CAA TYPE I COURSE LINE COMPUTER

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SUMMARY

The CAA Type I Course Line Computer was designed and built at the Technical Development and Evaluation Center It was installed in a DC-3 type airplane in August 1948 and is still being used for test demonstration purposes

This report discusses the principles of operation, the details of the circuits used and the calibration and adjustments required to make the Type I Course Line Computer operable Also, discussion of the theory of basic computers which lead to the design of the Type I Course Line Computer, and methods of modifying the computer to use two bearings or two distances are presented and discussed

INTRODUCTION

With the conception of distance measuring and omnirange equipments, it was realized that data were available to operate a device which would provide guidance and distance information to a point remote from the radio station and that such a device could be very useful The DME and omnirange provided an airplane with a fix with respect to the radio station, but unless the course were along a radial to or from the radio station, there was no direct indication as to whether or not a desired course was being made good, or of the distance to a desired destination or waypoint The course line computer provides such information When the co-ordinates of a waypoint remote from a radio station are set into the course line computer, and the course-heading control is set to the bearing of the desired course, the course deviation indicator provides guidance along the selected course and the "distance-to-go" meter indicates distance to the selected waypoint Also, when the co-ordinates of a waypoint have been set into the computer, the course-heading control functions in a manner similar to the omnibearing selector The straight line from the airplane to the remote point may be determined by turning the course-heading control until the course deviation indicator is centered The magnetic bearing from the airplane to the waypoint may be read from the course-heading control, and the distance from the airplane to the waypoint may be read from the "distance-to-go" indicator

The first working airborne model of course line computer was built by Minneapolis-Honeywell Regulator Co on contract with the CAA Technical Development and Evaluation Center This model was built using components immediately available without regard to weight It performed satisfactorily and with a precision nearly equal to the CAA Type I Course Line Computer[1] The Collins Radio Co produced the first course line computer designed for commercial use

RTCA Special Committee No 31 on Air Traffic Control recognized the value of course line computers That committee recommended that tests and development be completed so that computers would be ready for general use by 1951 In line with that recommendation, to establish a minimum state of the art with respect to the manner of setting in the data and presentation of indications, and to arrive at some reasonable size and weight requirements for an airborne computer, the TDEC has been actively investigating the computers built by various manufacturers, and has built one developmental model — the CAA Type I Course Line Computer, which is the subject of this report

THEORY OF OPERATION

Operation of the CAA Type I Course Line Computer

The CAA Type I Course Line Computer requires that three pieces of geographic data be manually set in These are the polar co-ordinates of the desired destination with respect to the radio station and the magnetic bearing of the desired course The co-ordinates are designated as the destination-distance co-ordinate and destination-azimuth co-ordinate The destination co-ordinates are derived from a map before the computed course is flown, and are set into the computer on the appropriate dials The bearing of the desired course is set on the course-heading dial The distance measuring equipment and omnirange receivers are turned on and tuned to the desired station and the output of the omnirange receiver is switched to the computer The computer has the distance and direction from the airplane to the radio station servoed into it continuously This

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[1] Francis J Gross and Hugh A Kay, "Initial Flight Tests and Theory of an Experimental Parallel Course Computer", Technical Development Report No 83, dated September 1948

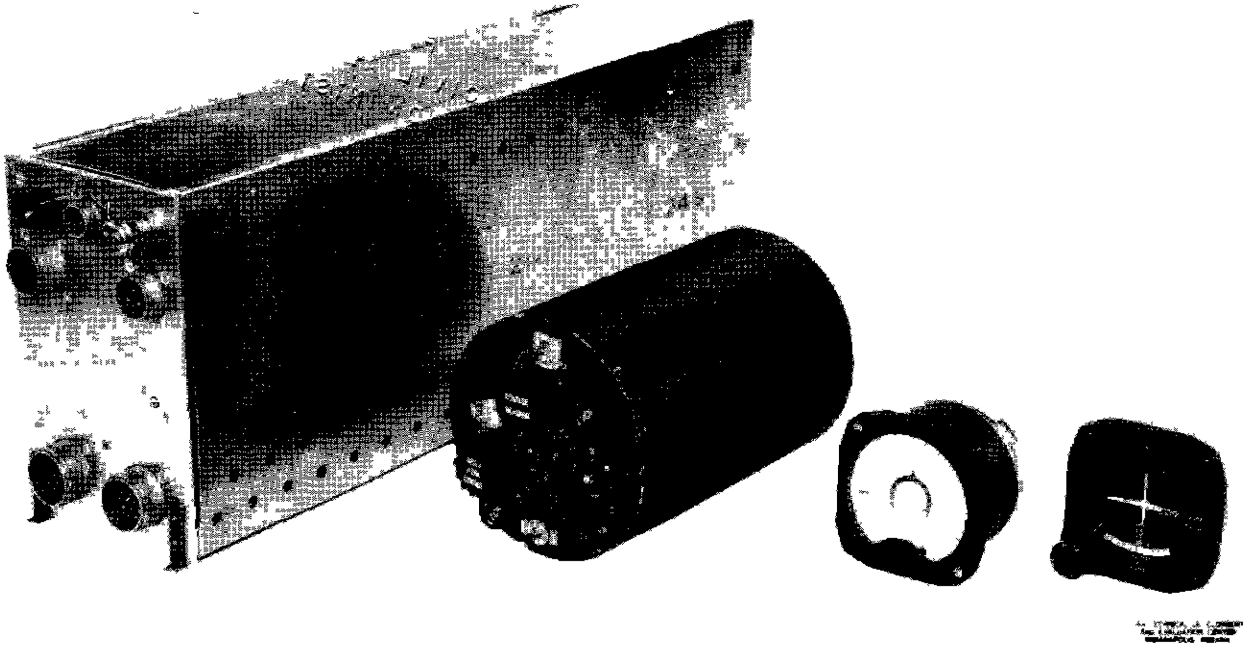

Fig 1 Components of the CAA Type I Course Line Computer

information is combined with the map data previously set and the computer produces and presents off-course and distance-to-go information on the course deviation and the distance-to-go indicators shown in Fig 1

Geometry of Computed Paths

Referring to Fig 2, the radio station at point S consists of omnirange and distance measuring ground equipments, magnetic north being indicated by the arrow The desired destination is indicated by point D, the desired course by line CD, the position of the airplane by point P The polar co-ordinates of the destination D with respect to the radio station S are r_d and θ_d This information must be read from a map and set in to the computer on the destination-distance co-ordinate and the destination-azimuth co-ordinate dials respectively The polar co-ordinates of the airplane with respect to the ground station are r and θ The magnetic bearing of the desired course is θ_c The displacement from course is e and the along track distance-to-go from plane to destination is D_d It will be observed that the distance-to-go D_d is the distance along the desired course from the destination D to a line perpendicular to the course and passing through P The distance-to-go will be the same as the distance from the airplane to the destination when the displacement from course e is zero

A line is drawn perpendicular to CD through station S and intersecting line CD at point E Angle PSE is designated as α_1 and angle DSE as α_2 The displacement from course is

$$e = r_d \text{ Cos } \alpha_2 - r \text{ Cos } \alpha_1 \tag{1}$$

and the distance-to-go is

$$D_d = r_d \text{ Sin } \alpha_2 + r \text{ Sin } \alpha_1 \tag{2}$$

A line FG is drawn through S, parallel to line CD The angle NSG = θ_c

Then

$$\alpha_1 = \theta - \theta_c - 90^\circ \tag{3}$$

and

$$\alpha_2 = \theta_c - \theta_d + 90^\circ \tag{4}$$

The computer continuously and simultaneously solves these four equations to obtain e and D_d, and presents the results on the course deviation indicator and the distance-to-go indicator, respectively

The Computer Mechanism

To accomplish the above operations in the computer, the addition of angles required to give α_1 and α_2 are performed mechanically The sines and cosines of α_1 and α_2 are derived by means of rotating electro-magnetic resolvers The values are then modified by potentiometers to perform the multiplica-

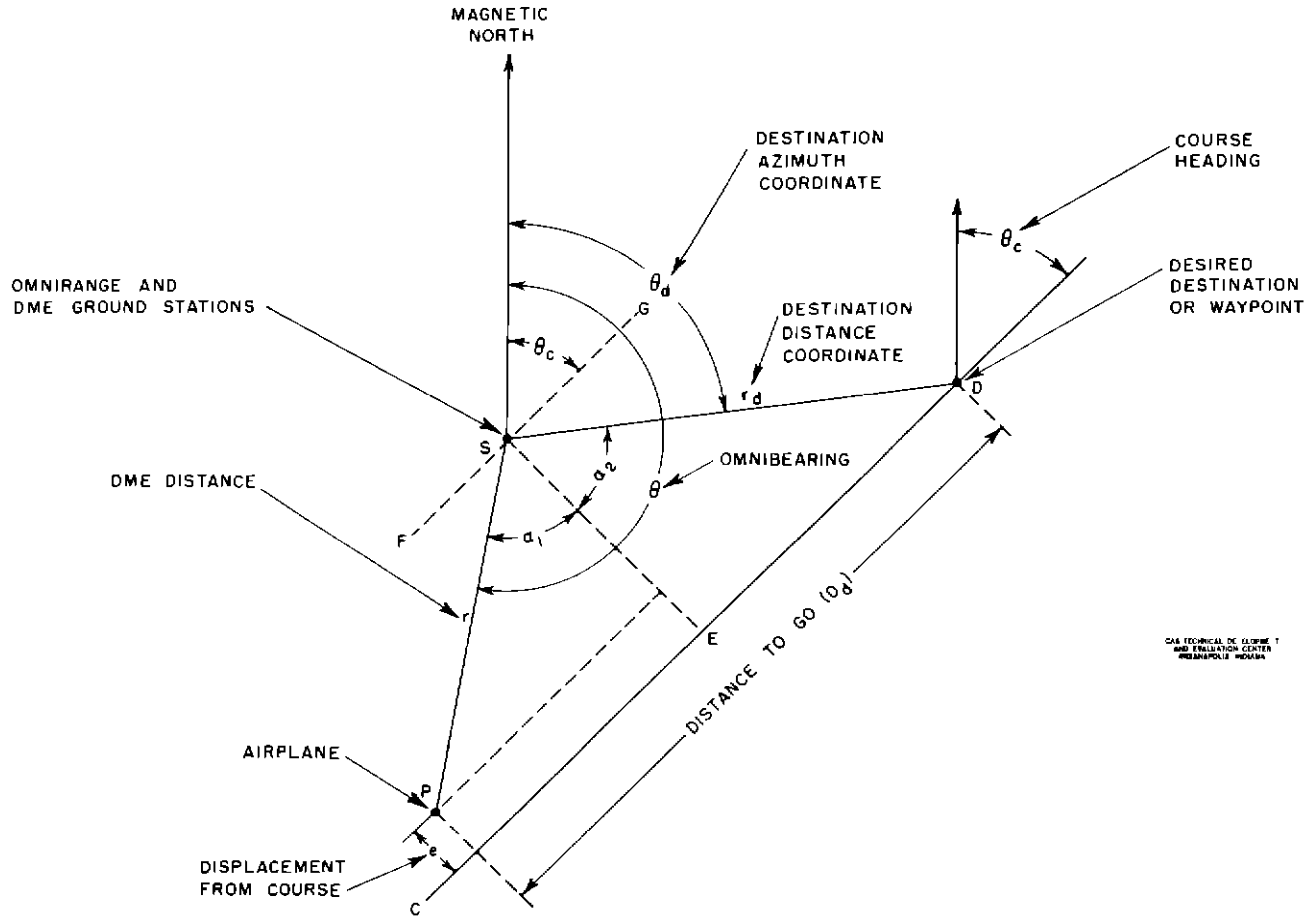

Fig 2 Geometry of a Computed Path Using CAA Type I Course Line Computer

tions by r and r_d, and the sums are obtained by means of parallel summing networks This is shown in Fig 3

A 400-cps voltage E is applied to the rotors of two resolvers, each having a 2-winding stator arranged so that the output of one stator winding will be proportional to E multiplied by the sine of the angle between the rotor and a reference point on the stator, and the output of the other winding is proportional to E multiplied by the cosine of the angle The stators are mounted in a subassembly so that they may be rotated together, and are turned by the dial which indicates course heading One rotor is connected to a dial which reads Destination-Azimuth Co-ordinate The other rotor is servoed to the omnirange receiver With this arrangement, the angle between the rotor and stator of one resolver is α_1 and the angle between the rotor and stator of the other resolver is α_2, and the stator windings produce voltages proportional to E Sin α_1 and E Cos α_1 from one resolver and E Sin α_2 and E Cos α_2 from the other resolver The outputs from the destination-azimuth co-ordinate resolver are fed to a dual potentiometer on which is set the destination-distance co-ordinate r_d The output from the omnirange resolver is fed to a dual potentiometer which is servoed to the distance measuring equipment Thus, the voltages on the wipers of the destination-distance co-ordinate potentiometer are proportional to Er_d Sin α_2 and Er_d Cos α_2, and the voltages on the wipers of the distance measuring potentiometer are proportional to Er Sin α_1 and Er Cos α_1 The two components of voltage having cosine terms are subtracted (one from the other) through summing resistors to give a voltage proportional to the displacement from course $e = Er_d \text{ Cos } \alpha_2 - Er \text{ Cos } \alpha_1$ The voltages having sine components are added to give a voltage proportional to the distance-to-go $D_d = Er_d \text{ Sin } \alpha_2 + Er \text{ Sin } \alpha_1$ In order to interpret these voltages on meters, they are first fed to cathode follower amplifiers, then to differential rectifier circuits to operate

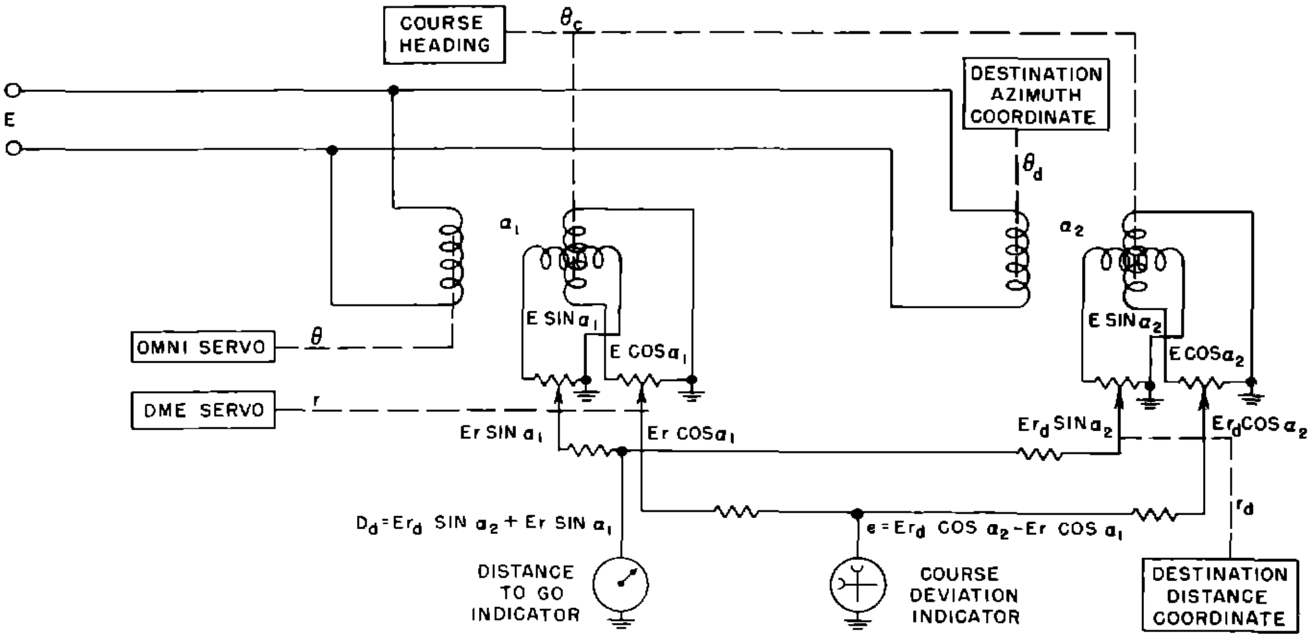

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Fig 3 Computing Circuits of the CAA Type I Course Line Computer - Schematic Diagram

zero center dc instruments

DESCRIPTION OF THE CAA TYPE I COURSE LINE COMPUTER

General

The various components of the equipment are shown in Figs 1, 4, 5, 6 and 7 The equipment consists of four units joined by an interconnecting cable a control box, an amplifier unit, a distance-to-go indicator and a course deviation indicator The control box weighs 7 5 pounds, and the amplifier complete with dust cover and shockmount weighs 21 9 pounds, so that the installed weight is 29 4 pounds exclusive of indicators and cables The control box contains the omnirange phase shifter and servo motor, the two resolvers, the destination potentiometer and the master power switch The resolvers are mounted inside of a cylinder The cylinder is supported on bearings at each end and can be turned by the course heading dial Connections to the resolver are made through slip rings as shown in Fig 5 The destination-azimuth co-ordinate dial is on the shaft of one of the resolvers The omnirange servo motor turns the shafts of the omnirange phase shifter and the second resolver as shown in Fig 6 The destination-distance co-ordinate dial is connected to the shaft of a 2-section heliopot potentiometer which may be seen in Fig 6

The amplifier unit contains the omnirange and DME servo amplifiers, the phase shifter adapter amplifier, the two indicator amplifiers and the DME motor and potentiometer The servo amplifiers and phase shifter adapter amplifier were built in individual sub-chasses plugged into the main chassis by means of octal tube bases and sockets as shown in Figs 4 and 7 A schematic wiring diagram of the computer is shown in Fig 8

DME Servo

To obtain a potentiometer setting proportional to the DME range voltage, the DME motor is made to drive the wiper of potentiometer R12, Fig 8 Potentiometers R13 and R42 are adjusted to give the proper calibration of the DME servo The potentiometers are energized with a voltage from the DME plate supply, so that variation in the DME plate-supply voltage will not effect the settings of the DME servo The DME distance signal is fed through a rate network R16 and C6 to the input of the DME servo amplifier and back to the wiper of potentiometer R12 If the voltage on the wiper of R12 is equal to the distance signal, there will be no input voltage to the DME amplifier, i e , across resistors R14 and R15 The circuit network which includes R14, R15, R17, R57, R58, C29, T4, RA5, RA6, RA7 and RA8 is a ring modulator which converts the dc volt-

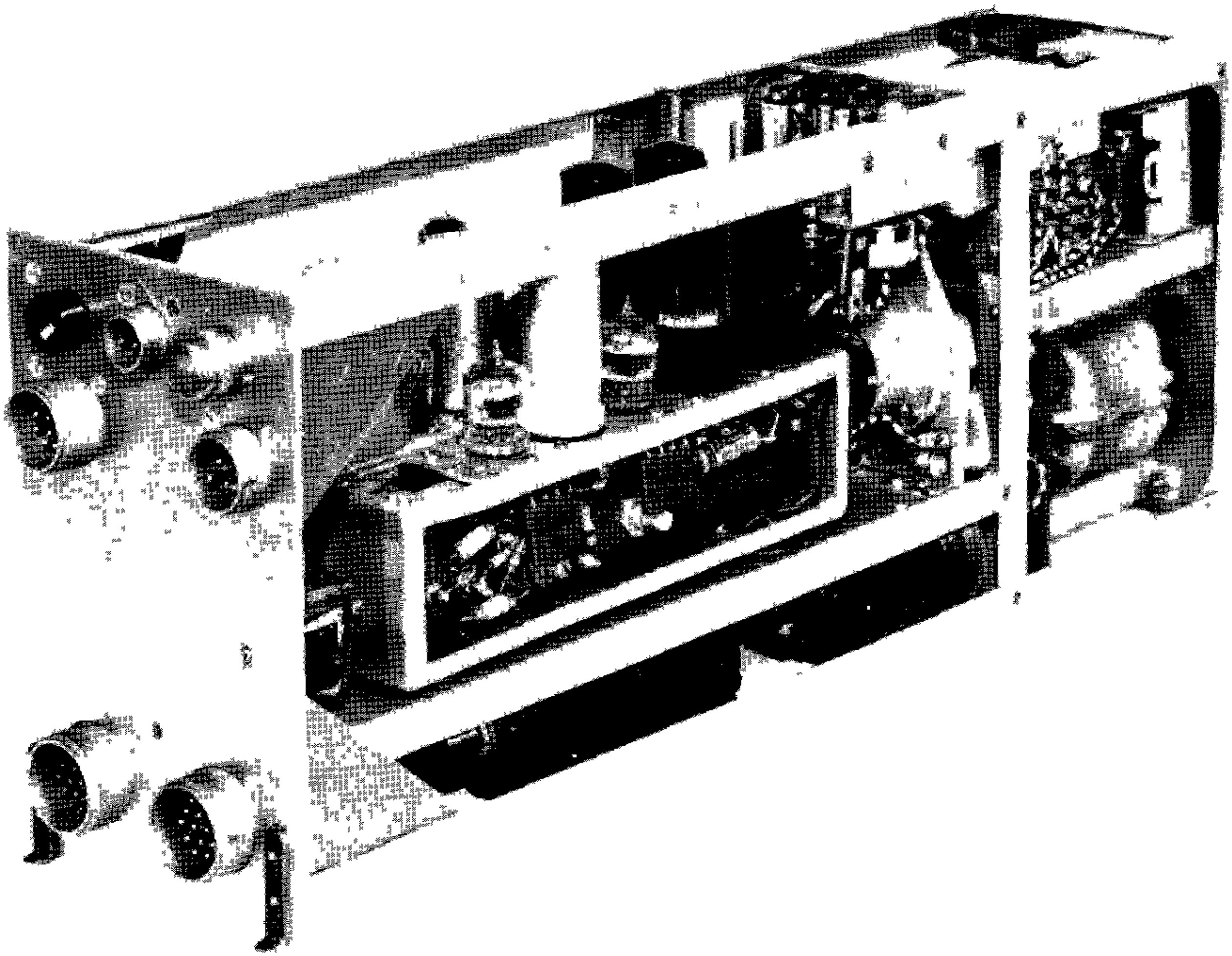


Fig 4 CAA Type I Course Line Computer Amplifier Unit Left Oblique, Cover Removed

age appearing across resistor R14 and R15 into an ac voltage appearing across the output terminal of transformer T4 Four stages of class A resistance coupled amplification follow transformer T4 and drive a discriminator stage The discriminator consists of two 6V6 tubes which have 400-cps voltage applied to their plates from each end of the secondary winding of transformer T2S2 The center tap of the transformer winding supplies the signal phase winding of a 2-phase motor which drives the wipers of R12, R26 and R27 Thus, if there is a change in the DME distance signal, there will be a dc voltage applied to the amplifier which is converted to an ac signal, amplified and applied to the control grids of the 6V6 tubes This signal will be in-phase with the ac voltage applied to the plate of one 6V6 and that tube will conduct However, it will be 180° out-of-phase with the voltage applied to the plate of the other 6V6, and that tube will not conduct This permits a half-wave rectified current to pass through a single phase of the distance motor M2 A condenser in parallel with the signal phase of the motor filters the discriminator output so that the motor receives 400-cps signal voltage and runs to drive the wiper of R12, so that the voltage from that wiper to ground is equal to the DME distance signal The reference phase of M2 is supplied from a secondary winding of the power transformer through a phase shifter condenser C28

Omnirange Servo

Voltage from the omnirange receiver which normally would be fed to the course deviation indicator is brought into the computer amplifier unit through terminals D and E of the omnirange receiver connector It is fed through resistor R3 and condenser C4 to

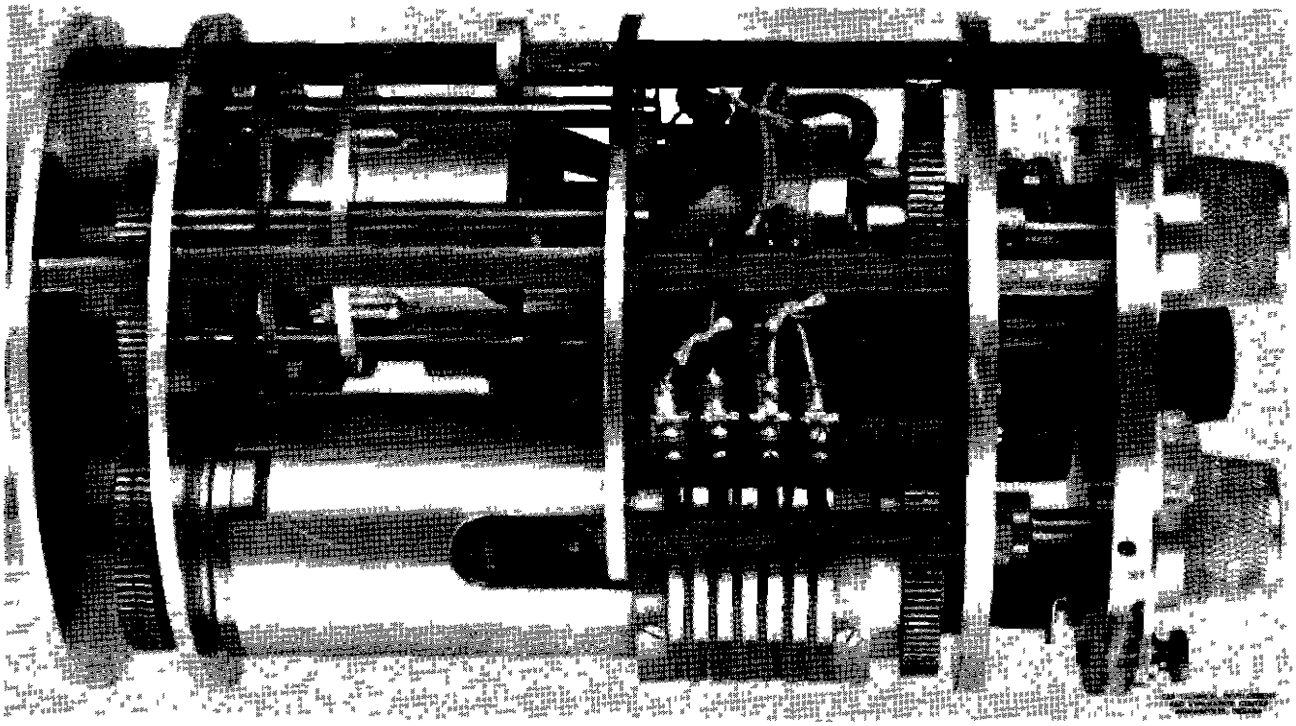


Fig 5 CAA Type I Course Line Computer Control Box, Cover Removed, Viewed From Upper Left Side

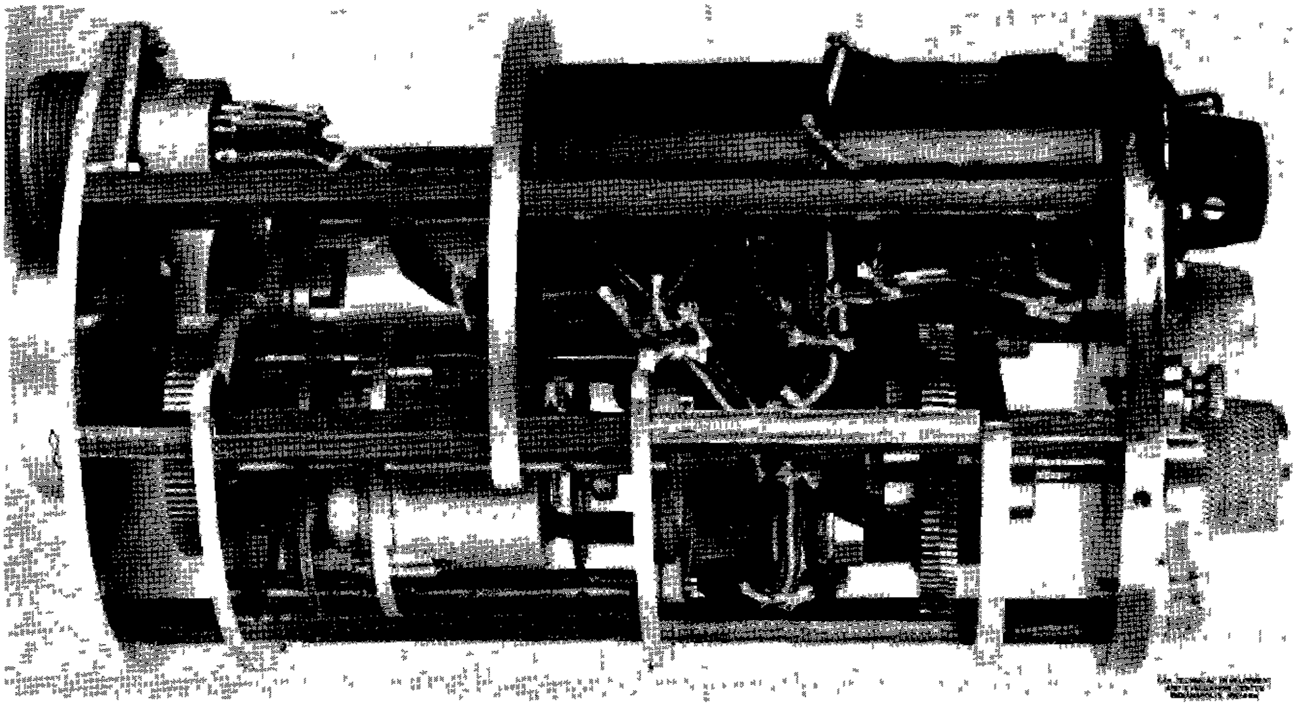


Fig 6 CAA Type I Course Line Computer Control Box, Cover Removed, Viewed From Upper Right Side

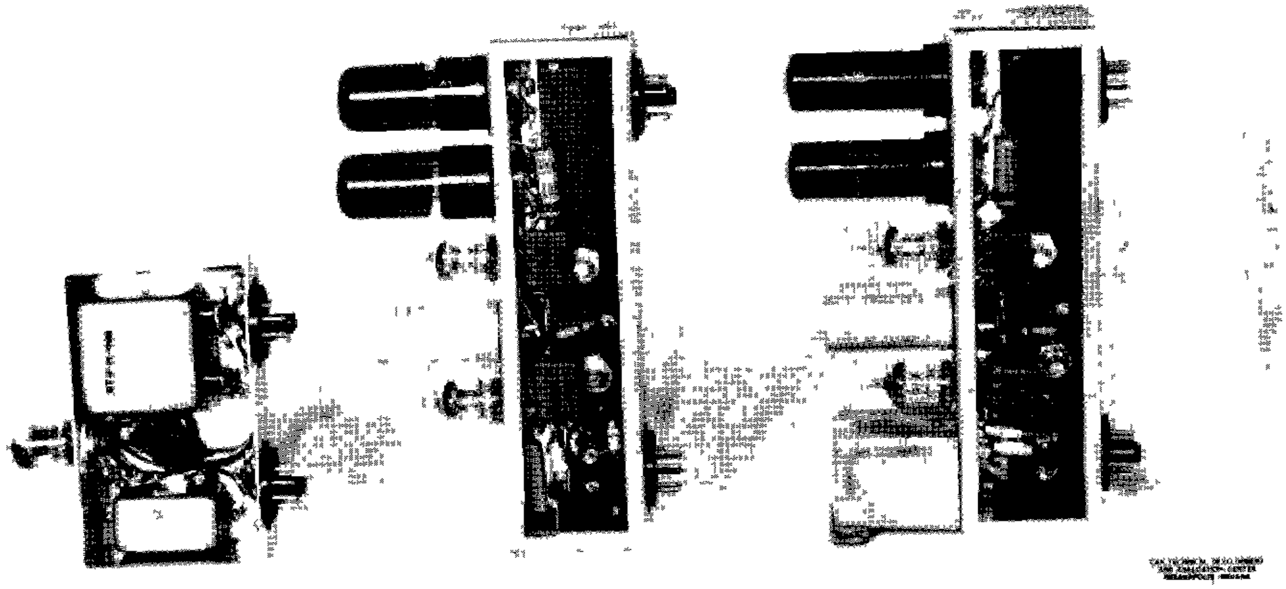


Fig 7 CAA Type I Course Line Computer "Plug-In" Amplifiers, Removed From Main Chassis, Left Side View

a dc/ac converter network This network consists of R49, R50, R51, R52, R53, C21 and crystal rectifiers RA1 and RA2 The output is coupled through condenser C22 to the grid of an amplifier The output of this modulating network is equivalent to that used in the DME amplifier However, it eliminates the need for an input transformer Four stages of class A amplification follow the modulator circuit and feed the control grids of two 6V6 discriminator tubes as in the case of the DME servo The center tap of the secondary winding supplying the discriminator feeds the signal windings of the omnirange servo motor housed in the control box, and drives the omnirange phase shifter M3, resolver M4 and velocity generator M6

The velocity generator M6 is a 2-phase asynchronous generator, one phase being excited from transformer T2S4 which also excites the reference phase winding of the omnirange servo motor M1 When the shaft of the velocity generator M6 is not turning, there is only a very small residual voltage induced in the signal phase However, when the shaft is turning, there is a voltage induced into the signal phase which is proportional in amplitude to the velocity of rotation of the shaft and which is of a phase determined by the direction of rotation of the shaft This velocity voltage is fed back through R3 and C4 to the input of the servo amplifier, and supplies a damping or anti-hunt signal

The phase shifter M3 used in this computer is equivalent to the ones used with the Collins Type 51R-1 and 51R-2 receivers However to use this phase shifter with the Aircraft Radio Corp Type ARC-15 omnirange receiver it is necessary to match the phase shifter impedance to the ARC-15 receiver This is done with the phase shifter adapter circuits These circuits consist of 1,000-ohm resistors in each phase of the incoming signal and an amplifier in the rotor circuit of the phase shifter, so that the output to the receiver appears across a 100,000-ohm resistor R45

Computing Circuits

The computer circuits (described under Theory of Operation) are energized as follows T1S5 supplies 15 volts, 400-cps, which is fed to the rotor windings of the resolvers contained in the control box Voltages are induced in the stator windings of the resolvers which are proportional to the sine and cosine of the angles between the rotor and stator windings In the destination-azimuth resolver the angle between the rotor and stator windings is produced by turning the stator windings through an angle equal to the course heading, and the rotor windings through an angle equal to the destination-azimuth coordinate In the omnirange resolver the angle between the rotor and stator windings is produced by turning the stator windings through an angle equal to the course heading, and turning the rotor windings through an angle equal to the omnirange indication The omnirange resolver rotor is positioned by the omnirange servo motor Referring to Fig 8, the voltage appearing between slip rings 1 and 5 is equal to E Sin α_1, between slip rings 2 and 5 it is equal to E Cos α_1, between 3 and 5 it is equal to E Cos α_2, and between 4 and 5 it is equal to E Sin α_2 These voltages are fed to potentiometers R26, R27, R28 and R29, respectively The wipers of R28 and R29 are adjusted by the destination-distance co-ordinate setting and the voltages appearing on them are equal to Er_d Cos α_2 and Er_d Sin α_2 The wipers of potentiometer R26 and R27 are adjusted by the DME servo motor and the voltages appearing on these wipers are equal to Er Cos α_1 and Er Sin α_1, respectively The voltage on the wiper of R28 is added to the voltage on the wiper of R27 through summing resistors R30 and R31 and the resultant voltage is applied to the grid of the course deviation amplifier The voltages on the wipers of potentiometers R26 and R29 are added together through the summing resistors R22 and R23 and applied to the grid of the distance-to-go indicator amplifier The displacement from course is indicated by the course deviation indicator used for localizer and omnibearing indications The course deviation amplifier has an output sufficient to give five dots deflection for a displacement from course of five miles A modified radio altimeter indicator is used for the distance-to-go indicator The distance-to-go amplifier produces an output such that full scale on the indicator represents about 75 miles

Alarm Circuit

The alarm circuit monitors the plate-supply voltage in the computer, signal in the DME gate and the phase shifter transfer relay, and performs the usual indications for the omnirange receivers These functions are accomplished by a relay operated by the computer plate-supply voltage, another operated by the DME alarm and a pair of contacts on the phase shifter transfer relay The contacts of these relays are connected in series with the flag alarm of the omnirange receiver in such a manner that the failure of any one of the four monitored circuits causes the flag circuit to open and the course deviation indicator flag to come into view

Power Circuits

The power supply for the computer is quite conventional Two transformers are energized from the aircraft 110-volt 400-cps single phase supply by grounding the power-supply switch in the control box One transformer supplies signal voltage for the computer, the indicator amplifiers and the modulator circuits The other transformer supplies the plate-supply rectifier tube, the discriminator tubes, the reference phase of the motors and the heaters of the tubes

TESTS AND RESULTS

Adjustments and Calibration

After the computer was constructed, it required the control dials to be properly oriented, the phase adapter amplifier to be calibrated, and the distance-repeat-back potentiometer to be calibrated For these purposes a test mockup was made An Aircraft Radio Corp Type ARC-15 receiver was connected to a Collins Type 479S signal generator and the output of the receiver was fed to the computer This provided omnirange signals for test purposes A Hazeltine Model 1355 distance measuring equipment and Aircraft Radio Corp Type H-13A signal generator provided distance signals

The dials were oriented as follows

The destination-distance co-ordinate dial was set so that zero indication corresponded to zero resistance between the wipers of potentiometers R28 and R29

The course-heading dial was oriented by first setting the destination-distance co-ordinate dial to zero miles A medium distance signal (approximately 50 miles) was then fed to the DME servo circuit The resolver cylinder was rotated until the voltage across the slip rings 1 and 5 on the resolver cylinder was zero The course-heading dial was then adjusted to read 180° or south

The destination-azimuth co-ordinate dial was adjusted by first setting a distance of approximately 50 miles on the destination-distance co-ordinate dial The shaft of the destination-azimuth co-ordinate resolver was adjusted so that the voltage between slip rings 4 and 5 was zero The destination-azimuth co-ordinate dial was then set to 180° or south The distance-to-go meter was observed to read a positive distance

The DME servo was calibrated next Both the course-heading dial and the destination-azimuth dial were set to 0° or north The destination-distance co-ordinate dial was set to zero distance A zero miles signal was fed from the DME to the computer The DME servo zero adjust potentiometer R13 was adjusted so that the distance-to-go meter read zero Next, the destination-distance co-ordinate dial was readjusted to 70 miles, and a 70-mile signal was fed from the DME to the computer The DME servo linearity potentiometer R42 was adjusted so that the distance-to-go meter read zero After this adjustment was made, the zero miles setting was checked Then a calibration curve was taken by comparing the distance signal fed from the DME with the setting of the destination-distance co-ordinate dial required to give zero distance-to-go indication

Next, the distance-to-go meter was calibrated With the destination-distance co-ordinate dial set to zero, the deflection of the distance-to-go meter was noted for each 10-mile signal from the DME These positions were laid out as a scale for the distance-to-go indicator The following procedure was used to adjust the phase adapter amplifier The destination-distance co-ordinate dial was set to zero and a distance signal of approximately 50 miles was fed to the DME servo amplifier Under these conditions the course deviation indicator was centered when the direction signal supplied by the omnirange receiver was 0°, or north, and the course-heading dial also was set to north But, as the signal from the omnirange receiver was varied, the course deviation indicator did not center when the course-heading dial was set to the same value as the omnirange receiver signal A curve of receiver signal versus difference between receiver signal and course-heading dial setting to center the course deviation indicator was plotted This curve had a prominent double frequency component which is characteristic of error curves in omnirange receivers It was found that changing the values of resistors R46 and R48 in the phase shifter amplifier greatly affected the shape of the error curve With some selection it was possible to reduce this error to a satisfactory value After this was done, it was necessary to readjust the course-heading and destination-azimuth co-ordinate dials as described previously

Accuracy of Calibration

After the previously mentioned calibrations had been performed, a number of courses were synthesized, using the test equipments used for the calibration During these tests the course deviation error was never more than one-half mile, and the arrival at destination error was never more than one mile However, it was found that the course deviation and distance-to-go indications contained variable errors of as much as ten per cent which were a function of the 400-cps supply voltage These percentage errors do not affect the zero indications, but affect only the sensitivity of the indications Thus, the course deviation indicator accurately indicates when the chosen course is being made good, but in case of a departure from course, the deflection of the course deviation indicator for a given departure is a function of the supply voltage Likewise, the distance-to-go indicator accurately indicates the arrival of the airplane at the waypoint However, when there is an indication of other than zero on the distance-to-go indicator, that indication varied with changing supply voltage

Flight Tests

The CAA Type I Course Line Computer was first installed in TDEC airplane N 181 in July 1948, and was checked and found operable Although priority of other work prevented the making of a flight specifically to determine the over-all accuracy with which courses could be made good over the ground, observations made by engineers and pilots substantiated the findings made during the bench tests The computer was used very extensively in conjunction with demonstrations of omnirange and DME equipments and was still in operation during 1950

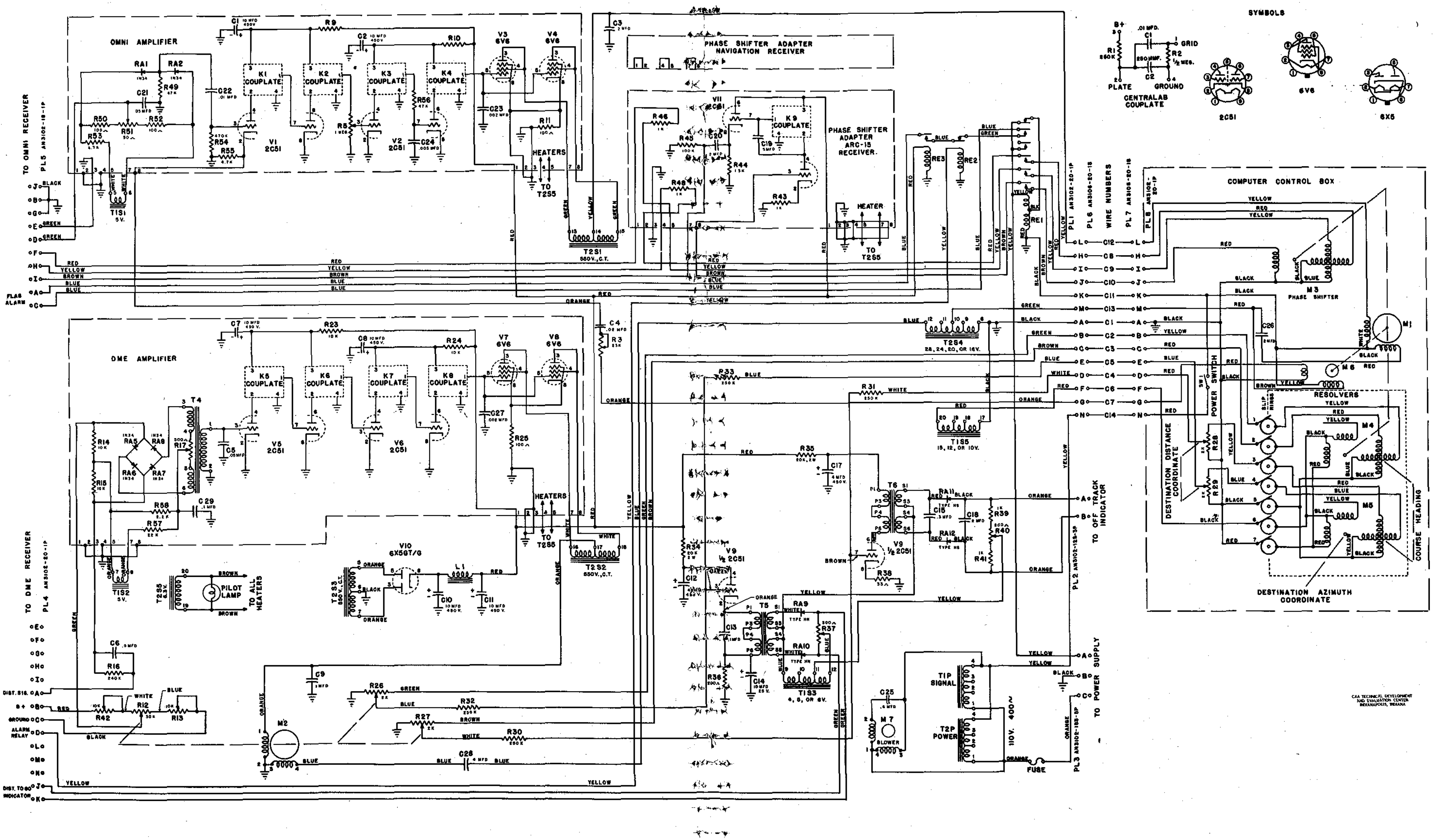


Fig. 8 CAA Type I Course Line Computer, Schematic Wiring Diagram

APPENDIX I

Some General Considerations of Computed Courses

The CAA Type I Course Line Computer evolved from analytical geometry considerations and polar co-ordinate data that could be obtained from omnirange and distance measuring information Thus, referring to Fig 1A, if north is used as the reference direction, the angle θ measured clockwise from north, and the distance D measured from the radio station to P (any point within the range of the radio station) then the two pieces of data, θ and D, define a unique fix with respect to the station

A course line computer can be any mechanism or electric circuit which will indicate whether the position of an airplane, as given by the above data, satisfies a predetermined formula A simple formula is

$$\sin \theta - D = e$$

where e is the error voltage and is a measure of the displacement of the airplane from the computed course This equation describes a circle of diameter D_1, passing through the station and having its center on a line 90° from the reference line and at a distance $\frac{D_1}{2}$ from the station The mechanism of a computer which will solve this equation is shown in Fig 1B and consists of a potentiometer energized from a voltage source E, having its wiper movement proportional to D, and a sine-taking resolver having voltage E impressed on its primary winding and its rotor turned through angle θ The outputs of these two components are connected in series and their difference is measured For an airplane to make good the desired circle, it would be flown so as to keep the difference equal to zero A conceivable application would be to have the radio station aboard an aircraft carrier with the reference line along the axis of the carrier Then the airplane could be made to approach the fantail of the carrier in a pattern similar to that which is often used aboard aircraft carriers today

Another conceivable use of this type of computer might be to replace the localizer for runway approaches This would provide a turn out of a down-wind approach, much as is used under present day visual flight rules conditions This might prove very desirable under certain traffic conditions However, present day omnirange and DME equipments do not provide sufficiently accurate data for this application A second type of computer is indicated in Fig 2 In this type of computer, a straight-line parallel to the reference axis is desired From analytical geometry considerations, Fig 2A the equation of the straight line AB is

$$D \sin \theta = K$$

For computer operation, this equation should be rewritten

$$D \sin \theta - K = e$$

where e is error and can be used to correct the airplane back to the line AB The electrical circuit shown in Fig 2B consists of a voltage source fed to a manually adjustable potentiometer, where the constant K is set in, and to a potentiometer which is adjusted proportionately to the distance D The output of this potentiometer in turn feeds a resolver which takes the sine of the angle θ The two voltages are then connected so as to measure their difference, $e = D \sin \theta - K$

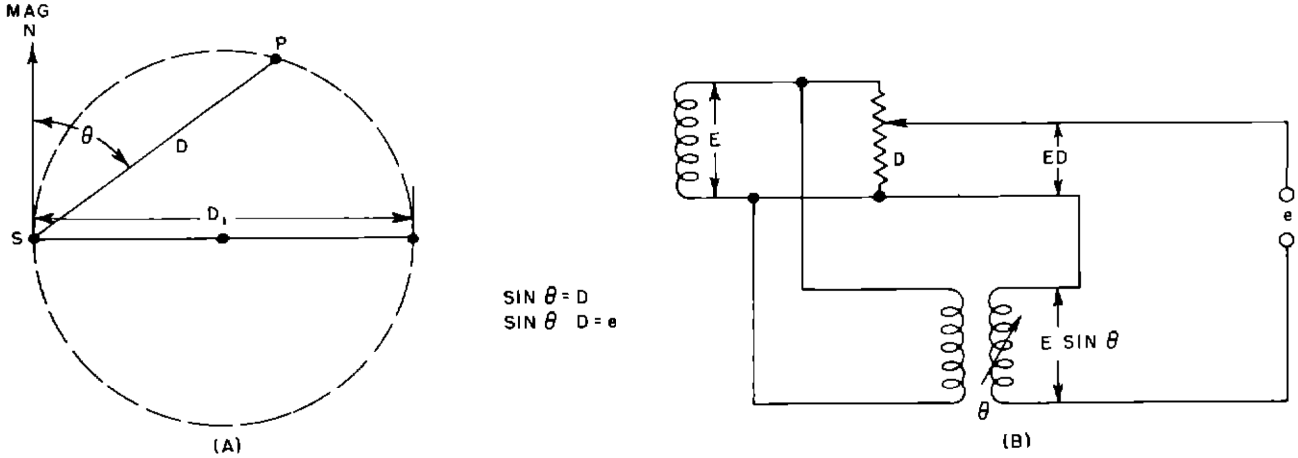


Fig 1 Basic Computer for a Circle

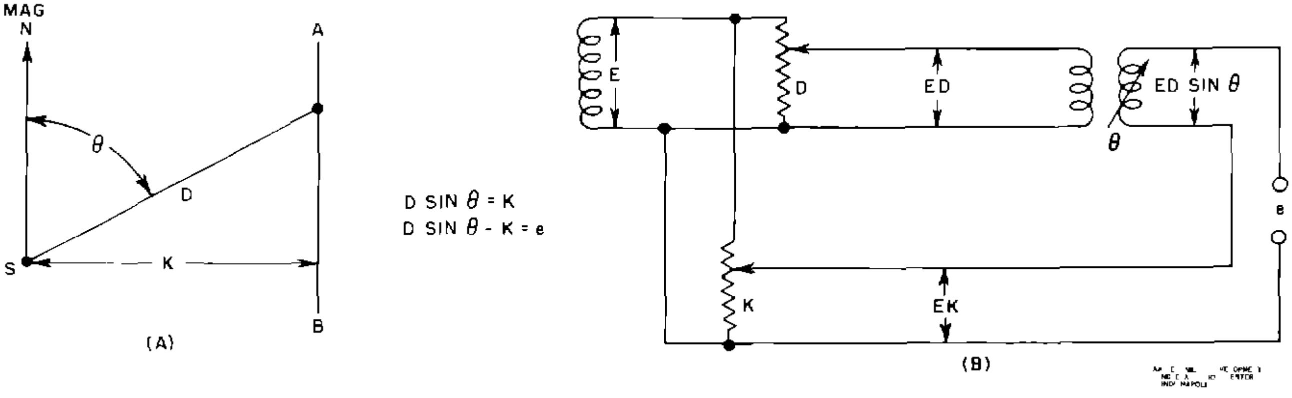


Fig. 2 Basic Computer for a Straight Line

This simple computer will give course guidance along the line AB, but does not provide a way to show progress along that line or for choosing lines at any angle except parallel to the reference direction. The bearing of the line AB may be changed if the frame of the resolver can be adjusted from a reference point independently of the rotor of the resolver. If this can be done, then the angles, through which the frame and the rotor are moved, are mechanically added and the computation is done for a line having a bearing of θ_1 as shown in Fig. 3A.

Progress from the base of a perpendicular to the course line through the station can be obtained if the resolver gives the cosine of the angle θ_2, or the difference of the angles $\theta - \theta_1$. Thus, in its simplest form, a computer to supply off-track and distance-to-go information consists of the equipment shown in Fig. 3B.

In this computer, the factor K_1 is the distance along the course from the foot of the perpendicular through the station to the desired destination, or waypoint. The factor K_2 is the distance along the perpendicular from the course to the station. Since it is desirable to work with a given destination or waypoint rather than a perpendicular to a desired course which changes with each course heading to the desired destination, it was decided in designing the CAA Type I Course Line Computer that a destination potentiometer and resolver would be used to obtain the perpendicular component of voltage and the along-track component of voltage necessary to set into the computer in Fig. 3A to get off-course and distance-to-destination information, also, for impedance matching reasons, the resolvers were put ahead of the potentiometer. This resulted in the resolver circuit shown in Fig. 4, which is discussed in the earlier paragraphs of this report.

Giving further consideration to the computer shown in Fig. 1, a 4-leaf rose pattern is generated if the resolver is geared to turn

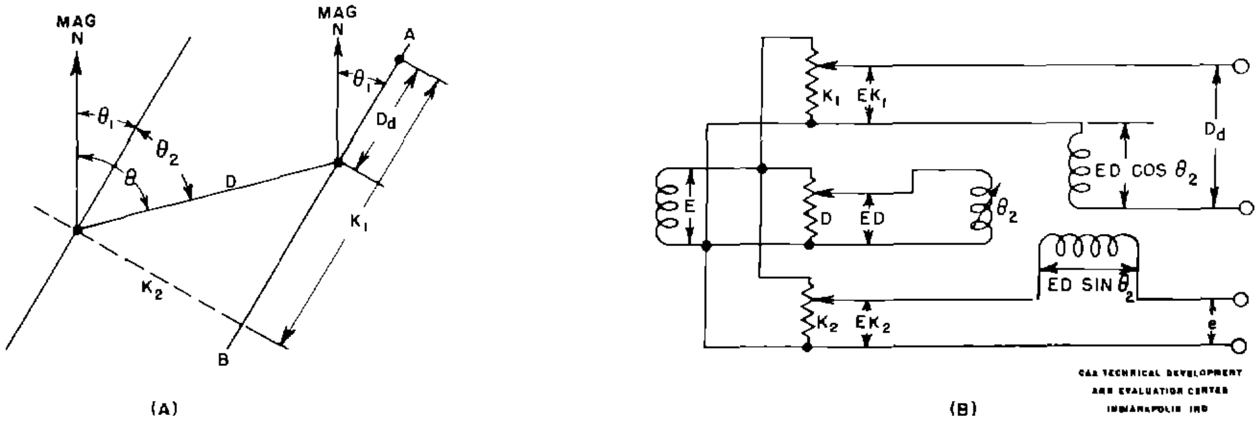


Fig. 3 Development of Straight Line Computer to Provide for Any Direction of Course and "Distance-to-go" Computation

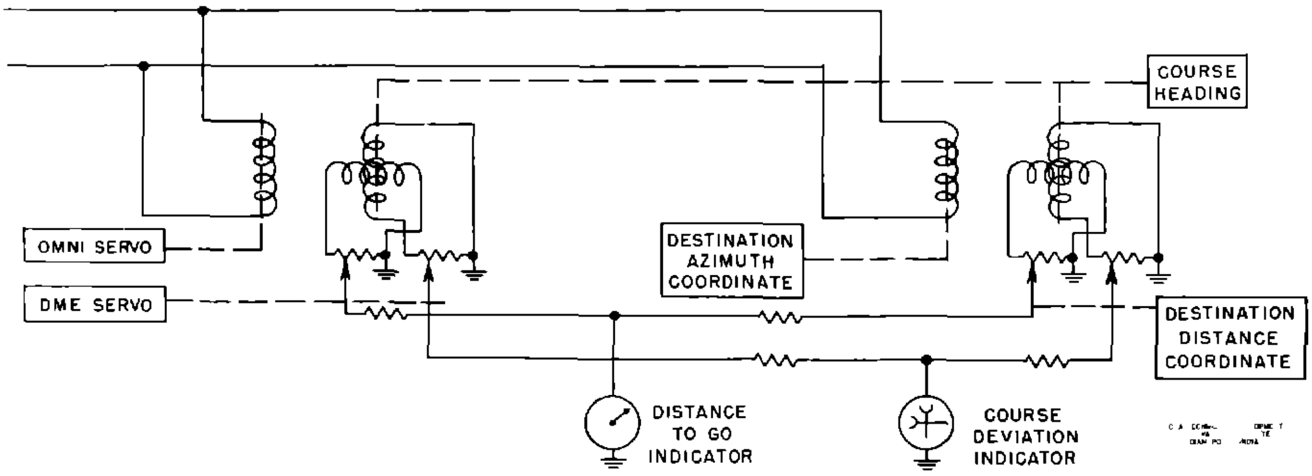


Fig 4 Further Development of the Straight Line Computer to Eliminate Need for Offset Distances - The CAA Type I Course Line Computer

twice as fast as the angle θ The mathematical equation is

$$D - \sin 2\theta = e$$

The computer circuit is the same as that of Fig 1B However, the pattern is as shown in Fig 5A

If the equation $D - \sin 3\theta = e$ is used in the same computer, then a 3-leaf rose is generated as shown in Fig 5B Thus, it is fairly obvious that any figure which can be represented by a simple equation based on polar geometry can be represented by a number of potentiometers and resolvers connected in the proper order Thus, consider

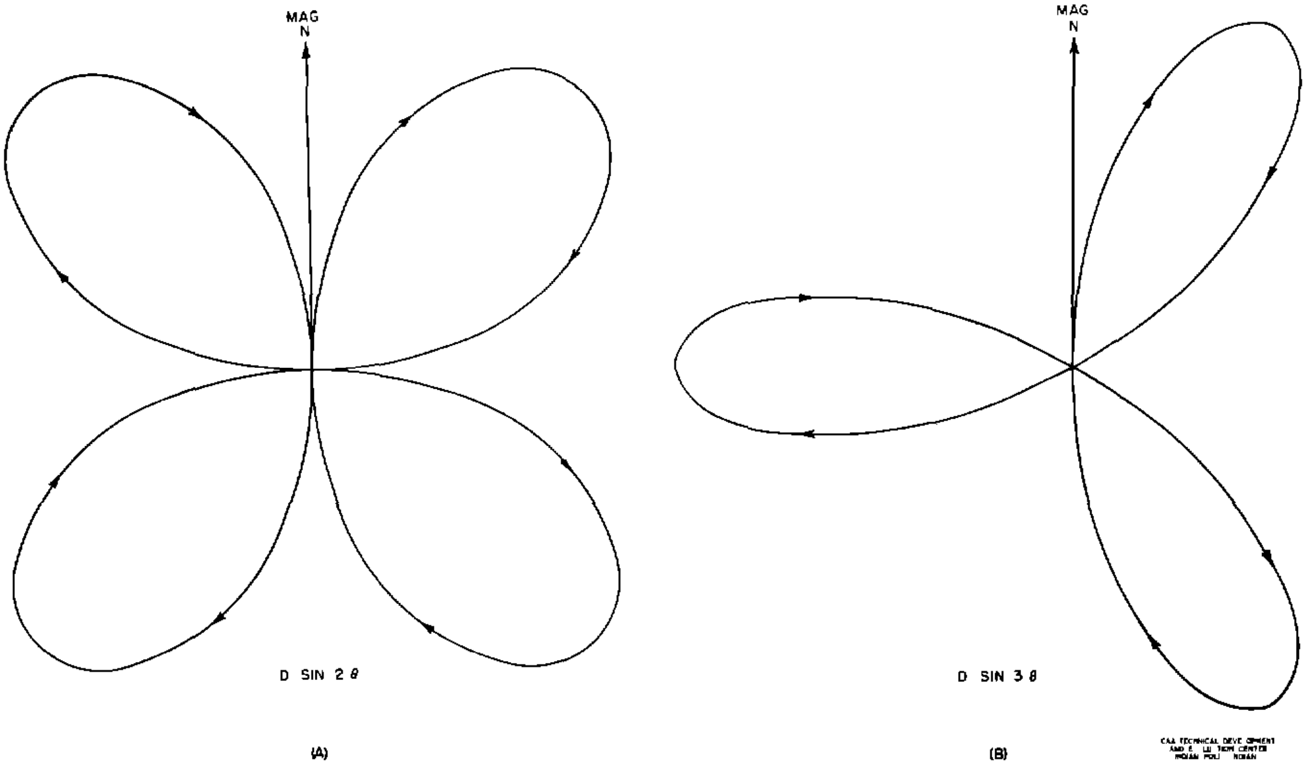


Fig 5 Multi-Leafed Rose Computer Courses

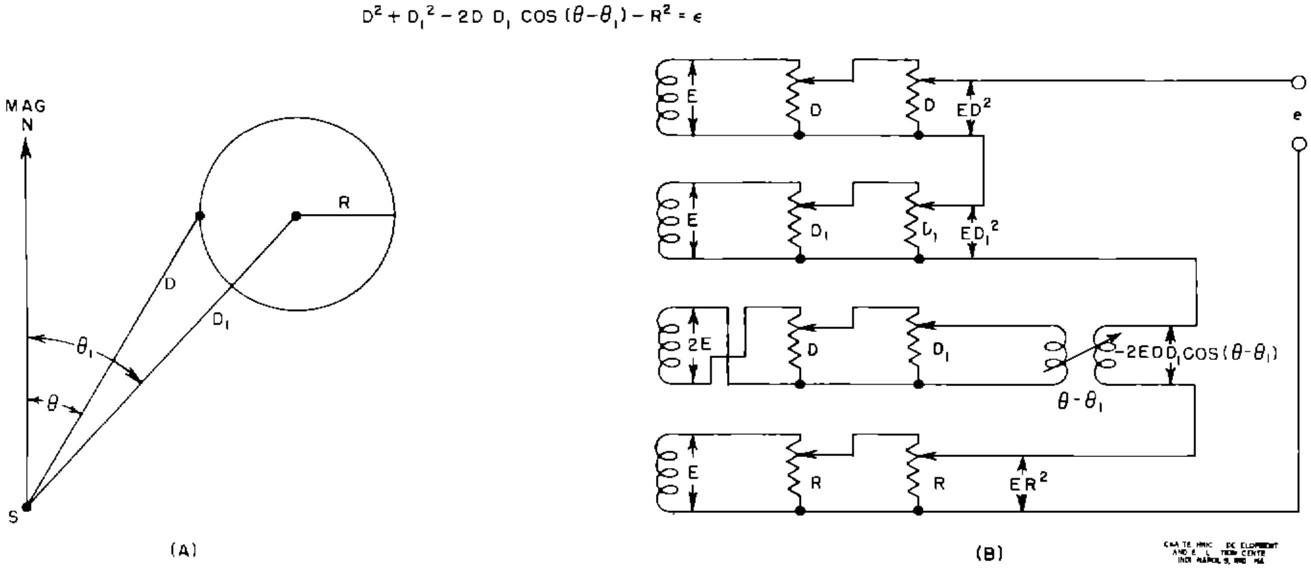


Fig 6 A Computer for a Remote Circle

the polar equation for a circle located remotely from the origin Such a circle is shown in Fig 6A The computer equation is

$$D^2 + D_1^2 - 2DD_1 \operatorname{Cos}(\theta - \theta_1) - R^2 = e$$

In Fig 6A, D represents the distance from the origin to any point on the circle along a line at an angle θ from the reference line, D_1 represents the distance to the center of the circle along a line at an angle θ_1 from the reference line and R is the radius of the circle The electrical circuit is shown in Fig 6B Each factor in the original equation is represented by an element in the computer circuit and each term, as shown in this equation, is energized from an isolated voltage source It will be noted that, throughout these examples, the resolvers have been indicated as electro-mechanical devices having magnetically coupled rotor and stator windings This type of resolver is readily available commercially and presents the advantage of having a relatively low impedance level and, therefore, being comparatively free from loading effects However, any device which will extract a sine or cosine as needed and will fit in with the impedances being used in the related circuits can be used One computer has been built using potentiometers wound on a square form with two wipers which moved in a circle around the center of the square winding, thus producing sine and cosine voltages of the displacement of the wipers from the axis of the winding

The circular pattern indicated in Fig 6A readily suggests a method of forming a circular holding pattern in the presence of strong cross winds, and a method of smoothly transferring from one straight-line computed course to another

The circuit shown in Fig 4 can be modified to produce circular patterns as shown in Fig 6A by changing it as shown in Fig 7 The course deviation signal indicated in Fig 4 is used to drive a servo motor which is connected to the course-heading dial A pointer on the shaft of this motor will, at all times, indicate the direction to the destination, or center of circle Then the distance-to-go indication is compared with a voltage set proportional to the radius of the desired circle Thus if the distance from the destination or holding point is held constant, the airplane will make a circle about the holding point, the bearing of the holding point from the airplane always being indicated by the position of the course heading servo

This approach to the problem of course line computers provides a fairly simple method of producing any desired track in space which can be defined by an algebraic equation having only linear or sine and cosine terms

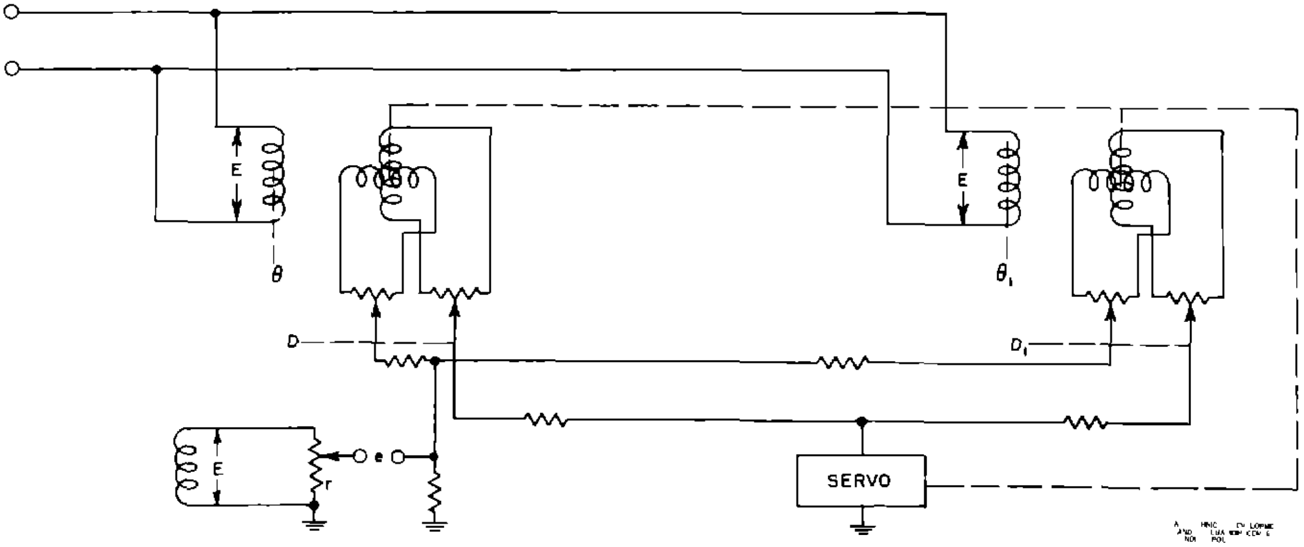


Fig 7 Modification of the CAA Type I Course Line Computer Circuits to Provide a Remote Circle Course

APPENDIX II

Computers Based on Two Bearings or Two Distances

Thus far in this report, all computer operation has been based on distance and bearing information received from one ground station location Undoubtedly, this type of information provides the simplest, most straight-forward data for the operation of course line computers However, under certain conditions, it may be desirable to have courses computed from other data In view of the fact that the present omnirange program is well advanced, while distance measuring equipment is available only on an experimental basis (at this writing), there may be a period when courses based on data from two omnirange stations will be of operational value Also, it is possible that courses based on distances from two stations may be of some value The following discussion will show how data from two omnirange stations or from two DME stations can be used for course line guidance The two bearings, or two distances will be used to find a bearing and distance from one station, and the course line computed by the methods used with the Type I Course Line Computer

The 2-Bearing Computer

In Fig 8, two omnirange stations are located at points S_1 and S_2 The distance between the stations is r_{12}, θ_{12} is the bearing from S_1 to S_2 and θ_{21} is the bearing from S_2 to S_1 The bearing from S_1 to the airplane at P is θ_1, and θ_2 is the bearing from S_2 to P

In the triangle S_1 S_2 P,

$$\theta_{12} = \theta_{21} + 180^\circ$$

$$\alpha_3 = \theta_{12} - \theta_1$$

$$\alpha_4 = \theta_2 - \theta_{21}$$

$$\alpha_5 = 180^\circ - (\alpha_3 + \alpha_4)$$

Using the law of sines,

$$\frac{r_{12}}{\mathrm{Sin}\,\alpha_5} = \frac{r}{\mathrm{Sin}\,\alpha_4}$$

or

$$r_{12}\,\mathrm{Sin}\,\alpha_4 = r\,\mathrm{Sin}\,\alpha_5$$

For computing purposes

$$r_{12}\,\mathrm{Sin}\,\alpha_4 - r\,\mathrm{Sin}\,\alpha_5 = e$$

From this equation, r may be computed using the electro-mechanical circuit shown in Fig 9 Using this circuit, r and θ_1 give a distance and bearing fix of the airplane position P from station S_1, and may be fed into a Type I computer

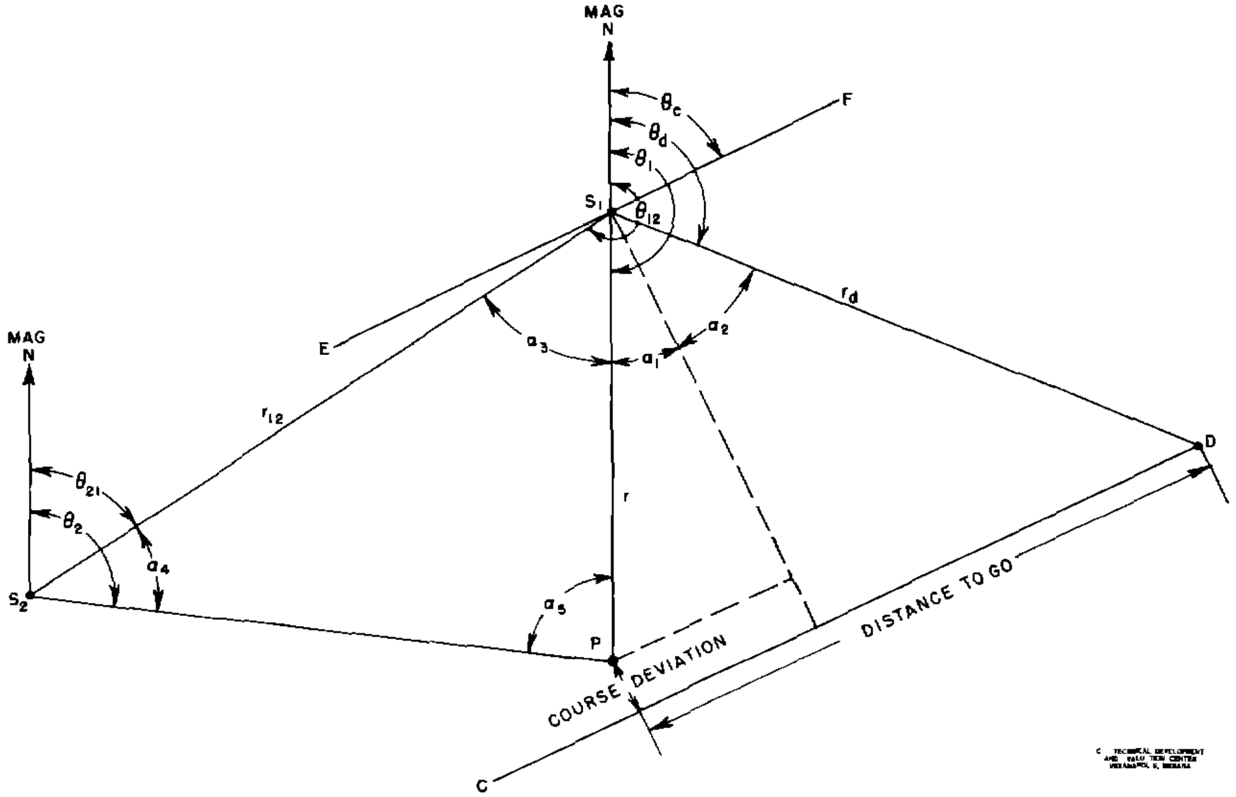


Fig 8 Geometry of a 2-Bearing Computer

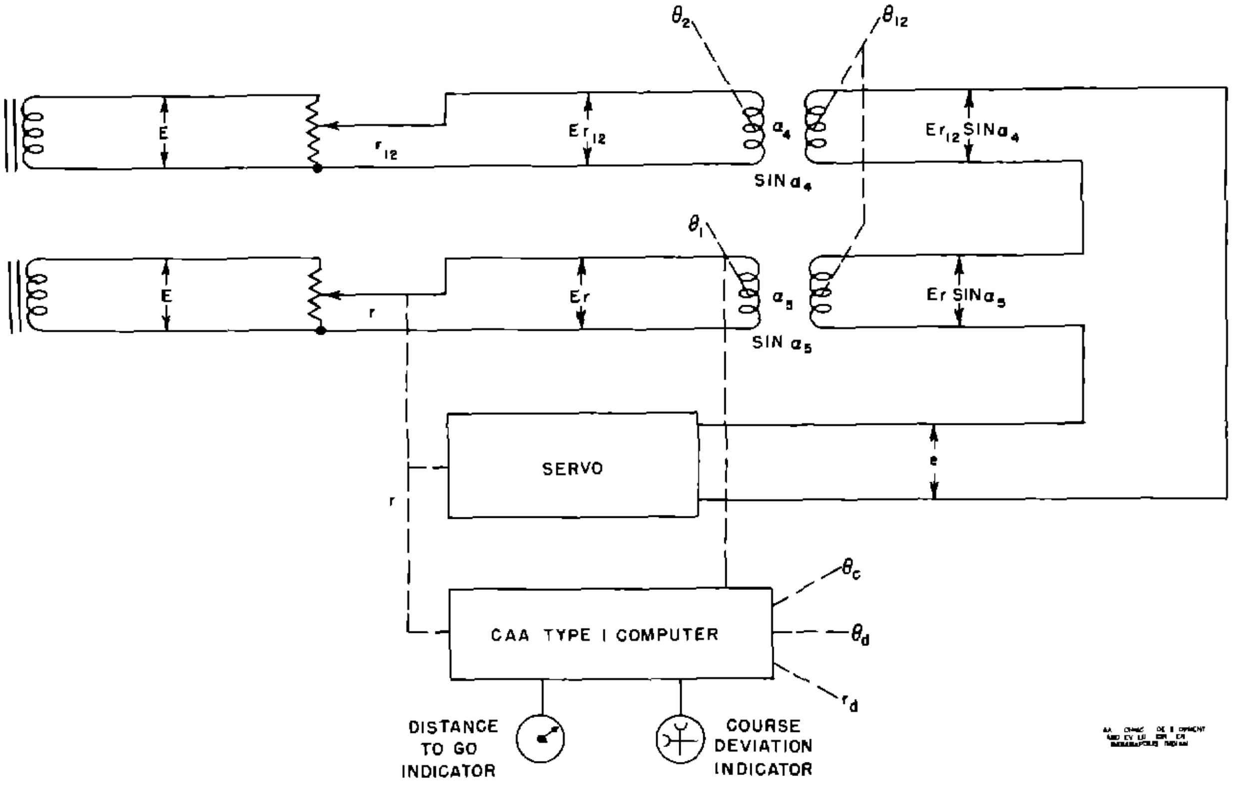


Fig 9 A Course Line Computer Based on Bearings From Two Omnirange Stations

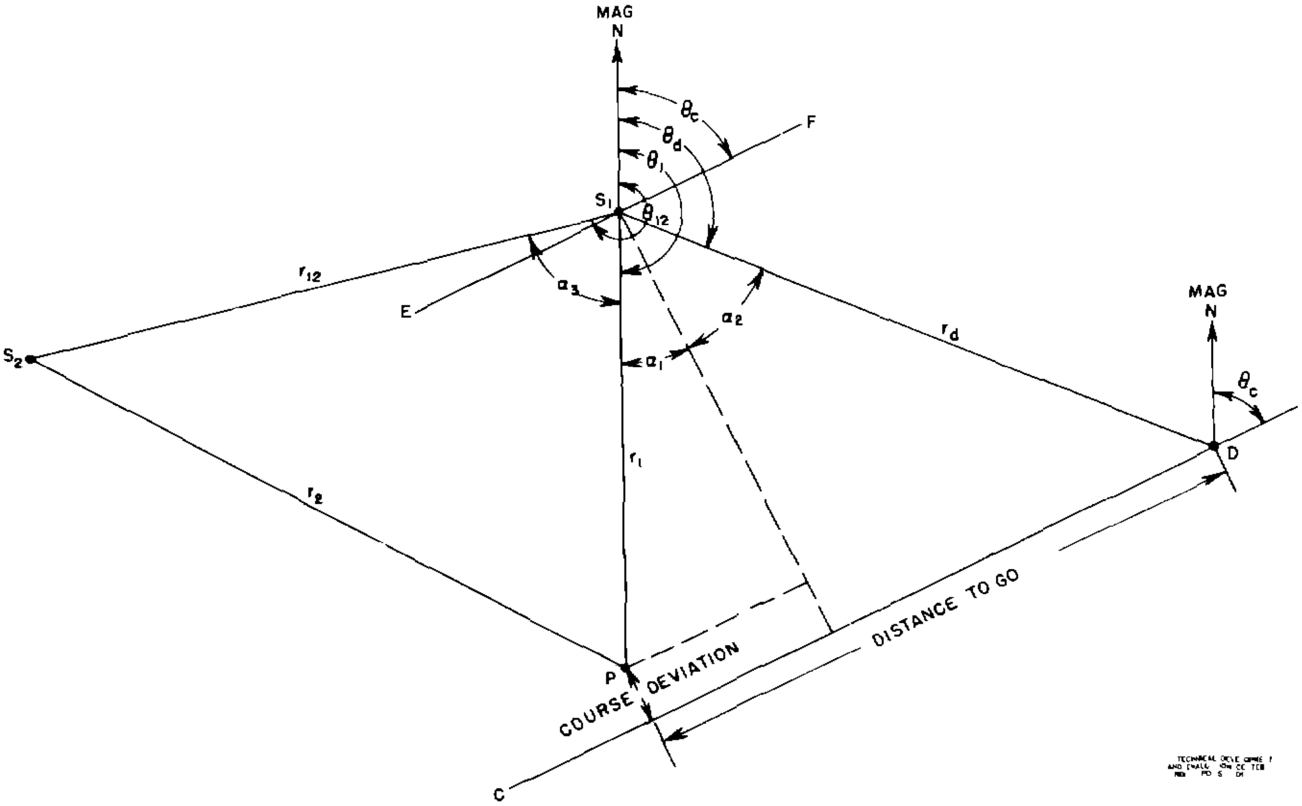


Fig 10 Geometry of 2-Distance Computer

The 2-Distance Computer

In Fig 10, two DME stations are located at points S_1 and S_2 The airplane P is at distances r_1 and r_2 from stations S_1 and S_2, respectively Then, θ_1 is the bearing of the airplane P from S_1, and θ_{12} is the bearing of S_2 from S_1

Then

$$\theta_1 = \theta_{12} - \alpha_3$$

Using the law of cosines in the triangle $S_1 S_2 P$

$$r_2^2 = r_{12}^2 + r_1^2 - 2r_{12} r_1 \text{Cos } \alpha_3$$

or rewriting the equation for servo operation

$$r_2^2 - r_{12}^2 - r_1^2 + 2r_{12} r_1 \text{Cos } \alpha_3 = e$$

This equation may be solved for α_3 by the electro-mechanical circuit shown in Fig 11 and the results combined with θ_{12} and set into the Type I computer

Disadvantages of the 2-Bearing and 2-Distance Computers

The methods presented for the course line computers, based on two bearings or two distances, are not intended to represent the only solutions to these problems However, as compared with the course line computer, based on one bearing and one distance, the 2-bearing computer and the 2-distance computer each possess the following disadvantages

1 Two additional pieces of map data must be set into the computer These are the distance and direction between the ground stations

2 One additional servo must be added to the computing circuits

3 There are certain regions where small errors in the radio information give unreliable computer indications This is shown for the 2-bearing computer in Fig 12

The method used for the calculation of the contours of error is developed in Fig

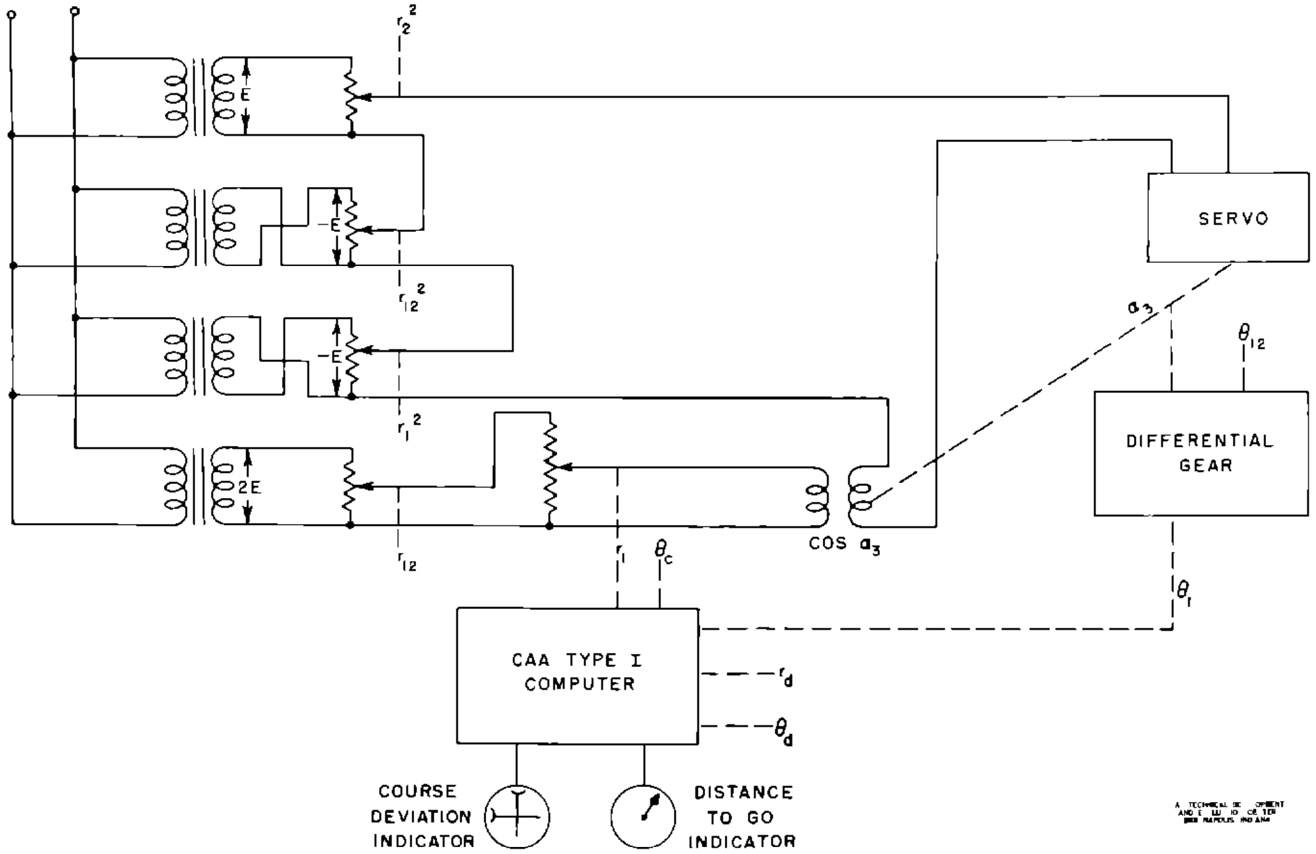


Fig 11 A Course Line Computer Based on Distances From Two DME Stations

13 Assume points L and M are omnirange stations located 100 miles apart and point P is an airplane In the $\angle$LMP measurement, the angles A and C may be in error by ±1° Then the area around P, bounded by the quadralateral NOSR, is the region of error, and the maximum error will be either NP or OP Values of NP and OP were calculated and the larger of the two plotted to give the contours shown in Fig 12, the errors being shown in miles for stations located 100 miles apart, and 1°over-all bearing error for each station

A similar plot can be made for courses based on two distances In addition, the 2-distance computer is subject to an ambiguity due to the fact that the point P, Fig 10, may lie on either side of line $S_1 S_2$ This ambiguity can be resolved, but its resolution imposes an additional mechanical requirement on the equipment

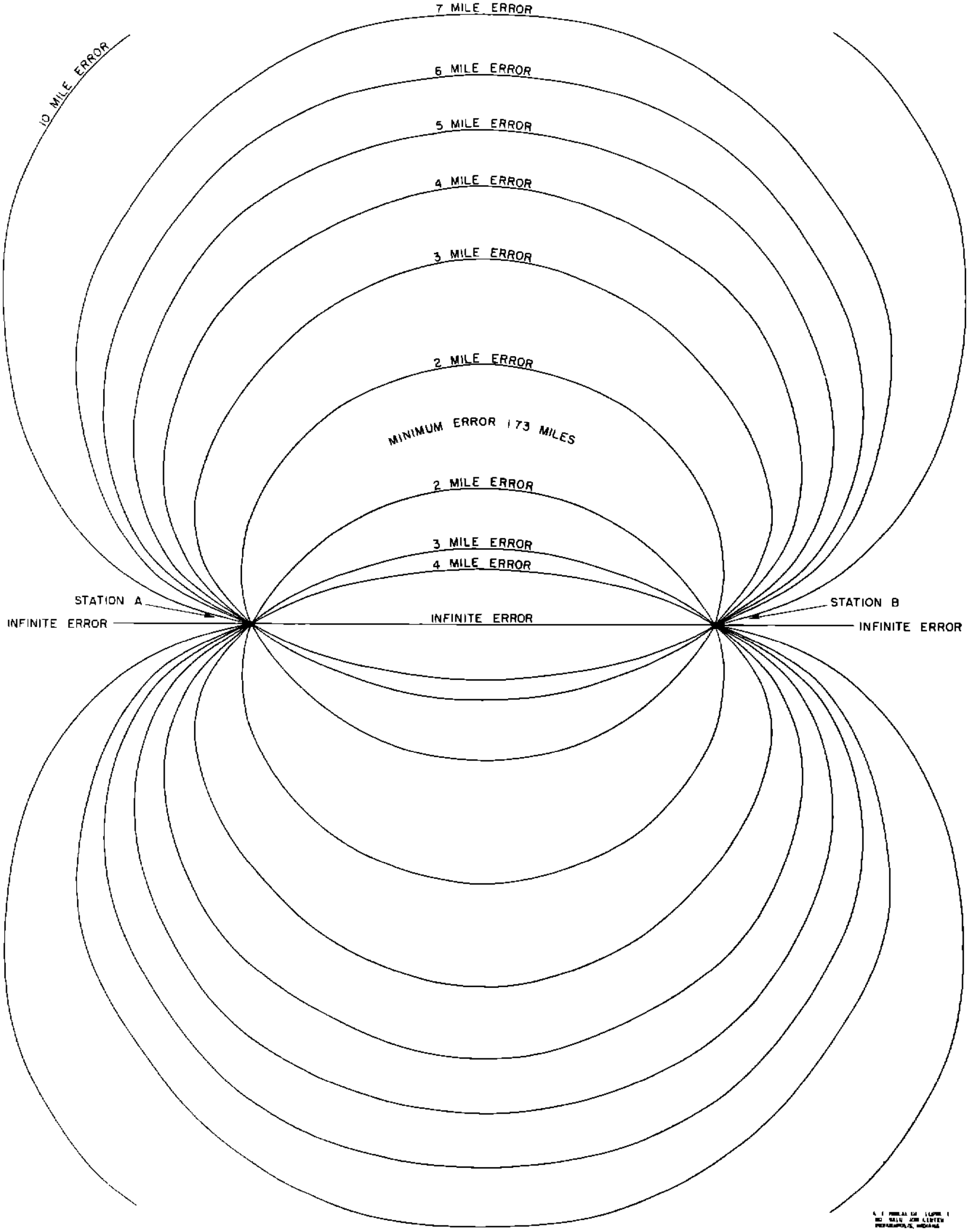
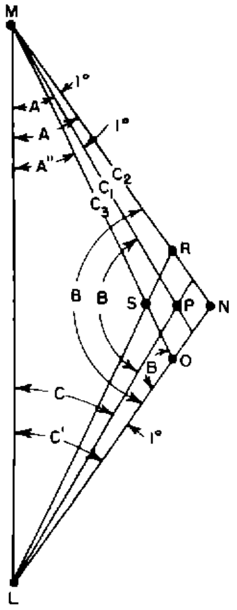


Fig 12 Maximum Errors in a Course Line Computer Based on Bearings From Two Omnirange Stations



$$180^\circ = A + B + C$$

$$180^\circ = A + B' + C'$$

$$180^\circ = A' + B + C'$$

$$C' - 1^\circ = C$$

$$A'' + 1^\circ = A$$

$$180^\circ = A' + 1^\circ + B + C' - 1^\circ$$

$$= A + B + C = A'' + B'' + C'$$

$$B = B$$

$$NP = \sqrt{C_1^2 + C_2^2 - 2C_1C_2 \cos 1^\circ}$$

$$OP = \sqrt{C_1^2 + C_3^2 - 2C_1C_3 \cos 1^\circ}$$

$$LM = 100 = b$$

$$MP = C_1$$

$$MN = C_2$$

$$MO = C_3$$

$$\frac{\sin C}{C_1} = \frac{\sin B}{b}$$

$$\frac{\sin C'}{C_2} = \frac{\sin B}{b}$$

$$\frac{\sin C'}{C_3} = \frac{\sin B'}{b}$$

$$C_1 = \frac{b \sin C}{\sin B}$$

$$C_2 = \frac{b \sin C}{\sin B'}$$

$$C_3 = \frac{b \sin C}{\sin B''}$$

$$= \frac{b \sin C}{\sin B}$$

Fig 13 Method of Calculating Errors in 2-Bearing Computer