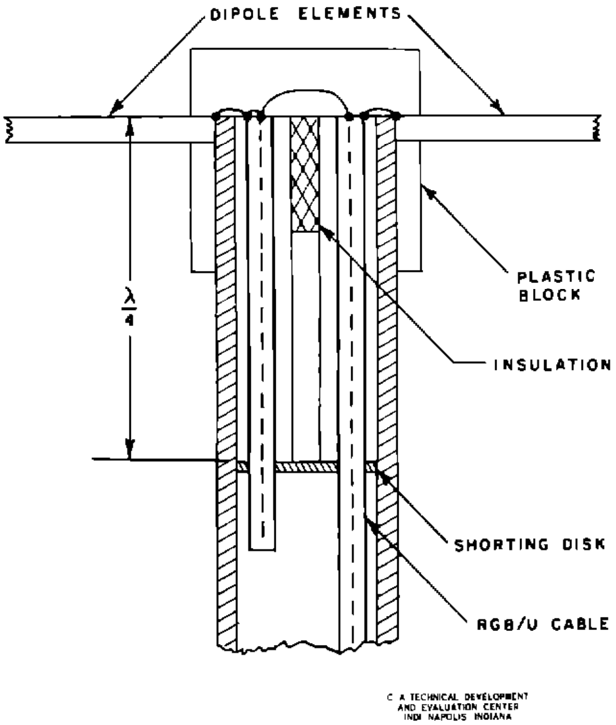

Fig 12 Construction of Portable Polariscope Dipoles

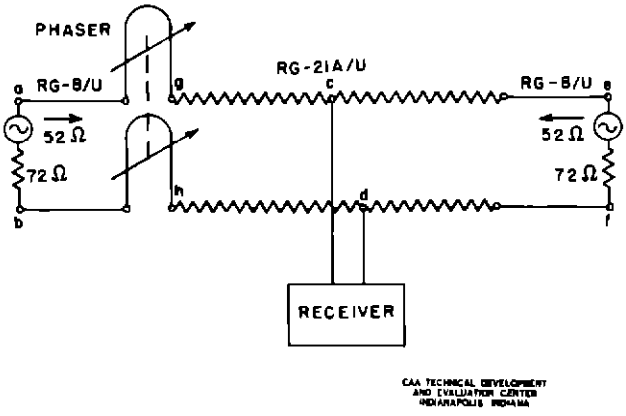

Fig 13 Equivalent Circuit of Portable Polariscope

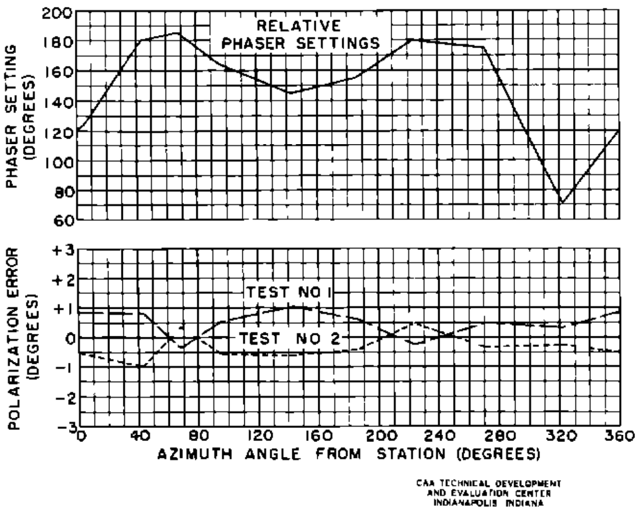

Fig 14 Polarization Error at Tilden VOR

Using the Portable Polariscope

The equipment required for using the portable polariscope in the field includes the portable antenna assembly, two 30-foot lengths of RG-8/U coaxial cable, phaser, control box, a navigational receiver with a 150-0-150 microammeter connected in parallel with the course deviation indicator, and a small, 60-cps, 110-volt generator to operate the equipment A Bendix Type MN-85BA navigational receiver and power supply together with a 110-volt, 60-cps motor generator set, battery chargers, and 28-volt batteries were permanently installed in a panel truck for use with the portable polariscope This made a self-contained mobile unit that could be used wherever it was possible to drive the truck

To measure the polarization error of a VOR station, a site was selected more than 500 feet and less than three miles from the station The antenna assembly was set up as shown in Fig 8, with the dipole supporting section along a radial from the station and the horizontal-dipole end toward the station The truck was parked parallel to the antenna supporting section at a distance of 30 feet

As shown in Fig. 11, switch S-1 on the control box was placed in the CALIBRATE position and the bearing FROM the station was determined and recorded The sensitivity was then determined by the same method used with the laboratory polariscope S-1 was then placed in the TEST 1 position, and the phaser was adjusted for maximum deflection of the microammeter The microammeter reading and the phaser setting were recorded as Test 1 The switch was then placed in the TEST 2 position, and the phaser was adjusted for maximum microammeter deflection These readings and the phaser setting were recorded as Test 2 The phaser position found for Test 1 and Test 2 should be very nearly equal

Fig 14 shows a plot of the polarization error measured at various points in azimuth around an omnirange station

The polariscope readings compare closely with the polarization-error measurements obtained in flight Polarization-error measurements were conducted in a Douglas C-47 aircraft approximately 20 miles from the VOR station at an altitude of 1,000 feet above ground and using a navigational receiver and a tail-mounted VOR receiving antenna A description of the tests follows

1 30° Wing Rock

Heading toward the station, the aircraft is banked ± 30° The nose of the aircraft is held at a constant heading during this maneuver The course-deviation-indicator current is recorded and converted to degrees of course displacement

2 Eight Ways Over a Ground Checkpoint

While the course-deviation-indicator current is being recorded, the aircraft is flown on eight different headings (a daisy pattern which crosses a point at every 45° heading) over a specific ground checkpoint The recording is marked as the plane crosses the checkpoint, and the indicated bearing is compared with the magnetic bearing The zero reference point is taken on the heading to the station

3 360° Circle

With the airplane headed toward the station and the tests started from a ground

TABLE I

COMPARISON OF POLARIZATION ERRORS MEASURED BOTH ON THE GROUND AND IN AIRCRAFT

Bearing	Aircraft Tests			Polariscope Test
	8-Ways	30° Wing Rock	360° Circle	
(degrees)	(degrees)	(degrees)	(degrees)	(degrees)
322	± 0 56	± 0 16	± 1 37	± 0 61
272	± 0 375	± 0 06	± 0 52	± 0 23
272*	± 0 375*	± 0 75*	± 1 72*	± 2 38*

*Error deliberately increased

checkpoint, a 360° circle is flown at a constant 30° bank The course-deviation current is recorded during this circle and converted into degrees of error from the azimuth course which was flown at the beginning of the circle Since the aircraft in the 360° circle changes azimuth with respect to the VOR, this deviation is computed in degrees and subtracted from the course-deviation-indicated error Subtraction of the known error results in the numerical value of polarization error

Table I shows the errors measured at a four-loop omnirange station [3] This information was obtained to show a comparison between polarization errors measured both on the ground and in aircraft Measurements were made along the same radial from the VOR and at approximately the same time The aircraft and ground measurements were expected to agree in direction of change but not in magnitude, because the polarization error varies with the type of aircraft and with the location of the receiving antenna on the aircraft No attempt was made in designing the polariscope to make its readings agree in magnitude with the aircraft measurements of polarization error

The table shows that the ground measurements agree in trend but not in absolute magnitude with the aircraft 30° wing-rock measurement Results show that the polariscope measurements changed from 0 61° to 0 23°, a ratio of 1 to 0 377, while the 30° wing-rock measurements changed from 0 16° to 0 06°, a ratio of 1 to 0 375 Again the polariscope measurements changed from 0 23° to 2 38°, a ratio of 1 to 10 35, while the 30° wing-rock measurements changed from 0 06° to 0 75°, a ratio of 1 to 12 5 The eight-ways test and the 360° circle test changed in the same direction as the 30° wing-rock test but not in the same amount

[3] S R Anderson, H F Keary, and W L Wright, "The Four-Loop VOR Antenna," CAA Technical Development Report not yet published

TESTS OF CONTROLLED POLARIZATION ERROR

In order to study the effects of vertically polarized radiation which has various magnitudes and phase angles and which is from an omnirange antenna array, the system shown in Fig 15 was installed A single horizontal loop radiated carrier and sideband energy in such a manner that a fixed bearing was obtained at any point in azimuth The phase relationship between the reference and variable signals radiated from the loop was the same at all points in space This relationship was held constant during all the tests A vertically polarized antenna was fed from the No 2 output of the goniometer and contained sideband energy which was in quadrature with the 30-cps energy fed to the loop antenna The feed line from the goniometer to the vertical antenna contained a tapped, shorted quarter-wave transformer and 50 feet of RG-21A/U in order to reduce the power It also contained a phaser which made it possible to vary throughout a range of 200 degrees the r-f phase of the energy fed to the vertical antenna with respect to the carrier With this feed system it was

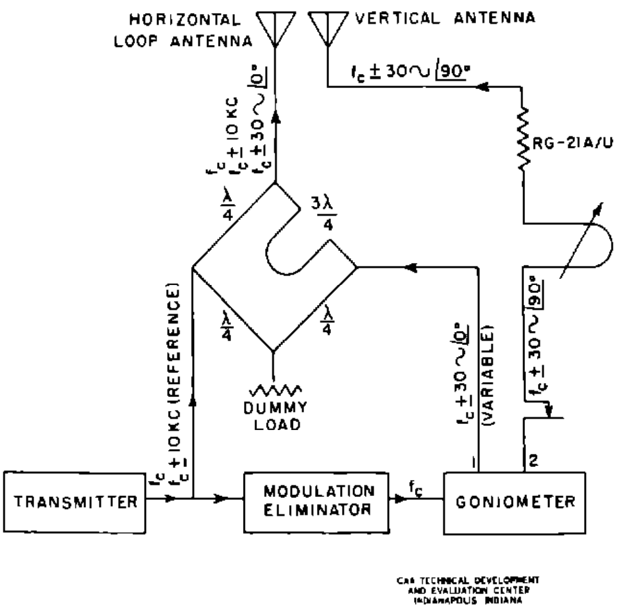

Fig 15 Polarization Error Test Installation

possible to adjust the magnitude and r-f phase of the sideband energy radiated from the vertical antenna

This installation satisfied all the requirements to produce various magnitudes of polarization error The loop antenna and the vertical antenna were installed so that their vertical axes coincided, thereby producing fixed patterns of uniform relative phase in all directions of azimuth Tests made with a field-strength meter showed that the ratio of horizontally to vertically polarized radiation from the horizontal loop was approximately 15 to 1 The ratio of vertically to horizontally polarized radiation from the vertical antenna was approximately 20 to 1 When only the loop antenna was excited, no polarization error could be measured in an airplane or with the polariscope When a small amount of power was applied to the vertical antenna, polarization error was immediately noticeable both in an airplane and with the polariscope This error was proportional to the voltage applied to the vertical antenna

Previous attempts to reduce polarization errors had indicated that the r-f phase angle between the horizontally and vertically polarized radiation had a direct relationship to the amount of polarization error experienced in aircraft Further investigation of this hypothesis was conducted, using the system shown in Fig 15 The amount of power fed to the vertical antenna was adjusted to produce a polarization error of ± 4 5° This was produced with a power ratio of about 40 to 1 between the vertical antenna and the sideband power in the horizontal loop Aircraft with three different types of receiving-antenna installations were flown on eight different headings over a point, and the phaser in series with the vertical antenna was changed through 200° for each heading The course-deviation-indicator voltage was recorded for each phaser setting Figs 16A, B, C, and D are plots of push-pull error versus the phaser setting recorded in the aircraft for flights in the cardinal directions These curves seem to indicate that between the vertically and horizontally polarized waves there is not a single r-f phase relationship that produces minimum polarization error for all types of aircraft and receiving-antenna installations The error produced in the receiver is dependent upon the characteristics of the receiving antenna as well as upon the signals produced at the omnirange station. However, reducing the magnitude of the vertically polarized radiation from the station will reduce the polarization error indicated by an aircraft receiver

Extensive tests were conducted with the portable polariscope to determine the effect of the proximity of fences, power lines, and the instrument truck It was found that acceptable readings can be obtained if the antenna assembly is located not less than 20 feet from low wire fences and 200 feet from overhead wires Greater proximity usually increased the amount of polarization error observed It was found that the instrument truck had least effect when parked parallel to the antenna supporting sections Thirty feet of separation between the truck and the antenna assembly was found to be adequate to eliminate any proximity effect It was also necessary to be within the line of sight of the omnirange antenna to obtain reliable readings

A method of checking the portable polariscope equipment without using auxiliary instruments was devised To make the following tests, it was necessary to modify the navigational receiver by putting a milliammeter in the cathode circuit of the first r-f stage The readings on this meter were a function of the signal strength present at the receiver-antenna terminals To check the equality of the electrical characteristics of the two antennas, they were installed one at a time in the horizontal antenna position with their feed lines connected directly to the receiver The milliammeter readings should be the same with either antenna connected With one antenna installed in the horizontal position and the control box, phaser, and receiver connected in the usual manner, the feed line from the antenna was connected

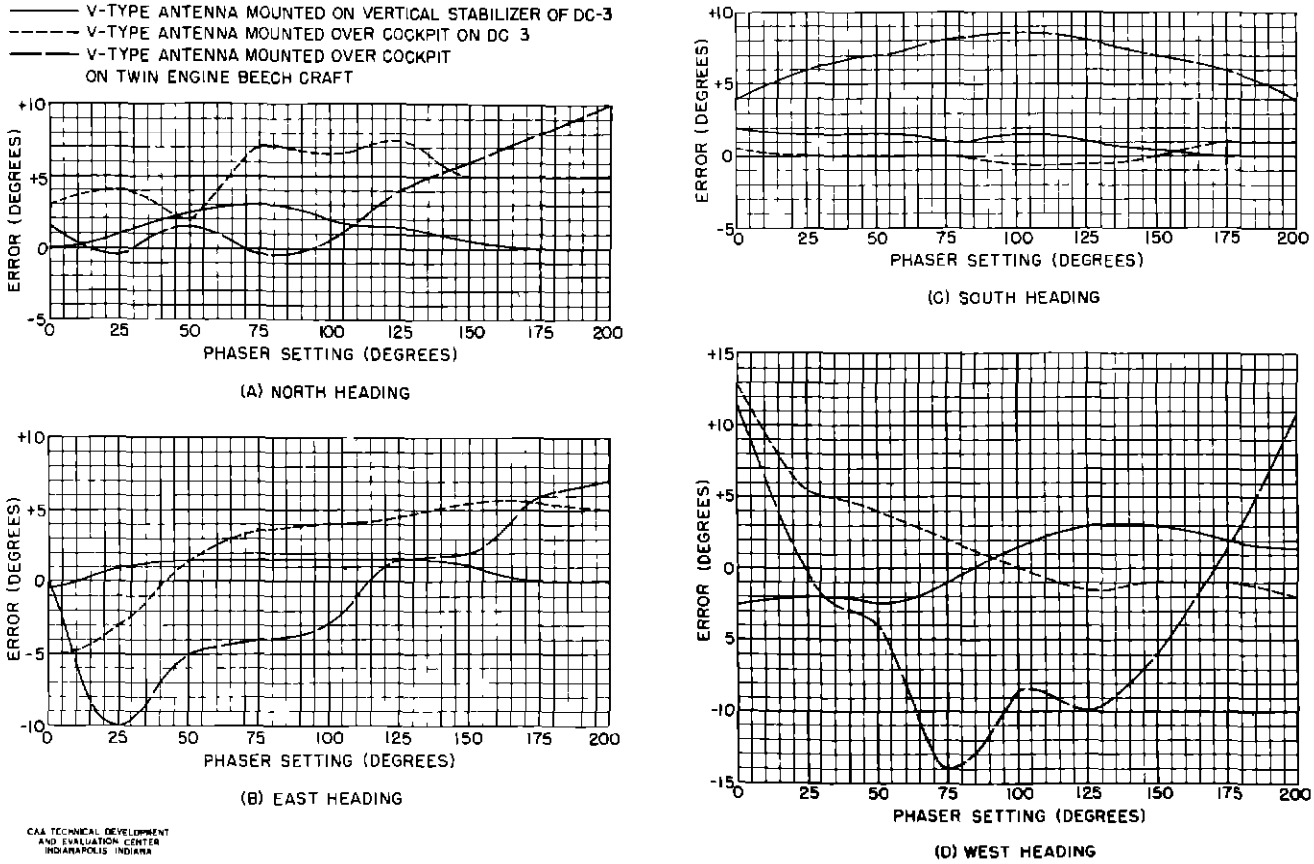

Fig 16 Push-Pull Errors Versus Phaser Settings

first to the phaser and then to the horizontal input of the control box The milliammeter readings obtained in these tests were very nearly equal but higher than those obtained when the attenuators were not in the circuit Moving the phaser settings and switching from Test 1 to Test 2 positions did not produce large changes in the milliammeter readings By analyzing the results of the foregoing tests, it was possible to locate trouble that might be present in the portable polariscope equipment

ANALYSIS OF THE POLARISCOPE

The antenna system used with the laboratory and portable polariscopes is the equivalent of a dipole antenna tilted at 45° and with a means of varying the r-f phase angle between the vertically and horizontally polarized components A dipole in space tilted at 45° is capable of receiving vertically or horizontally polarized radiation equally well The same is true of the polariscope antennas The phase angle between the vertical and horizontal waves is directly related to the spacing between the polariscope dipoles required for a maximum deflection of the course deviation indicator or of the microammeter As previously explained in this report, the vertically polarized radiation which causes bearing error is the 30-cps amplitude-modulated sideband energy, the audio phase of which is in quadrature with the desired 30-cps sideband energy containing the correct bearing information The r-f phase of this vertically polarized sideband radiation may be at any phase angle with the carrier

To produce maximum effect in a receiver, the carrier and sideband radiations must be in the proper r-f phase with each other This is shown vectorially in Fig 17 The equation of an amplitude-modulated wave may be written as

$$e = E_0 \sin 2\pi f t + E_0 m \sin 2\pi f t \sin 2\pi f_s t \quad (5)$$

The first component of Equation (5) is the carrier frequency, and the second component is an expression for the sidebands A

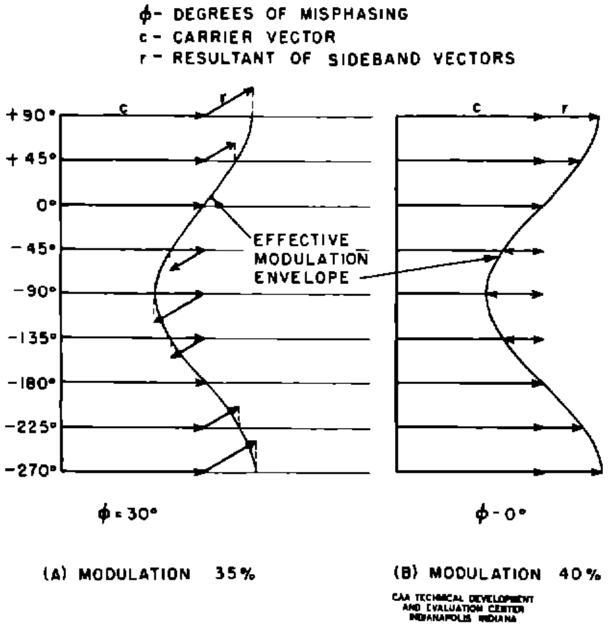

Fig 17 Effect of Phase Angle on the Depth of Modulation

more general expression for the sideband components is

$$E_0 m \sin(2\pi f t + \phi) \sin 2\pi f_s t \qquad (6)$$

where ϕ is the angle between the carrier vector and the resultant of the sideband vectors When ϕ has any value other than 0° or 180°, the effective depth of modulation of the radiated wave is reduced as shown in Fig 17 because the detector in the receiver responds only to the component of the vector r that is in line with the carrier vector c

By use of the polariscope, it is possible to measure the phase angle ϕ Consider, for example, that the vertically polarized sideband energy leads the carrier by an angle of 30° The carrier signal is picked up by the horizontal antenna of the polariscope, and the sideband signal is picked up by the vertical antenna Since the two antennas are in the same plane, the voltage produced at the receiver where the two signals are mixed will also have the same 30° phase angle and will not produce maximum depth of modulation, as is shown in Fig 17A If the spacing between the vertical and horizontal antennas of the polariscope is adjusted or if the length of one of the feed lines is changed, it is possible to have the two signals arrive at the receiver in phase and thereby have the maximum effect The error measured with the polariscope then represents the maximum attitude error an aircraft could experience when banked 45°

It should be noted that the sideband energy which contains the correct bearing information is received by the horizontal antenna of the polariscope along with the carrier and reference signals The vertically polarized sideband energy contains bearing information which is in quadrature with that contained in the horizontally polarized radiation When the vertically polarized signal is properly phased by adjusting the polariscope, it produces its maximum amount of error in one direction When its phase is changed 180° by reversing the cable connections or by adding 180° of r-f transmission line, the vertically polarized sideband radiation produces its maximum effect in the opposite direction This is the equivalent of rocking an aircraft from a 45° bank in one direction to a 45° bank in the opposite direction Such readings are recorded as Test 1 and Test 2 on the polariscopes

CONCLUSIONS

The polariscope was originally developed as a tool to aid in the development of a new VOR antenna array, however, its use is not limited to this application It is a valuable tool for measuring the relative amplitude and phase of vertically and horizontally polarized radio signals from any source The portable polariscope provides a convenient, economical method of measuring polarization errors on any radial from an omnirange station, and its use is invaluable when adjustments or repairs are made at a station in an attempt to reduce polarization error Its use has eliminated much costly and time-consuming flight testing

The results obtained with both the laboratory and portable polariscopes indicate that the amount of polarization error produced by an omnirange station can be accurately measured These results have been substantiated by flight tests

The tests reported indicate that, between the carrier and the vertically polarized sideband energy, there is no optimum phase angle which produces minimum polarization error for various types of aircraft and receiving-antenna installations

GPO 81-105329