THE CAA-RTCA
INSTRUMENT LANDING SYSTEM

PART I

DEVELOPMENT AND INSTALLATION

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Technical Development Report No 35

October 1943

U S. DEPARTMENT OF COMMERCE

CIVIL AERONAUTICS ADMINISTRATION

WASHINGTON, D C

TABLE OF CONTENTS

FIGURE INDEX

Figure		Page

THE CAA-RTCA INSTRUMENT LANDING SYSTEM
PART I - DEVELOPMENT AND INSTALLATION

SUMMARY

This report describes the radio instrument landing system designed and constructed under contract with the Civil Aeronautics Authority by the International Telephone Development Company and installed at the Indianapolis Municipal Airport The installation was completed and accepted in October 1939

The system provides for instrument landing in four directions, through the use of fixed ground stations Three elements are involved (1) a localizer of the equi-signal type, (2) a glide path using the constant intensity principle, and (3) inner and outer markers having vertically directed radiation

New methods have been developed which permit the modulation of the r-f output of a radio transmitter at two separate audio frequencies simultaneously with negligible cross modulation and distortion New horizontally polarized loop radiators have also been developed Both are valuable contributions toward the solution of the localizer problem New ideas on the control of horizontal patterns have been developed to produce straight line constant intensity glide paths

International lead has been achieved for the United States as a result of this work on radio instrument landing systems The technique has been of inestimable value in aiding the development of the ultra-high-frequency radio range system

INTRODUCTION

A complete description of several types of instrument landing systems has been presented in Technical Development Division Report No 1 by W E Jackson entitled "The Status of Instrument Landing Systems" and dated October 1937 That report described in detail the features of the several systems and set forth definite recommendations for an improved system based on the experience gained by the airlines, the Bureau of Air Commerce, the Federal Communications Commission, and the Radio Technical Committee for Aeronautics These recommendations were drawn up on June 23, 1937, by the organizations mentioned and were later revised and approved by the Radio Technical Committee for Aeronautics on December 17, 1937 The recommendations as finally approved and recommended by the R T C A are as follows

1 Runway Localizer

   a The runway localizer shall operate on an ultra-high frequency, preferably in the band 92-96 megacycles, or, if the localizer transmitter is operated as a separate unit, in the band 108-112 megacycles

   b The localizer course shall be straight, i e , one which has no bends or multiple courses perceptible to a pilot flying in still air

   c The difference in the magnitude of the two patterns of the localizer shall be 0 5 db at 1 5° either side of the center line as measured with a linear detector

   d The vertical needle of the cross-pointer indicator shall give a 10° deflection indication for a 1 9° angular deviation from the center line of the runway

   e The distance range of the runway localizer shall be at least 20 miles at 3000 feet altitude

   f There shall be freedom from interference pattern effects perceptible to the pilot both in elevation and azimuth

2 Glide Path

   a The glide path shall operate on an ultra-high frequency, preferably in the band 92-96 megacycles

   b A smooth glide path shall be provided, i e , one which is free from interference pattern effects perceptible to the pilot when on the localizer course

   c The system shall be capable of adjustment to provide a suitable glide path

3 Markers

   a The markers shall operate on 75 megacycles

   b It shall be possible to positively identify each marker both aurally and visually by modulation and keying The modulation frequency of the inner marker shall be 1300 cycles and that of the outer marker shall be 400 cycles

   c A normal arrangement of markers would be

      (1) At the normal intersection with the glide path

      (2) Near the boundary of the airport, the exact location to be determined by local conditions

d The inner markers shall have a field strength adjustment so that when installed in the boundary position the beam will cause useful indications of a visual device within 700 feet either side of the on-course path and for 300 feet along the glide path trajectory Indications from this marker shall be receivable to an altitude of 2000 feet

e The outer markers shall have sufficient power to accomplish a similar visual indication with the same beam pattern at 2000 feet altitude

4 Monitor System

a Satisfactory means for indicating visually the operation of all equipment shall be provided at a central point

b Whatever form of visual indication may be employed shall be smooth in performance and have no irregular characteristics

5 General Characteristics

a Frequency of emission of all of the elements of the system shall be equivalent to that obtained with a low temperature-Frequency coefficient quartz crystal

b The number of fixed or portable equipments required will depend on conditions prevailing at individual airports

c The installation of the foregoing equipment shall not constitute an obstruction to a normal approach to a runway

6 The installation of the best known type of approach and runway lights appears to be a most desirable measure in combination with instrument landing facilities

Specifications were prepared early in 1938 by the Radio Development Section for the development and installation of an instrument landing system at Indianapolis that would provide for four directions of approach and be completely controlled and monitored from a master control unit in the control tower These specifications were based on the R T C A recommendations and the considerable experience gained since the first instrument landing tests in 1928 by the National Bureau of Standards This experience was gained with the experimental installations at College Park, Md , Newark, N J , Oakland, Calif , and Indianapolis, Ind The experience of other organizations with other systems also was available and was used in preparing the specifications These other organizations and systems included United Air Lines-Bendix System, at Oakland, Calif , the Washington Institute of Technology System, at College Park, Md , and Pittsburgh, Pa , the United States Army Air Corps System, Dayton, Ohio, and the Lorenz System of C Lorenz A G , Berlin, Germany An installation of the Lorenz System was made at Indianapolis in 1937, through the courtesy of the International Telephone & Telegraph Company

In May 1938 a contract was awarded to the International Telephone Development Company, Inc , which was lowest bidder for the development of a system in accordance with the C A A specifications The equipment was designed and constructed at the Federal Telegraph Company plant in Newark, N J , and was installed at Indianapolis, Ind The installation work included considerable development of radiation patterns to provide suitable localizer courses and glide paths in the various locations required for four directions of approach The general airport layout is shown in figure 1

The system was completed in October 1939, and was accepted by the Authority All of the transmitting equipment involved in the system was designed and tested for satisfactory operation from minus 40° to plus 60° Centigrade, for as high as 95 percent relative humidity, and for wide variations in supply voltage The receiving equipment also was designed to operate over these limits

TRANSMITTING AND MONITORING EQUIPMENT

(a) Cable System

The entire instrument landing system (except outer markers) is operated from power obtained from the main line termination in the Administration Building, Municipal Airport, Indianapolis There are two main power lines which follow separate routes and terminate at the Administration Building In case of failure of service over the normal circuit, the auxiliary power circuit is automatically cut in The instrument landing system is connected to this service, and underground cables have been extended to the 12 stations on the airport, as illustrated in figure 2 The service is 2300-volt, 60-cycle, single phase Individual transformers at the glide path and localizer buildings step this voltage down to 230 and 115 volts The inner markers obtain 115-volt service from the adjacent glide path building transformers The outer markers obtain 115-volt, 60-cycle, single-phase power from individual line extensions of the Indianapolis Power & Light Co

Also shown in figure 2 are the 12-pair telephone cables which extend from the Administration Building tower to the various stations One pair to each station carries a nominal 48 volts direct current from the tower control unit for control of the various transmitters Over this same pair, monitoring signals are returned to the control tower A separate pair of the cable is used for telephone communication, although with the equipment provided, this service also can be handled over the control pair by interrupting the monitoring service One pair of each cable is used to carry 48 volts direct current to turn on the obstruction lights at each building The 48-volt relay control circuit is operated by an alternating current relay connected in the field boundary light circuit Other pairs of the cables are spares The outer markers are controlled and monitored over a pair of leased telephone lines Telephone communication is handled over the same leased pair

A portable hand telephone of the sound power type with magneto hand generator, as shown in figure 3, is provided for communication

(b) Transmitters

There are four transmitters involved in each direction of approach These are inner marker, outer marker, localizer, and glide path Each has the same basic crystal oscillator circuit and first multiplying stage as shown in the localizer and glide path transmitter diagram, figure 4 The crystals are sealed in nitrogen in Premier 500 type holders and are maintained at a temperature of plus 80° Centigrade by thermostatic control

The inner and outer marker transmitters are identical, except for their modulation frequency and rate of keying These characteristics are included in the general tabulation following

Table of Transmitter Characteristics

	Marker	Glide Path	Localizer
F (Carrier)	75 Mc	93 9 Mc	109 9 Mc
F (Modulation)	1300/400 cycles	60 cycles	90/150 cycles
F (Crystal)	4166 6 kc	3912 5 kc	4579 17 kc
Output (watts)	5	300	300
Input (volts)	110	220	220
Input (watts)	290	——	——
High voltage supply	300	Adj (2250 max)	3000
Low voltage supply	None	1440	1500
Bias (volts)	100	100	100
Tubes			
Osc	802 (3)**	802 (3)	802 (3)
#1 Mult	807 (3)	807 (2)	807 (2)
#2 Mult	807 (2)	304B (2)	304 (2)
#3 Mult	None	304B (2)	304B (2)
#1 Amp	807 (1)	100th* (1)	100th*(1)
#2 Amp	None	250th* (1)	250th*(1)
Line Mon	6H6	6X5	6X5
Main Rect	5Z3	836	836
Aux Rect	None	5Z3	5Z3
Bias Rect	Selenium	Selenium	Selenium

* Eimac tubes, used in pairs
** Number in parenthesis indicates order of multiplication of frequency

Views of a marker transmitter are given in figures 5, 6, and 7 A simplified schematic diagram of a marker transmitter is given in figure 8

The following points are of particular interest in the marker transmitter

1 Each transmitter contains a 48-volt direct-current telephone-type relay, the contacts of which close upon application of the 48-volt direct-current control voltage across the control line terminals and cause the transmitter to start There are no other relays

2 Each transmitter contains a type 913 cathode ray tube on which the percentage of modulation can be determined This tube operates only when the local "on" switch is operated at the transmitter

3 The unbalanced output of the last stage is converted to a balanced output in the circuit shown in figure 9

4 A type 6H6 tube is included in each transmitter to rectify part of the output signal for use in remote monitoring

5 A non-ring-through transformer is used in the transmitter monitor circuit so that telephone calling signals on the line will not damage the monitor meter

6 All sides of the transmitter are removable by loosening thumb nuts, and the components are arranged to give maximum accessibility for servicing

7 The input line voltage is held constant by an automatic voltage regulator

The glide path and localizer transmitters are identical in physical size and construction except for the high voltage supply to the output stage The glide path transmitter has 60-cycle alternating-current voltage applied to the final stage while the localizer transmitter has well-filtered direct current The electrical features are given in the tabulation Some of the special features of the localizer and glide path equipment are illustrated in figures 10 to 17, inclusive Others are as follows

1 The transmitters are started and stopped by operation of a 48-volt polar relay The polar relay closes in one direction for normal operation but can be reversed by the control tower operator to permit "local" operation at the station

2 The input line voltage is held constant by special 230-volt regulators

3 Fuses are not used in the transmitter Circuit-breaker type switches are used for protection and power control

4 The transmitters are kept under light air pressure by a blower to provide cooling Air intake openings are provided with filters to exclude dust and insects

5 A diode rectifier is used in the output coupling circuit of each transmitter to provide tuning indication

6 Thermostatically controlled heaters are used to insure stability of the output tank circuits at low temperatures

7 The localizer transmitter contains a rectifier-filter unit and a left-right instrument to operate in connection with a remote field monitor to indicate the course

(c) Localizer, Glide Path, and Marker Buildings

Each localizer building consists of a 10' x 12' x 15' frame structure bolted to a concrete floor The roof is pitched and has composition asphalt shingles No metal, except nails, is used in the building construction A 2-inch wire mesh horizontal counterpoise is installed inside the building 7 feet, 3 inches above the floor to preserve a symmetrical and stable radiated pattern The loop antenna radiators are supported above the counterpoise with their tuning sections extending below the counterpoise The general installation plan is shown in figures 18 and 19

Two of the buildings contain wing additions as shown in figure 18 Each of these wings accommodates a loop which is parasitically excited

The S E Localizer building (fig 20) has a specially constructed water-tight concrete basement which houses the transmitting equipment The antenna and counterpoise system is located in a small wooden house mounted directly over the basement Internally the station resembles those constructed above ground An electrically operated automatic sump pump was installed to remove water collecting in the basement In the six months period of observation the only water which entered came through the wall around the power conduit This leak was repaired and no further difficulty was encountered In future installations this conduit should enter over the top of the wall

Each localizer has a 2300-volt power transformer and obstruction light external to the building, except the S E localizer, which has no obstruction light and has its transformer in the building The transmitter, modulator, voltage regulator, and line switch boxes are mounted inside the building beneath the counterpoise, and the loop radiators are located above the counterpoise

All glide path buildings (see fig 21) are identical and are of frame construction on concrete bases similar to the localizer structures The building dimensions are 12' x 12' x 11'7" high Two of these buildings (S W and N W) contain a dipole array with screen reflector (see fig 22) The N E glide path station used for S E direction of approach, and the S E glide path station used for the N E direction of approach, each provided a straight line glide path The antenna array was external to the building and consisted of two spaced loop radiators and screen (see fig 21)

All of the eight marker stations consist of aluminum boxes (fig 23) with watersealed removable covers The transmitter, voltage regulator, telephone box, and line switch are mounted internally (fig 24) The transmitter is mounted on a roller bearing sliding shelf so that it may be withdrawn quickly for servicing without lifting (fig 25) The antenna automatically disconnects upon removal of the transmitter Each marker station antenna consists of a pair of collinear, co-phased dipoles excited at their adjacent inner ends The outer marker antenna is 1/4 wavelength above its counterpoise, and the counterpoise is 1/2 wavelength above ground The inner marker antenna is 1/8 wavelength above its counterpoise, and the counterpoise is 3/5 wavelength above ground

In all stations of the system, except the N W and S W glide path stations, balanced two-wire shielded 7/8-inch outside diameter transmission line is used In the two glide path stations referred to, the line to the dipole antenna, being totally within the house and only about 5 feet long, is made of open, spaced copper tubing

(d) Localizer Radiation Patterns and Courses

1 Theoretical description

The basic localizer pattern, frequently referred to as the "bean" pattern, is shown in figure 26A This is produced by three loop radiators of the design shown in figures 30 and 31 and arranged as shown in figure 26B The bean pattern is actually the resultant of two other basic patterns generally referred to as the "clover-leaf" and "dumb-bell" patterns, respectively The clover-leaf and dumb-bell patterns are illustrated in figures 26C and 26D The clover-leaf is produced by the two outside radiators (2 and 3 in fig 26B) which are spaced 165 electrical degrees and excited 180° out of phase Both radiators are excited with equal amplitudes of 90-cycle and 150-cycle sideband energy (See fig 26B)

The orientation of the radiators is set so that the null of the clover-leaf is in exact alignment with the center line of the airport runway This null is very sharp and defines the runway center line precisely after it is once established However, since there is no signal along the runway center line from the clover-leaf, this pattern alone cannot serve for operation as the localizer Further, since both 90-cycle and 150-cycle signals are present in equal ratio throughout, left-right sensing is therefore absent

To establish an on-course signal with left-right sensing, the center radiator (loop 1, fig 26B) is excited with the carrier fully modulated with equal amounts of 90 and 150 cycles Operating alone, the center radiator would produce a circular pattern However, in the presence of the outside loops, (2 and 3), which are free to operate parasitically with the center loop, the dumb-bell pattern shown in figure 26D is produced The phase of the current in the center radiator is set at 90° with respect to the excitation supplied to the outer radiators, so that in space (to either side of the clover-leaf null) the side band energy combines with the modulated carrier of the center loop to give left-right sensing [1] Since the outer radiators produce a null on-course, the only signal received on-course is the 100 percent modulated carrier of the center radiator

It will be observed from the typical bean pattern of figure 26A that:

(a) Maximum radiation occurs at an angle of about 25° from the course

(b) The signal on-course is approximately 2 75 decibels less than that at 25° off-course

(c) The signal at right angles to the course is approximately 5 decibels less than that on-course

(d) The course sharpness is 1 2 decibels (per 1 5° off-course)

(e) There is an equal reciprocal (rear) course

The patterns here described are capable of being altered slightly by adjustment of outer radiator spacing and phasing and center radiator phasing These adjustments affect the sharpness of the course, the direction of the maximum radiation, the amount of signal on-course, and the ratio of maximum radiation to that at 90° from the course

It is evident that a spacing of outer radiators approaching 180°, which would give a minimum at 90° to the course, cannot be used because this would cause radiation in this direction to be only that resulting from the dumb-bell pattern and would thereby permit the course-indicating instrument in the aircraft to indicate on-course The difference between the 90-cycle and 150-cycle bean patterns, often referred to as "clearance", must always be great enough to avoid a false course or, preferably, to keep the instrument pointer always off scale except when in the true on-course area

2 <u>Method of modulation</u>

The method of modulation is illustrated in figures 26B and 27 A photograph of the modulator unit is given in figures 28 and 29 From the diagrams it is seen that the output of the localizer transmitter, consisting of unmodulated carrier, is first passed through the "lower or cross-modulation bridge" where it is divided into two channels for modulation at 90 and 150 cycles The corner of the bridge opposite the entrance corner is loaded with a network Z_1 which reduces cross modulation The circuit voltage at the point where Z_1 is connected is minimized by the reversal "H"

The current passing in the two vertical channels is modulated by closely coupled sections which are alternately tuned and detuned by specially shaped 150-cycle and 90-cycle rotors driven at 1800 r p m by a synchronous motor The modulated current of the two channels enters opposite corners of the "upper bridge", which permits each carrier to add in-phase and pass with the respective side bands to the center radiator (1), while the carriers to the outer radiators (2 and 3) cancel (by virtue of the reversal G), thus allowing only sidebands to excite these radiators The lengths of all lines are equal from the transmitter to the output of the upper bridge The lengths from the upper bridge to the radiators are chosen so as to provide correct relative phasing in the radiators

3 <u>Installations</u>

The first localizer installation was made at the N W corner of the airport The site is clear except for telephone wires to the rear along the Pennsylvania Railroad right-of-way, and the CAA Experimental Station building at a considerable distance to the east The general layout showing the position of the telephone wires is given in figures 32 and 33 There are 84 open wires in the pole line, and their average height is about twice that of the localizer antenna The distance to the wires is 284 feet The original three-loop arrangement, whose pattern is given in figure 33, curve A, when used at this site gave multiple courses as illustrated in the cross-course flight record, figure 34 In making these records, a standard 5-milliampere Esterline-Angus graphic recorder was adjusted so that its central position corresponded to "on-course" simultaneously with the vertical pointer of the airplane cross-pointer instrument Figure 35 is a photograph of the aircraft recording equipment A schematic diagram of this equipment is shown in figure 36 As the airplane was flown across the course, the recording pen moved across the graph and, as shown in figure 34, for the flights using the three-loop array, the pen crossed the center several times indicating several courses Records were obtained at three separate distances from the station

[1] Appendix 1

A mathematical analysis[2] of these records in conjunction with ground measurements (see fig 37) indicated definitely that the multiple courses were caused by reflections from the wires behind the station and indicated the particular section of the wires that was directly responsible During the investigation ground measurements were made between the station and the wires by means of a portable detector The variations in relative field strength on a line between the station and the wires, and equi-distant from each, are shown in figure 37 for two heights of the detector The percentages of reflection from the wires as determined from these data are 4 69 and 6 25, respectively

A temporary localizer antenna was set up using a screen which produced a localizer having only a forward course (see fig 32) Flight tests revealed no multiple course and proved conclusively that suppression of the signal toward the wires would be necessary The experimental screened antenna was not developed for permanent use, since it presented mixed polarization problems Further, in attempting to completely suppress the rear radiation, many indefinite courses are apt to appear because of reflections from the screen Accordingly an array of six loops was developed, three parasitically excited loops being added to the original three excited loops Their spacing and phase were adjusted to give a null of radiation at 54° from the rear course, in the general direction of the wires where the objectionable reflections were taking place The pattern resulting from the six-loop array is shown in figure 33, curve B The signal on the important section of the wires was reduced approximately 11 6 decibels over that of the conventional pattern It should be noted also that in the original curve A at 54°, the difference in 90-cycle and 150-cycle beam patterns was approximately 7 5 db In curve B the difference is only 2 5 db The more nearly they are equal in the 54° direction, the less will be the effect of the reflection on the forward course The limiting ratio is that which produces a false course in the 54° zone

Flight tests of the six-loop array are shown recorded in figure 34 It will be observed that the amplitude of the reflected wave has been greatly reduced and that the recording pen crosses the center only once, indicating no multiple courses The sharpness of the course remains practically unchanged over that of the three-loop array A rear course of reduced amplitude remains, which is reciprocal and free of multiples At all positions around the station except in the on-course zone, the difference between 90-cycle and 150-cycle signals is 2 5 db or greater

The second installation made was the N E localizer The general layout with respect to the airport is shown in figure 38 The three-loop pattern as obtained for this station is shown in figure 38, curve A The cross-course flight record at the S W outer marker is shown in figure 39, curve A, and from this record the course appears to be satisfactory However, bends were found to exist between the inner marker and the runway An analysis of the rate of change of bend along the runway confirmed the theory that reflections from the airport Administration Building were responsible[3]

To improve the condition, two parasitically excited loops were added to the array, as shown in figure 26 The pattern obtained with the aid of these is shown in figure 38, curve B It will be observed that the direction of maximum radiation here occurs closer to the course than for the three-loop array, but that the signal toward the Administration Building has not been greatly reduced Most important of all, however, is the increase in course sharpness from 1 2 db to about 2 2 db per 1 5° off-course Numerous flights were made with the five-loop array, and one of the graphic records obtained is shown in figure 39, curve B The cross-course flight records made at 600 feet altitude over the S W outer marker show characteristics similar to those of the three-loop array except for the improvement in sharpness It was noted that there was an improvement in the course between the inner marker and the runway, but noticeable bends were still present The bends are relatively small, however, and represent about 0 3° total variation of the course

In an attempt to further improve the conditions, a portable experimental five-loop array similar to that used in the N E localizer station was set up on the N E -S W runway center line at the N E boundary of the field Its location is plotted in figure 38 It was excited by power from the N E localizer station over about 800 feet of open two-wire transmission line The arrangement is shown in figures 40 and 41 The intention was to increase the angle between the on-course direction and the direction of the Administration Building so that alteration of the pattern to reduce the signal on the building could be accomplished more easily It was observed that the signal at 45° (which is the direction of the Administration Building from the portable localizer) was about 6 db less than that in the direction of the on-course This would be an improvement except for the fact that the distance to the Administration Building was now only 850 feet as compared to 1,500 feet for the original N E localizer Preliminary flight checks indicated no important improvement in the course The original station location was therefore retained

The S E localizer station had to be placed relatively close (440 feet) to the airport boundary because of the presence of private dwellings and power lines This required that the building be very low so as not to constitute a hazard to flying To accomplish this, the transmitter and its associated equipment, which normally occupy the lower half of the localizer building, were placed below the ground level in a water-tight concrete pit The conventional antenna spray was then constructed over the pit as shown in figure 20 The top of the structure is only 9 feet above ground level

This localizer used the regular three-loop array, and the pattern derived from this array was essentially the same as that shown in figure 33, curve A, for the N W localizer

When the localizer station was first operated, the power lines along the street behind the station caused a noticeable bend in the forward course These lines were about 20 feet high and about 100 feet from the station and ran at 45° to the localizer course An almost perfect course was obtained by adjustment of the antenna system outer radiators to reduce radiation at right angles to the course However, since the presence of the wires constituted a hazard to flying, they were subsequently removed by the local power company

[2] Appendix 1

[3] Appendix 2

The S W localizer was the last one to be installed It originally used a three-loop array, but it was later changed to have a five-loop array to decrease the bends in the course Its relation to the end of the S W runway is shown in figure 42 An experimental ultra-high-frequency radio range structure comprising a mass of mesh wire 30 feet high was located 350 feet in front of this localizer The pattern obtained from this station was similar to that shown in figure 38, curve B

The course produced by the S W localizer, even with the five loops, was not straight but had shallow bends noticeable particularly between the N E inner and outer markers When the radio range structure was later removed, the bends disappeared

(e) <u>Glide Path</u>

The four glide path station buildings were installed in accordance with the contract as shown in figure 2 The locations of the buildings were chosen as a result of past glide path experience and were placed 400 feet off to the side of the center lines of their respective runways The radiation pattern intended for these stations was a broad beam, the axis of which is directed along the runway In the use of the system, the airplane would follow a parabolic curve of constant field intensity as defined by the output of the glide path receiver

A number of antenna arrays were investigated with respect to the shape of glide path produced The most important of these are shown in figure 43 All of the paths shown in figure 43 were made using the N W glide path and approaching toward the N W Altitudes were determined by altimeter for the higher points and by observations from the ground for the lower points A Waco Model N airplane, NC-17, was used in the tests and all data are based on the same point of contact distance (2,100 feet) from the glide path station

It will be observed that paths B and C are nearly alike These paths were produced with highly directive arrays focused parallel to the runway The directivity caused these paths to be generally lower than path A which was produced by a simple dipole array Path D was produced by focusing a directive array toward the point of contact on the runway The position of the beam axis accounts for the irregularity at a distance of 9,000 feet Simple tests confirmed the theory that the vertical pattern in the direction of approach is affected by the change of beam axis direction This is particularly true of sharply directive patterns Controlling horizontal directivity in order to straighten the glide path is of little value when the glide path antenna is located only 400 feet from the runway, since the angle between a line parallel to the runway and a line to the point of contact, as observed at the glide path station, is too small to provide sufficient control of the radiation pattern

The directive patterns of the rhombic and stacked V antennas in the building 400 feet off the center lines are also undesirable because of the rapid change in the path when the airplane deviates right or left of the true course

Each of the paths A, B, and C in figure 43 is smooth and generally parabolic in shape Beyond the outer marker, however, the paths rise rapidly and, when followed during an approach, the rate of descent is greater than that considered desirable

Experiments in the use of a directive antenna array farther off the side of the runway had been conducted by the Lorenz Company of Germany Since the S E and N E glide path stations were approximately 1,400 feet from the center lines of the N E -S W and S E -N W runways, respectively, it was considered advisable to conduct further tests

The first set-up was made at the S E glide path station for the S W approach (approach when headed N E) and consisted of two collinear dipoles with screen reflector, as shown in figure 44 The current and phase relations in the dipoles were adjusted to give the radiation pattern shown on figure 45 The flight path resulting is shown in figure 46 The path is essentially straight from the outer marker to the inner marker, and gradually curves to the point of contact

Similar paths and patterns were produced using two-loop and four-loop arrays The two-loop array (fig 21) was permanently installed at both the S E and N E glide path stations for the N E and S E directions of approach, respectively

(f) <u>Marker Patterns</u>

The power of each inner and outer marker was adjusted arbitrarily to give a marker light indication of 8 seconds duration when the aircraft was flying over the station at 600 feet altitude at 100 m p h The marker receiver sensitivity was adjusted to give a 15-second marker light indication when the aircraft was flying at an altitude of 1,000 feet over the Indianapolis "Z" marker For these adjustments, the relative signals of the three markers at 1,000 feet altitude are as shown in figure 47 In normal use the inner marker indication is approximately 1-1/2 seconds when the aircraft is passing over the marker at an altitude of approximately 45 feet The duration of the outer and inner marker signals (8 and 1-1/2 seconds, respectively) has been found satisfactory for instrument landing

Vertical patterns of the two markers, taken with increased power output, are shown in figure 48 There are no minor lobes The pattern in the horizontal plane at 600 feet altitude has a cross-course length to thickness ratio of approximately 4-1

(g) <u>Monitor and Control System</u>

A simplified diagram of the monitor and control system is given in figure 49 In this system a control desk, figure 50, located in the Administration Building control tower, handles all functions

It contains a rectifier producing approximately 60 volts direct current which is switched to the various control lines to start the transmitters and hold them in operation The polarity of the direct-current supply is reversed by switches in the localizer and glide path circuits to provide interlocking on the transmitter "local control" switches The transmitter control relays are nominally 48 volts

The same lines used for the direct-current control circuit also carry the return monitoring audio signals The marker monitor signals (400 and 1,300 cycles) are derived from a 6H6 rectifier tube which is coupled to the output radio-frequency transmission line of the transmitter The glide path monitor signal (60 cycles) is obtained from a 6X5 rectifier tube coupled to the glide path transmitter output transmission line The localizer monitor signal (90-150 cycles) is obtained from a field monitor unit (see figs 16 and 17) located approximately 200 feet in front of the localizer station This localizer monitor operates the indicating devices on the transmitter as well as those on the control desk

Each monitor signal received at the control desk is individually adjusted for level, amplified, filtered, and rectified to operate the control desk indicating instruments The localizer indicating instrument is a zero-center instrument, and signals to operate it are derived from a balanced 90/150-cycle filter and special copper oxide rectifier units identical to those used in the localizer receivers The other filters used are combination filter-saturable reactor units, similar to those used in airline 27-A marker receivers The saturable reactors are operated by the rectified monitor signals which release 60-cycle alternating current to indicator lamps located above the indicating instruments to indicate the presence of monitoring signals Similar indicating lamps, also operated by the monitor signals, are located in appropriate positions on the miniature diagram of the airport (see fig 51) on the surface of the control desk The lamps indicate the locations of the stations operating

Each of the amplified monitor signals is connected to a commutating device (shown in fig 52) on the drive shaft of an Esterline-Angus recording milliammeter Through this commutating device the signals are connected in sequence to an amplifier and rectifier and thence to the recorder The individual levels are adjusted so that each causes the recorder pen to deflect to mid scale and provide uniform recorder amplitude (fig 53) for normal operation except for the runway identifying signal The runway identifying signal (there are four instrument landing runways) consists of rectified line voltage, the value of which is dependent upon the position of the runway selector switch To record the 90/150-cycle localizer monitor signal, the relative amplitudes of the 90-cycle and 150-cycle components are recorded separately, that is, as two individual monitor signals Each of the six monitor signals (inner marker, outer marker, glide path, localizer 90-cycle, localizer 150-cycle, and runway) is allowed to remain on the recorder approximately 10 seconds When the instrument landing system is turned off, the recorder is used as a voltmeter which is connected through an instrument rectifier to the 115-volt, 60-cycle line, and the recorder drive speed is reduced and operated by clock escapement Time markings in minutes and hours are continuously made on the margin of the chart by two impulse pens operated from a dry-cell battery through a precision clock

The signals applied to the recorder are also applied to the control grid of an 884 tube, the plate current of which normally holds an alarm circuit relay open Failure of any of the signals received by this tube from the commutator causes the relay to close and an audible alarm to sound in the control tower A red signal also lights on the control desk A push button marked "Silence" permits the operator to stop the audible alarm, but only correction of the faulty signal will allow the red signal to be extinguished A "restore" button is provided to reset the alarm circuit A time delay relay is used to prevent operation of the alarm during the normal warm-up period when the system is turned on Figure 54 shows the internal arrangement of the monitor desk A line voltage regulator, similar to those used with the marker transmitting equipment, is used with the control desk to insure constancy of monitor readings and reliability of the alarm circuit

A hand type, sound power telephone and magneto ringer are provided with the control desk To simplify the switching circuits, ringers at all 12 stations on the airport ring when the magneto is operated Separate pairs are used for telephone service to these stations to avoid interruption of monitor signals Non-ring-through transformers have been provided in the equipment so that telephone service may be handled over the monitor pair if it ever should be required The outer marker telephone service is handled over the same pair that is used for controlling and monitoring, however, the marker monitor signal is interrupted while the telephone is in use The outer marker ringing is individually selected at the control desk by four lever-type key switches

RECEIVING EQUIPMENT

(a) Receivers

Localizer, glide path, and marker receivers were procured with the instrument landing system The localizer and glide path receivers were of new design, and the marker receivers were type RUC (same as Western Electric Co , 27A) formerly adopted for airways marker service and containing filters for inner and outer marker operation All receivers were designed, constructed, and tested under conditions equivalent to those for airline ATC equipment The three receivers are shown in figures 55, 56, and 57

Schematic diagrams of the receivers are given in figures 58, 59, and 60 Each receiver is a crystal controlled superheterodyne, the crystal being hermetically sealed and less than 9 megacycles in frequency The basic features are as follows

Table of Receiver Characteristics

		Glide Path Receiver	Localizer Receiver	Marker Receiver
Carrier (Mc)		93 9	109 9	75 0
Crystal (kc)		7298	8325	7630 5
IF (kc)		6325	10,000	6325
Pass Filters (cycles)		60	150/90	3000/1300/400
Nominal Sensitivity		2500 μv	50 μv	150 μv
Selectivity (60 kc)		3 db	3 db	6 db
Selectivity (300 kc)		60 db	60 db	60 db
Image Response		-60 db	-60 db	-60 db
IF response		-60 db	-60 db	-60 db
Sig /noise		30 db	30 db	30 db
Output		0-600 μa, d c	Bal d c	Sig lamp & aural
Audio Selectivity*		15 db	15 db	20 db
Voltage Stability		±_0%	0 5° **	——
Temp Stability (-40 to +60°C)		±10%	3 5° **	——
Width***		5-3/16"	10-3/8"	5-3/16"
Weight		14 lbs	27 lbs	15 lbs
Vibrator		Non-Sync	Sync	Non-Sync
Tubes	Moc	6C6G	6_7	6J7
	IF	6SJ7	6SK7	6_7
	2nDet	6SQ7	6SQ7	6Q7
	Aud	6R7	6J5	6V6G
	OSC	6C8G	6N7	6N7

* Audio selectivity value at freq 25% below resonance
** Localizer vertical pointer movement in degrees
*** Std aircraft length and height is 19-7/16 x 7-11/16 inches

Each receiver is designed for operation from a 70-ohm concentric transmission line Power supplies are designed to operate from 12 volts direct current

Special features were incorporated in both localizer and glide path receivers to meet the specification requirements For example, temperature compensation of receiver sensitivity was necessary In the glide path receiver this was especially important Compensation had to be applied, in the glide path receiver, for momentary and prolonged change of battery voltage such as usually results from the starting of the airplane radio transmitter or the operating of landing lights For a prolonged drop in battery voltage, two types of compensation are employed, one to correct for the immediate change caused by reduction of recoi er plate voltage and the other to compensate for the gradual change in emission of the filaments In the localizer receiver, careful consideration in the design of the 90/150-cycle filter and its associated circuit was required to avoid variation of the indicated course for signal levels below that at which the receiver automatic volume control was in operation The rectifiers operating on the output of the 90/150-cycle filter had to be of special design and, as supplied, were balanced with respect to signal volume and temperature Under test at prolonged high relative humidity, difficulty of leakage in certain parts of the wiring and in the I F transformers had to be overcome

Characteristics showing the operation of all three receivers are given in figures 61 to 78, inclusive The installation of these receivers in the special receiver rack of airplane NC-17 is shown in figure 79

(b) Aircraft Receiving Antenna

The receiving antenna used in conjunction with the localizer and glide path receivers is new and unique in its design One antenna serves both receivers simultaneously The marker receiving antenna is of standard design (horizontal longitudinal dipole beneath the airplane) previously adopted[4] for airways marker reception (see fig 80)

The localizer glide path receiving antenna is a horizontal loop shown in figure 81 For a general understanding of the application of the loop antenna to 93 9- and 109 9-megacycle instrument landing

[4] W E Jackson and H I Metz, "The Development, Adjustment, and Application of the Z-Marker," Technical Development Report No 14, July 1938

[5] Andrew Alford and A G Kandoian, "Ultra-High-Frequency Loop Antennas," Supplement to Electrical Engineering Transactions Section, A I E E , January 1940

service, refer to figure 82 This figure illustrates the antenna circuit as a resonated two-wire transmission line AG, part of which, B, has been expanded to increase its radiation resistance to form the receiving loop The part (B) expanded represents only a small portion (approximately 1/8 wavelength) of the sinusoidal distribution of current along the line The length of line, section A, is chosen so that for the 93 9-megacycle frequency, the antinode of current is approximately at the center of the loop The line AG is made long enough (5/4 wavelength) so that a second antinode of current will be present at E The circuit is resonated to 93 9 megacycles by adjustment of stub G and condenser H The glide path receiver is connected to the line through a balancing circuit (see figs 9 and 83) L_1, L_2, C_1, which removes all in-phase currents in the antenna circuit and permits the use of a concentric line receiver input For the condition of balance

$$\omega L_1 = \omega L_2 = \frac{1}{2\omega C_1}$$

$$\text{where } \omega = 2\pi f$$

assuming no coupling between L_1 and L_2

At point E, where the impedance at 93 9 megacycles is minimum, any circuit such as I J may be attached, and if it is adjusted to present a high impedance at 93 9 megacycles, its presence will not affect the 93 9-megacycle circuit Accordingly, the circuit I J is connected at point E, and stub J and condenser K are adjusted until the entire circuit (including EG) is resonated to 109 9 megacycles It is obvious that the circuit EG is involved in the resonance of the circuit I J at 109 9 megacycles and therefore must be adjusted prior to adjustment of circuit I J

Some characteristic horizontal patterns of this type receiving antenna are shown in figures 84 to 86, inclusive

(c) Indicating Instrument

The type of instrument used on the airplane instrument panel is shown in figure 87 and a typical installation is shown in figure 88 The instrument is of the cross-pointer type, the vertical pointer normally resting at the center for indication of the localizer course and the other pointer resting at the bottom[6] for indication of the glide path

The characteristics of the vertical pointer are shown in figure 89 Originally these instruments were designed so that the vertical pointer was relatively insensitive except within the range of plus or minus 10° (see fig 89, curve A) This was to permit the airplane to depart from the relatively sharp localizer course in making procedure turns without having the vertical pointer ride against the left or right stop pins, thereby losing sense of movement with respect to the course It was subsequently decided that such a characteristic imposed a handicap upon the pilot in approaching the course because the rate of approach appeared to be non-linear The instruments were then converted to have linear sensitivity, as shown in figure 89, curve B

The characteristic of the horizontal, or glide path pointer, is given in figure 89, curve C The output of the glide path receiver is limited to avoid damage to the horizontal pointer movement

The resistance of each movement is approximately 1200 ohms and the full-scale sensitivity is 300 microamperes (plus and minus 150 microamperes for the vertical pointer) The damping factor is approximately 10 and the period 0 3 to 0 4 seconds

SPECIAL TEST EQUIPMENT

A radio-frequency potential measuring device (commonly referred to as "probe detector"), consisting of a small resonated circuit with sensitive radio-frequency milliammeter and a shielded excitation lead (see figs 90 and 91), was used during the process of matching line impedances and in measuring line balance The adjustment of concentric type lines was accomplished by first using a section of line, the outer sheath of which was provided with closely spaced slots through which the end of the detector could be inserted After adjustment, this section was replaced with a sealed section of the same physical dimensions

Field patterns of both localizer and glide path stations were taken using a dipole and detector type field meter, as shown in figures 92 and 93 This field meter was calibrated against a standard radio-frequency ammeter in the transmitter antenna by varying the transmitter output power The device was useful for taking patterns up to 300-feet radius from the station

For observance of localizer courses, the detector-filter unit as shown in figures 94 and 95 was used The 90/150-cycle filter employed was similar to that used in the localizer receiver Courses were also observed on the runways with a localizer receiver, the installation of receiver and loop receiving antenna being made in a field truck (see fig 96)

A conventional cathode ray oscillograph with horizontal sweep circuit was used during adjustment of the localizer modulator and its cross modulation load Resonated pick-up loops for use with an oscillograph were installed in each localizer house A typical pattern of the on-course signal is shown in figure 97

[6] Subsequently this instrument was inverted and operated as "follow the pointer" type

A General Radio type 736-A wave analyzer was used with the field detector unit for determination and adjustment of cross modulation

VERTICAL VS. HORIZONTAL POLARIZATION

In preparing this report first consideration was given toward a description and explanation of the equipment installed, and this included horizontally polarized loop radiators Selection of the correct polarization was not overlooked either in the specifications or in the development and tests Factors affecting the choice between horizontal and vertical polarization are described herein

When design work was started on this instrument landing system, experience with vertical polarization on ultra-high-frequency radio ranges had not been encouraging, at least insofar as the adoption of its technique to the production of critical localizer courses was concerned The results of laboratory experiments with vertical polarization were variable and unreliable, and were seriously affected by movement of personnel and equipment in the vicinity of the experimental set-up Horizontal polarization exhibited these difficulties only to a very small degree Field tests with a 125-megacycle portable radio range indicated superior performance for horizontal polarization

Most important of all, perhaps, was the evident need for horizontal polarization on the glide path Tests in 1937 at Indianapolis, both on 33 and 93 megacycles, indicated that vertical polarization gave irregular reflections at the approach end of concrete runways which caused serious distortion of the glide path This distortion was not experienced with horizontal polarization Therefore, to expedite the development, to select that which experience indicated as best, and to have both glide path and localizer alike, horizontal polarization was chosen for the localizer and temporarily installed pending the results of final tests of an equivalent vertical array

For the tests a set-up was made adjacent to the N E localizer station, as shown in figure 98 This set-up consisted of three vertical dipoles connected to the modulation system of the N E localizer station by balanced two-wire lines and adjusted to operate similarly to the three-loop horizontal array Course sharpness and signal strength of this vertical array were equal to that of the three-loop horizontal array

Flight records made on the front and back courses are shown in figure 99 in comparison with similar records of the three-loop horizontal array The occurrence of many wiggles in the localizer indicator in the cockpit is evident from the flight records of the vertically polarized array The records of the horizontal polarization are relatively smooth The large wiggles with vertical polarization are caused by reflections from trees and buildings [7]

Another comparison is given in the records of figure 100 These are made by taxiing the airplane along the runway toward the station The bends in the course of the vertically polarized array are caused by reflections from the airport Administration Building which evidently are greater for vertical than for horizontal polarization

As a result of these tests and of the factors brought out in the foregoing discussion, it was considered logical to adopt horizontal polarization Accordingly, the development was concluded with the complete installation of horizontal radiators

CONCLUSIONS

The following conclusions have been reached as a result of the experience gained in preparing the specifications and witnessing the design, manufacture, installation, and testing of the Indianapolis system The experience in operating the system to date and in observing the operation of other systems has been influential in the citing of qualitative comparisons

1 The radio transmitting equipment, including localizer, glide path, and marker transmitters, is fully reliable under the widest fluctuation of ambient temperature and voltage conditions ever to be encountered, is exceptionally well designed to facilitate inspection and servicing, and is as efficient electrically as contemporary designs of similar equipment

2 The radiating systems, particularly the localizer antennas, are new in design and very reliable The production of substantially pure horizontally polarized waves and of courses of exceptional sharpness and freedom from bends, multiples, pushing and pulling effects, etc , has resulted from the development of this localizer antenna array The principles can be applied to the ultra-high-frequency radio range development for both the aural and visual types

3 Based on present technique, experience, and results in work on U H F transmitting and receiving antennas, horizontally polarized waves are preferable to vertically polarized waves for localizer and glide path station use

4 The method of mechanical modulation in the localizer system as compared to previous mechanical systems is of outstanding importance for at least four reasons

(a) It permits reduction of cross modulation to less than 4 percent
(b) It reduces the power wasted here to cross modulation from 25 percent or more, to less than 10 percent
(c) It reduces harmonic distortion to 12 percent
(d) It stabilizes the localizer course against variation caused by tube failure

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[7] J M Lee and C H Jackson, "Preliminary Investigation of the Effects of Wave Polarization and Site Determination with the Portable Ultra-High-Frequency Visual Radio Range," Technical Development Report No 24, February 1940

5 The method of controlling and monitoring the system, while sound and complete in principle, is not entirely satisfactory in service It requires simplification to facilitate adjusting and servicing The alarm and recording circuits should be electrically isolated to minimize reaction Continuous operation of the instrument landing system indicates that the recorder should be operated slowly and continuously, and it should carry enough recording paper for at least one week of continuous recording

6 The aircraft receiving antenna, with its ability to be resonated to, and to receive simultaneously, two independent signals, is a contribution which reduces rather than increases the number of radio antennas required on aircraft The generally uniform horizontal pattern of this antenna has been found to be a desirable requirement which has not been obtained with vertically polarized receiving antennas

7 The receivers have been very reliable in their operation and calibration, and are satisfactory for use on commercial aircraft A weight and space reduction of the localizer receiver would be desirable

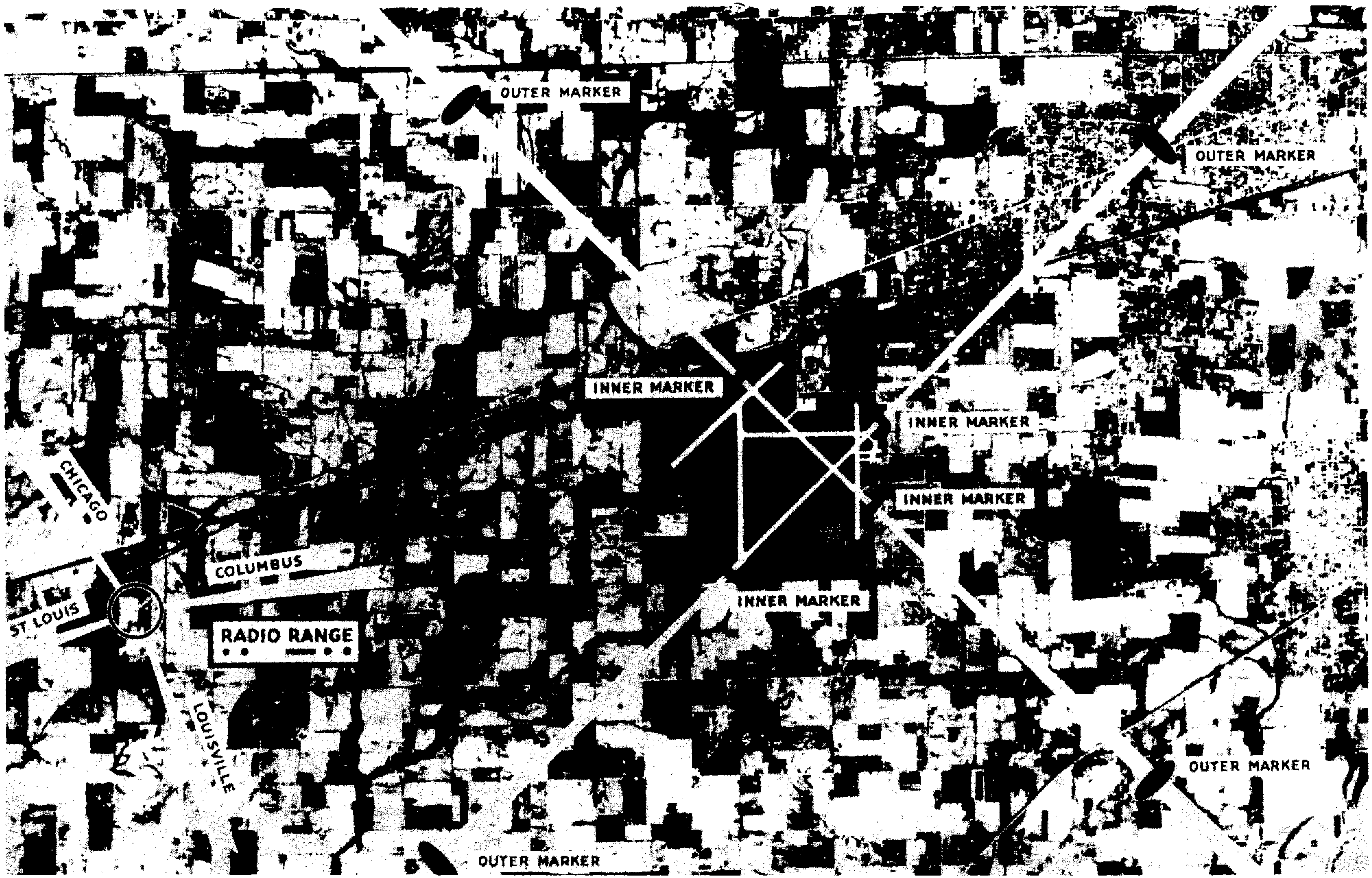

FIGURE 1. Aerial Photograph of the Indianapolis Municipal Airport.

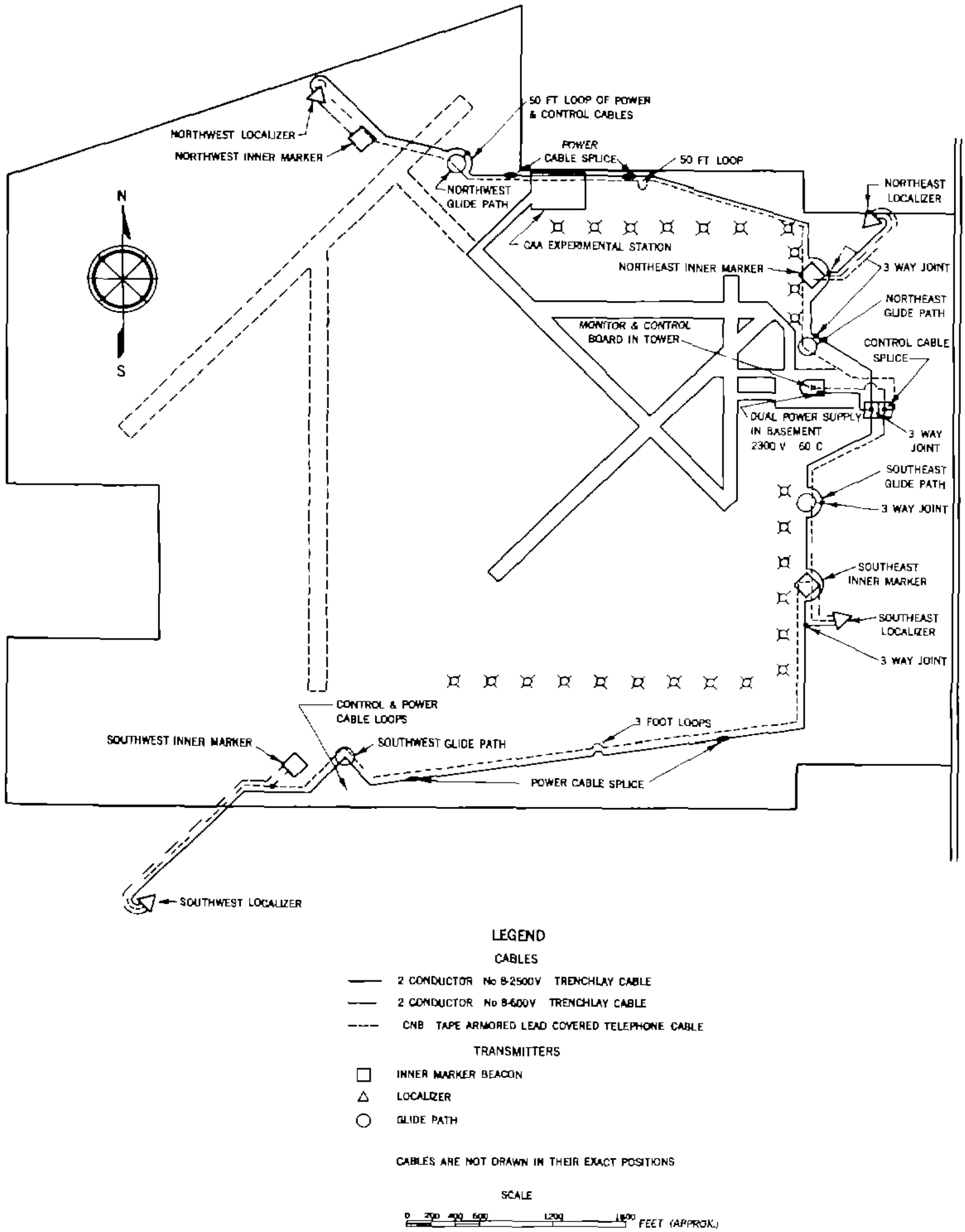

FIGURE 2. Underground Control and Power Cables, Indianapolis Instrument Landing System

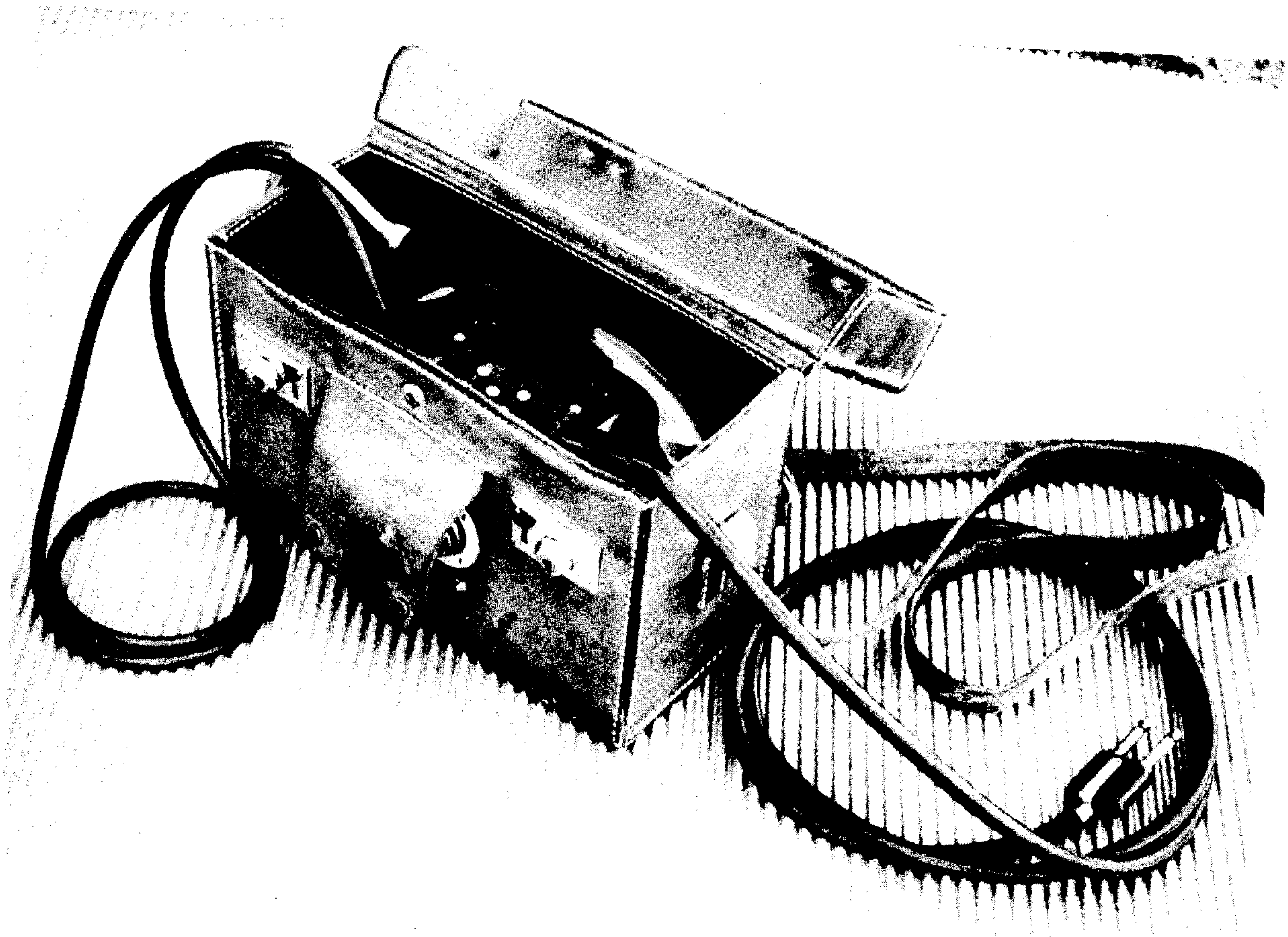

FIGURE 3. Portable Telephone Set.

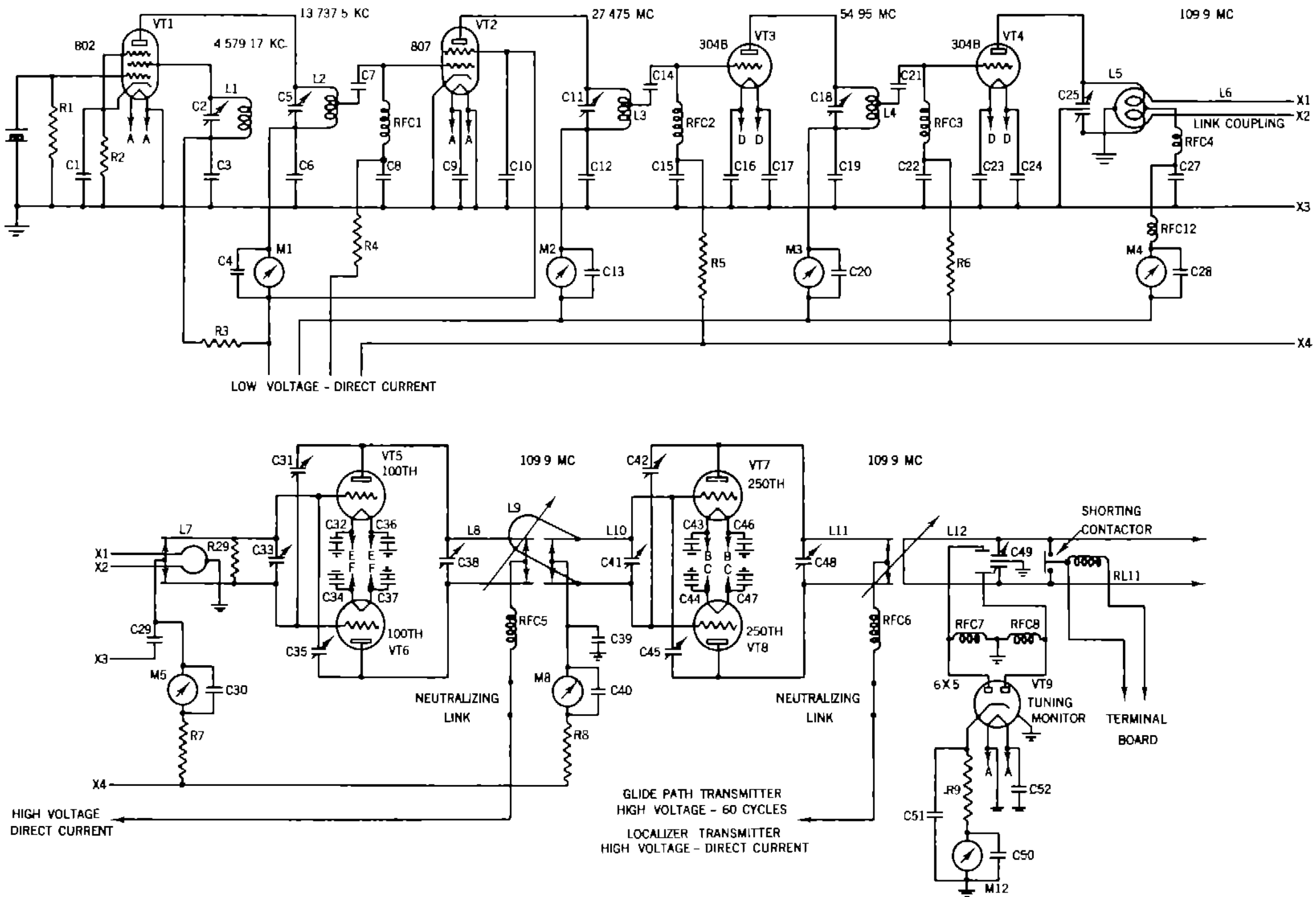

FIGURE 4. Basic Diagram for Localizer and Glide Path Transmitter.

FIGURE 5. Marker Transmitter, Front View.

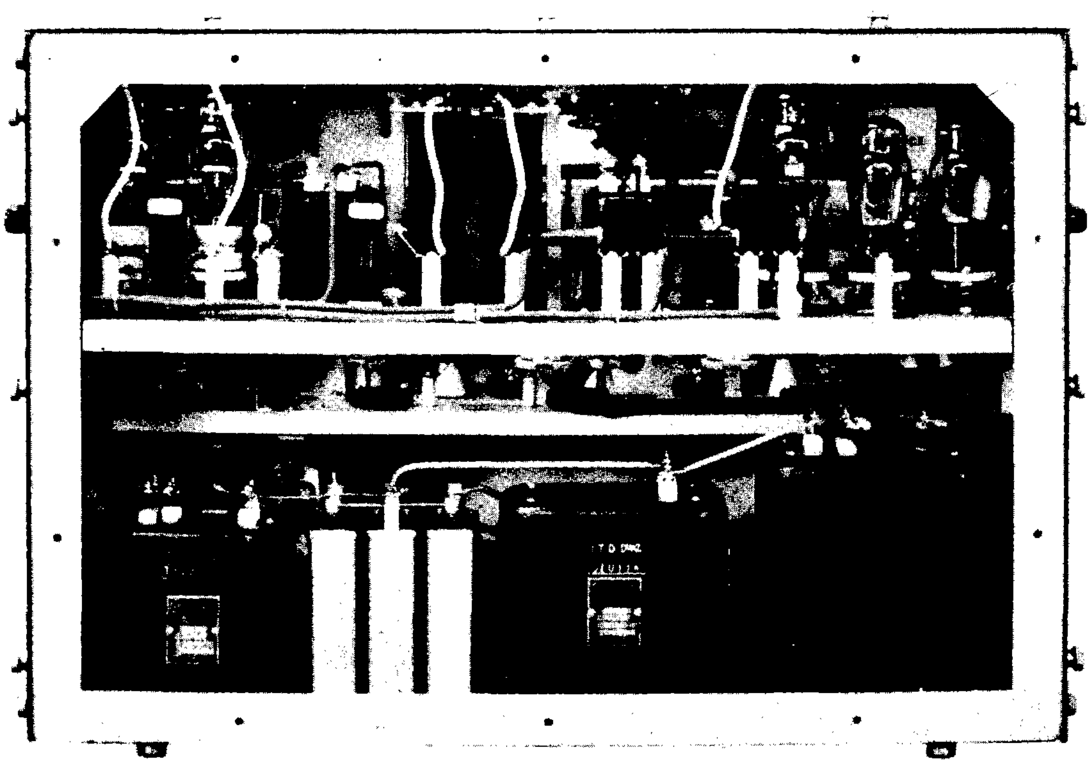

FIGURE 6. Marker Transmitter, Rear View, Open.

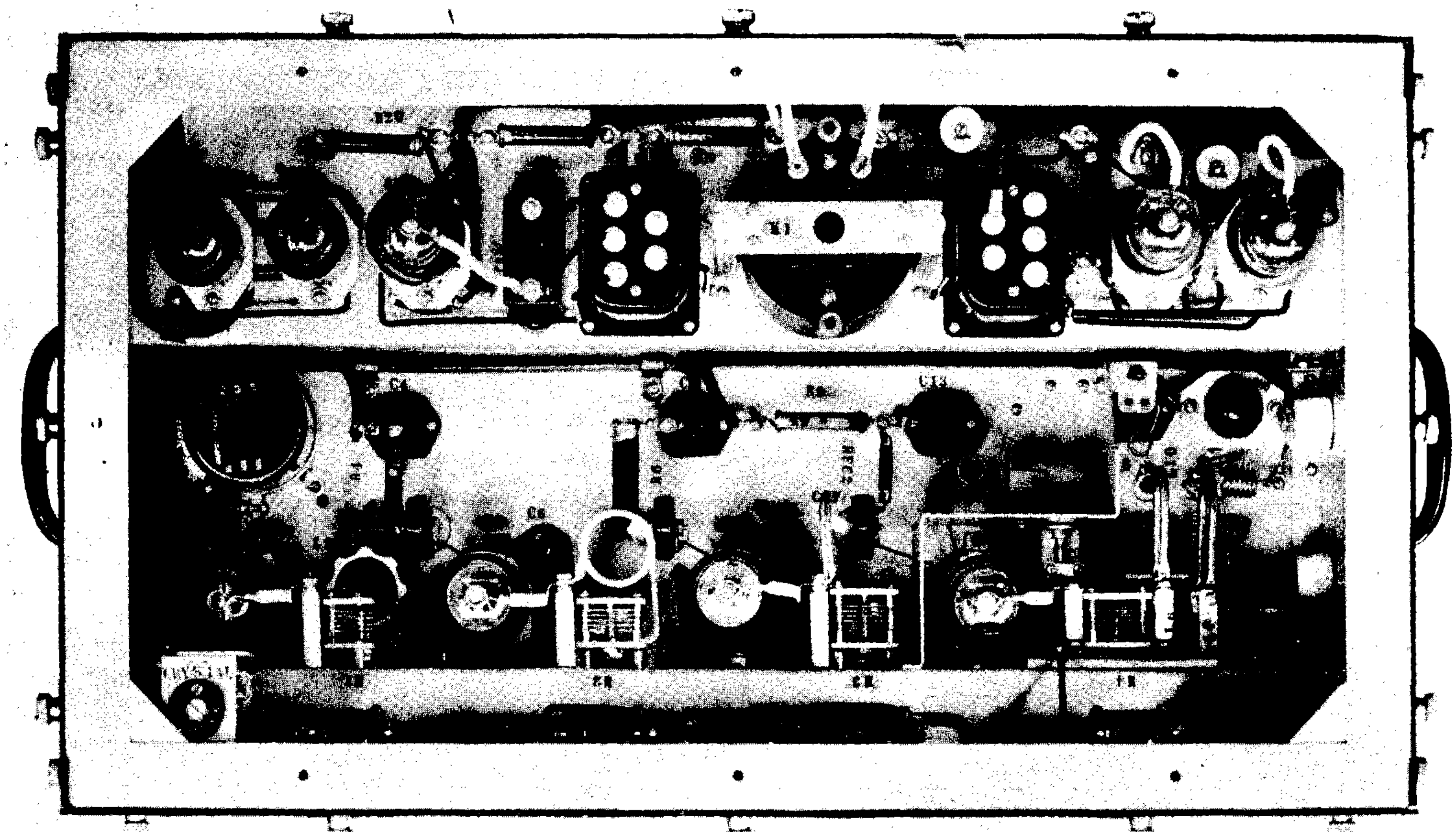

FIGURE 7. Marker Transmitter, Top View, Open.

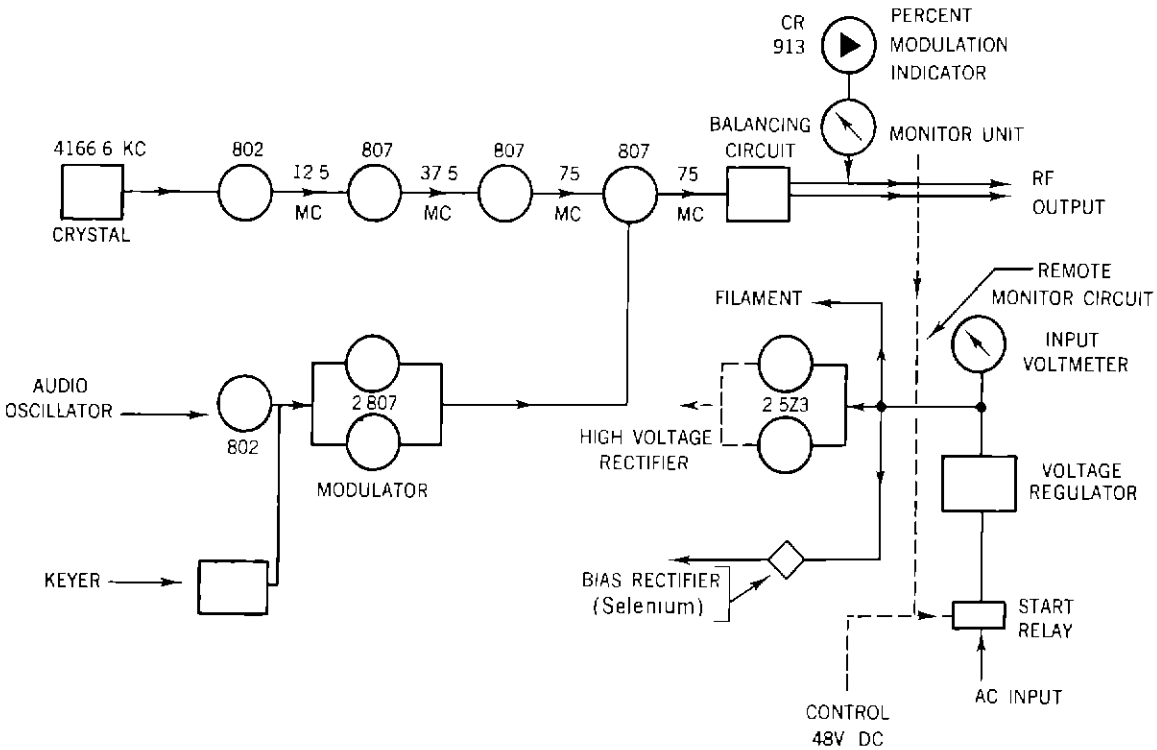

FIGURE 8 Simplified Diagram of 75 Mc Marker Transmitter.

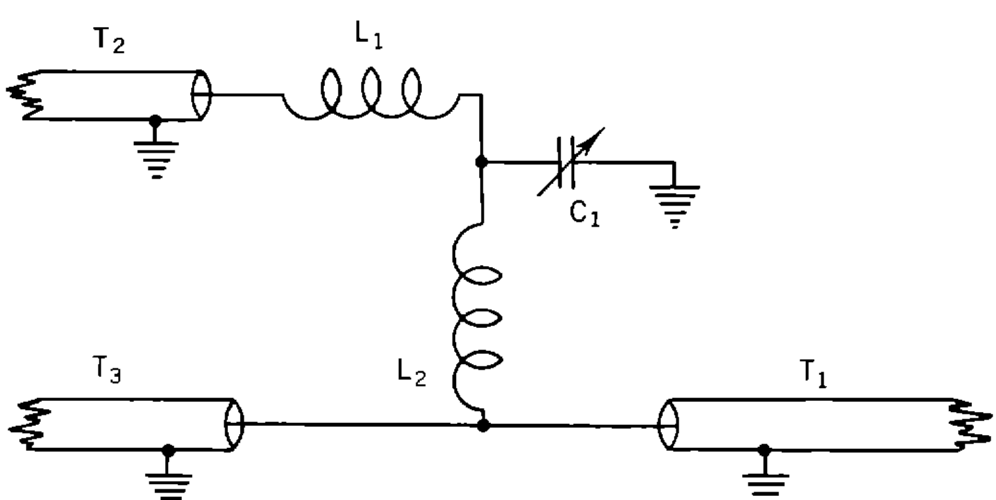

FIGURE 9. Circuit Balancing Network

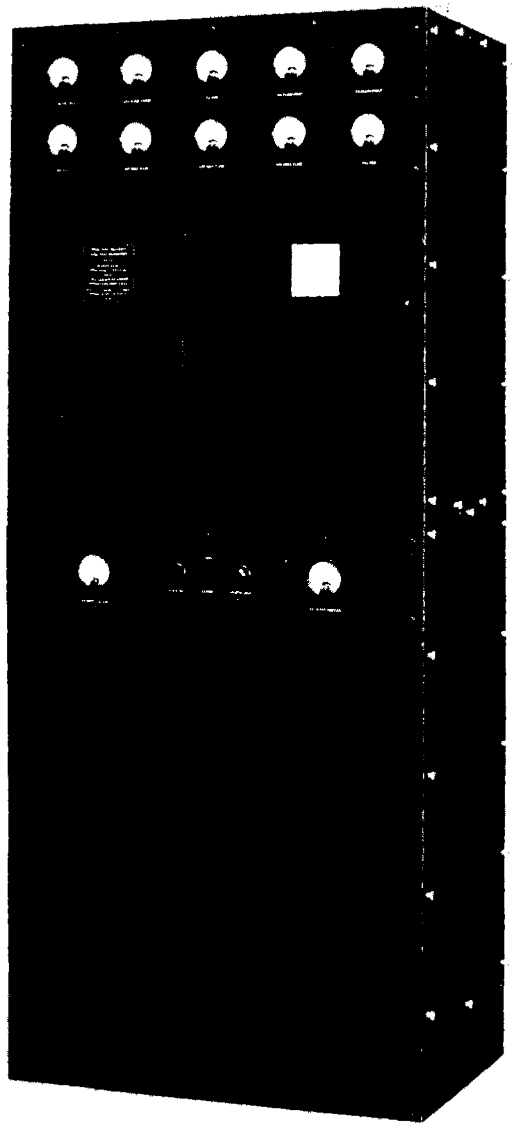

FIGURE 10. Glide Path Transmitter, Front View.

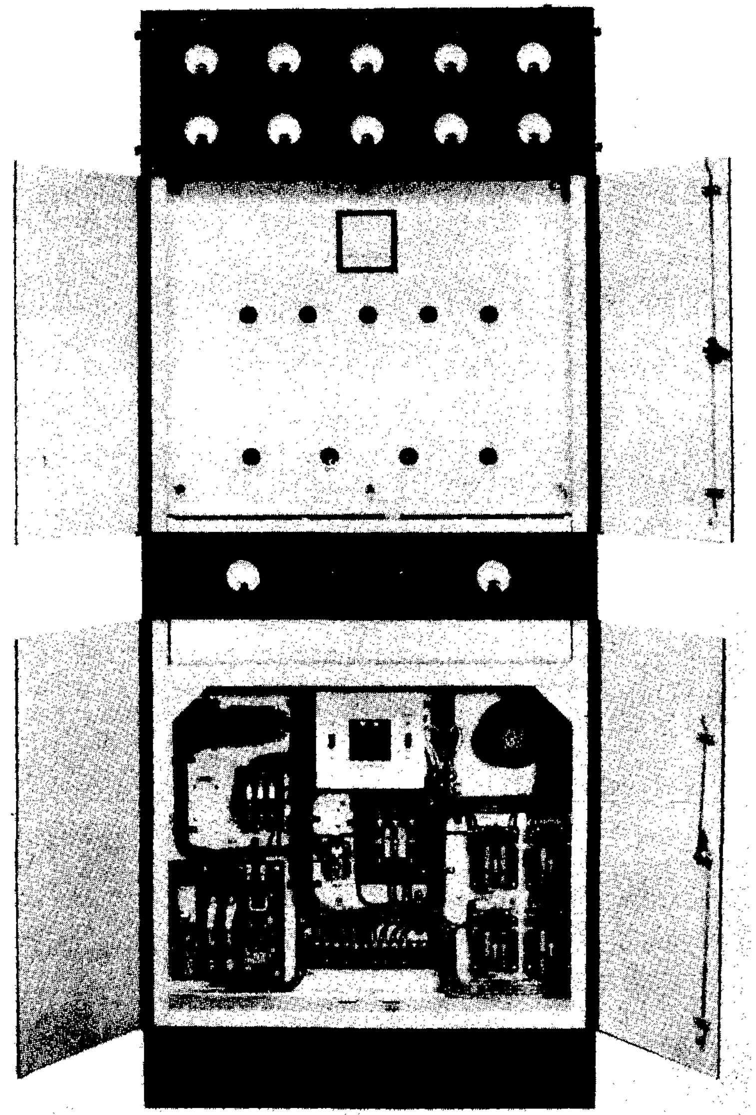

FIGURE 11. Glide Path Transmitter, Front View, Doors Open.

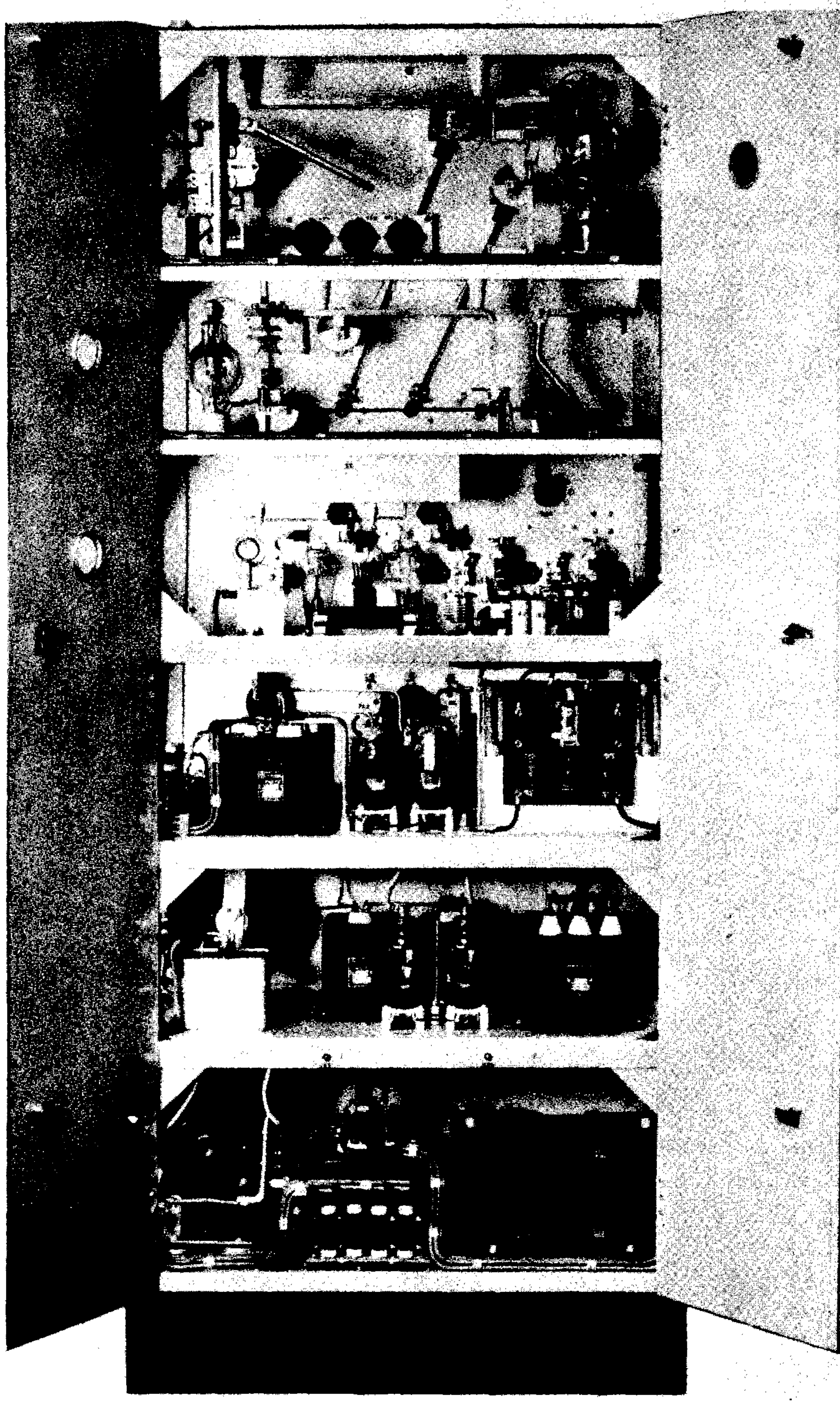

FIGURE 12. Glide Path Transmitter, Rear View, Open.

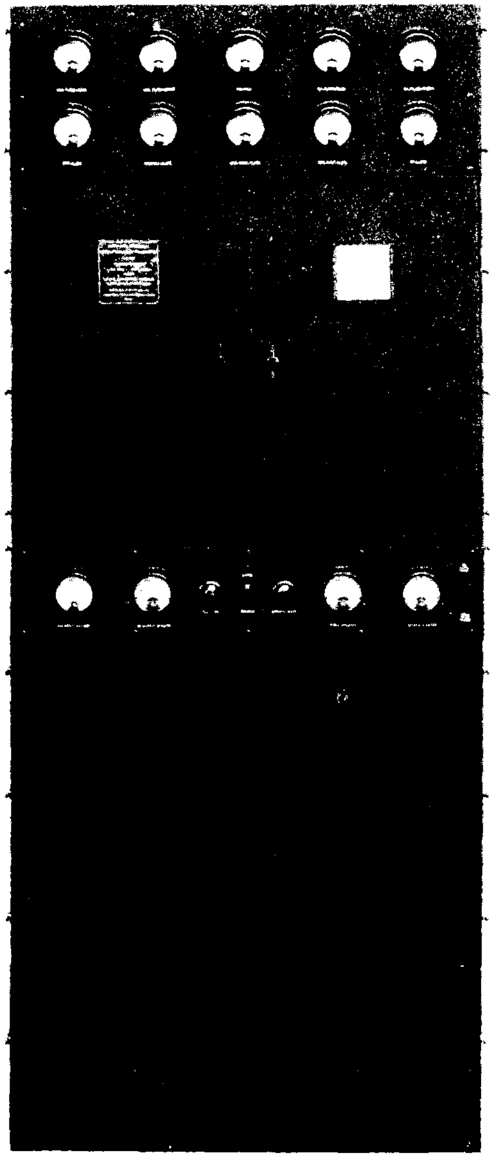

FIGURE 13. Localizer Transmitter, Front View.

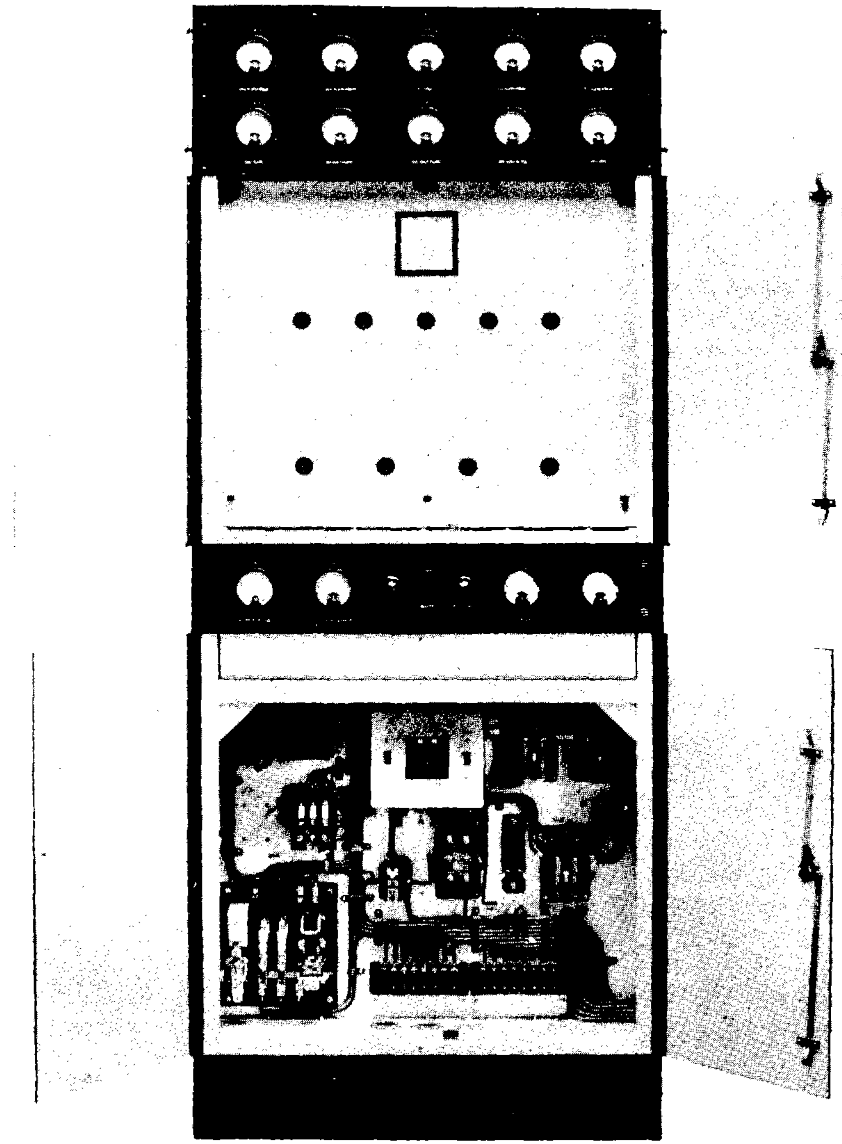

FIGURE 14. Localizer Transmitter, Front View, Open.

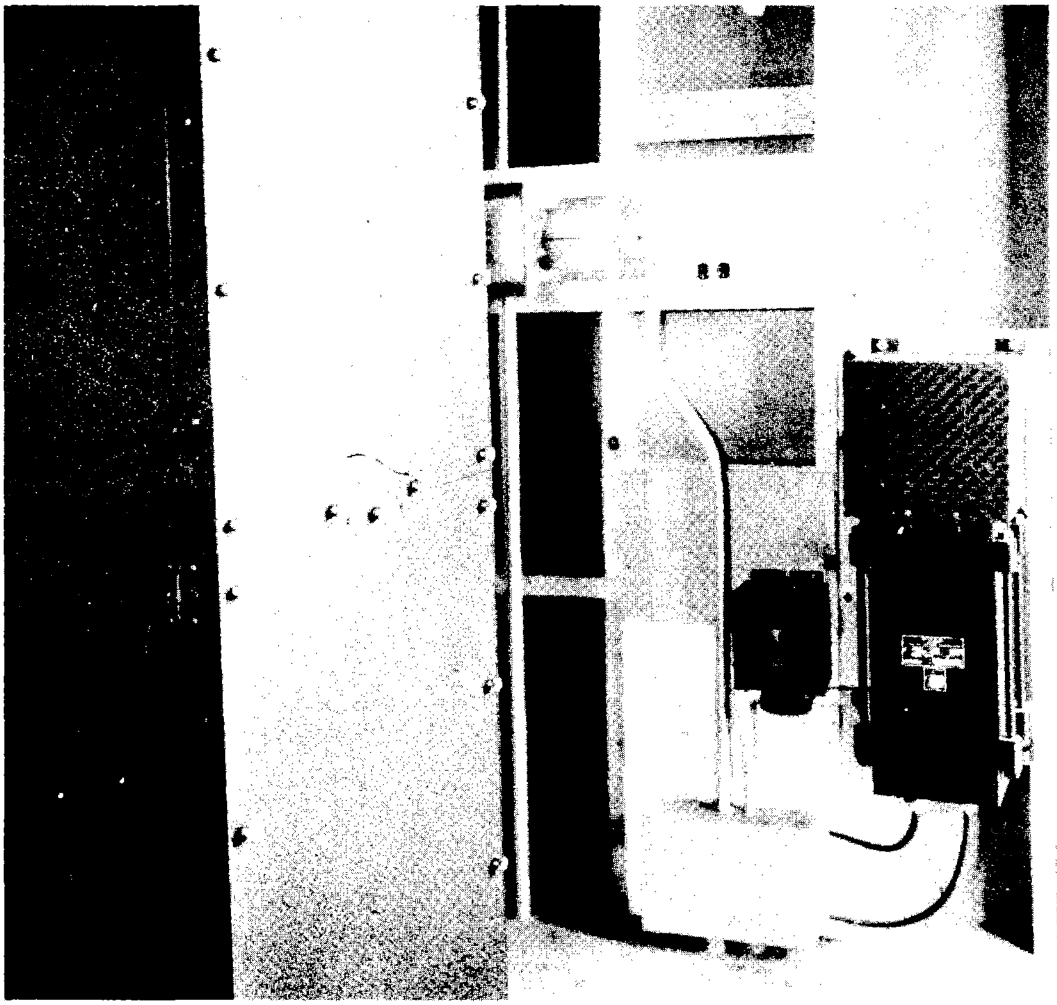

FIGURE 15. Voltage Regulator Installation.

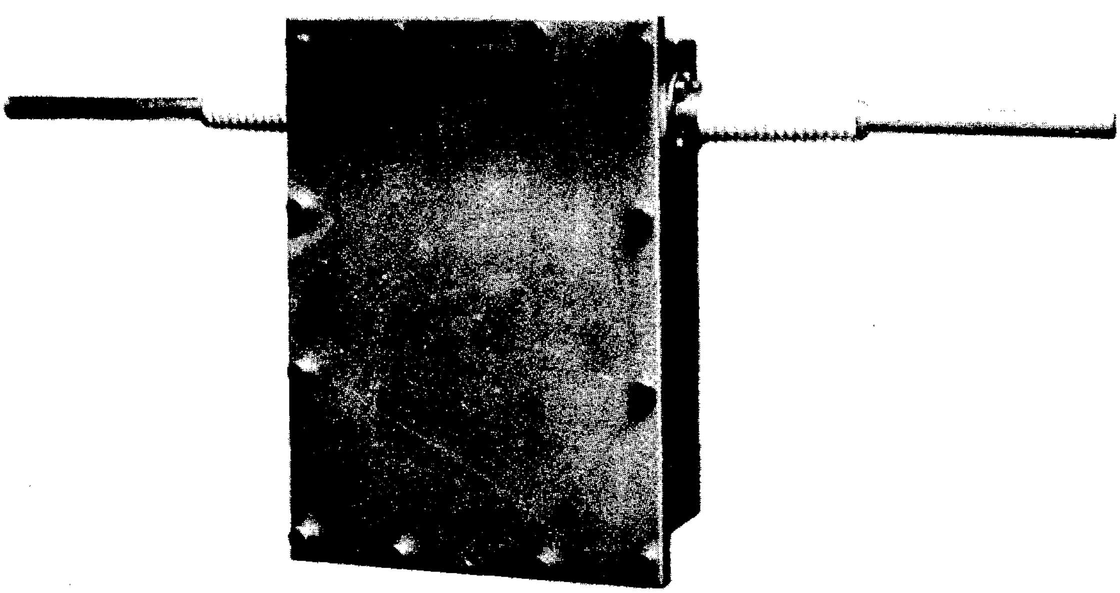

FIGURE 16. Localizer Course-Monitor Unit.

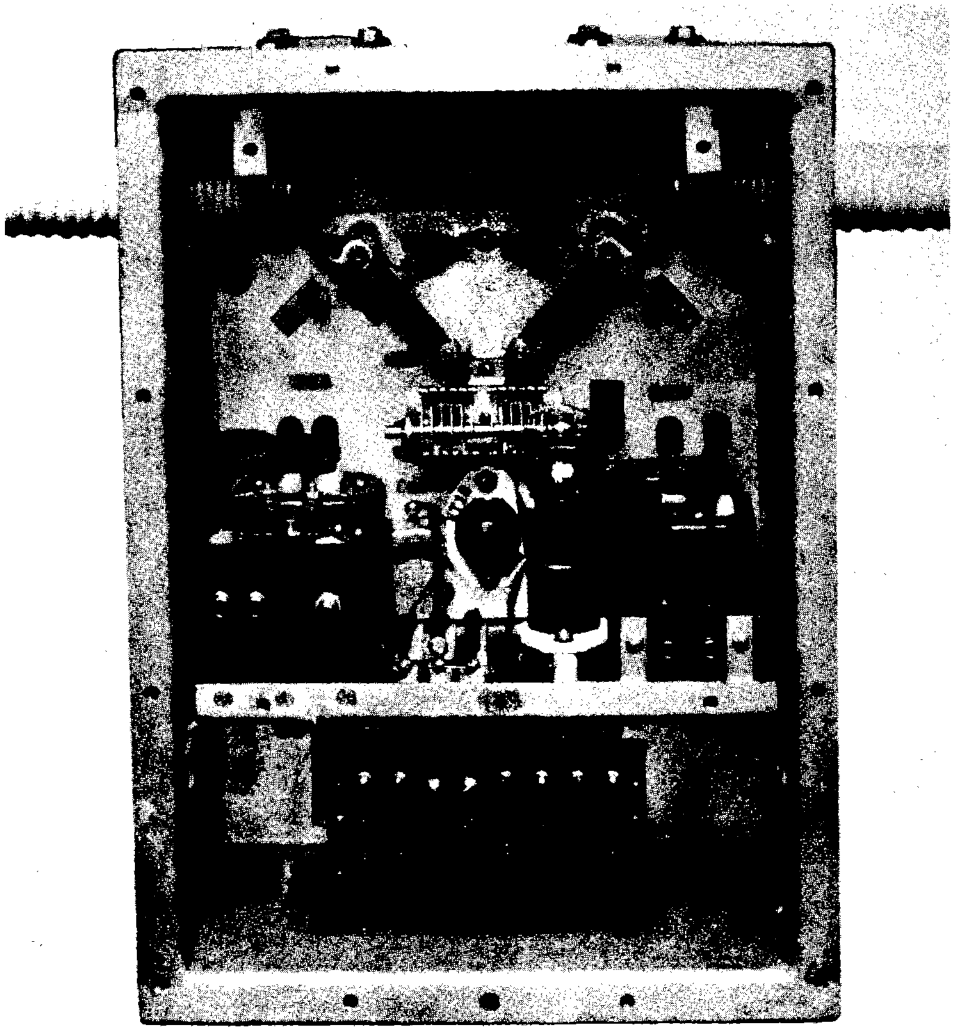

FIGURE 17. Localizer Course-Monitor Unit, Open.

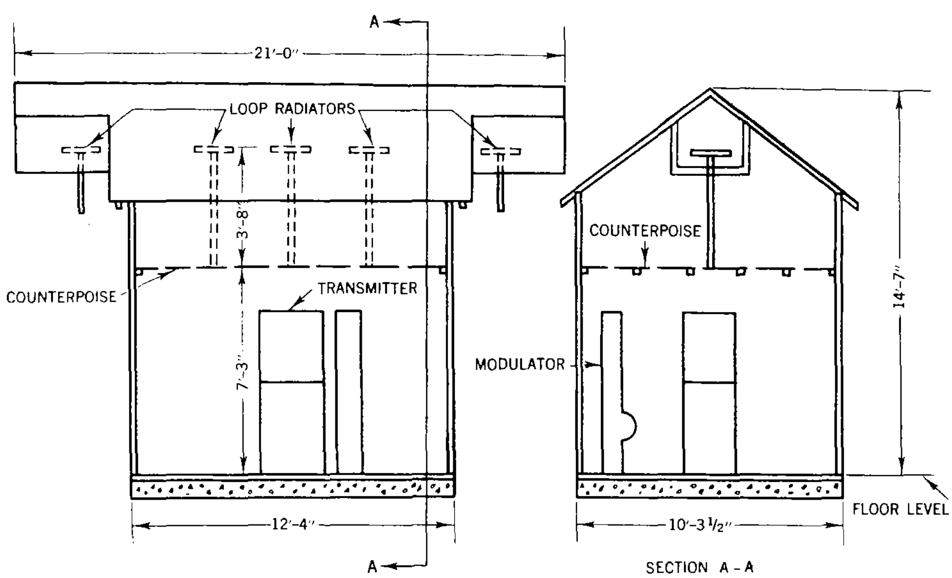

FIGURE 18. Localizer Building Diagram.

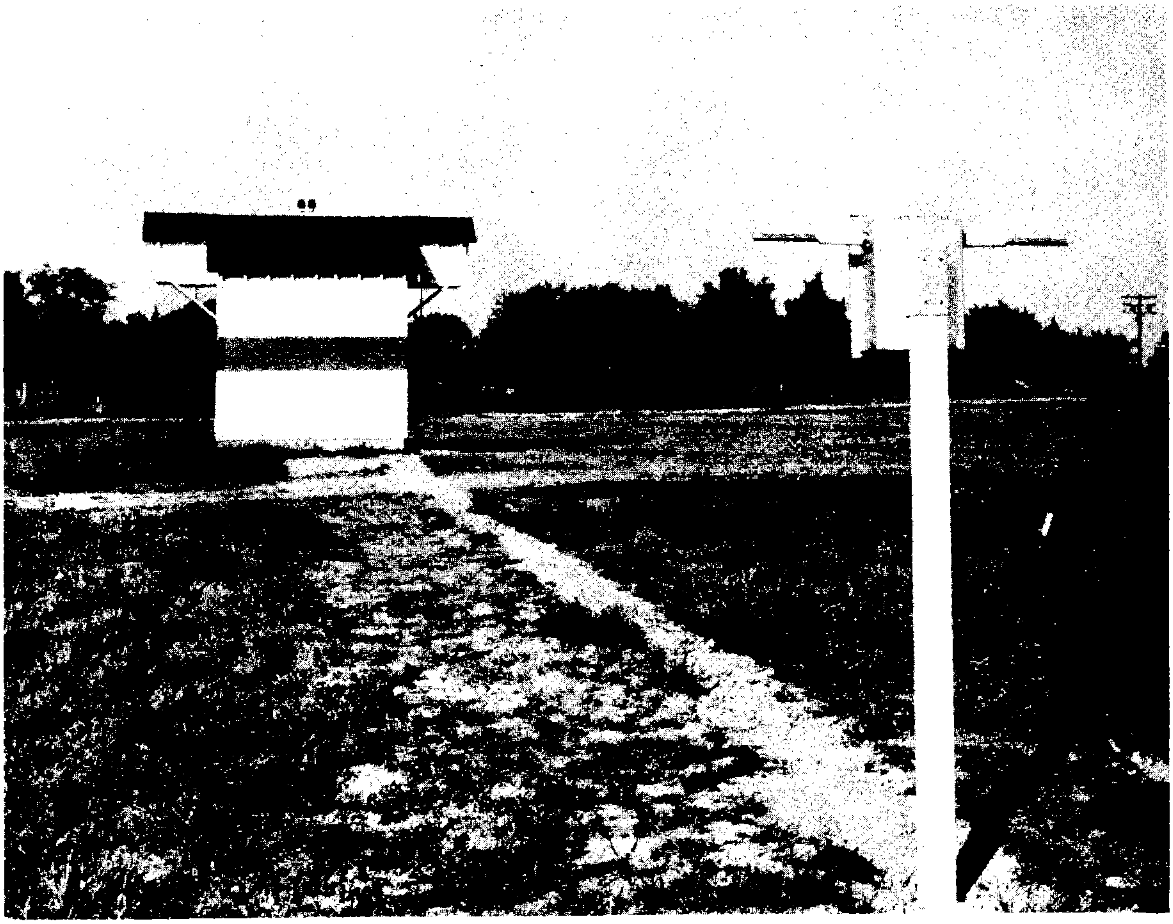

FIGURE 19. N.E. Localizer Building and Monitor.

FIGURE 20. S.E. Localizer Building.

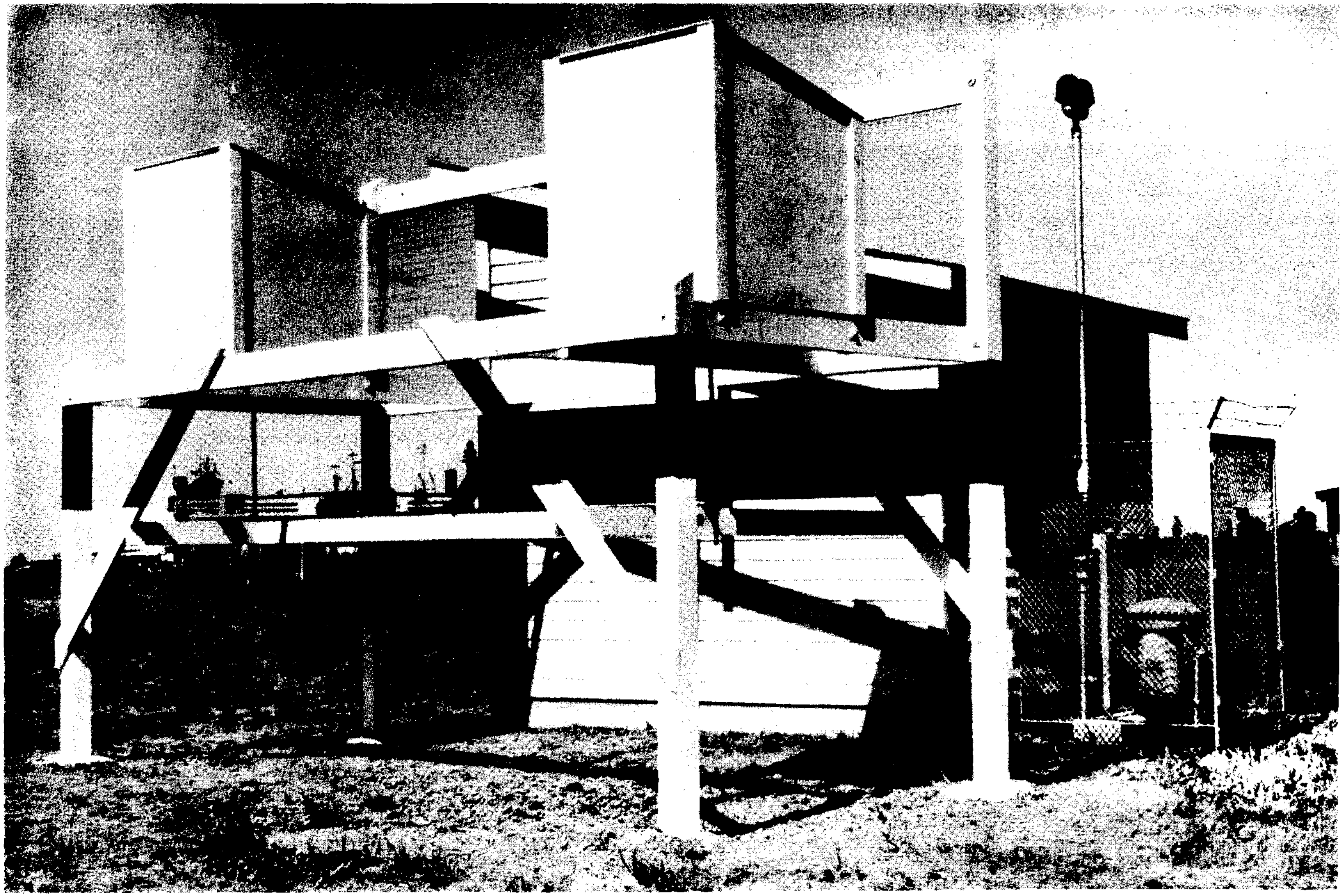

FIGURE 21. Glide Path Station (Straight Line Type).

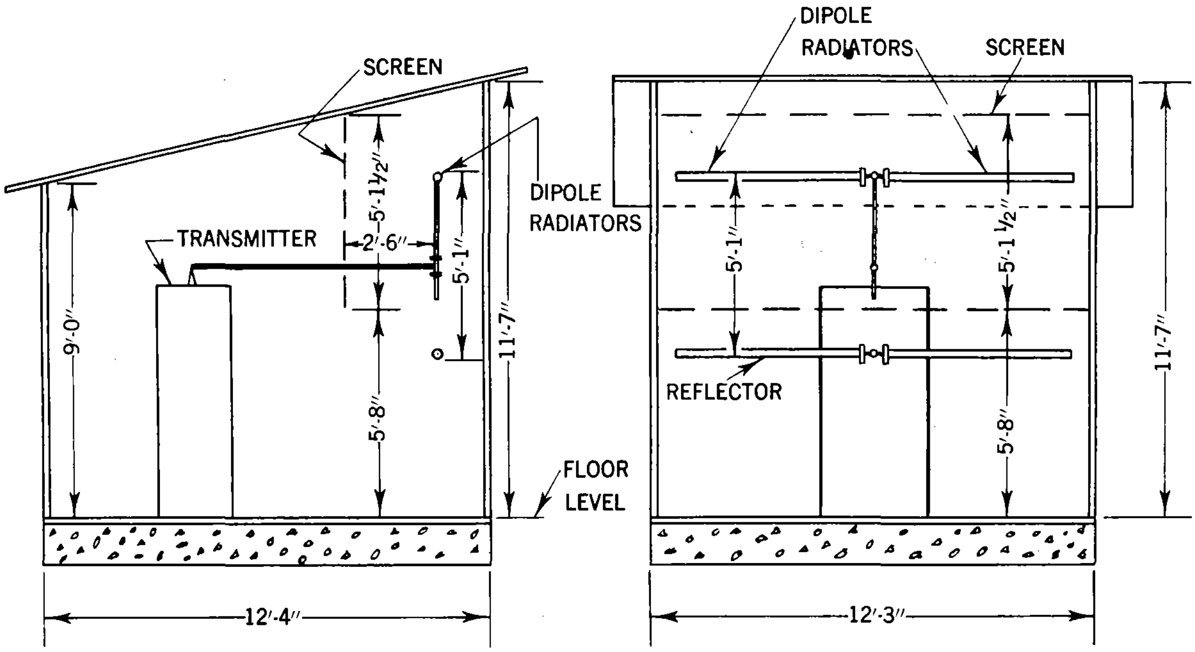

FIGURE 22. Glide Path Building Diagram.

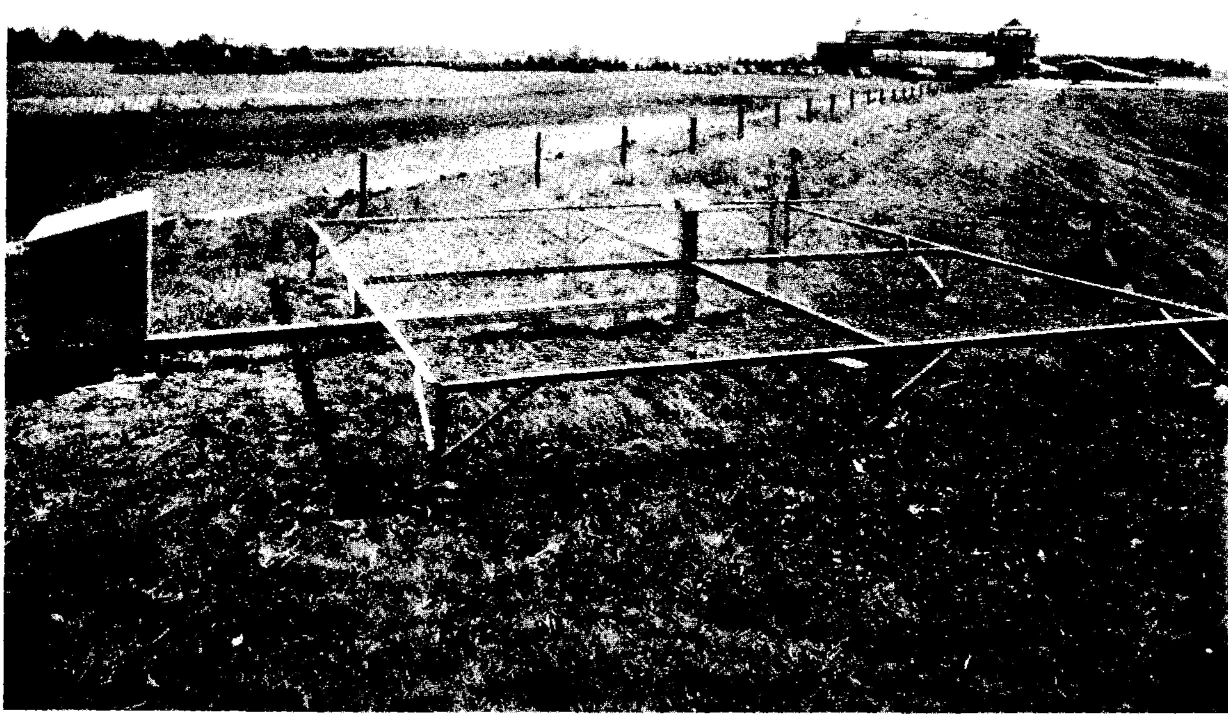

FIGURE 23. N.E. Inner Marker.

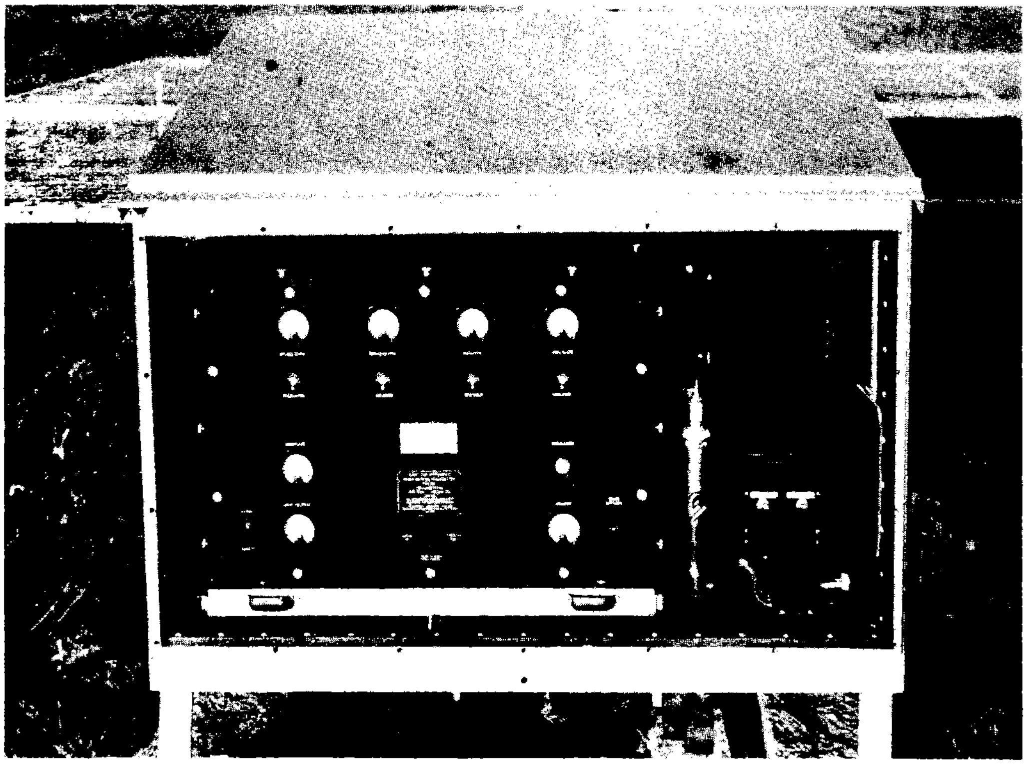

FIGURE 24. Inner Marker Open Showing Transmitter, Regulator, and Telephone Facility.

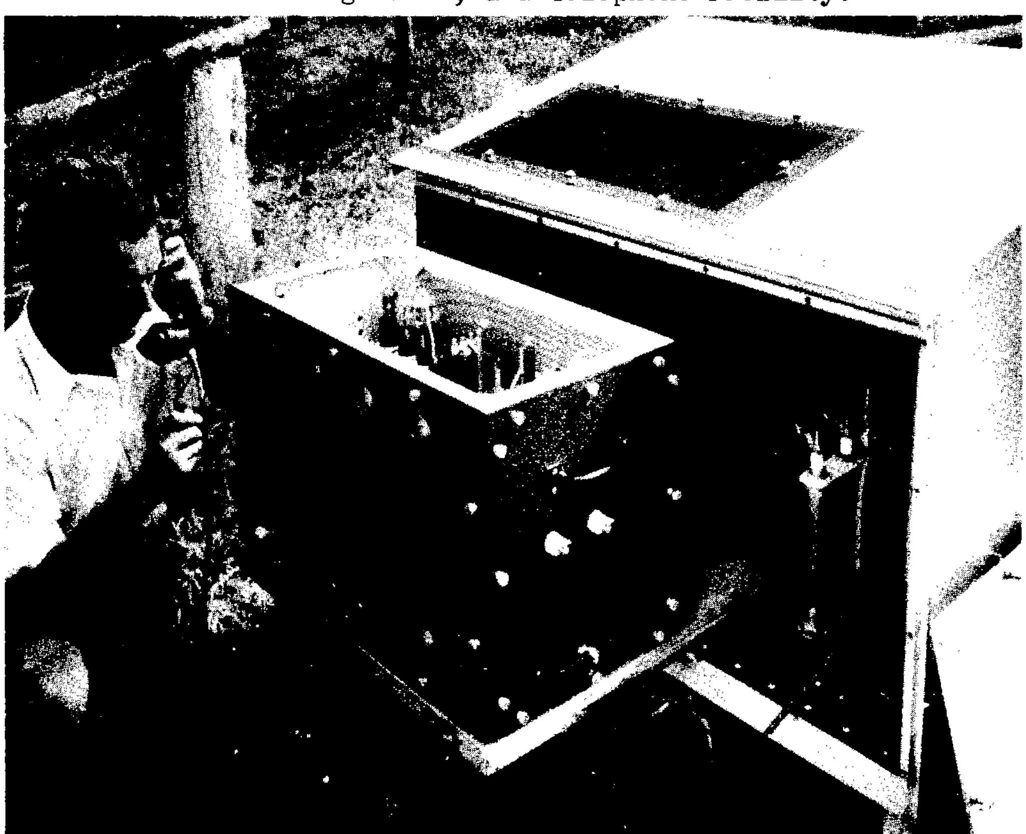

FIGURE 25. N.E. Inner Marker Open Showing Slide Tray Extended for Transmitter Servicing.

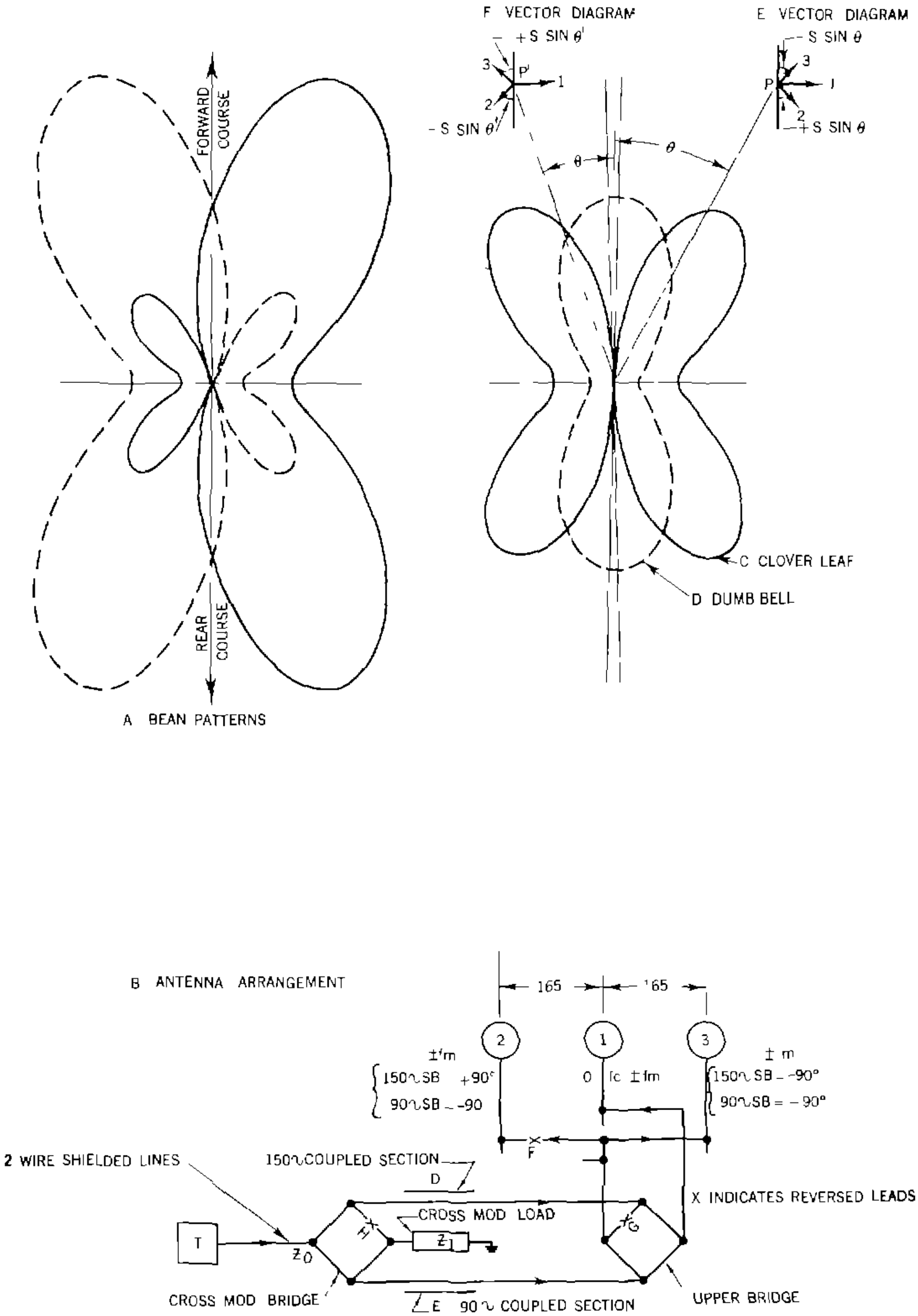

FIGURE 26 Analysis of Localizer Patterns.

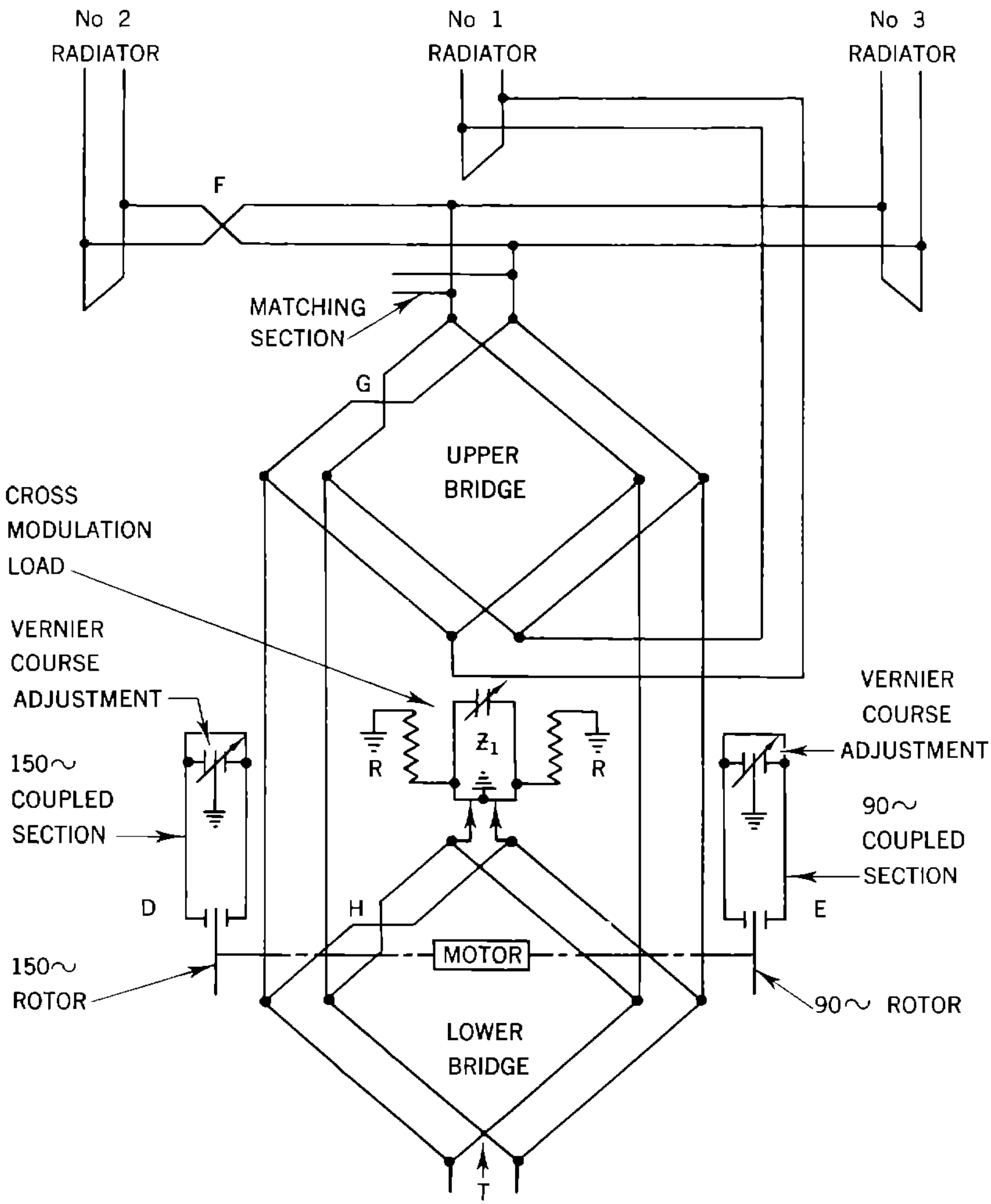

FIGURE 27. Schematic Illustration of Modulator Principles

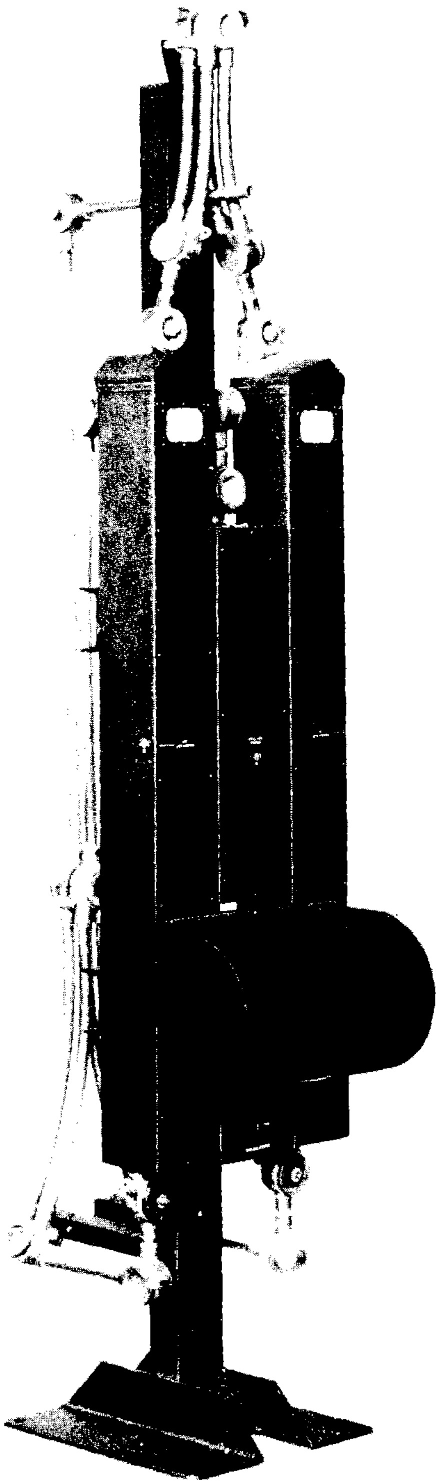

FIGURE 28.
90/150-Cycle Modulator Unit.

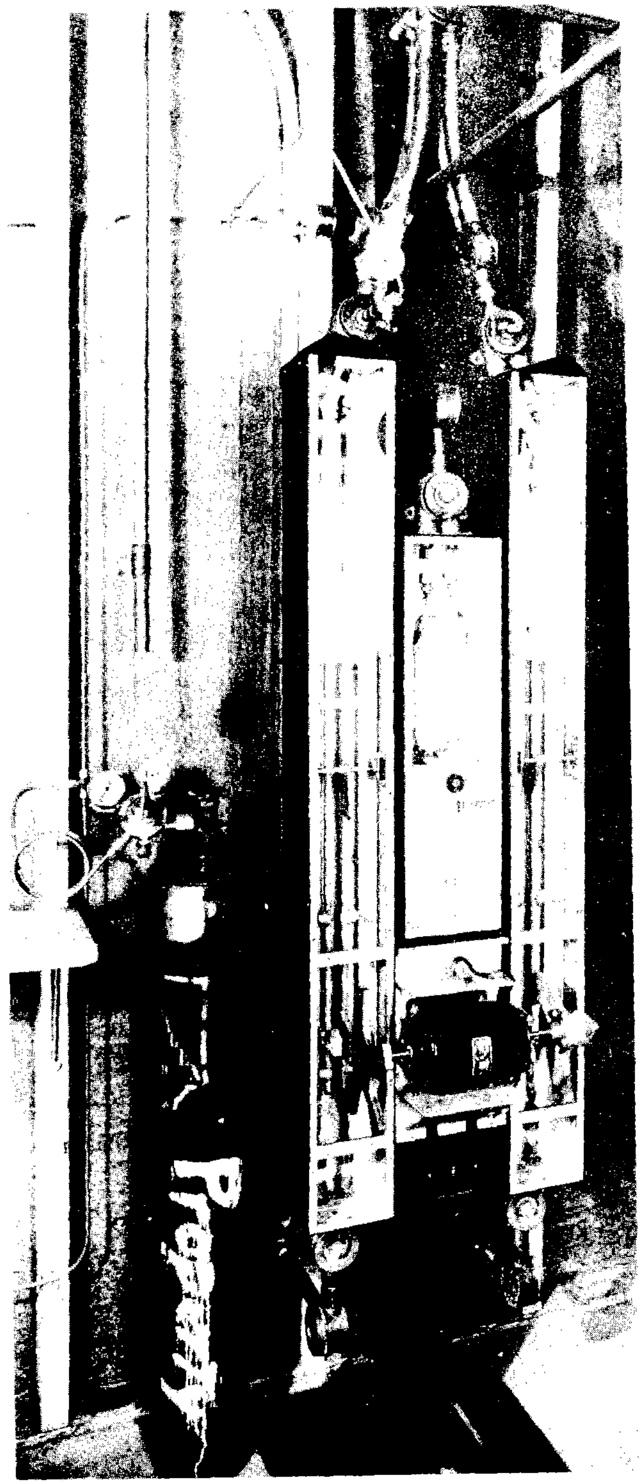

FIGURE 29.
90/150 Cycle Modulator Unit Open.

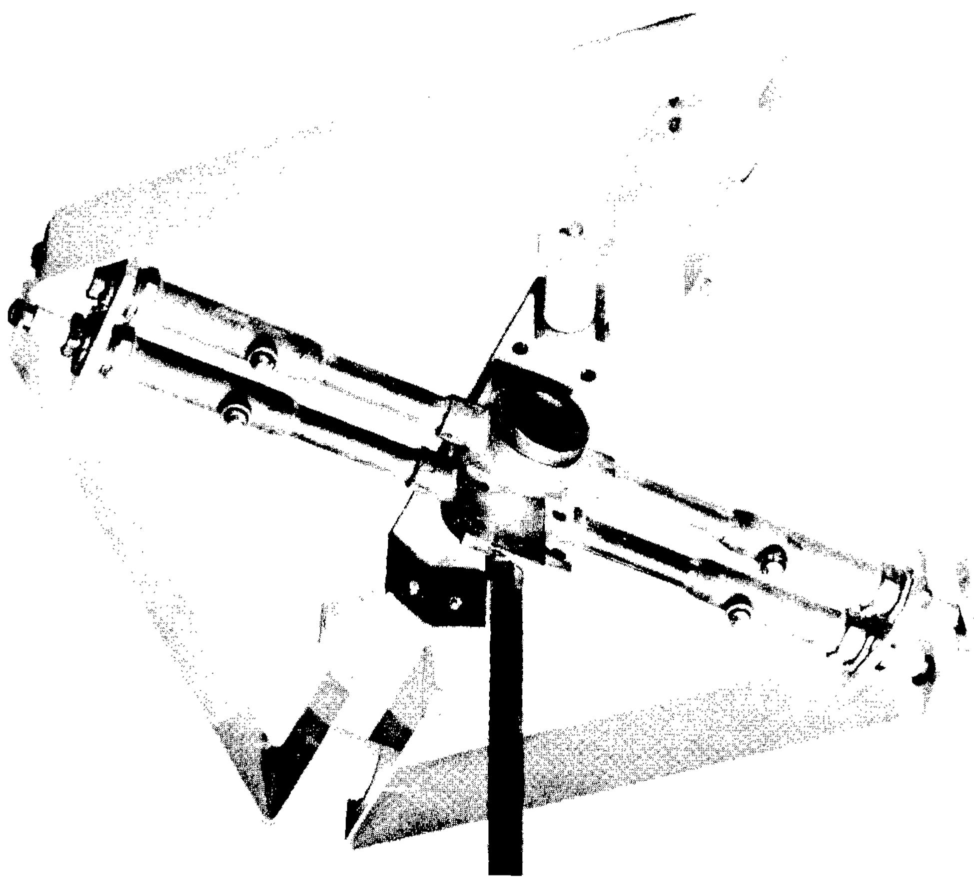

FIGURE 30. Single Loop Radiator.

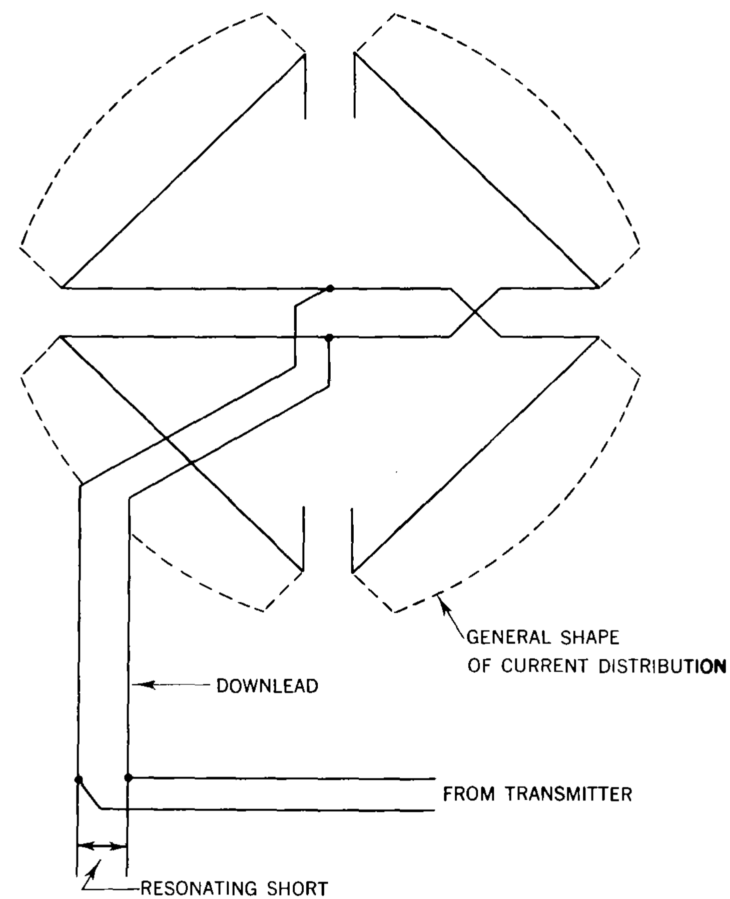

FIGURE 31. Schematic Diagram of Loop Radiator.

FIGURE 32. N.W. Localizer Building During Experimental Period.

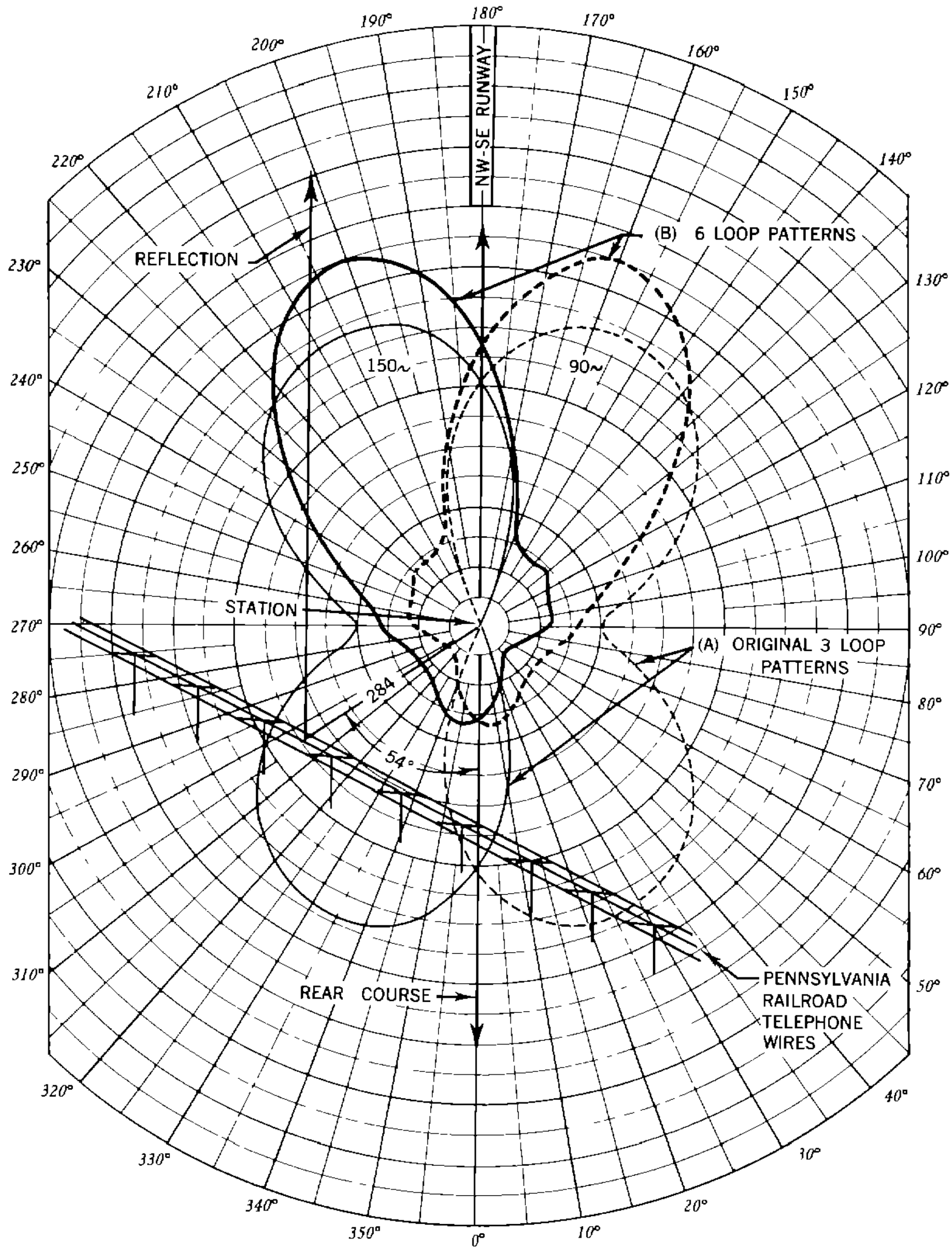

FIGURE 33 N.W. Localizer Pattern.

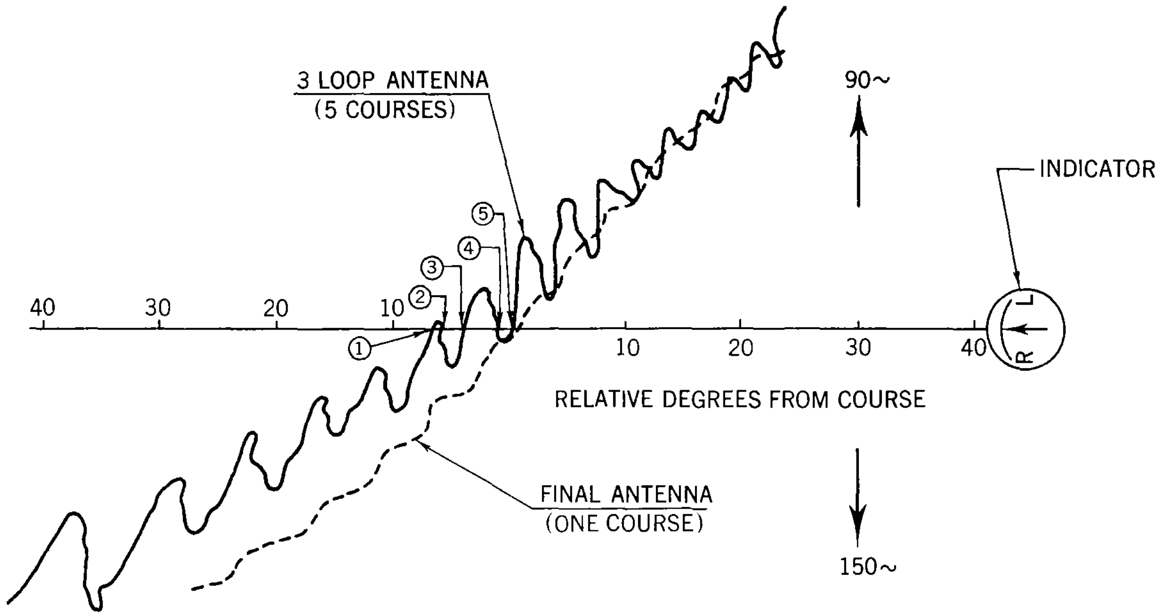

FIGURE 34. N.W. Localizer Cross-Course Flight Record at S.E. Outer Marker.

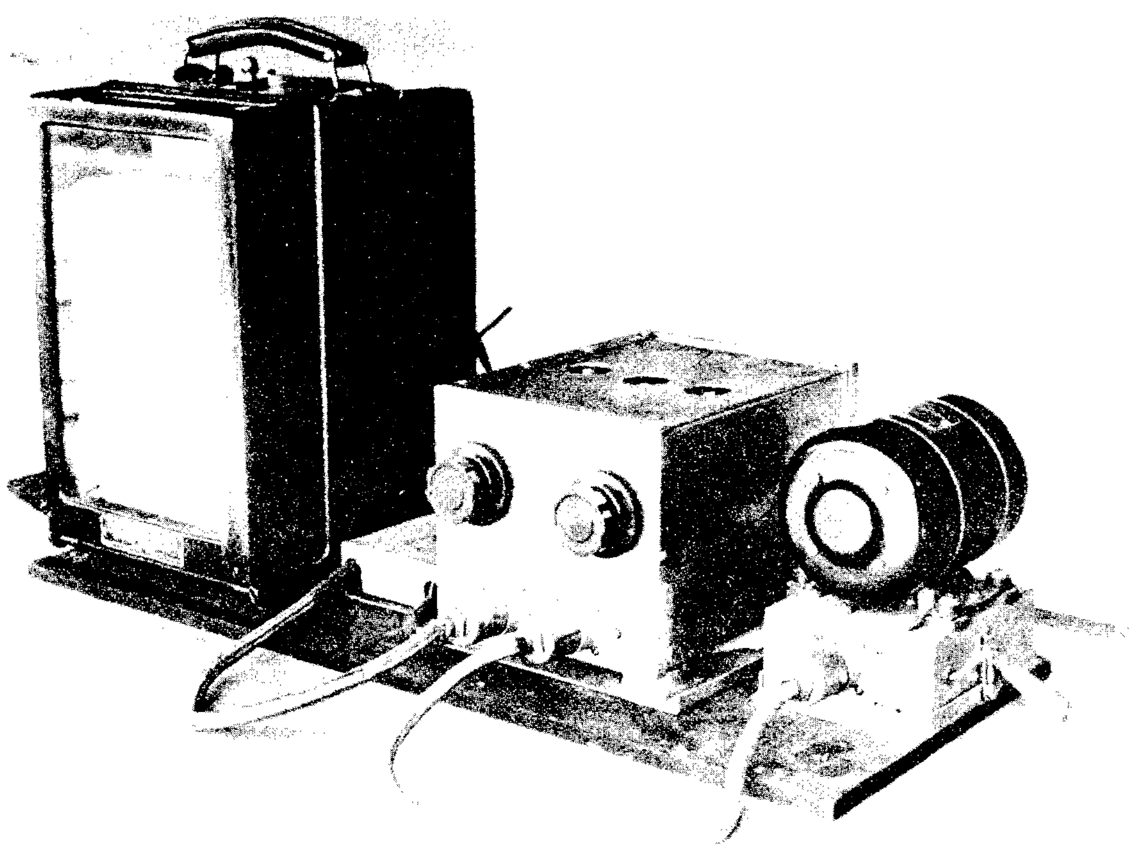

FIGURE 35. Recorder, Amplifier-Rectifier, and Dynamotor.

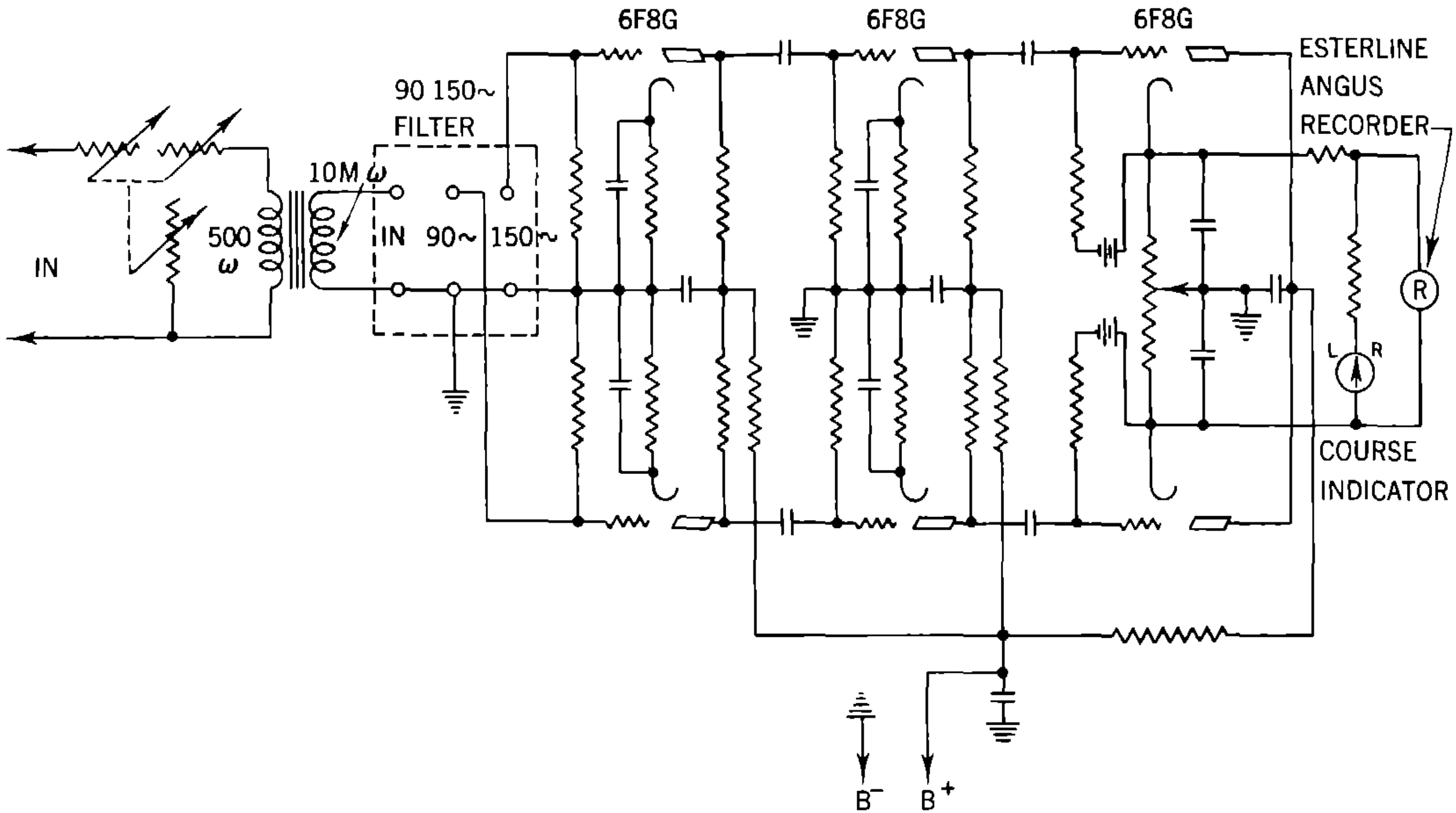

FIGURE 36. Schematic Diagram of 90/150-Cycle Amplifier-Rectifier.

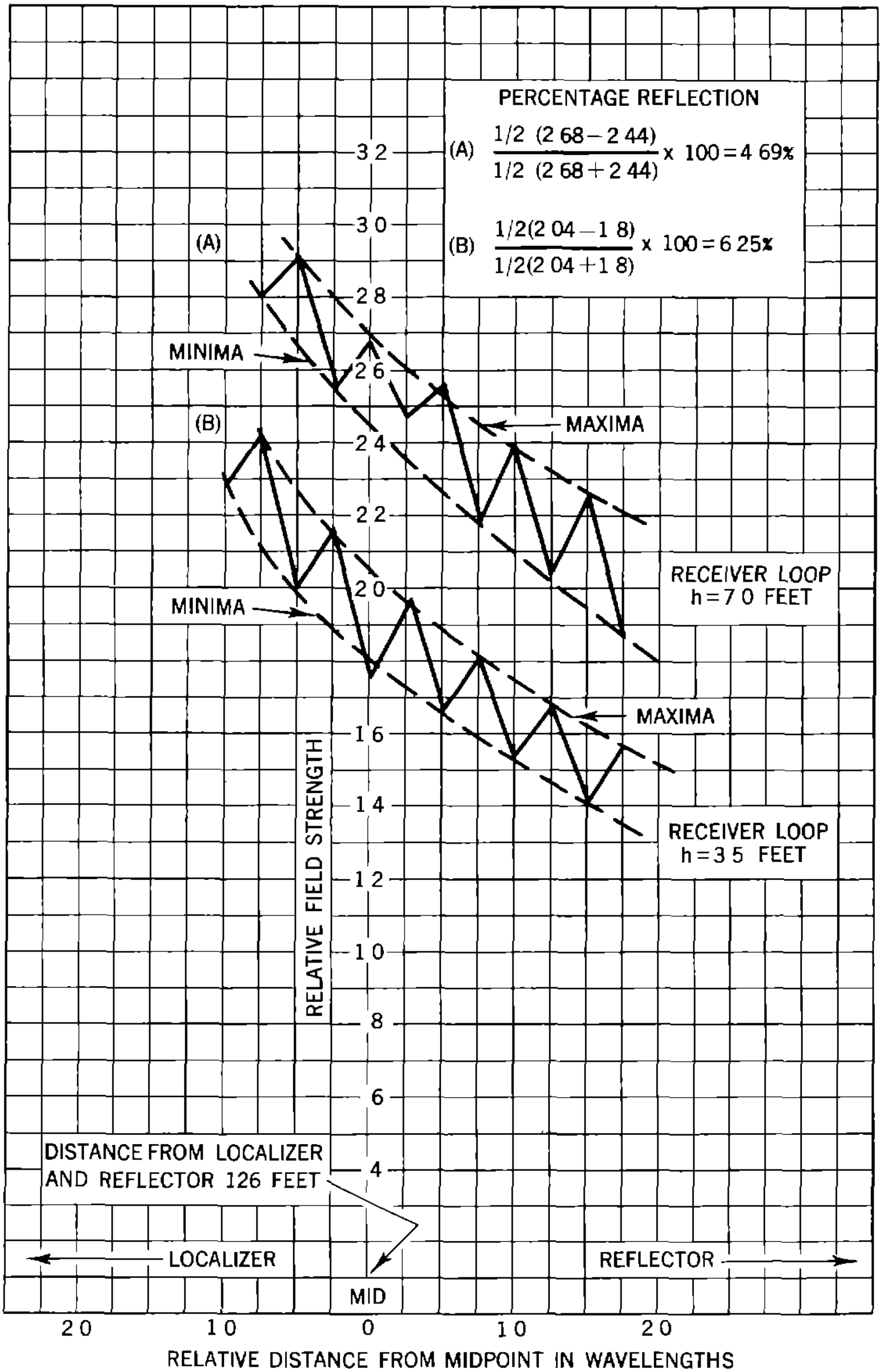

FIGURE 37 Experimental Determination of Reflection Values.

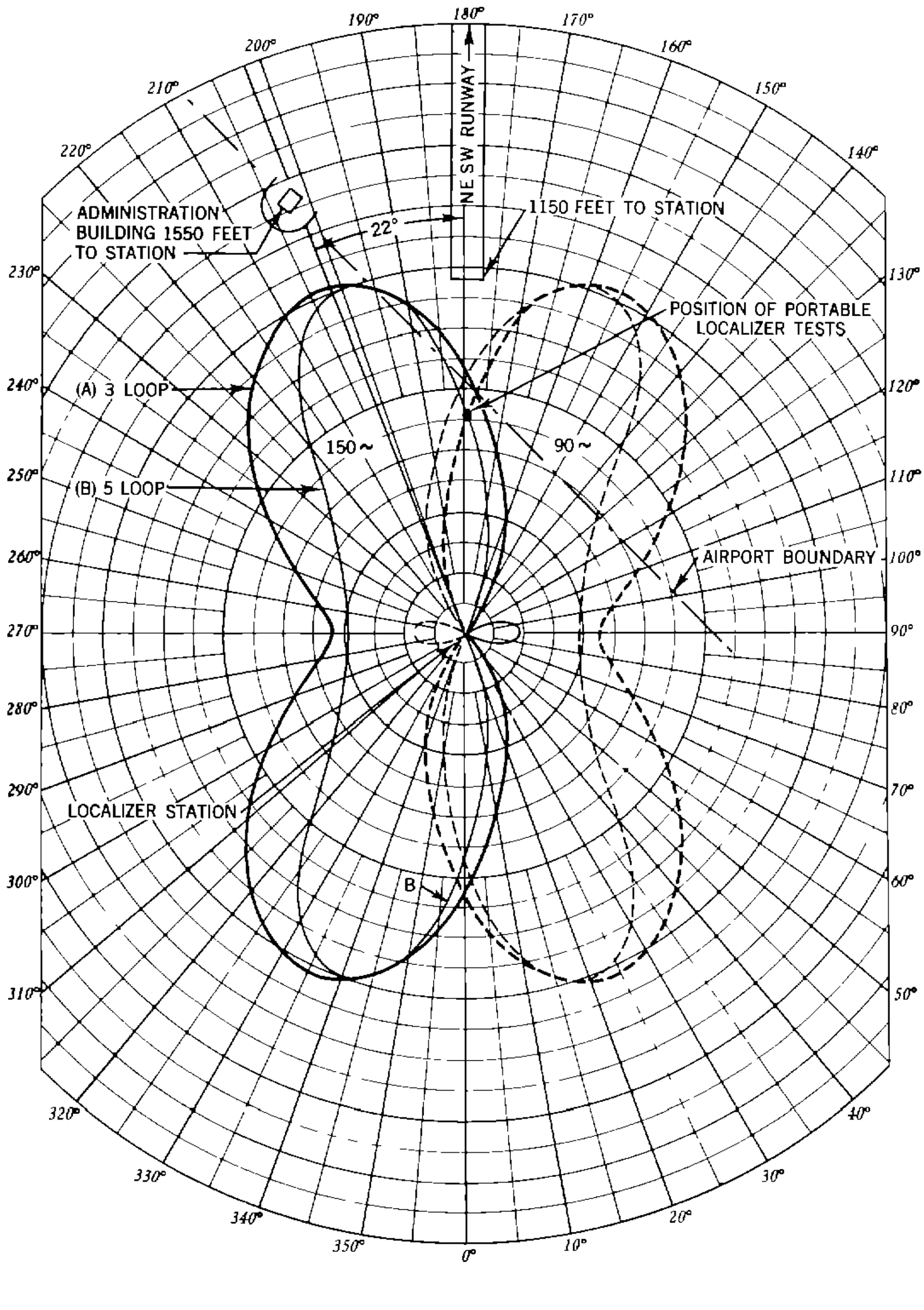

FIGURE 38. N.E Localizer Field Patterns.

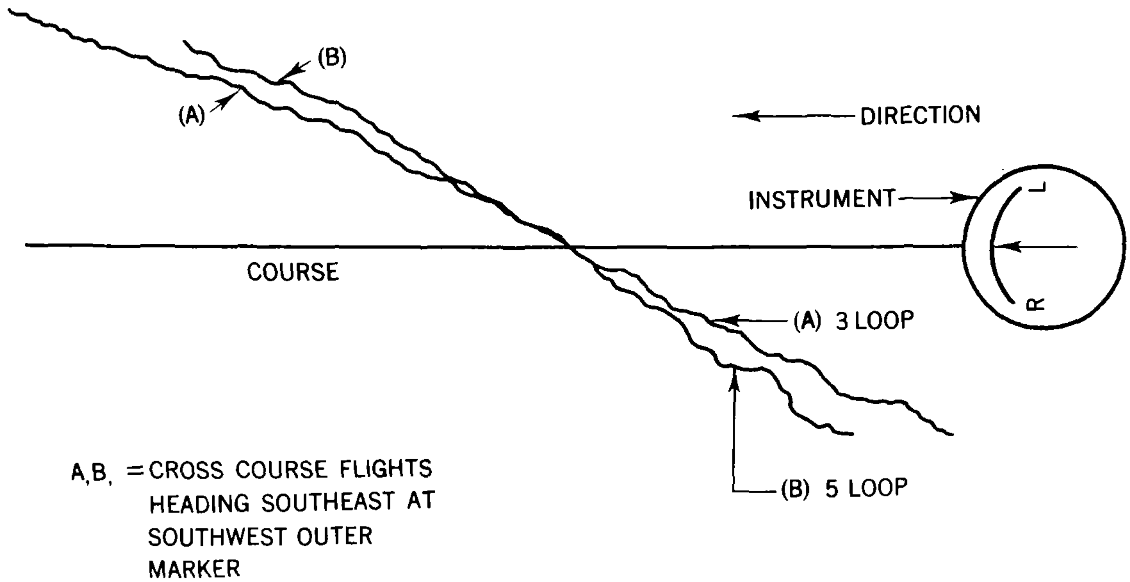

FIGURE 39. Flight Records of N.E. Localizer.

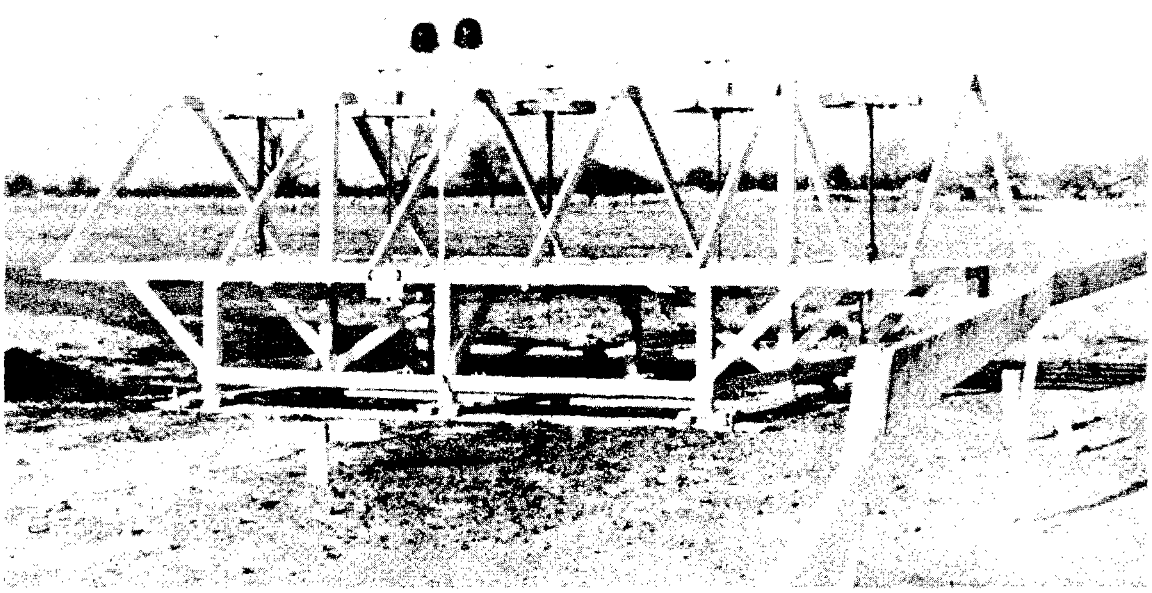

FIGURE 40. Portable Localizer Antenna Array.

FIGURE 41. Transmission Lines to N.E. Portable Localizer Antenna Array.

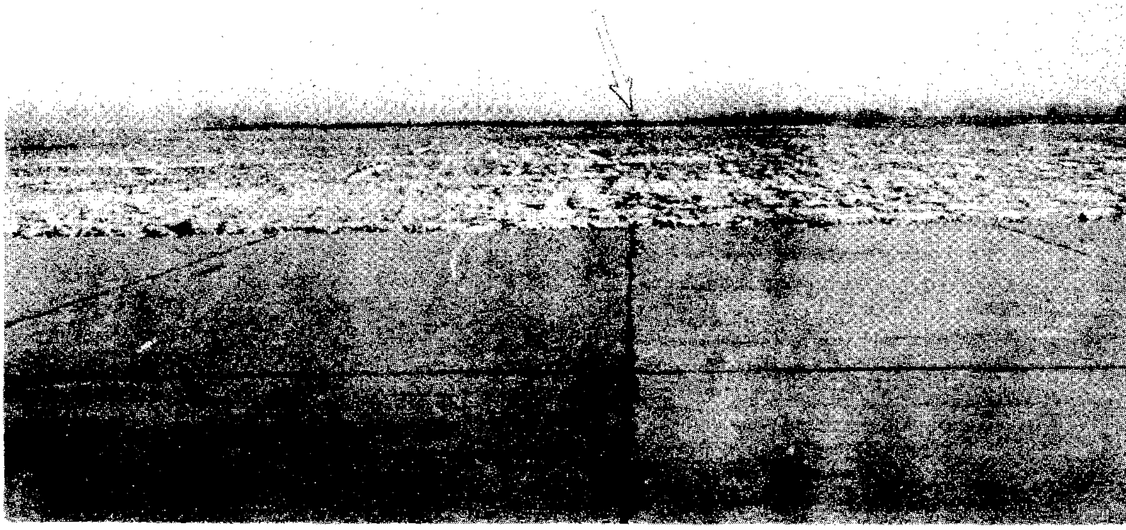

FIGURE 42. View of S.W. Approach.

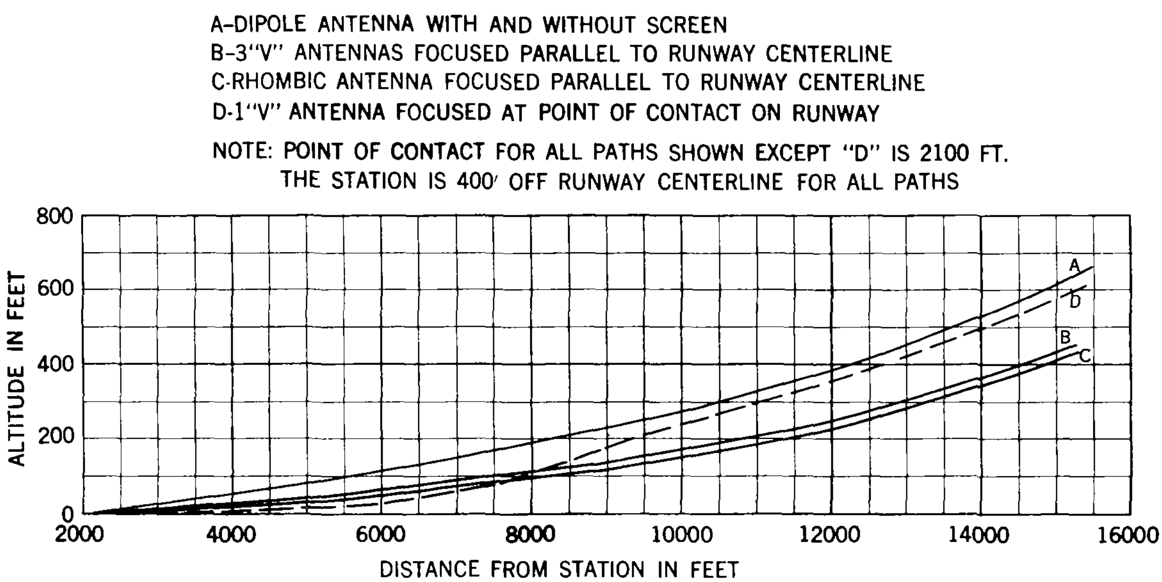

FIGURE 43. Comparison of Glide Paths.

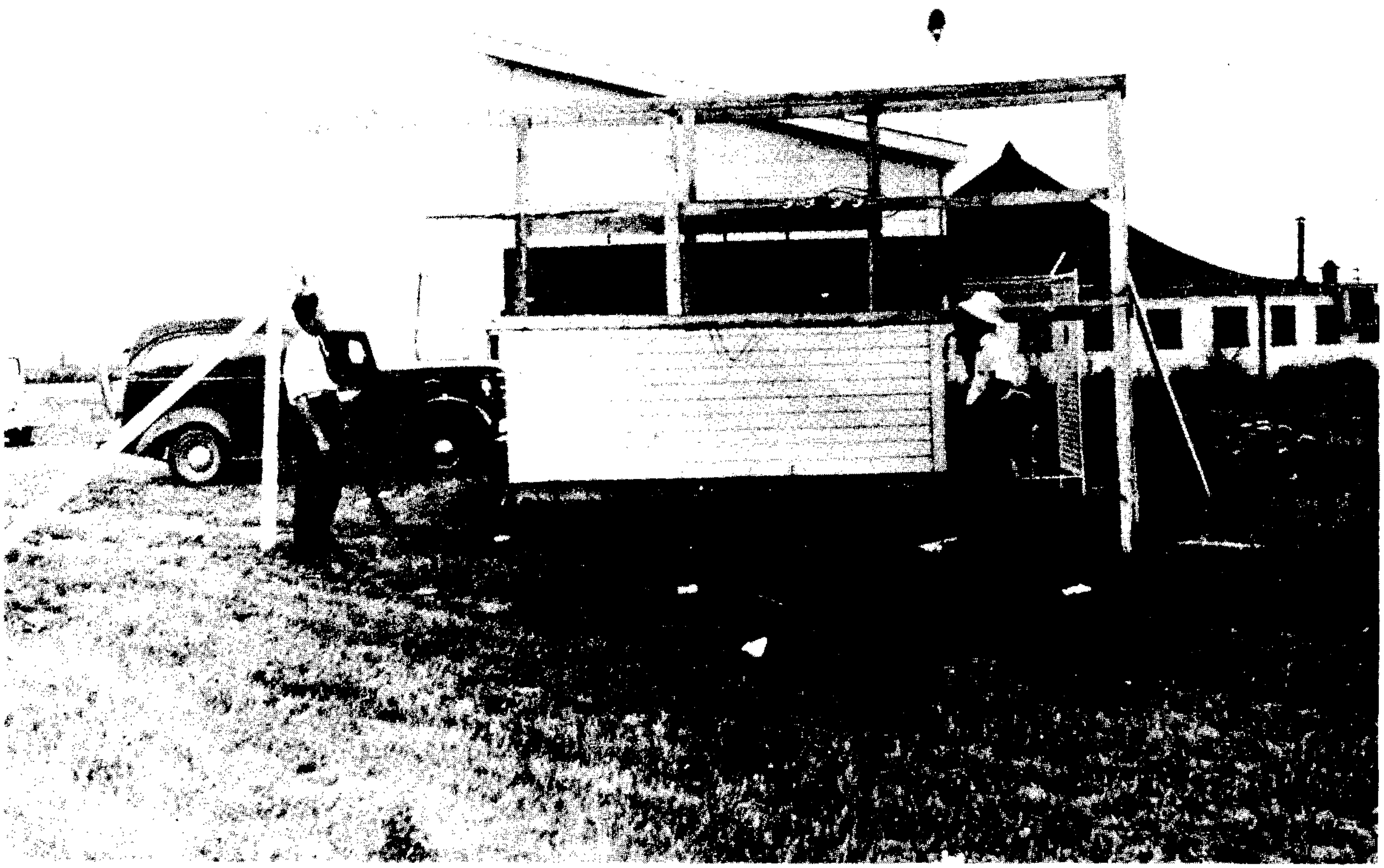

FIGURE 44. Glide Path Station Showing Dipoles and Reflectors for Straight-Line Glide Path (Lorenz Type).

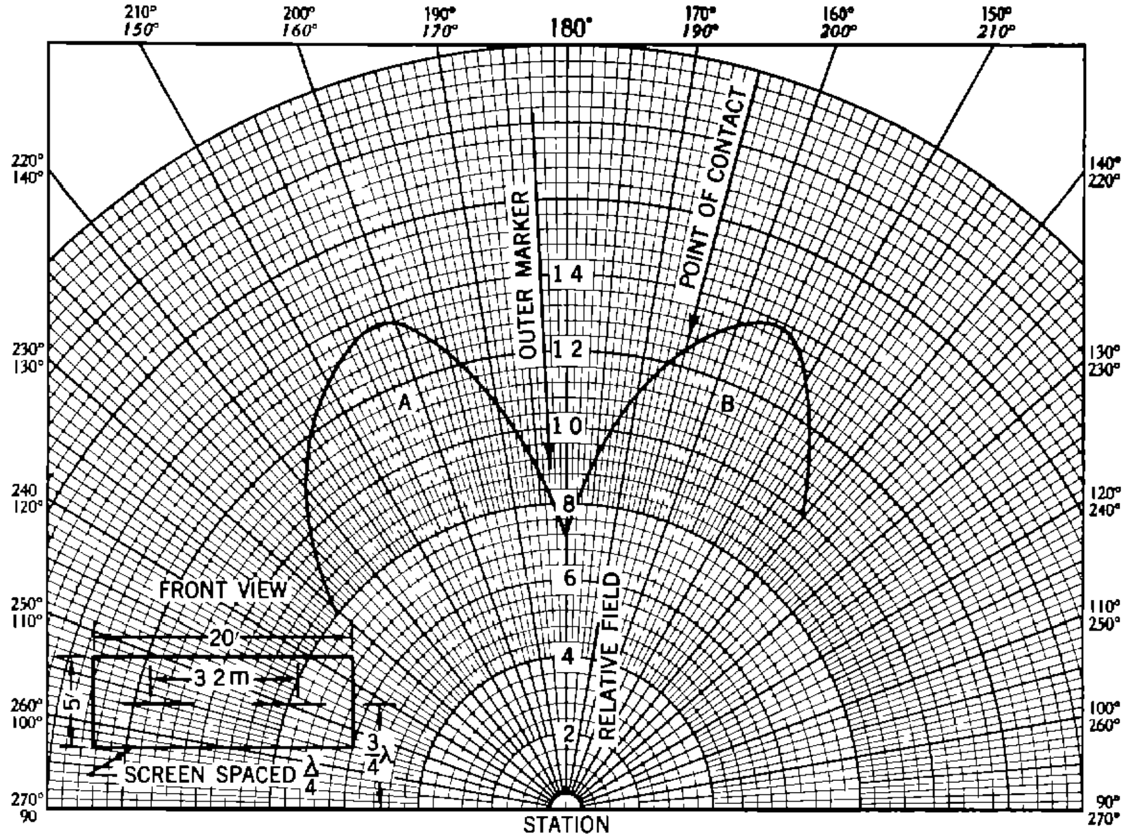

FIGURE 45 Field Pattern of Lorenz Type Array.

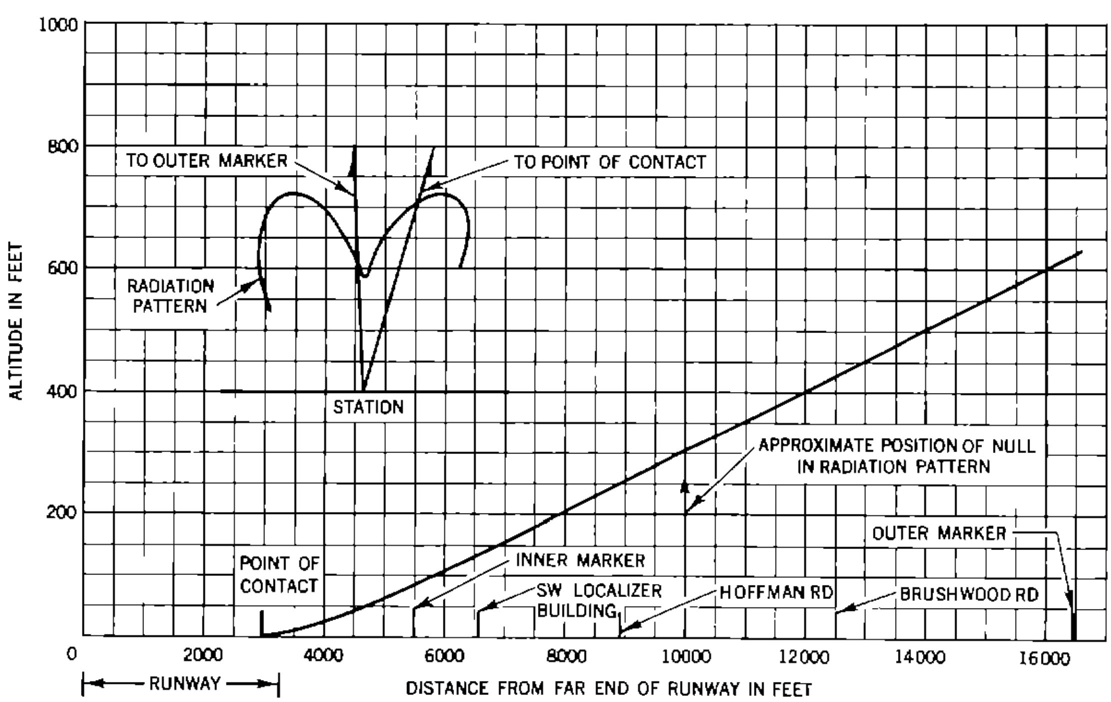

FIGURE 46 Glide Path Produced by Lorenz Type Array.

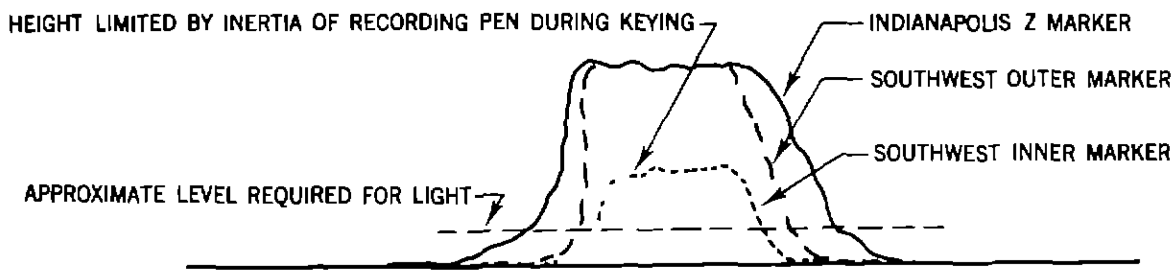

FIGURE 47. Relative Marker Signal Duration at 1000 Ft. Altitude. (Taken from Graphic Flight Records)

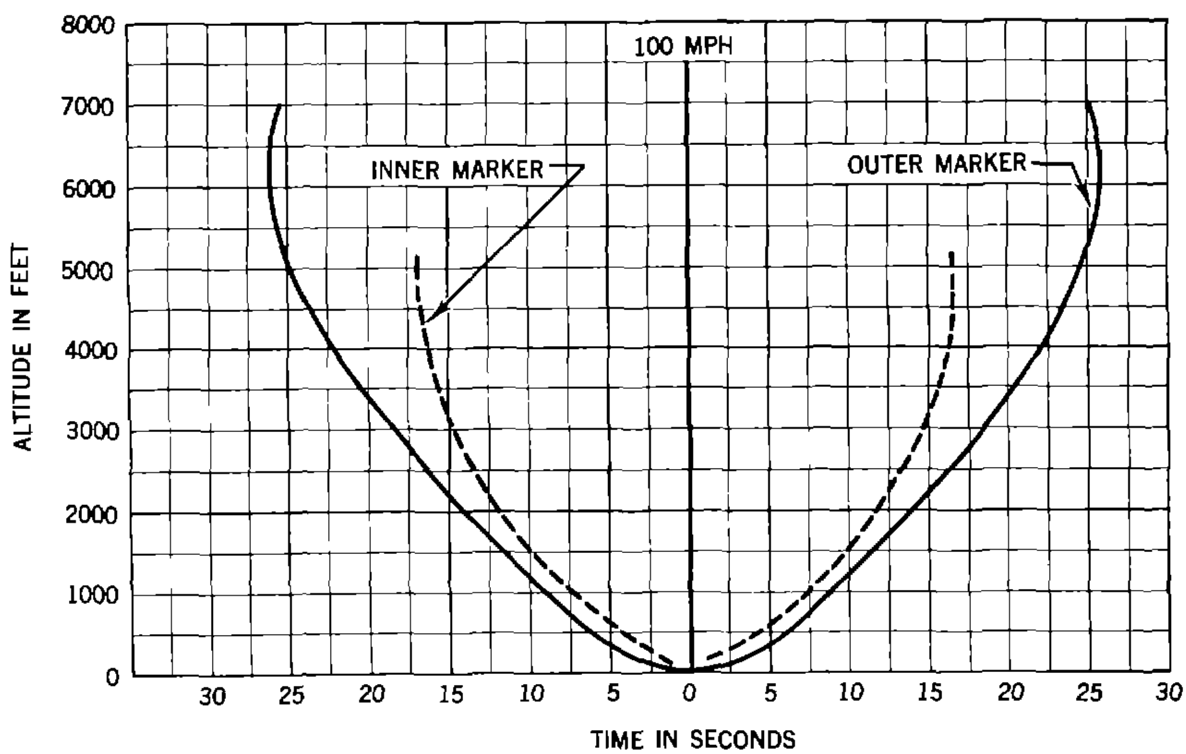

FIGURE 48. Vertical Characteristics - Inner and Outer Markers

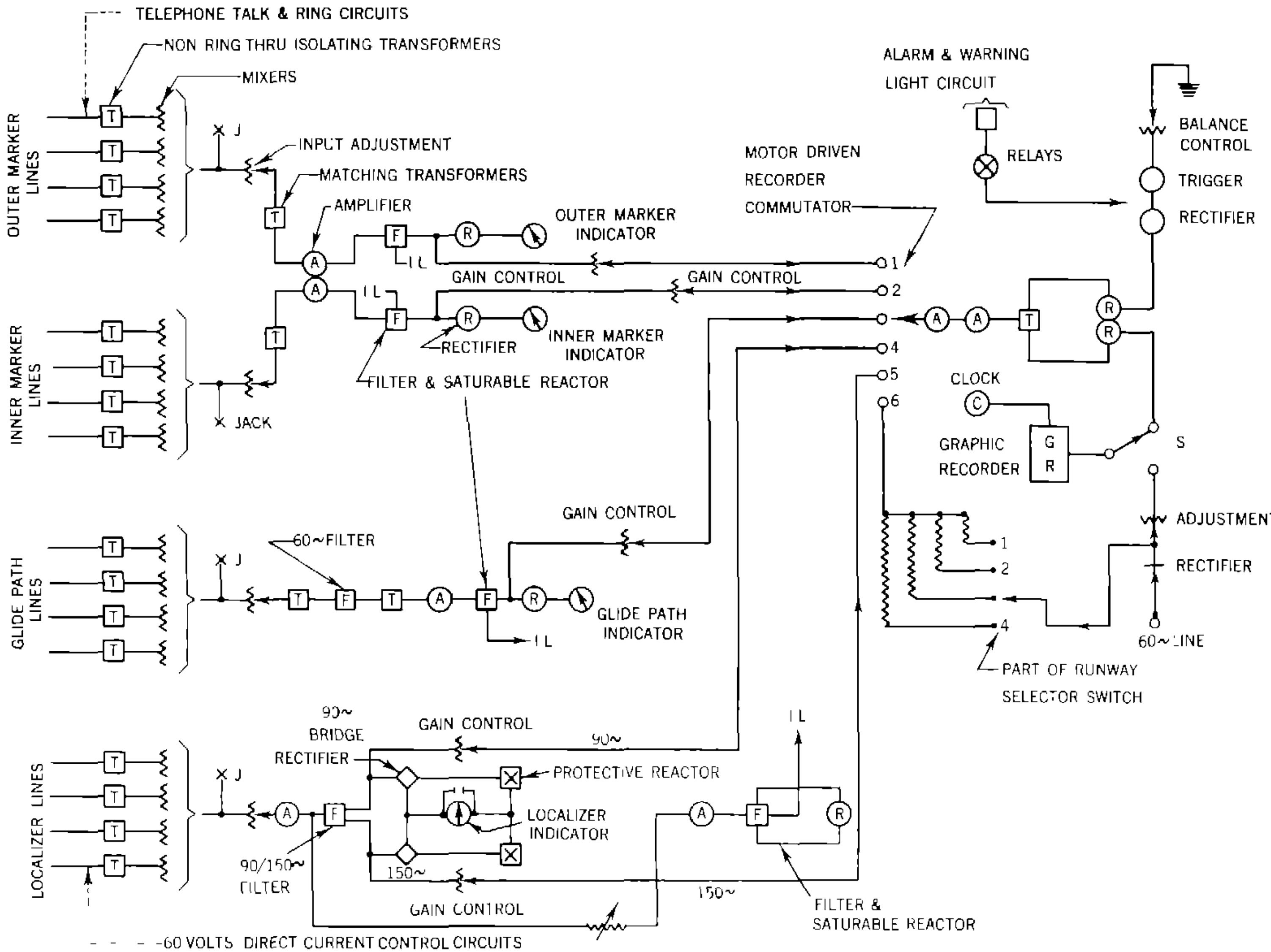

FIGURE 49 Functional Diagram of Monitor and Control Unit

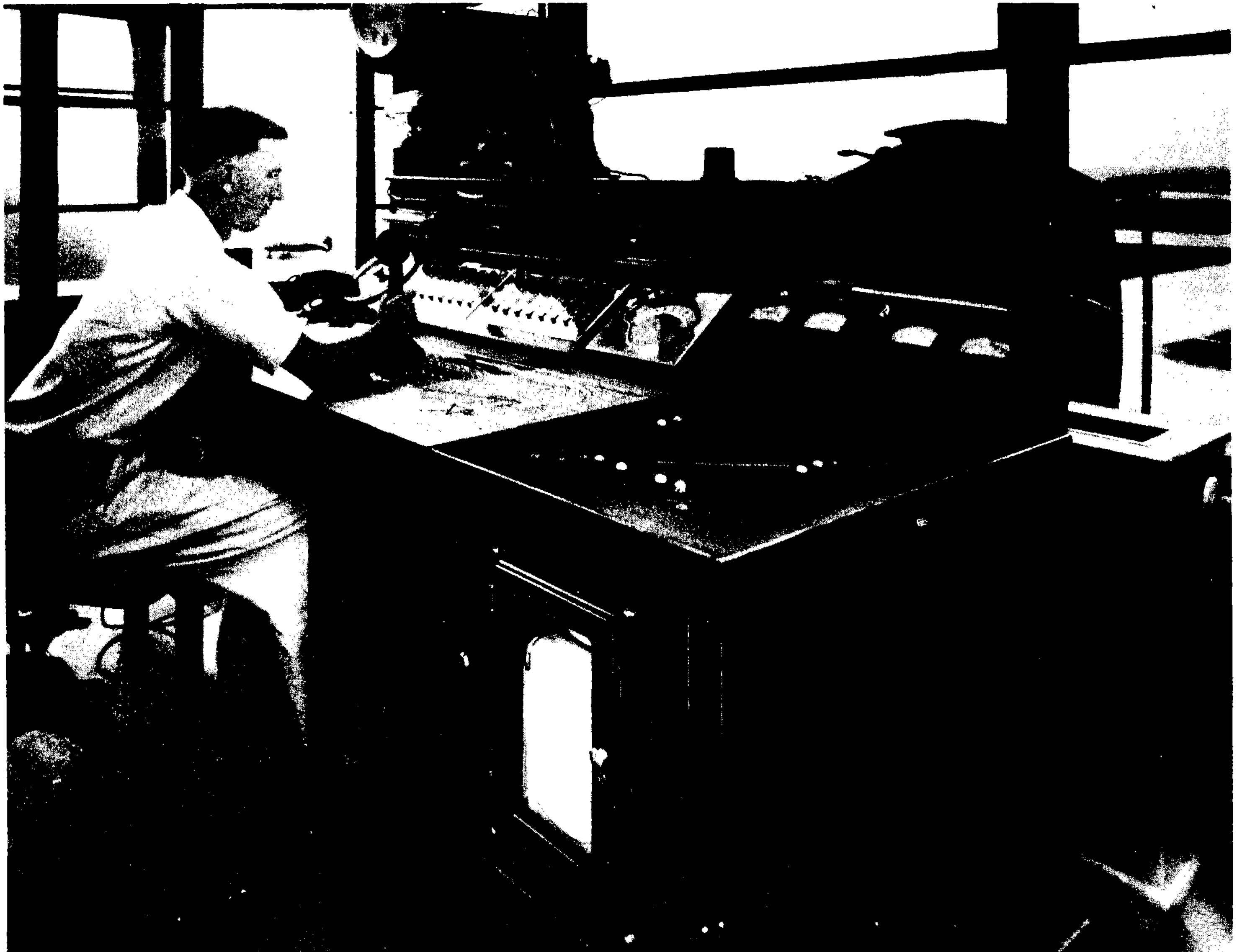

FIGURE 50. Monitor Control Desk Installed in Control Tower. (Right Foreground).

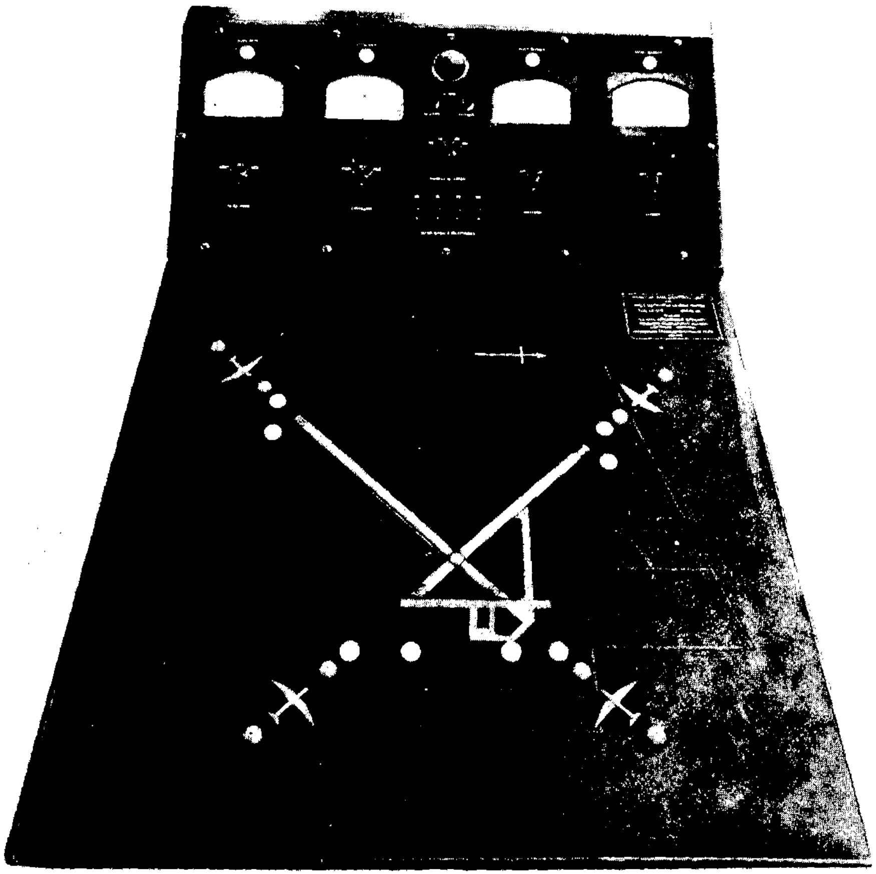

FIGURE 51. Monitor Control Desk. (Top).

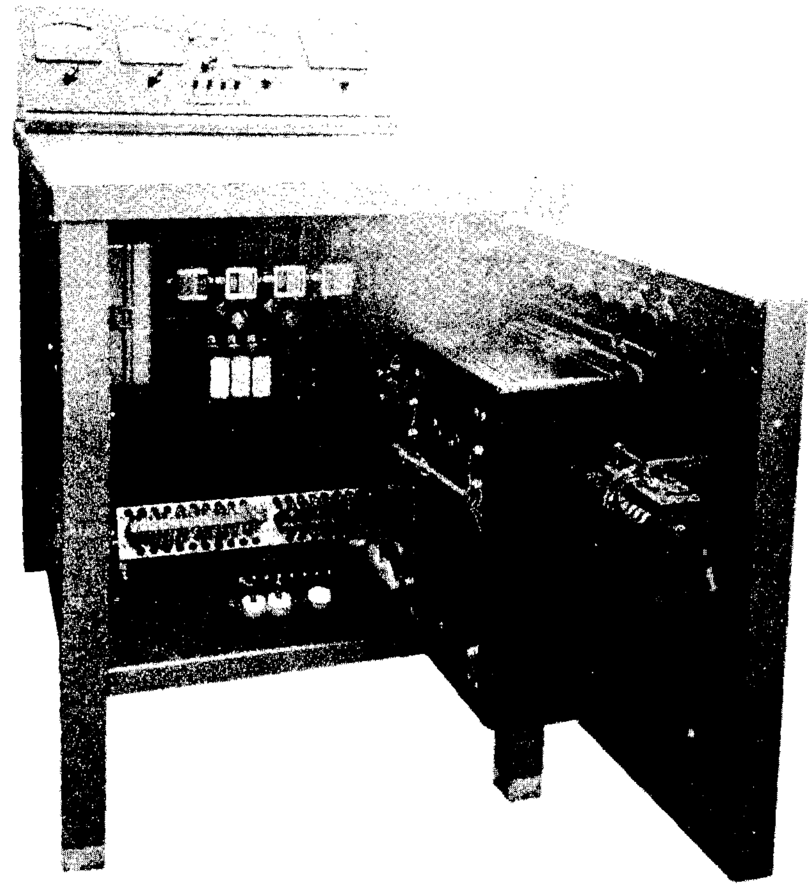

FIGURE 52. Monitor Control Desk - Front Interior View.

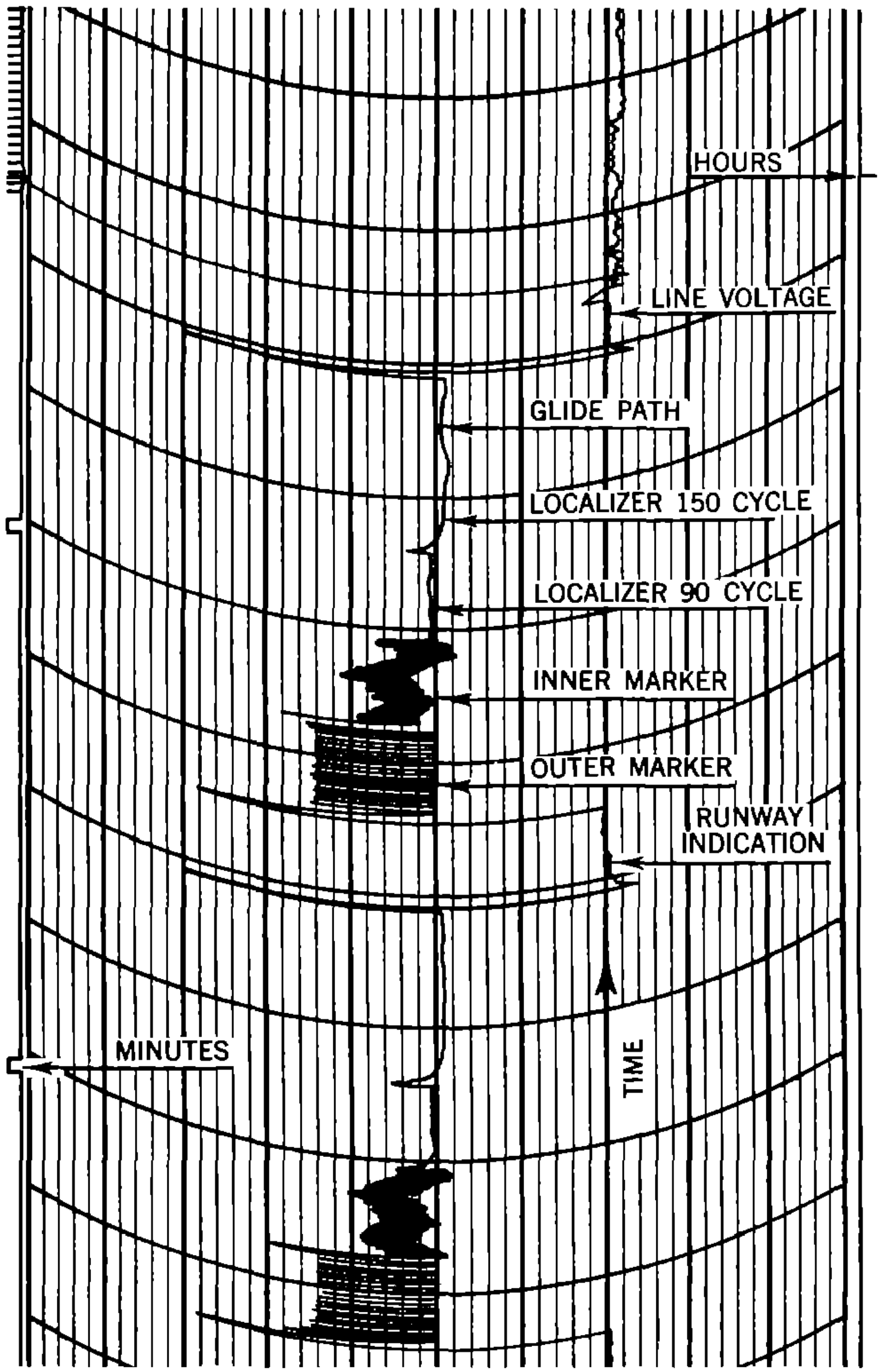

FIGURE 53. Graphic Record of Instrument Landing System Operation

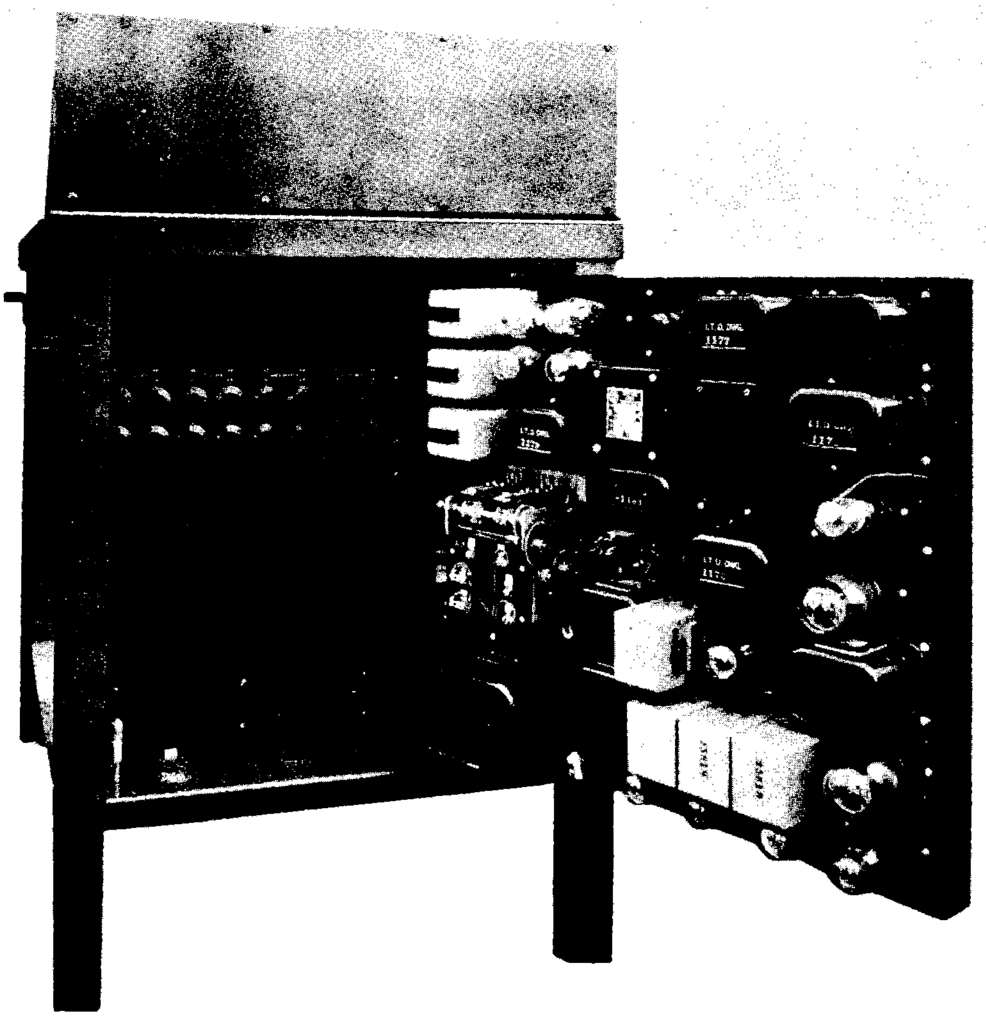

FIGURE 54. Monitor Control Desk - Rear Interior View.

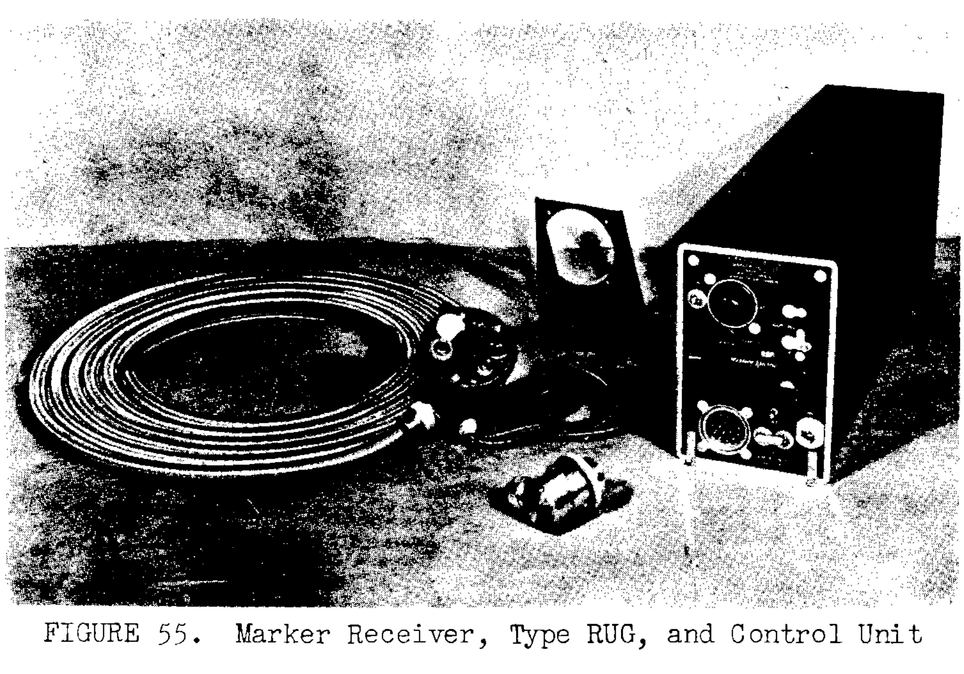

FIGURE 55. Marker Receiver, Type RUG, and Control Unit

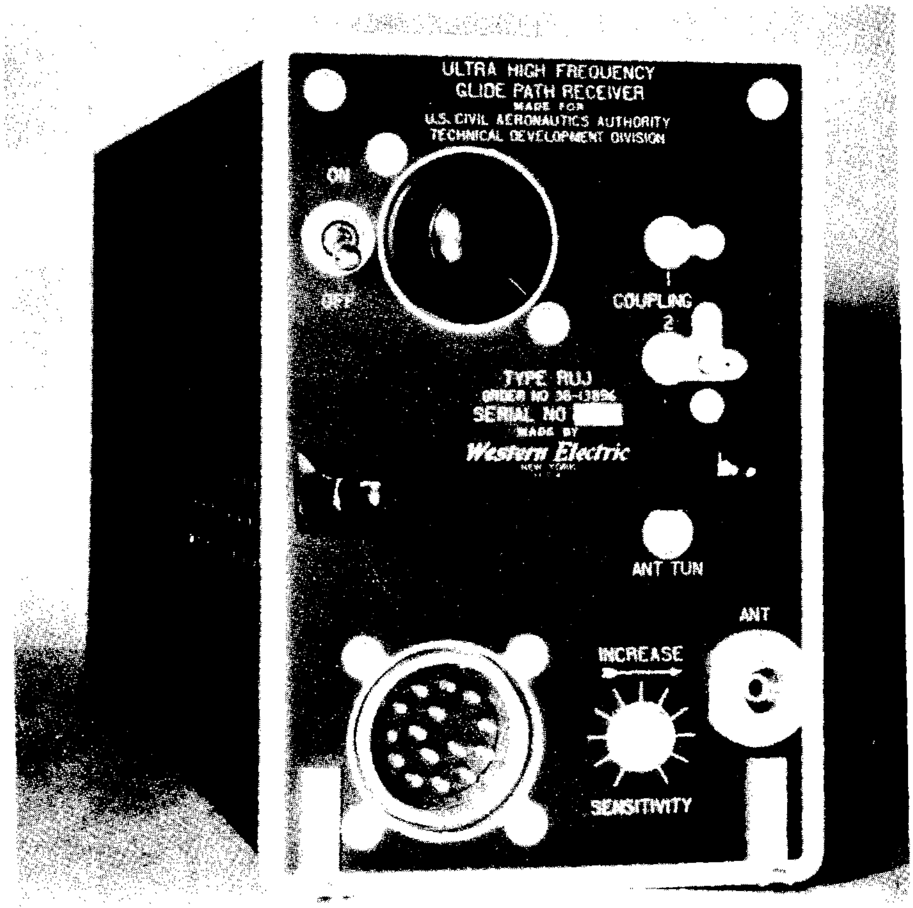

FIGURE 56. Glide Path Receiver, Type RUJ.

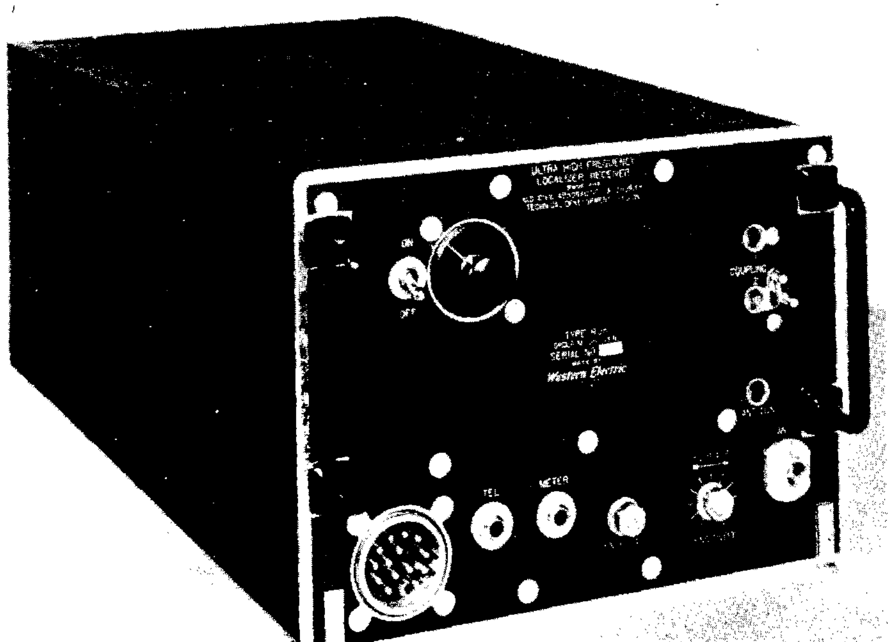

FIGURE 57. Localizer Receiver, Type RUK.

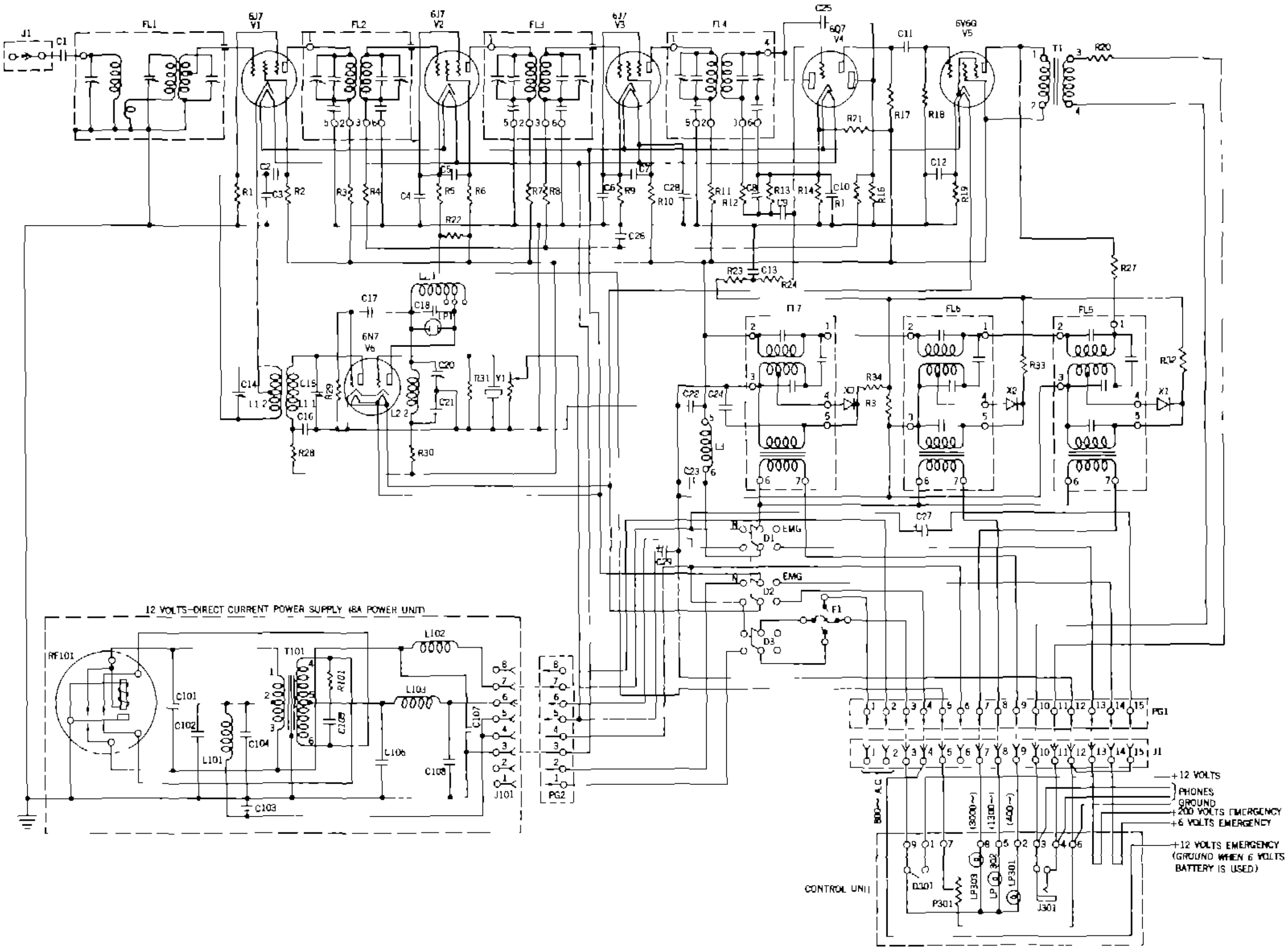

FIGURE 58 Type RUG Marker Receiver and Control Unit Schematic Diagram.

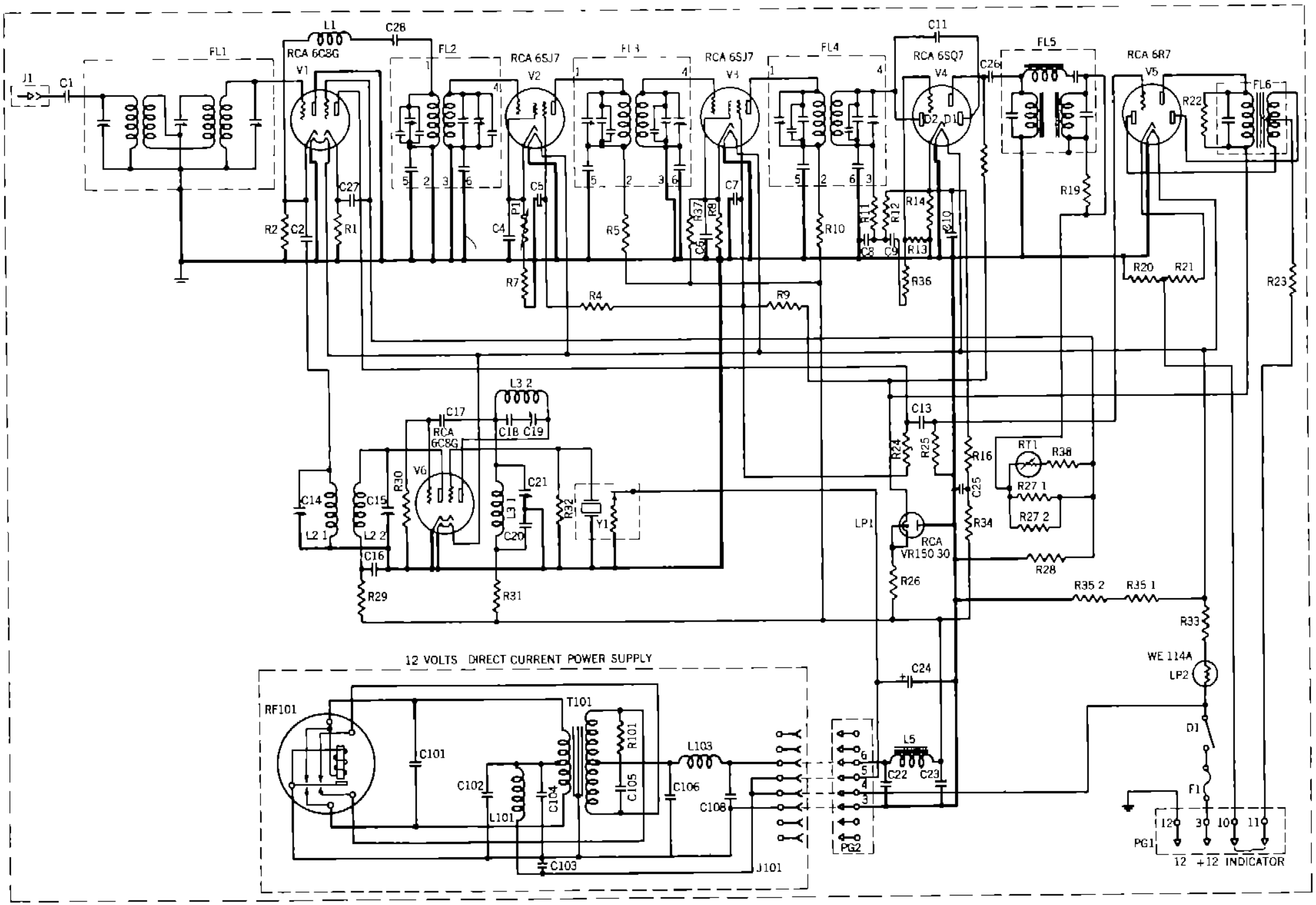

FIGURE 59. Type RUJ Glide Path Receiver, Schematic Diagram

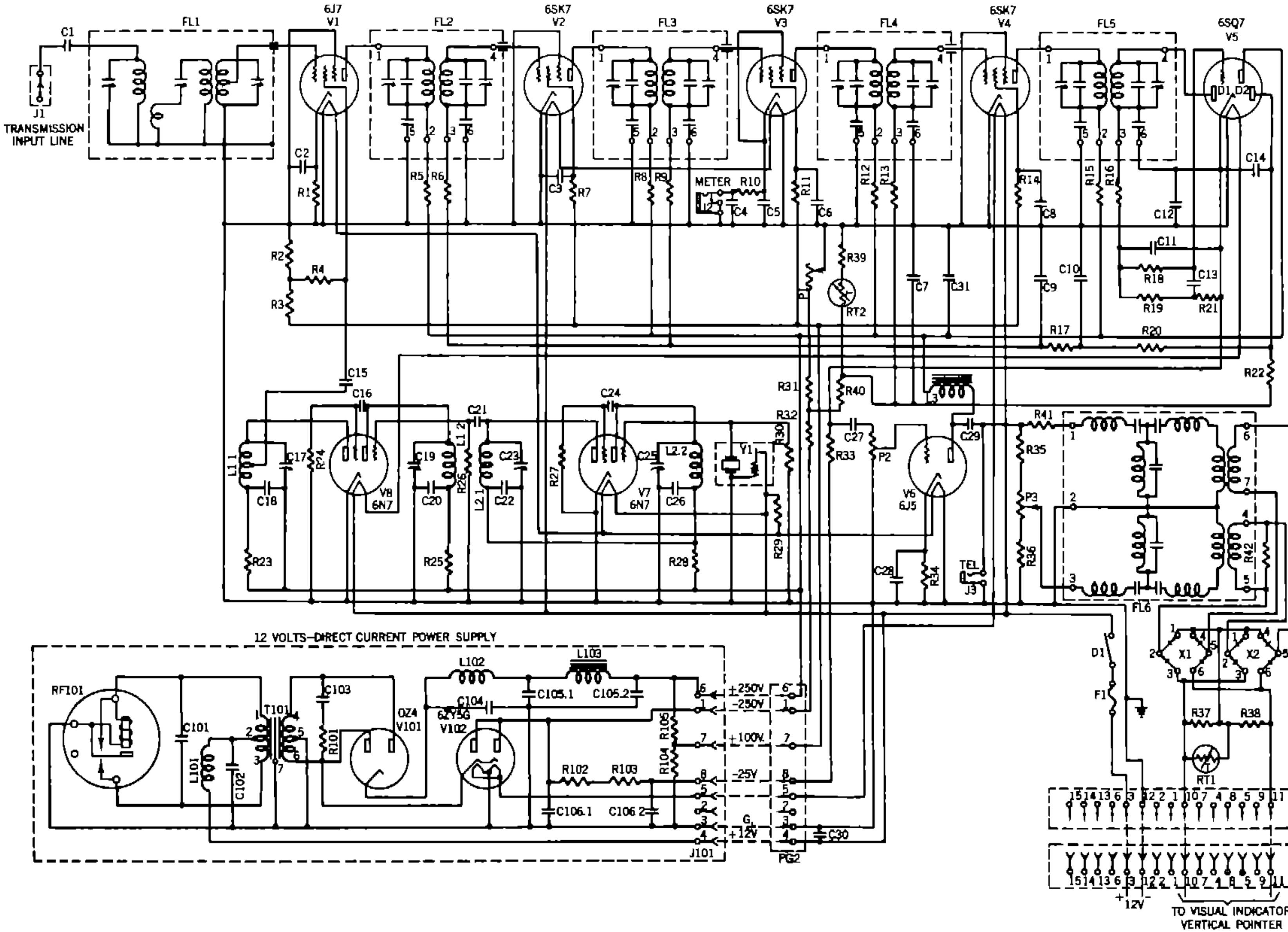

FIGURE 60. Type RUK Localizer Receiver, Schematic Diagram.

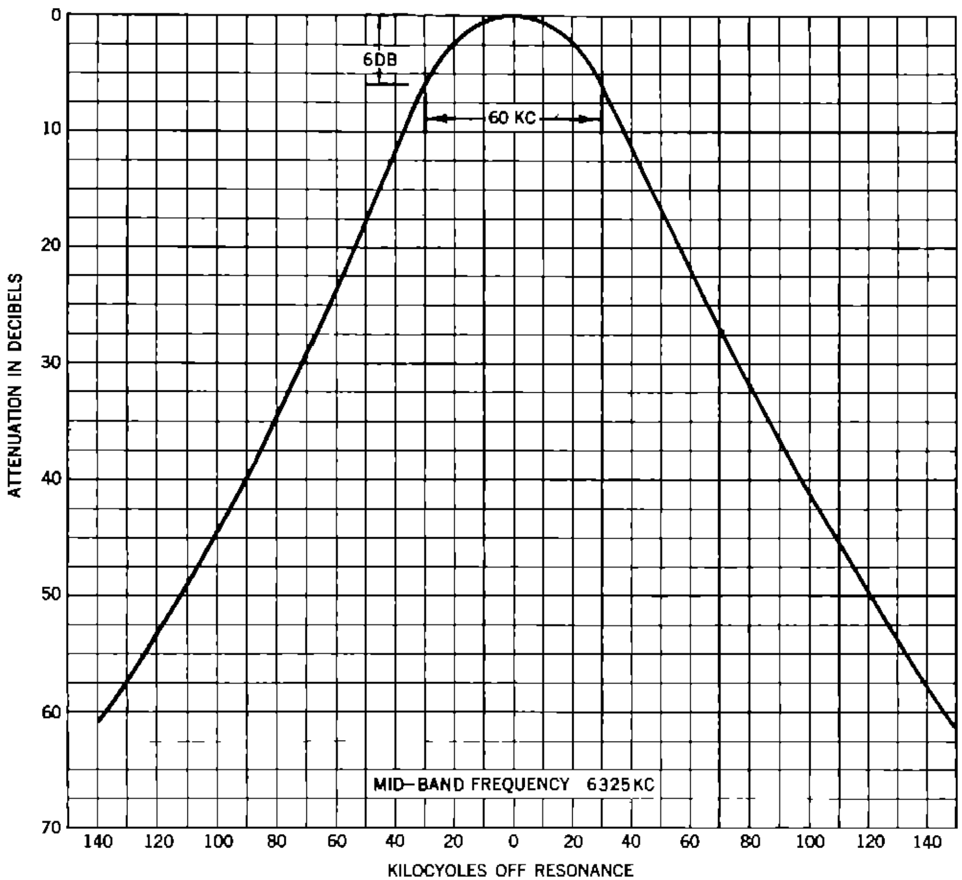

FIGURE 61 Type RUG Marker Receiver, Intermediate Frequency Selectivity

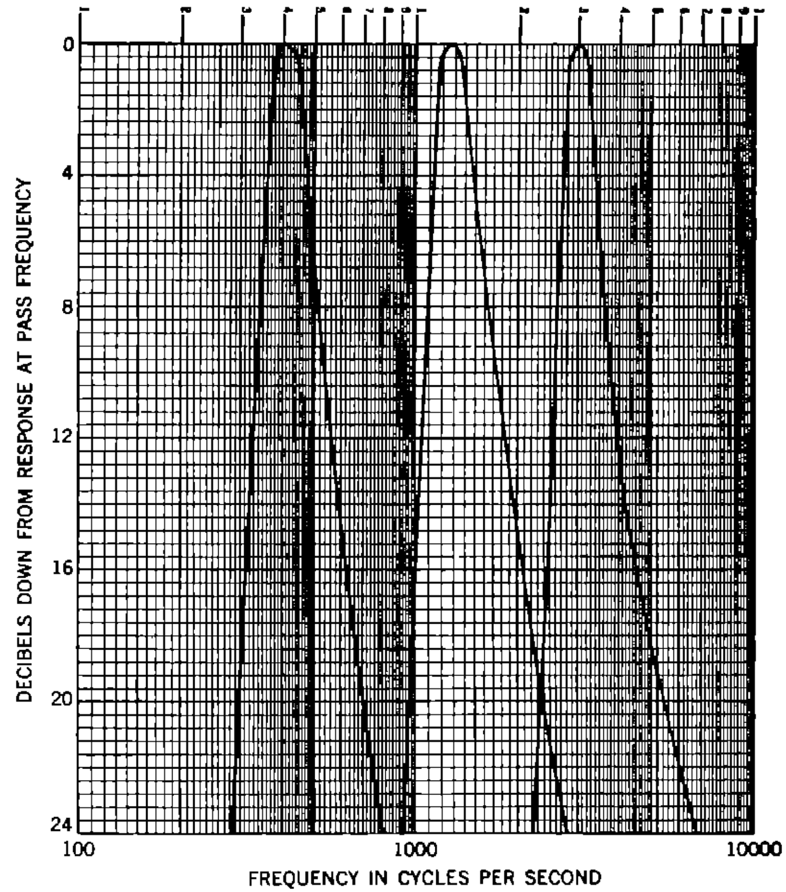

FIGURE 62 Type RUG Marker Receiver, Audio Frequency Selectivity

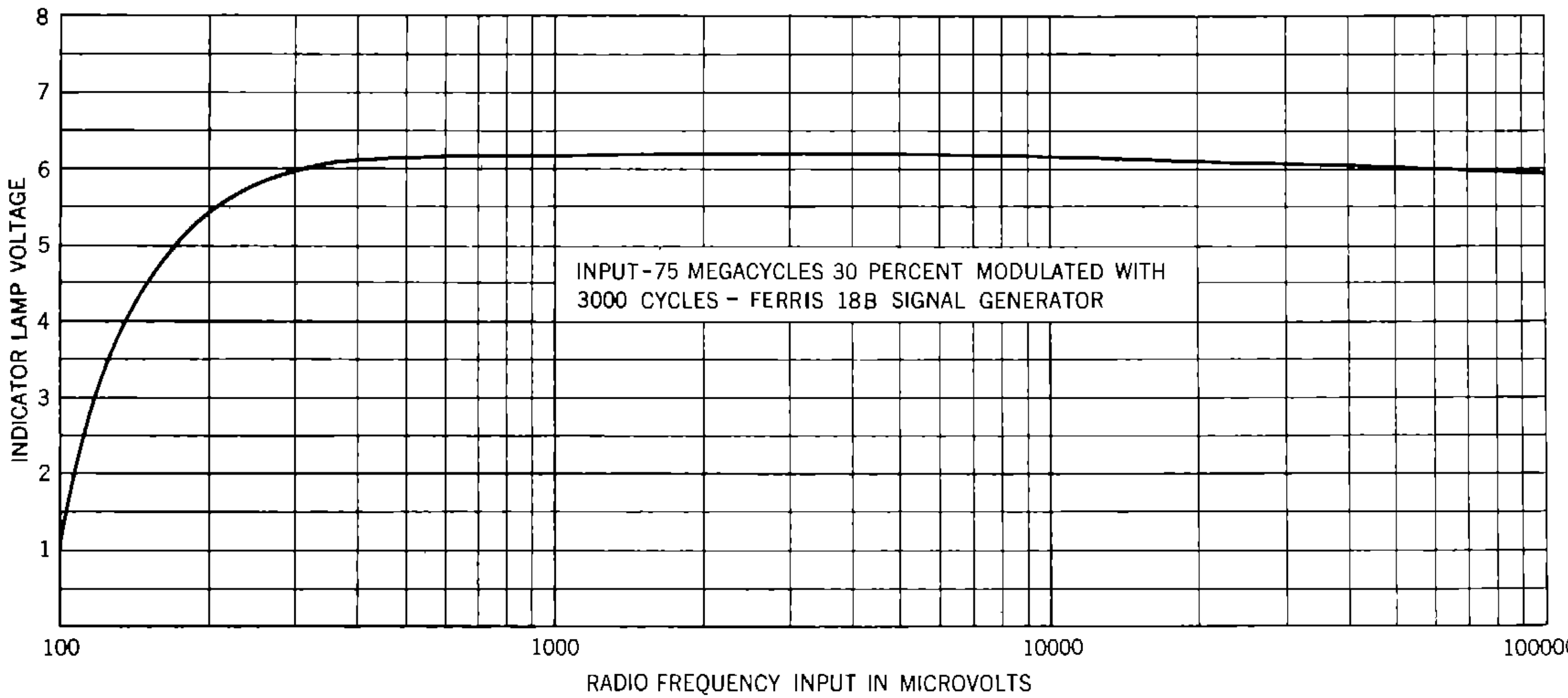

FIGURE 63. Type RUG Marker Receiver, Typical AVC Characteristic.

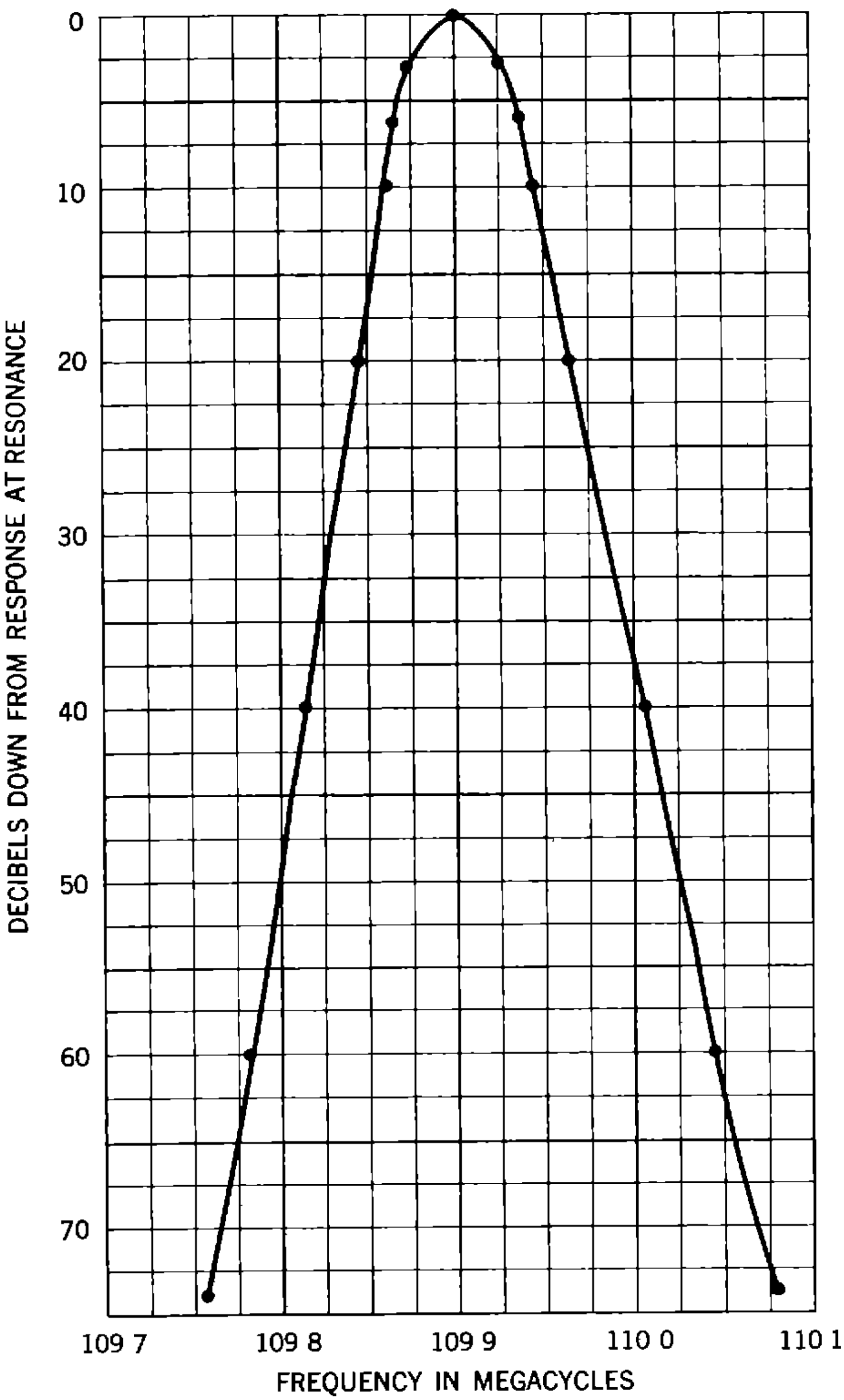

FIGURE 64. Type RUK Localizer Receiver, Radio Selectivity Curve.

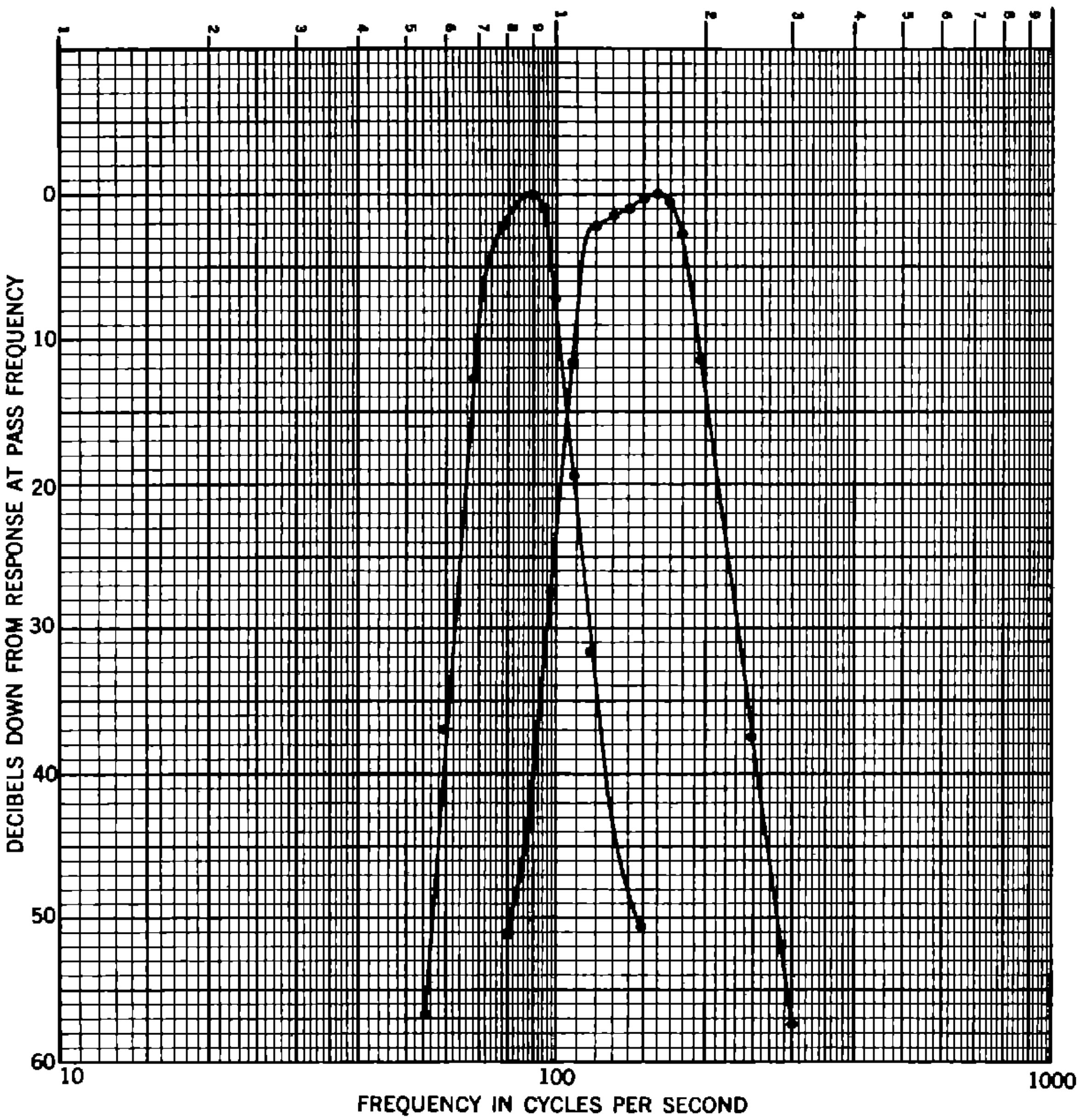

FIGURE 65. Type RUK Localizer Receiver, Audio Selectivity Curves.

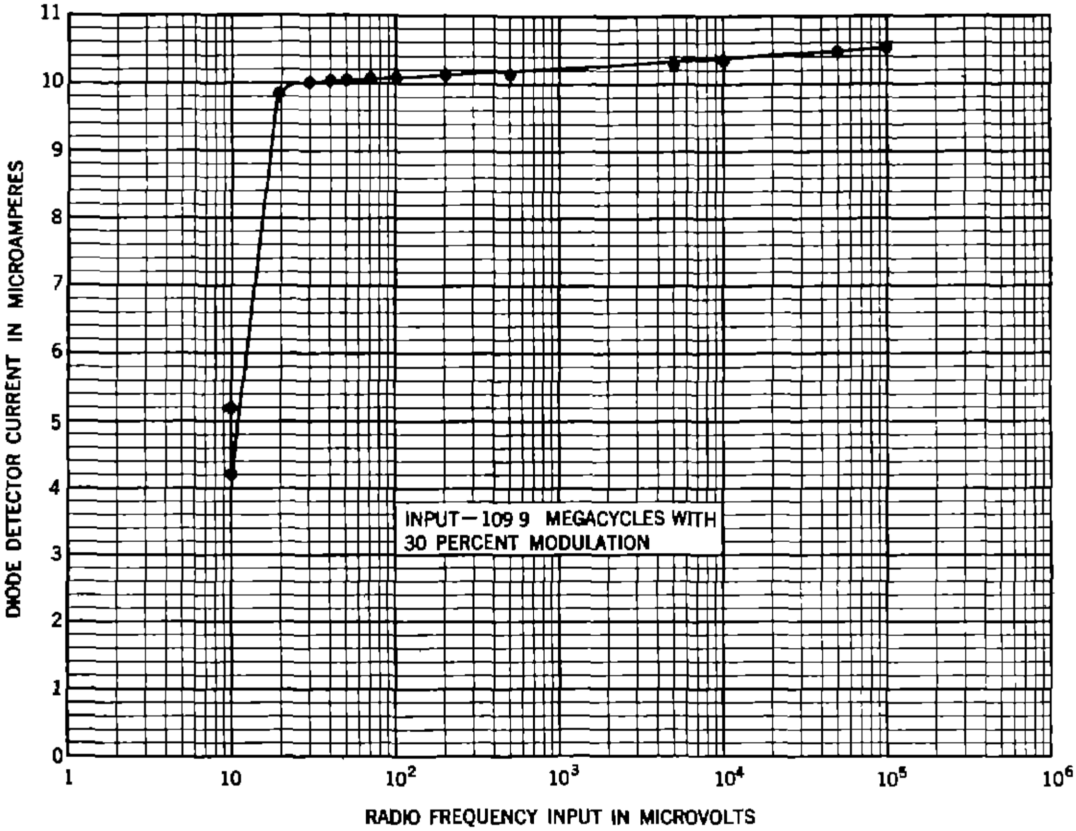

FIGURE 66. Type RUK Localizer Receiver, Diode Detector Current Curve.

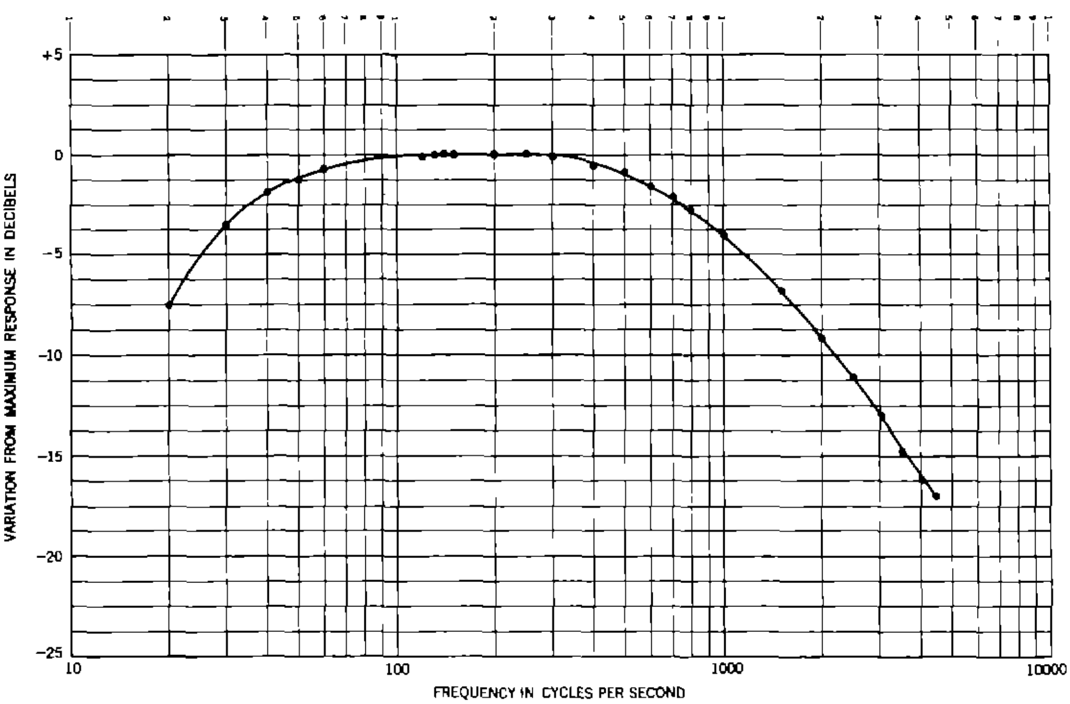

FIGURE 67 Type RUK Localizer Receiver, Audio Fidelity to Filter Input.

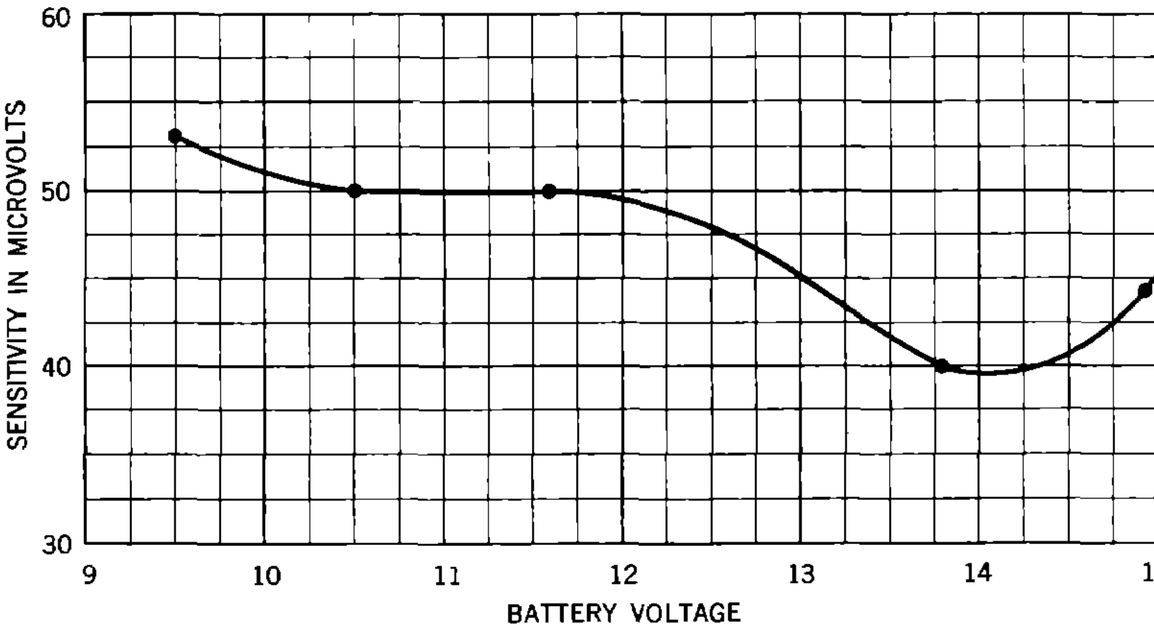

FIGURE 68. Type RUK Localizer Receiver, Sensitivity vs Battery Voltage.

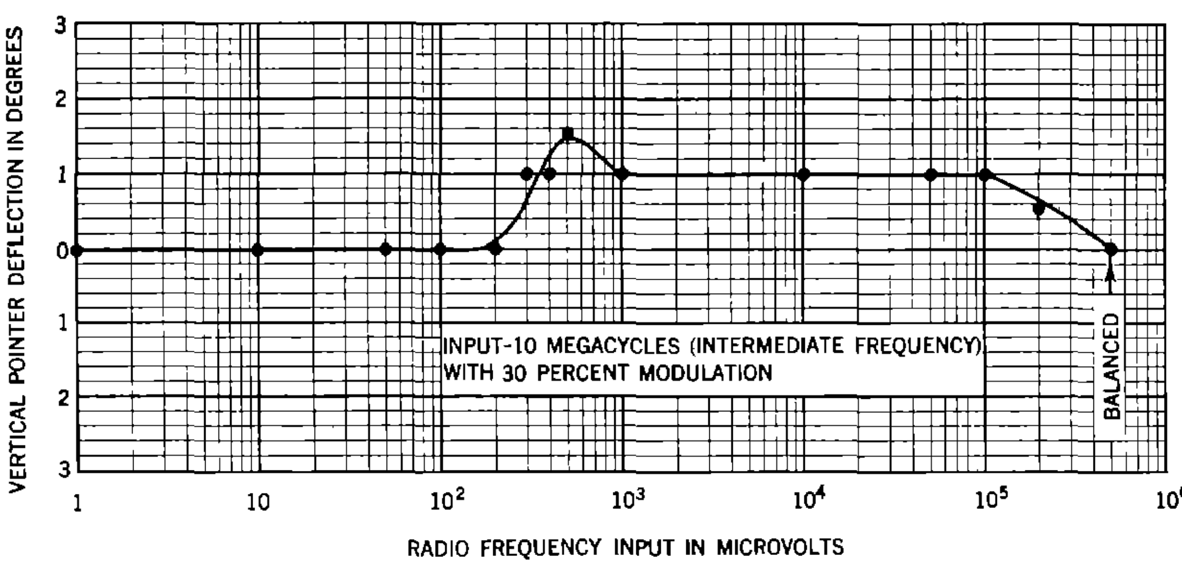

FIGURE 69 Type RUK Localizer Receiver, Output Balance Stability vs. Signal Level.

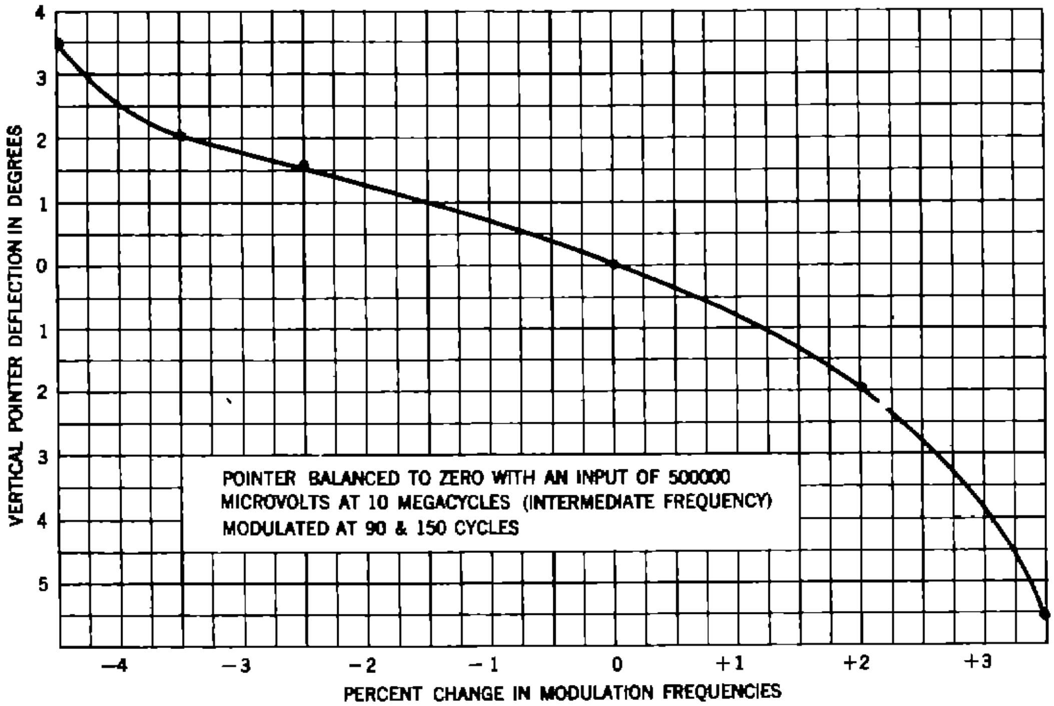

FIGURE 70. Type RUK Localizer Receiver, Output Balance Stability, vs. Modulator Frequency.

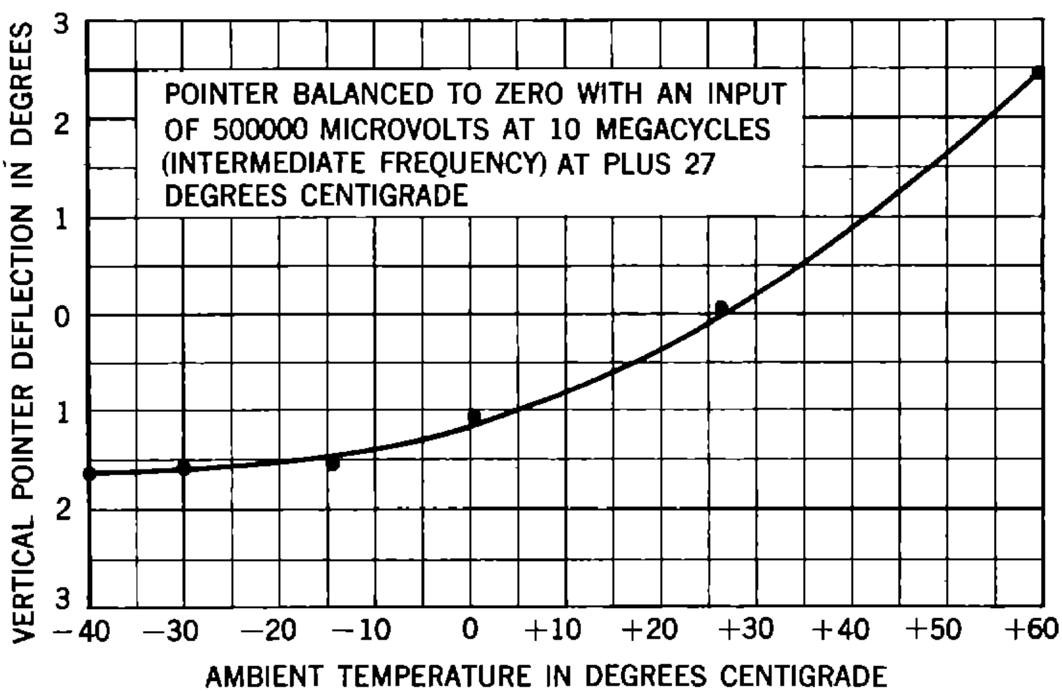

FIGURE 71. Type RUK Localizer Receiver, Output Balance Stability vs. Temperature.

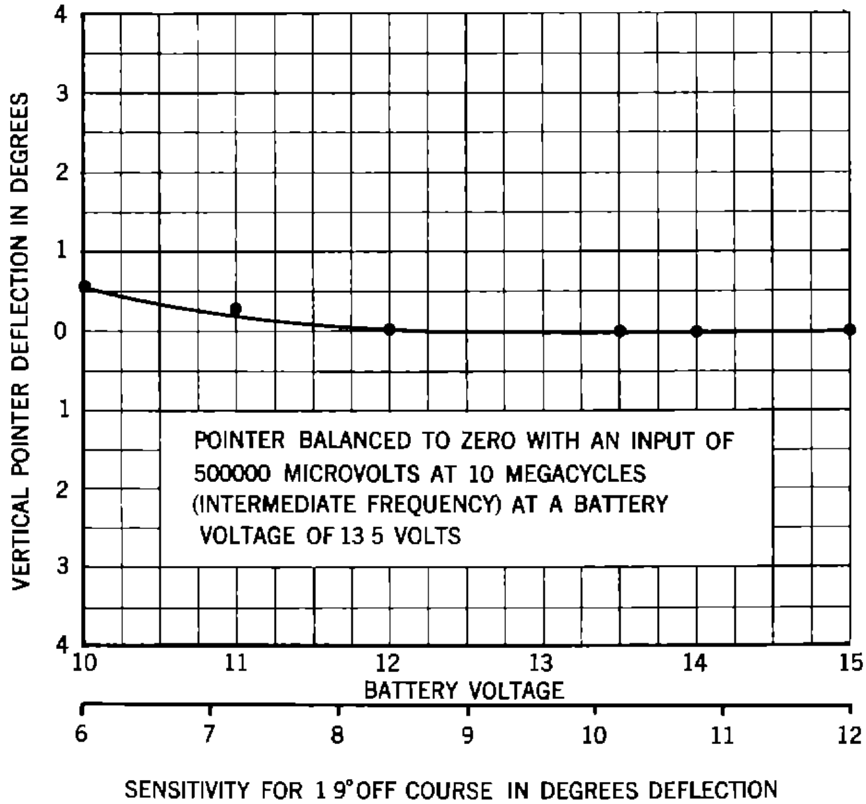

FIGURE 72. Type RUK Localizer Receiver, Output Balance Stability vs Battery Voltage

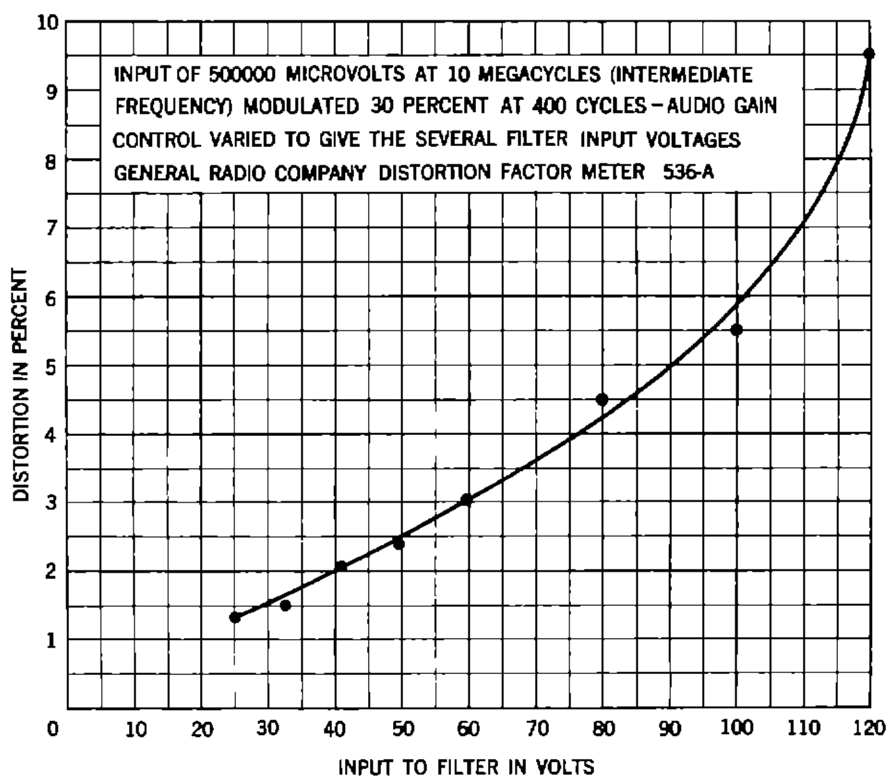

FIGURE 73 Type RUK Localizer Receiver, Distortion Curve

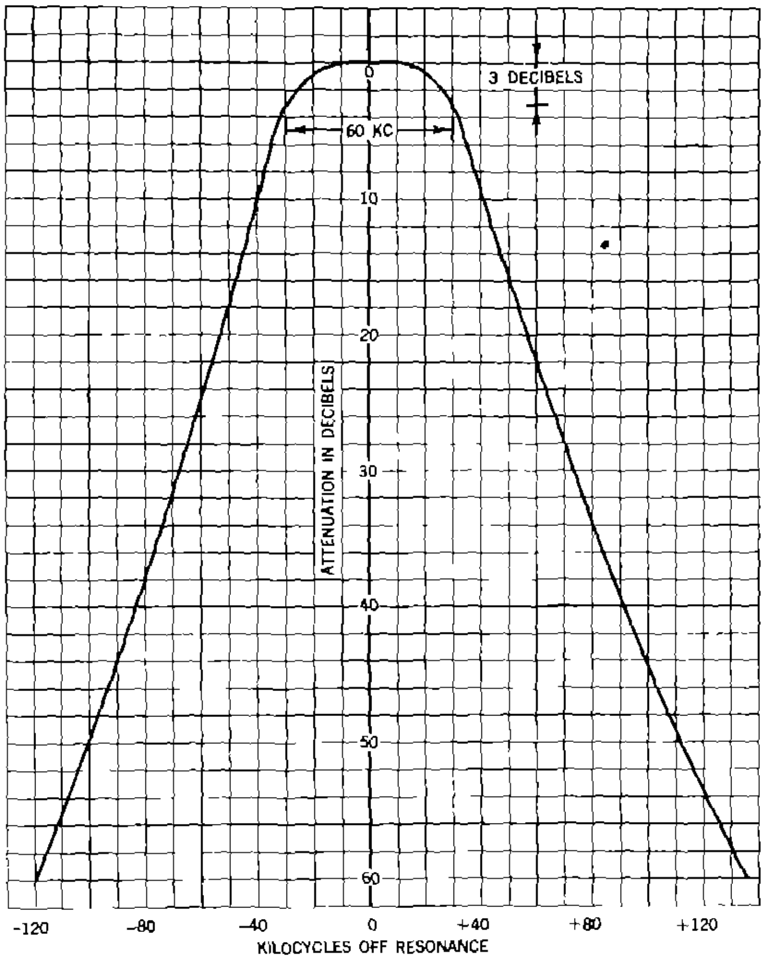

FIGURE 74 Type RUJ Glide Path Receiver, Intermediate Frequency Selectivity Characteristic

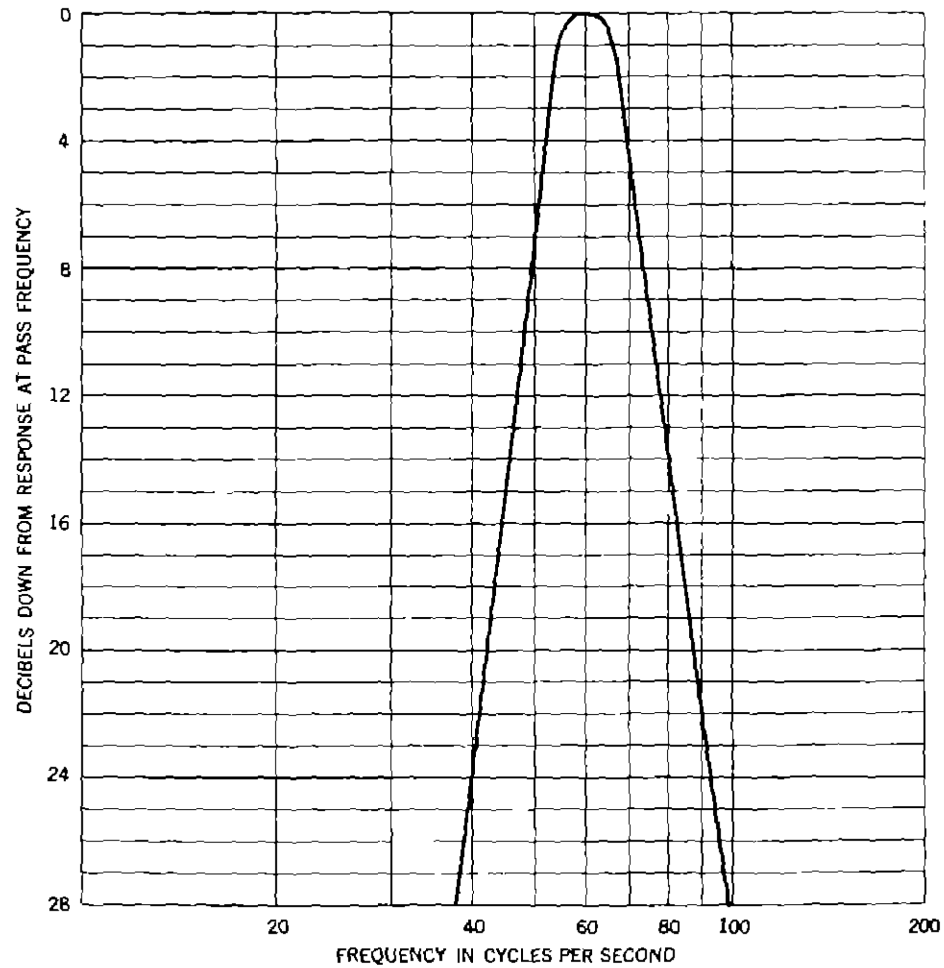

FIGURE 75. Type RUJ Glide Path Receiver, Typical Audio Selectivity Characteristic

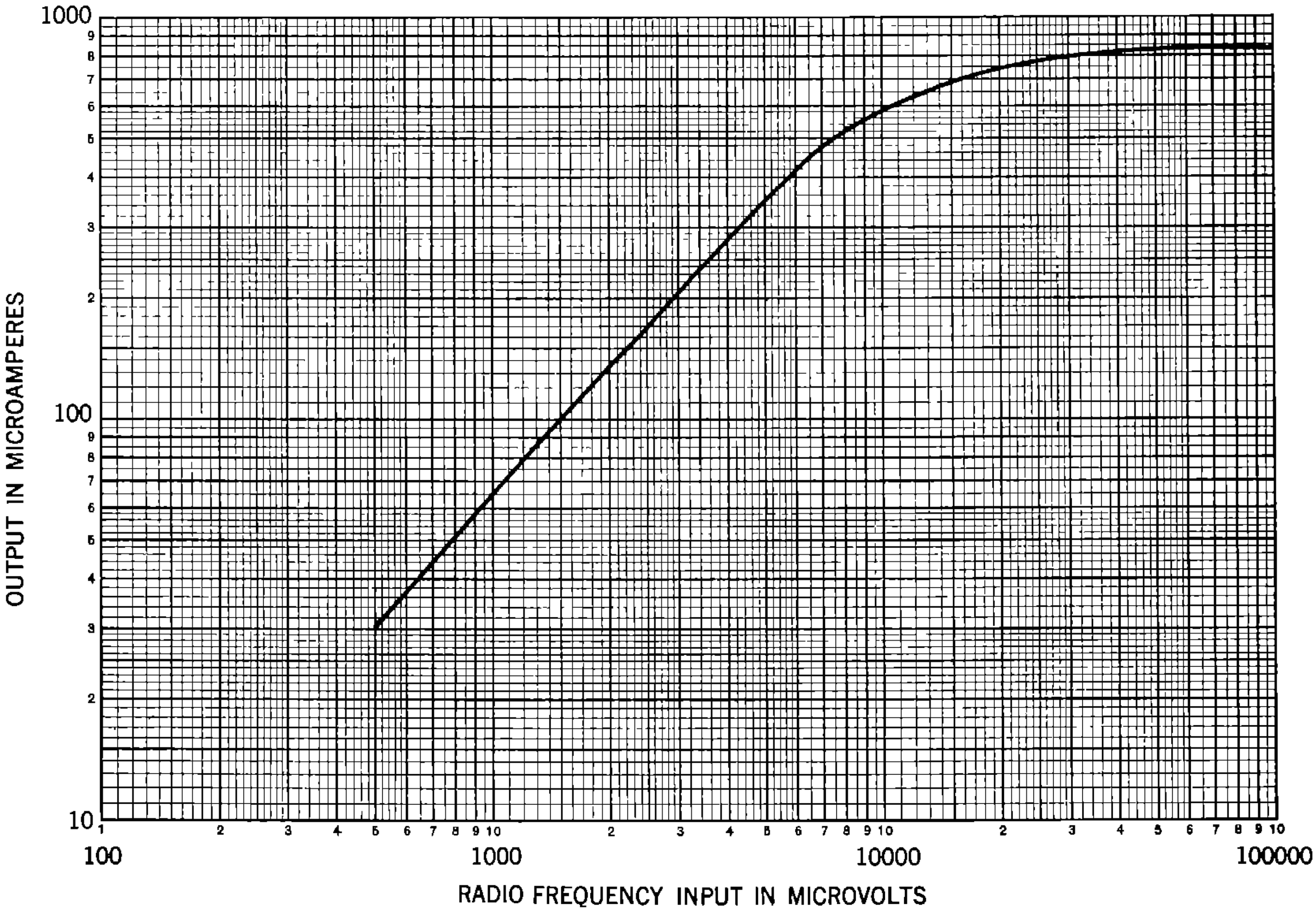

FIGURE 76. Type RUJ Glide Path Receiver, Typical Input-Output Characteristic.

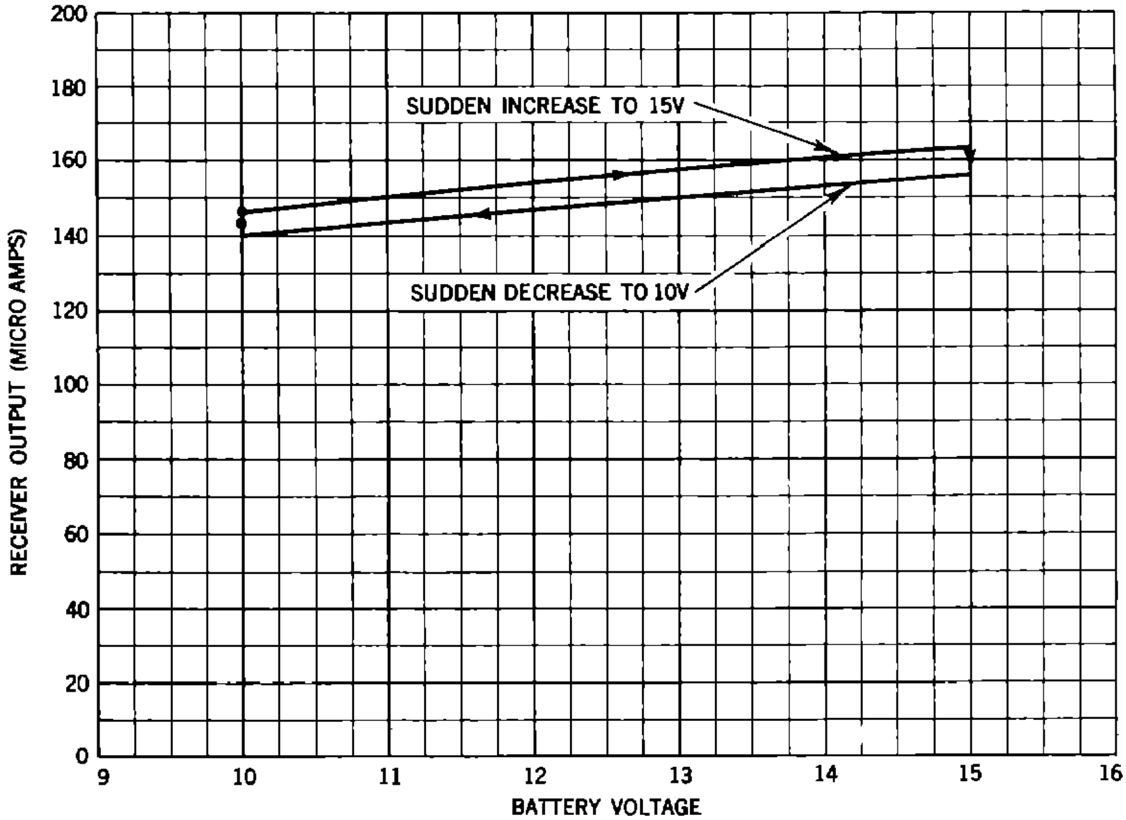

FIGURE 77. Type RUJ Glide Path Receiver, Battery Voltage Characteristic.

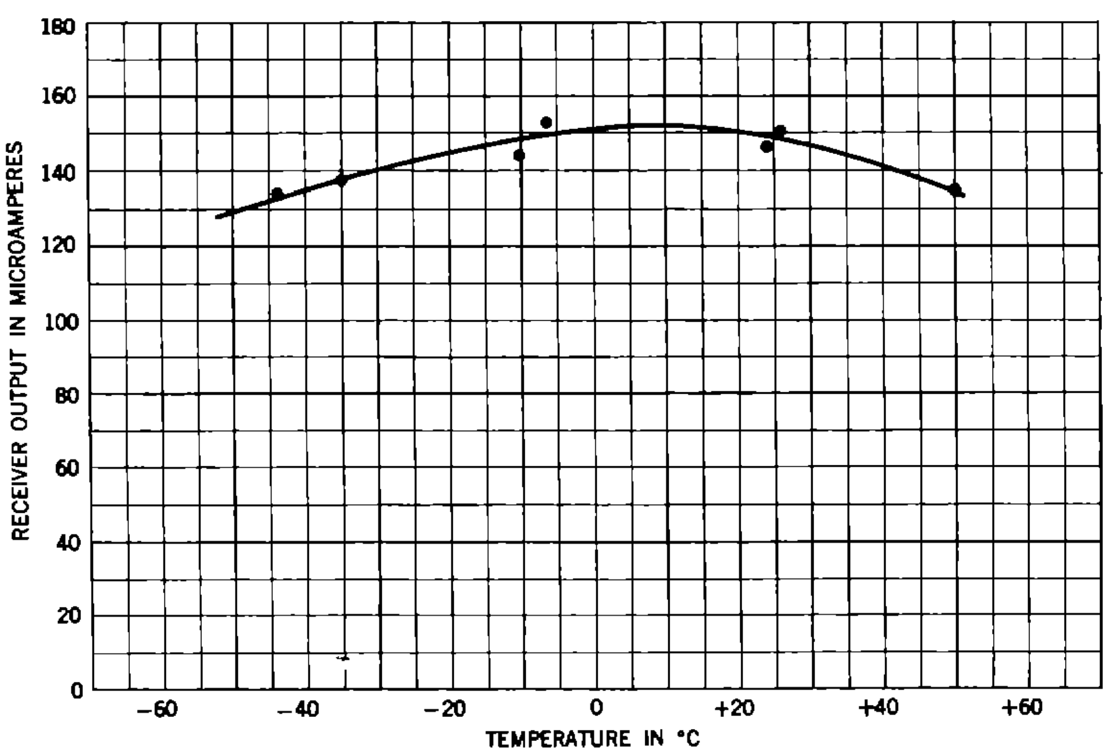

FIGURE 78. Type RUJ Glide Path Receiver, Temperature Characteristic.

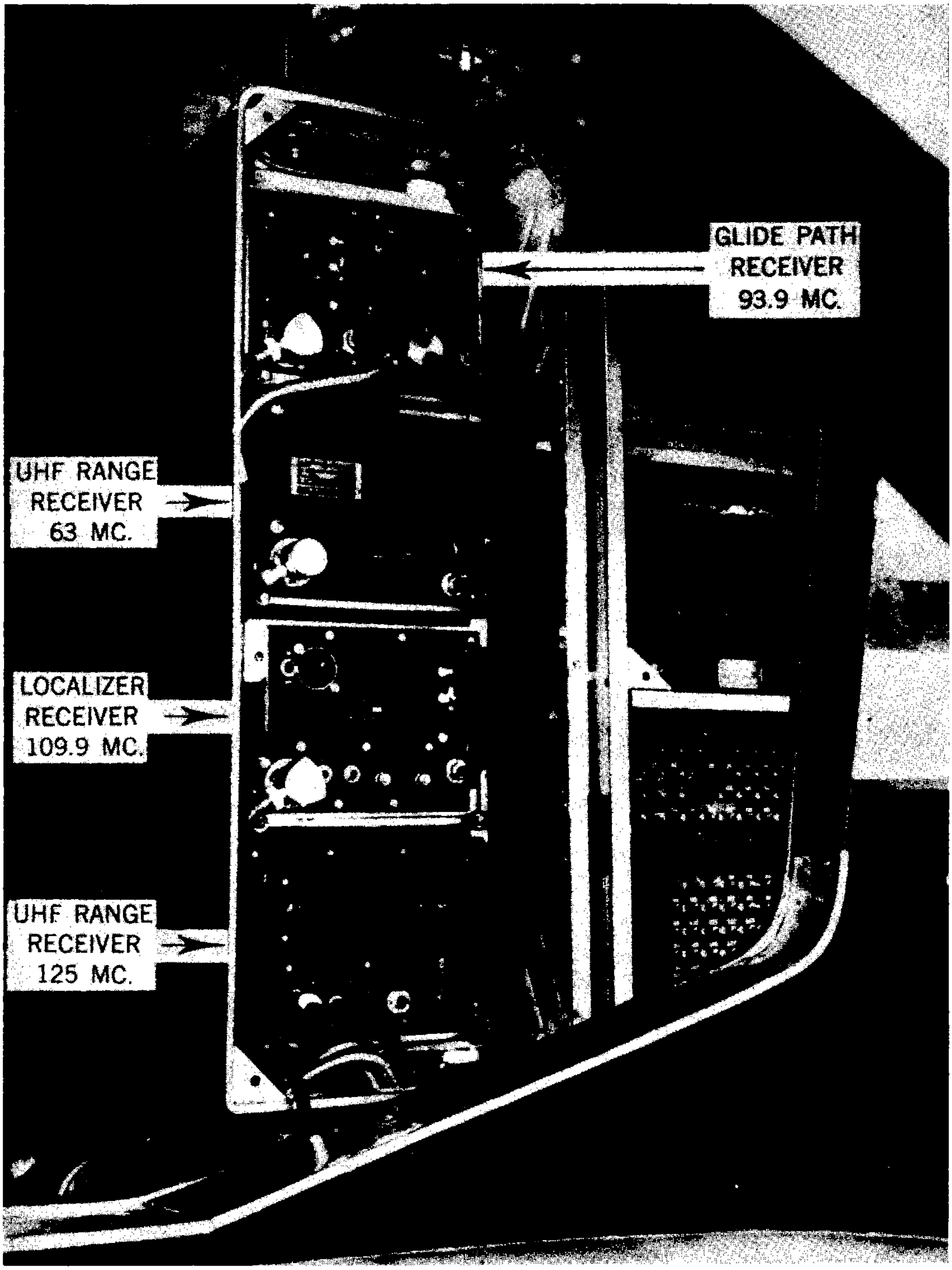

FIGURE 79. Ultra-High Frequency Equipment Rack in NC-17.

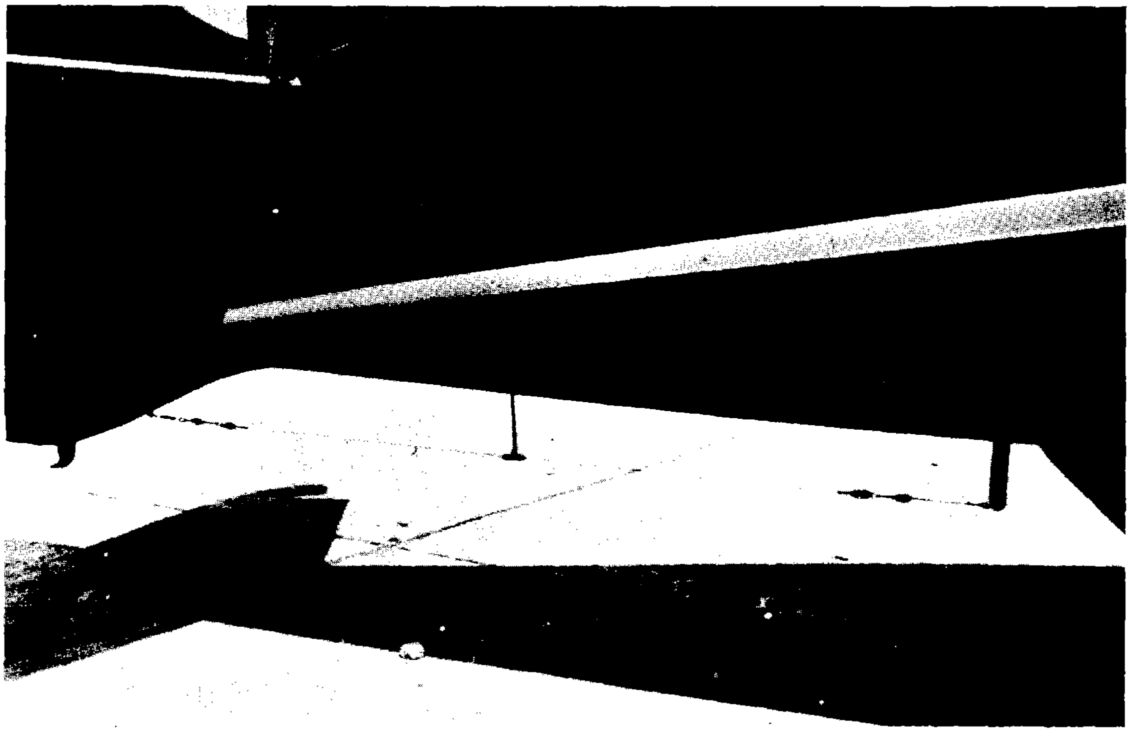

FIGURE 80. Horizontal Receiving Antenna for 75-Megacycle Markers.

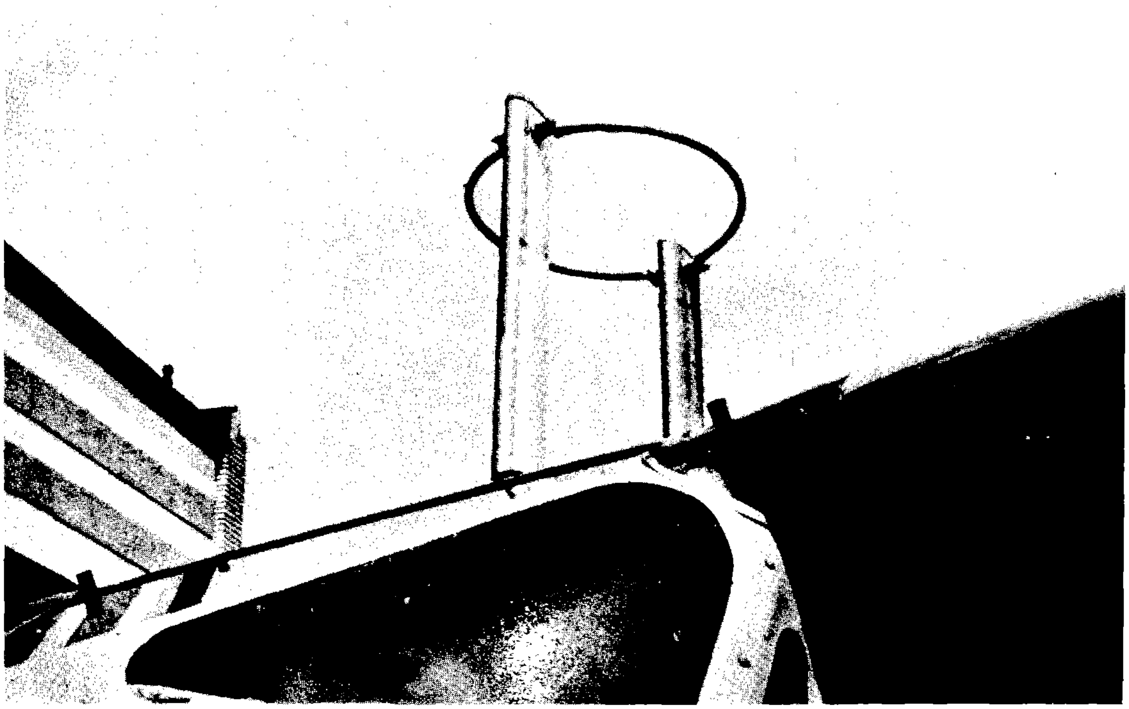

FIGURE 81. 93.9 Mc - 109.9 Mc Receiving Loop on NC-17.

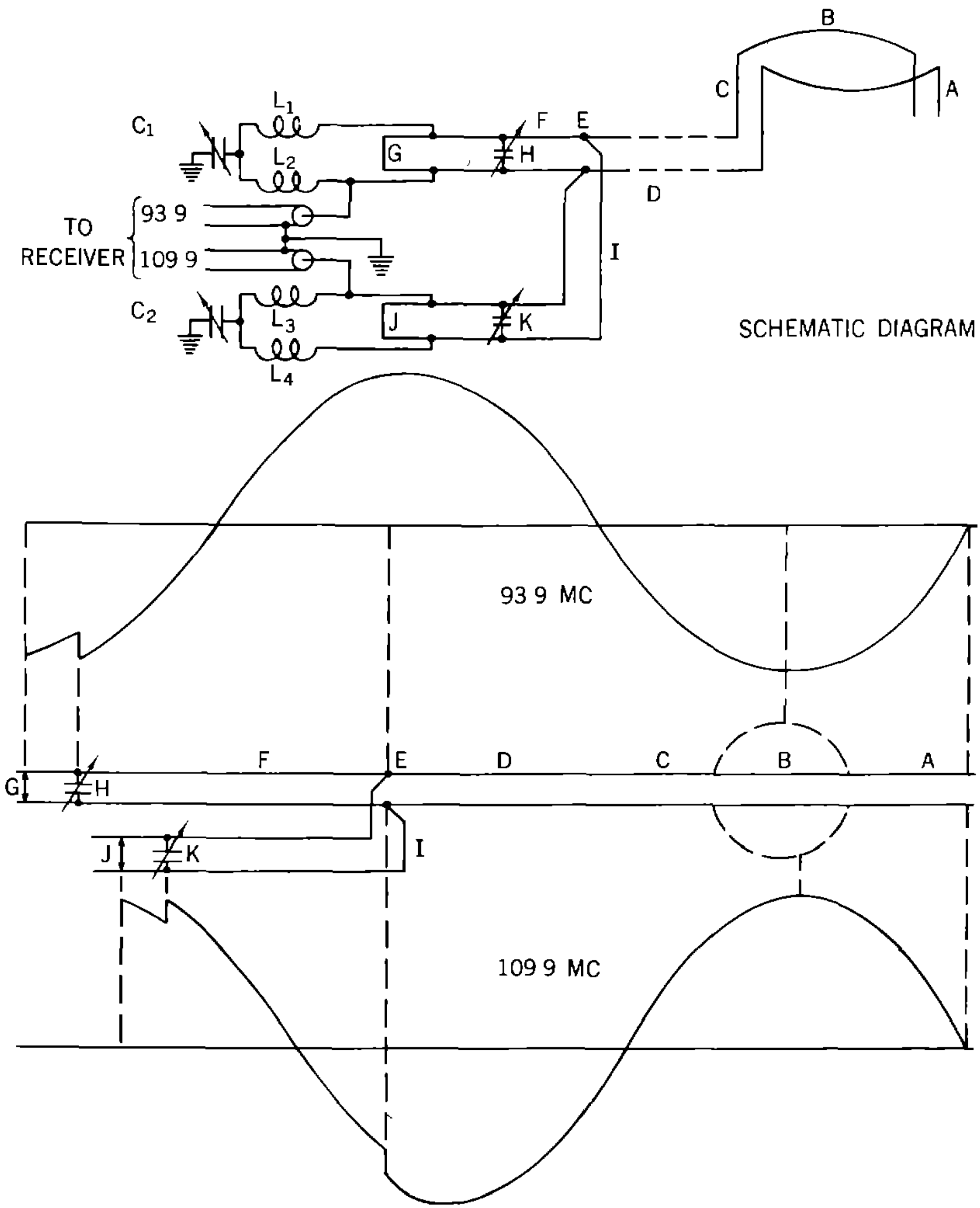

FIGURE 82 Dual Frequency Receiving Loop Diagram and Current Distribution.

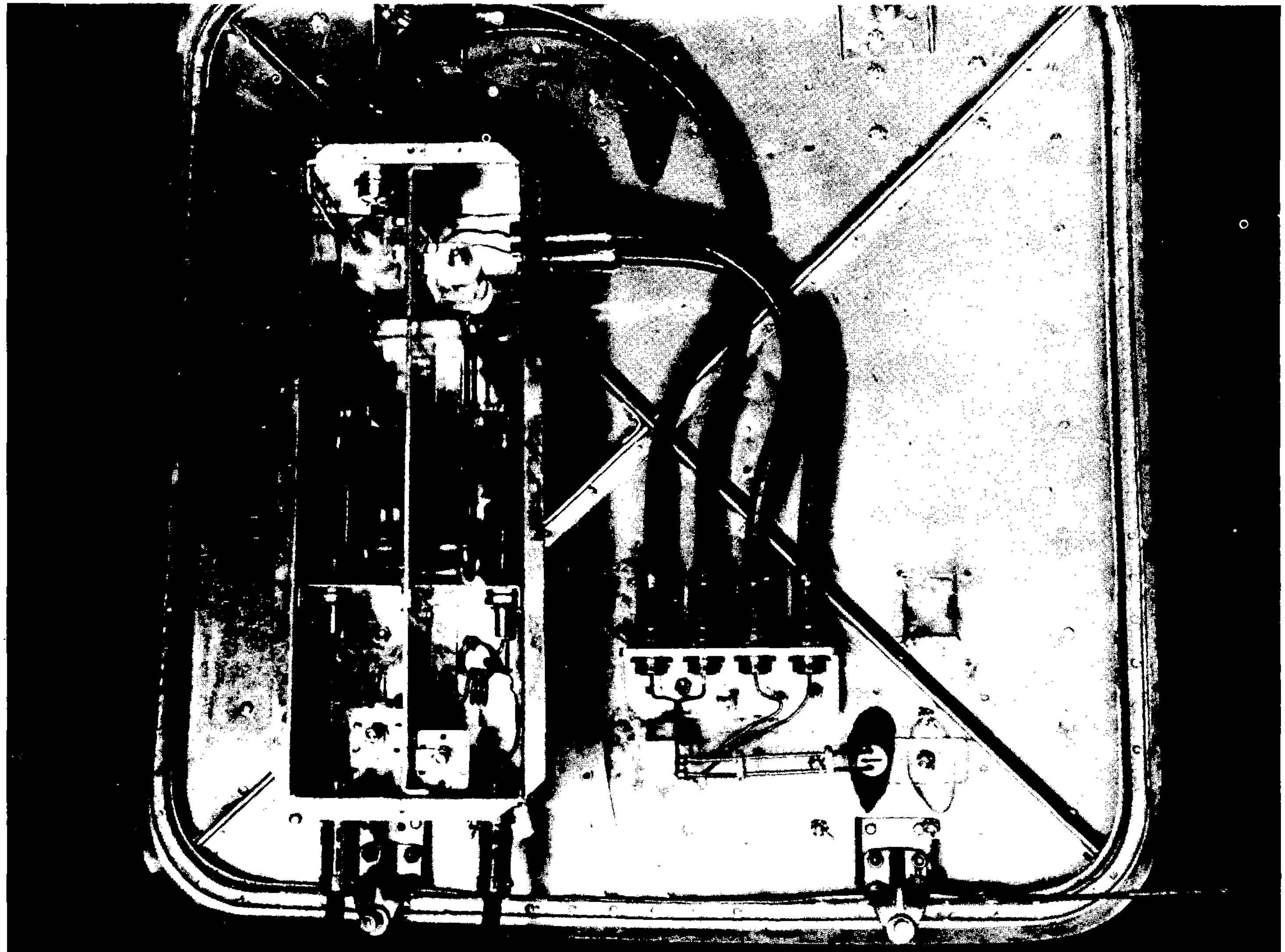

FIGURE 83. Receiving Loop Tuning and Balancing Unit on DC-3 Hatch Cover.

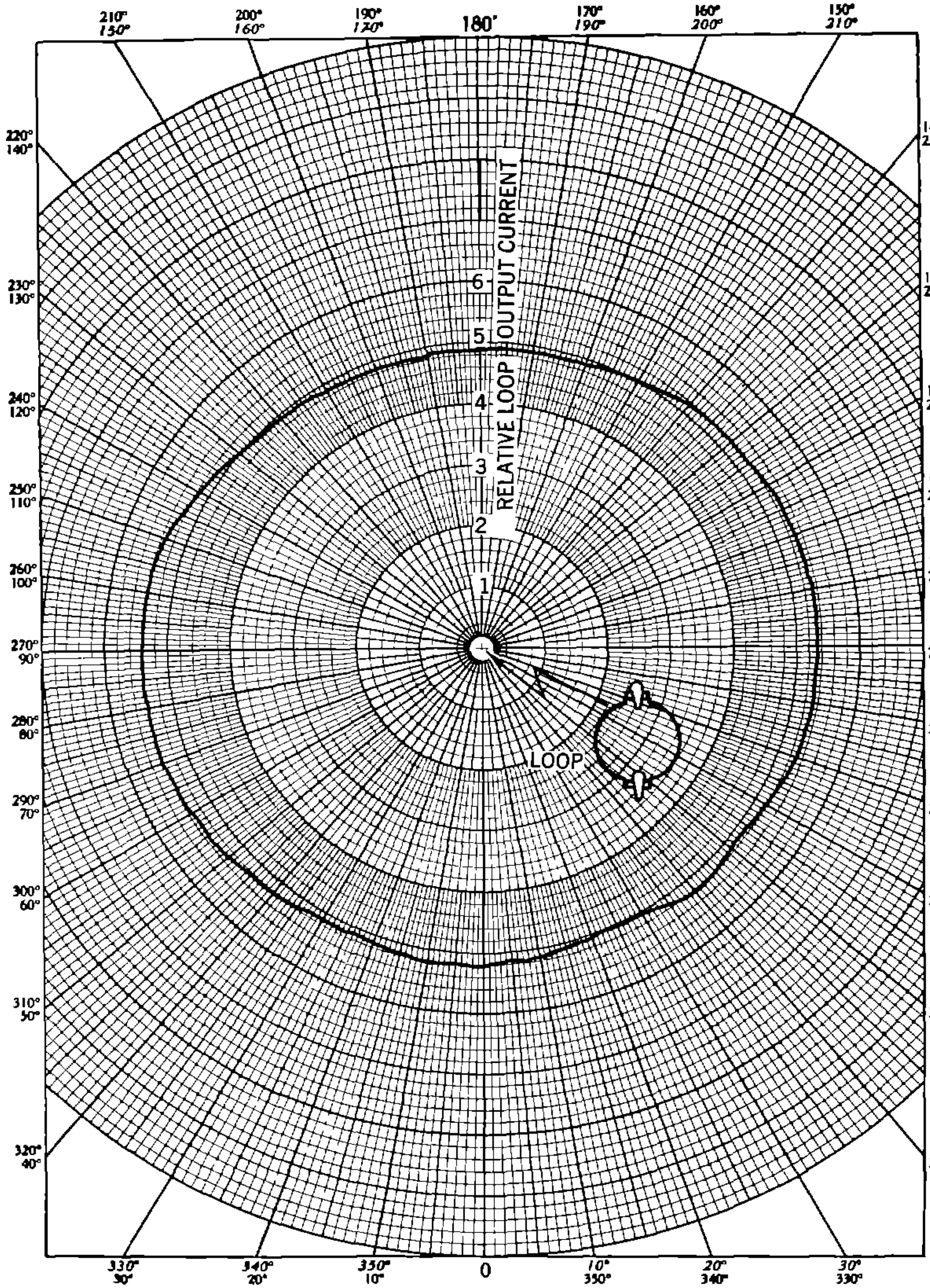

FIGURE 84. Receiving Loop Horizontal Pattern 93.9 Mc.

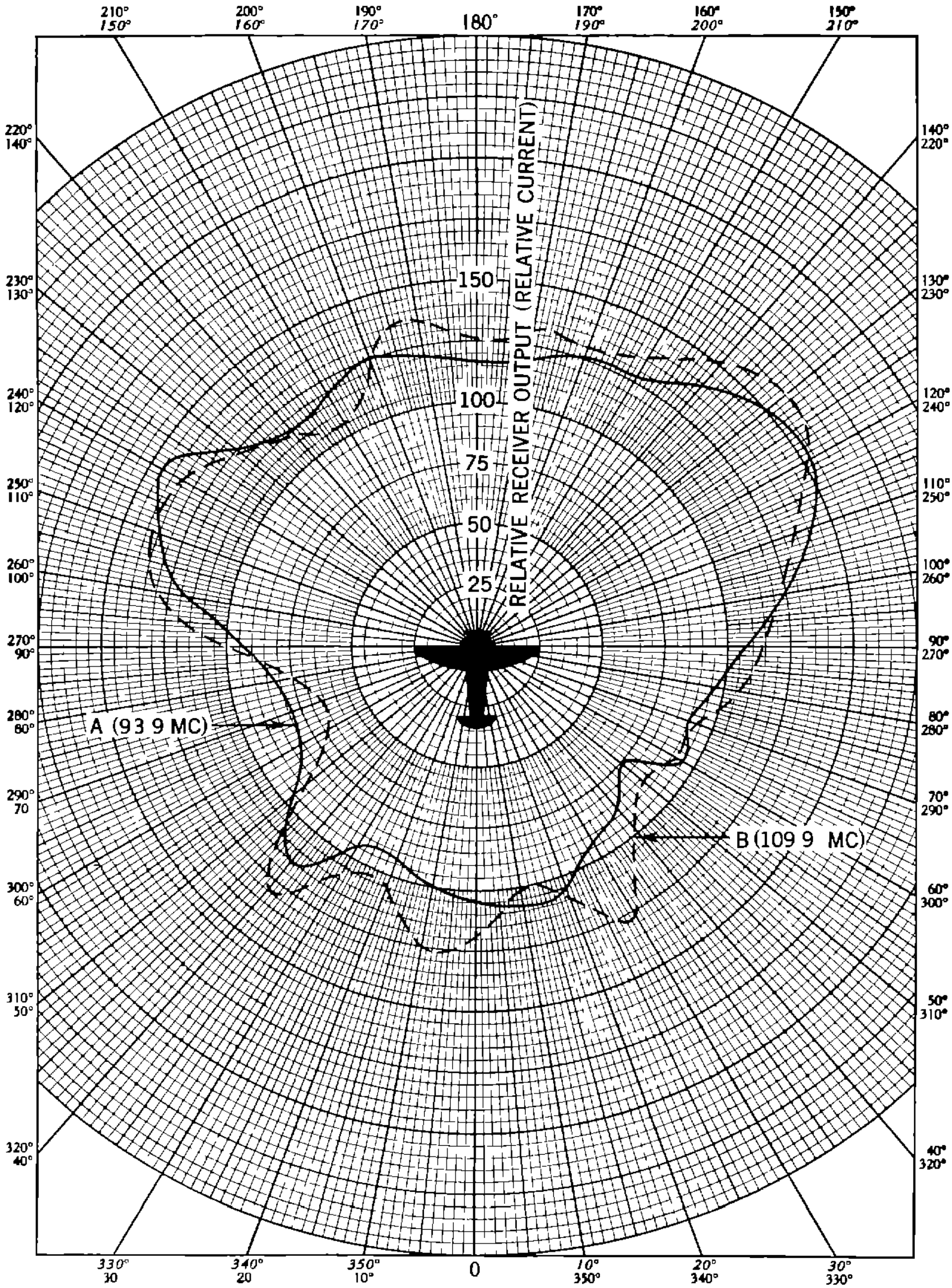

FIGURE 85 Receiving Loop Horizontal Patterns NC-17.

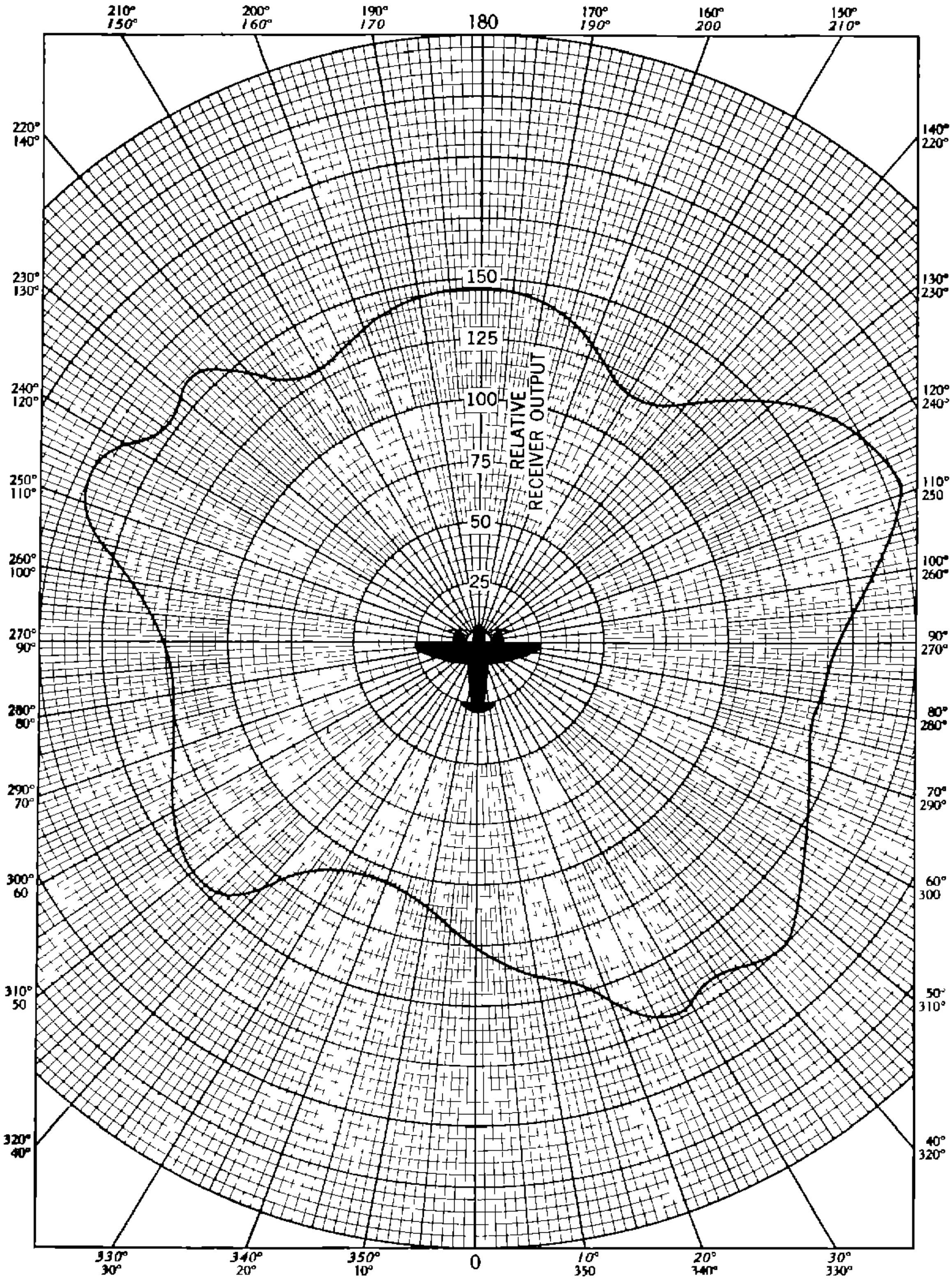

FIGURE 86. Receiving Loop Horizontal Pattern
United Air Lines Boeing (93 9 Mc).

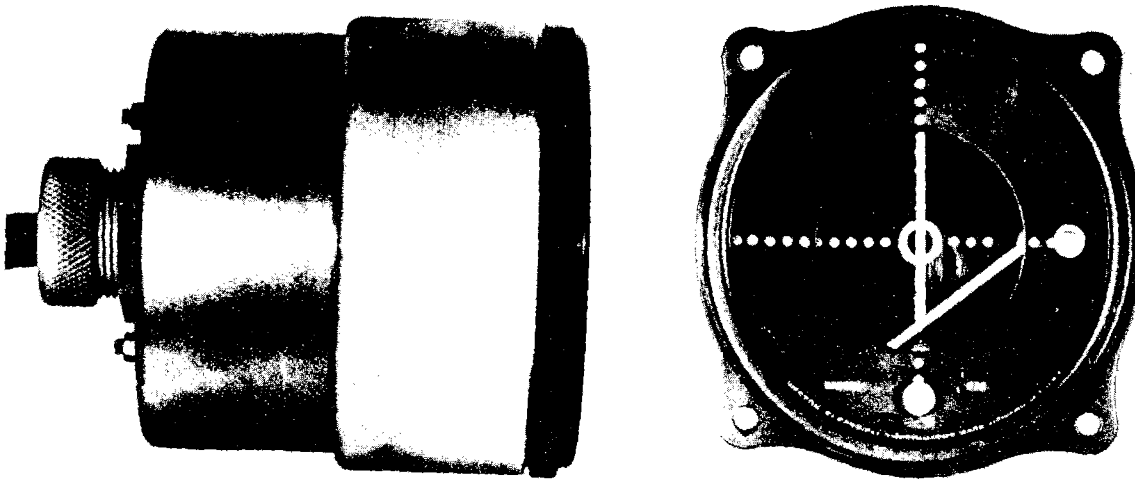

FIGURE 87. Cross-Pointer Instrument.

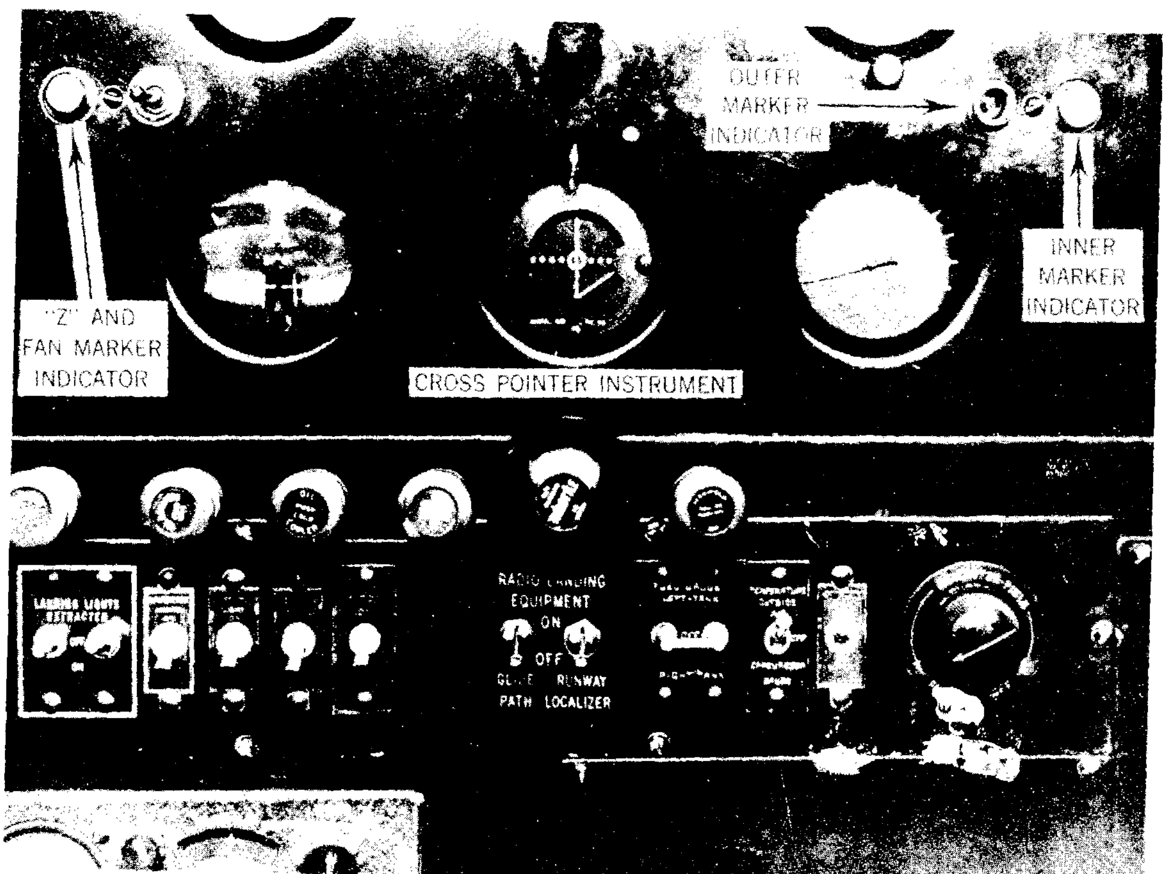

FIGURE 88. Instrument Panel on NC-17.

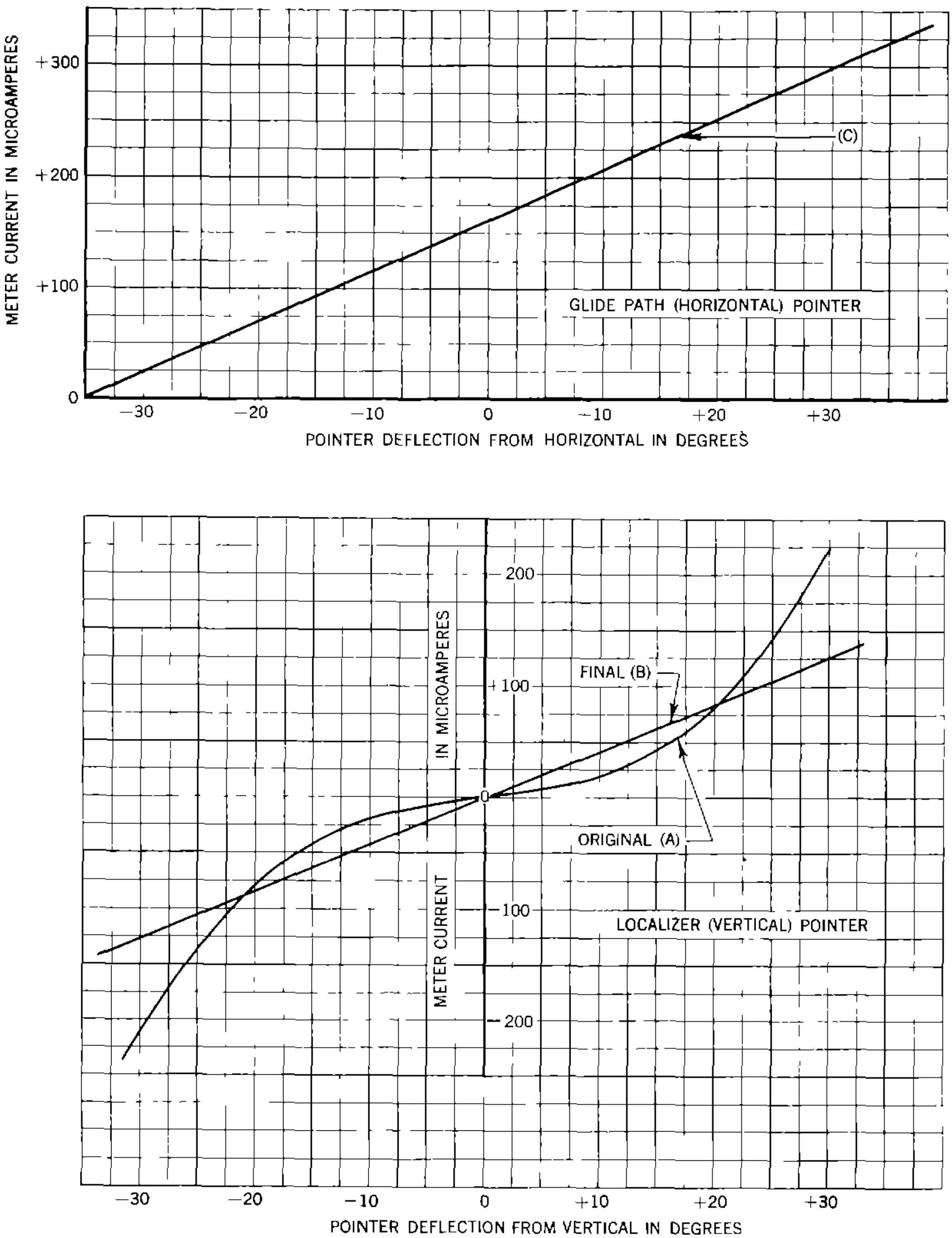

FIGURE 89. Cross-Pointer Instrument Characteristics

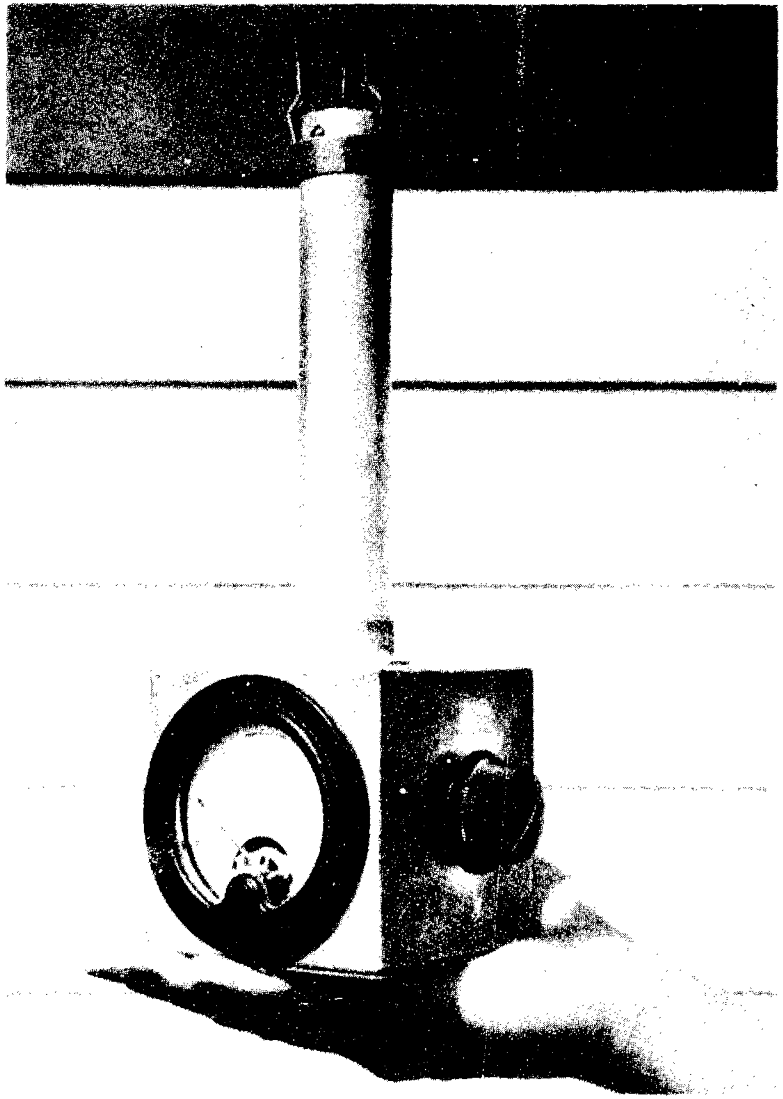

FIGURE 90. Probe Detector.

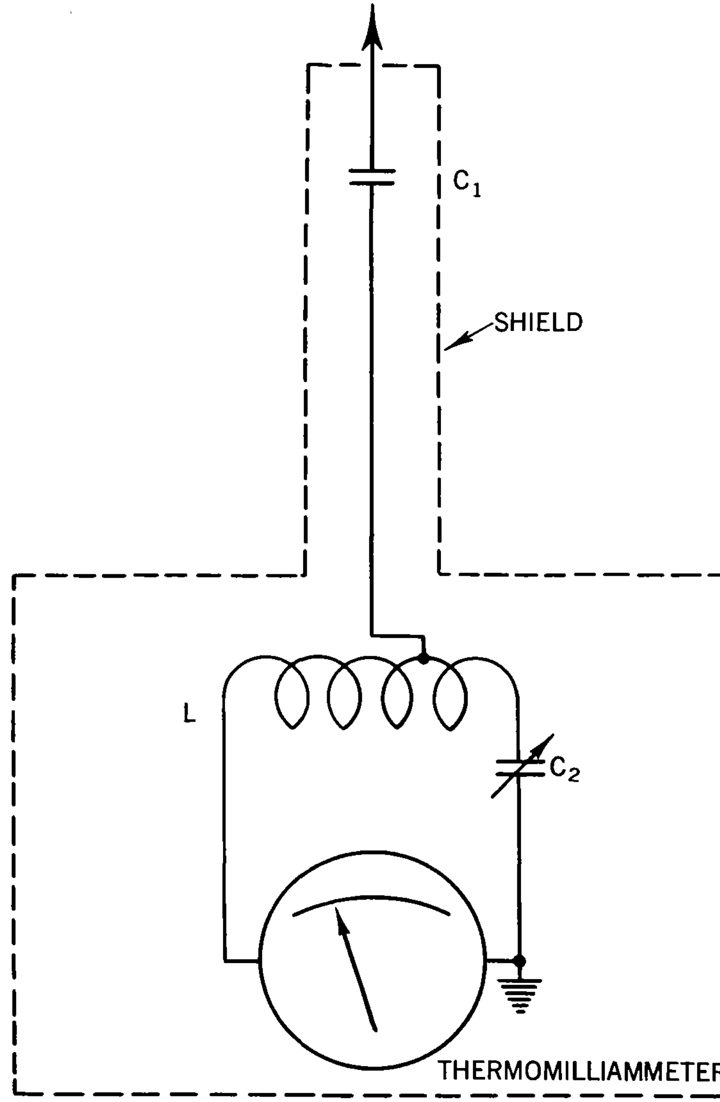

FIGURE 91. Probe Detector Diagram.

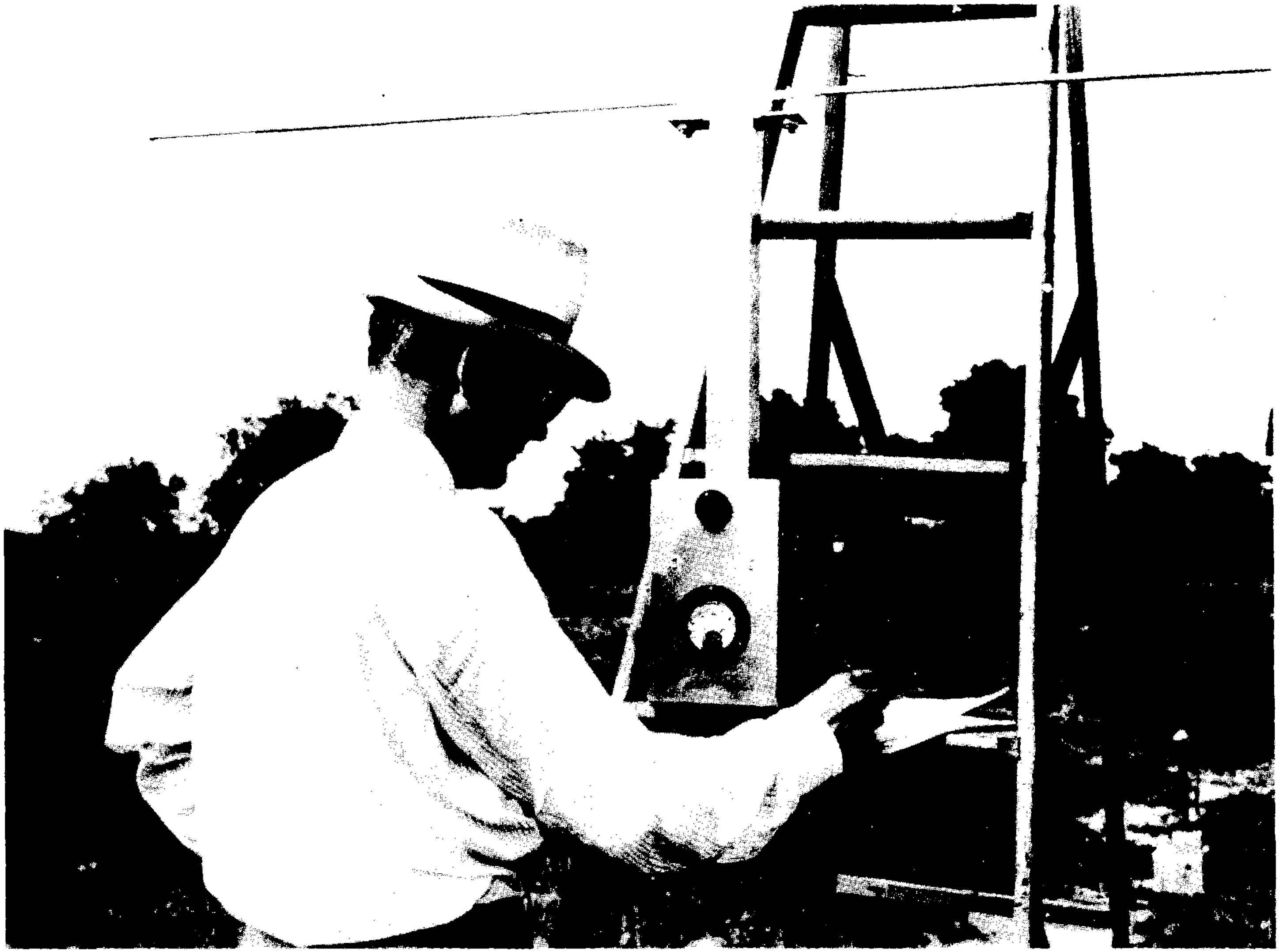

FIGURE 92. Ultra-High-Frequency Field Strength Meter In Service.

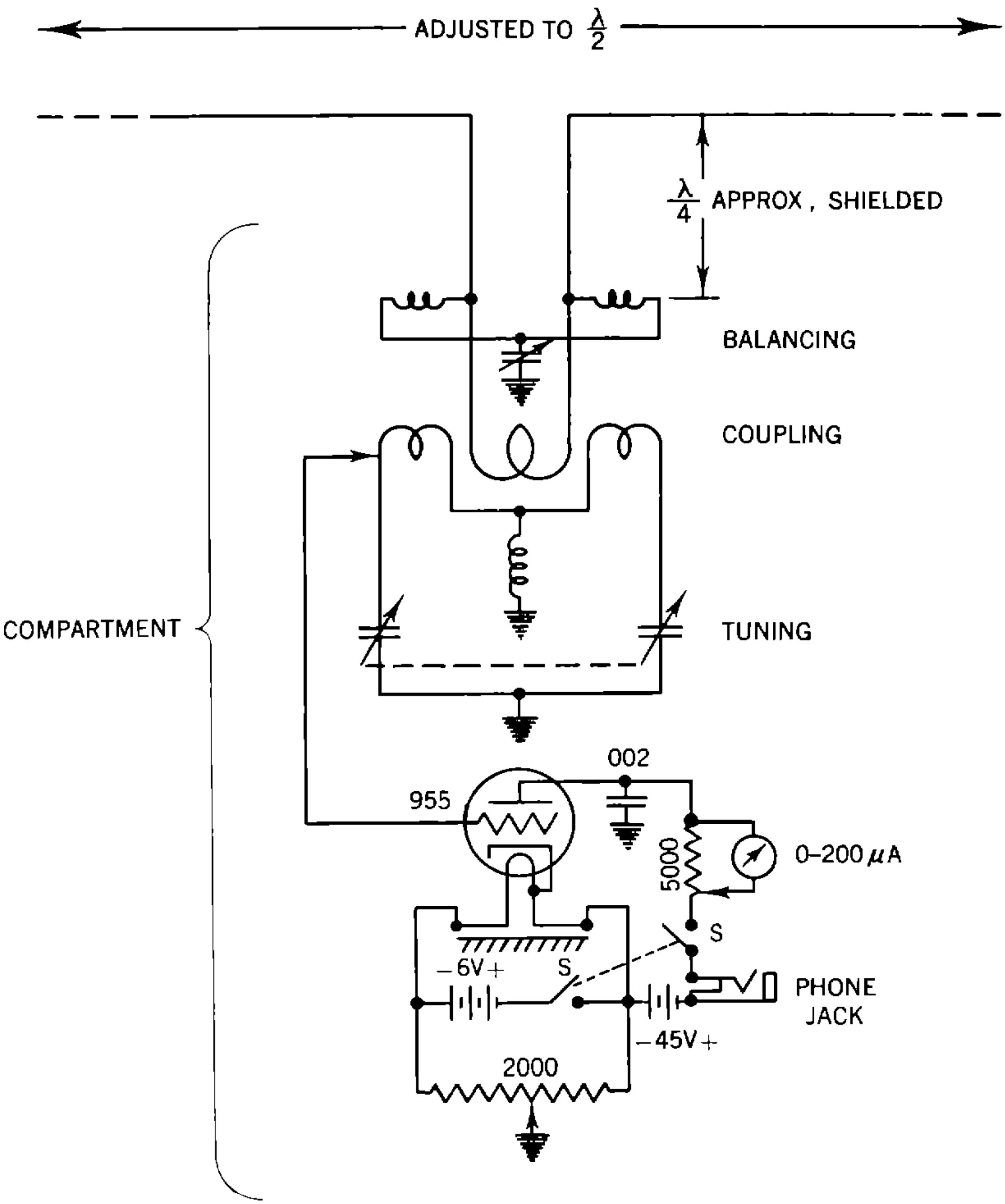

FIGURE 93. Portable Field Strength Meter Schematic Diagram.

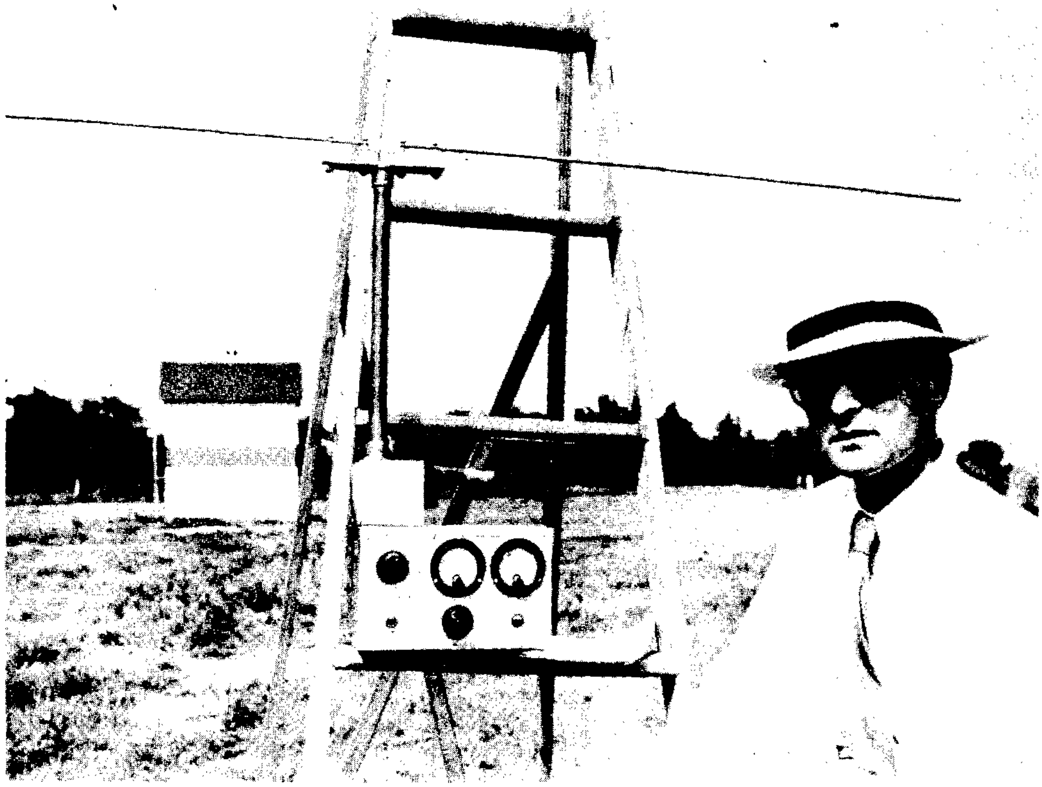

FIGURE 94. Portable Course Detector Used in Ground Checking Localizer Signals.

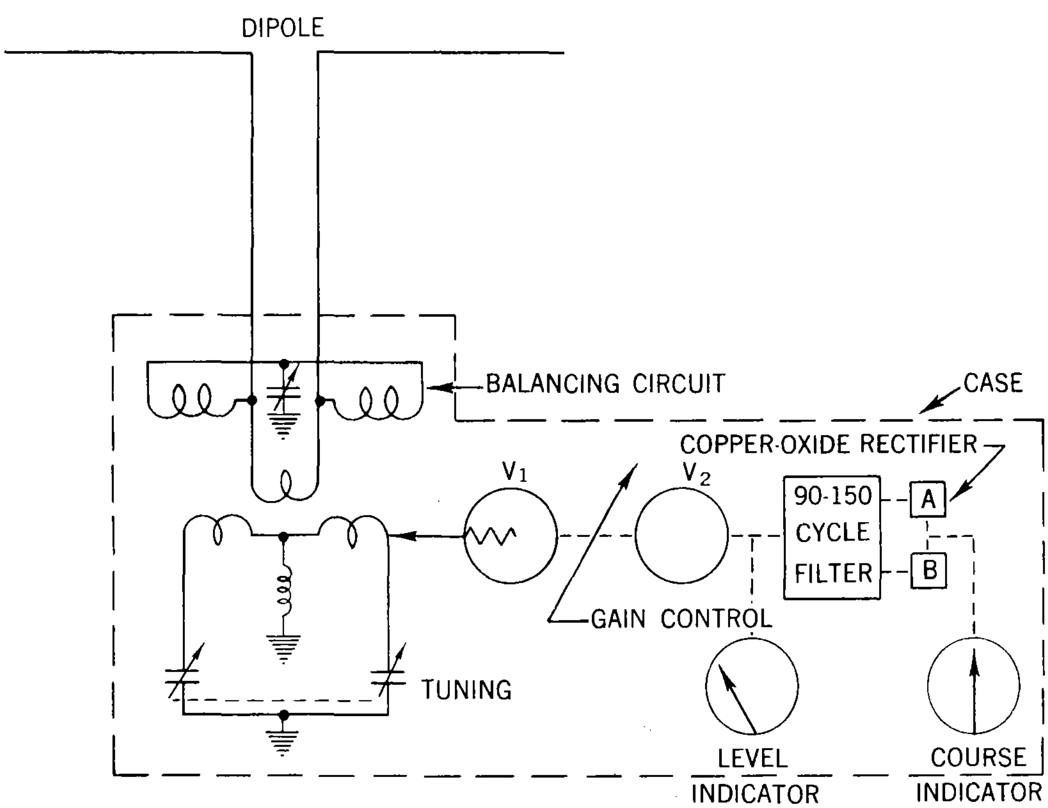

FIGURE 95. Portable Course Detector Schematic Diagram.

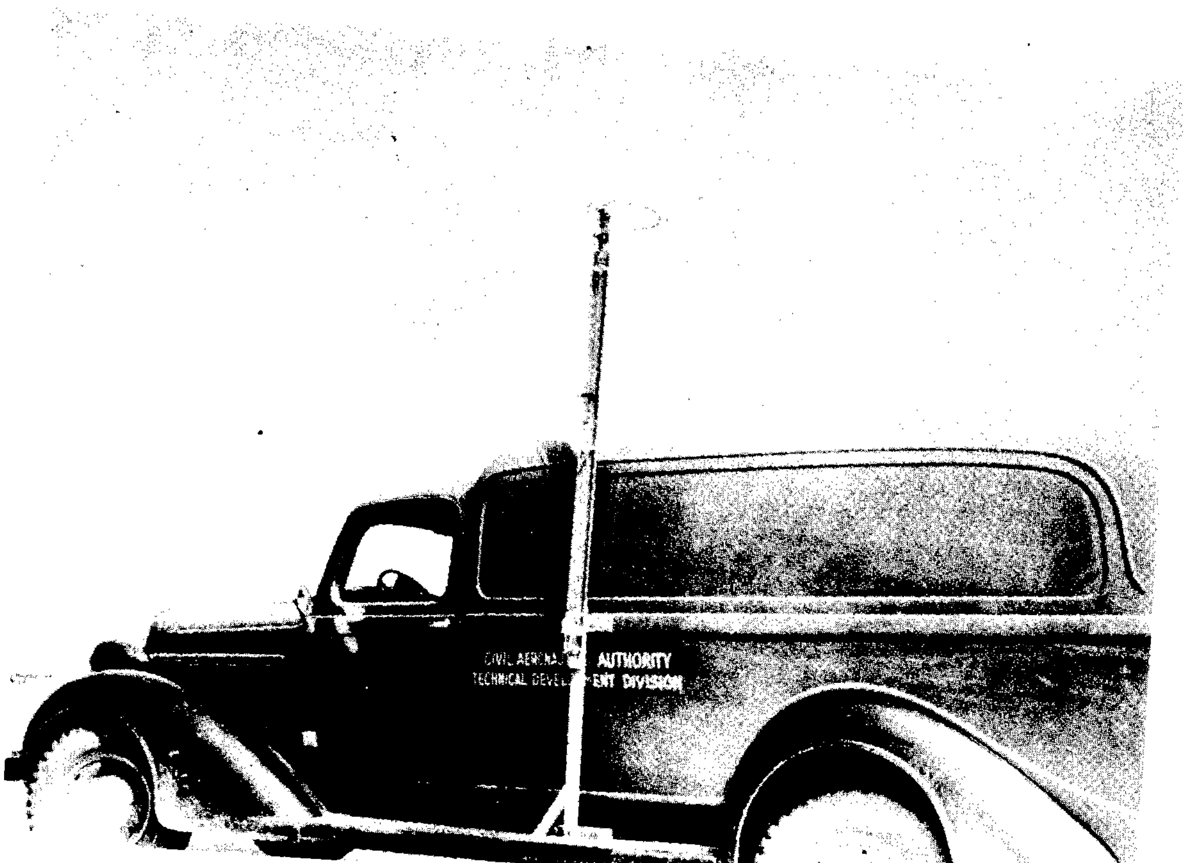

FIGURE 96. Loop Receiving Antenna Used for Ground Checking Localizer Signals.

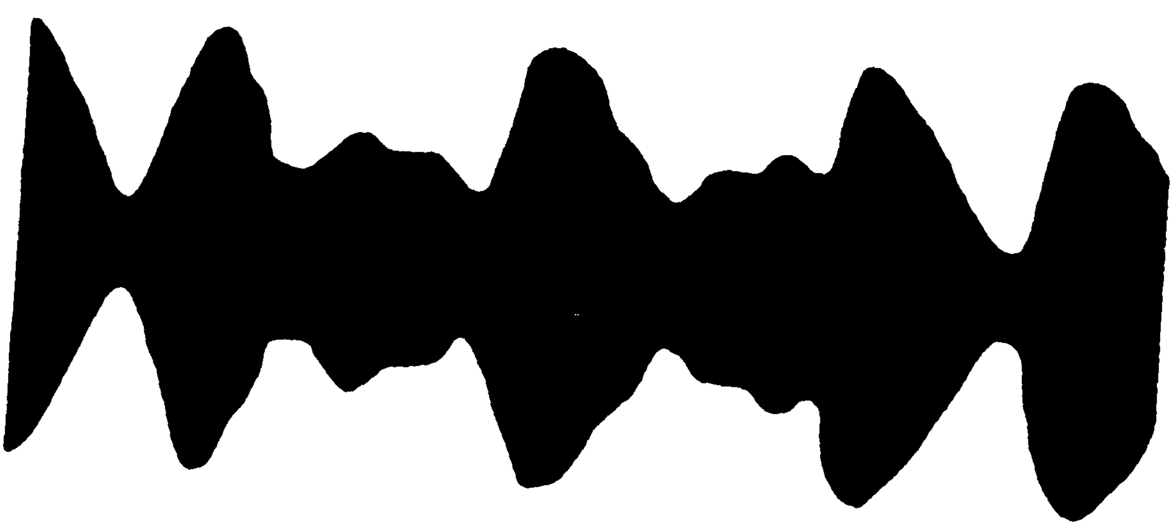

FIGURE 97. Sketch of Oscillograph Pattern for Localizer on-Course Signal.

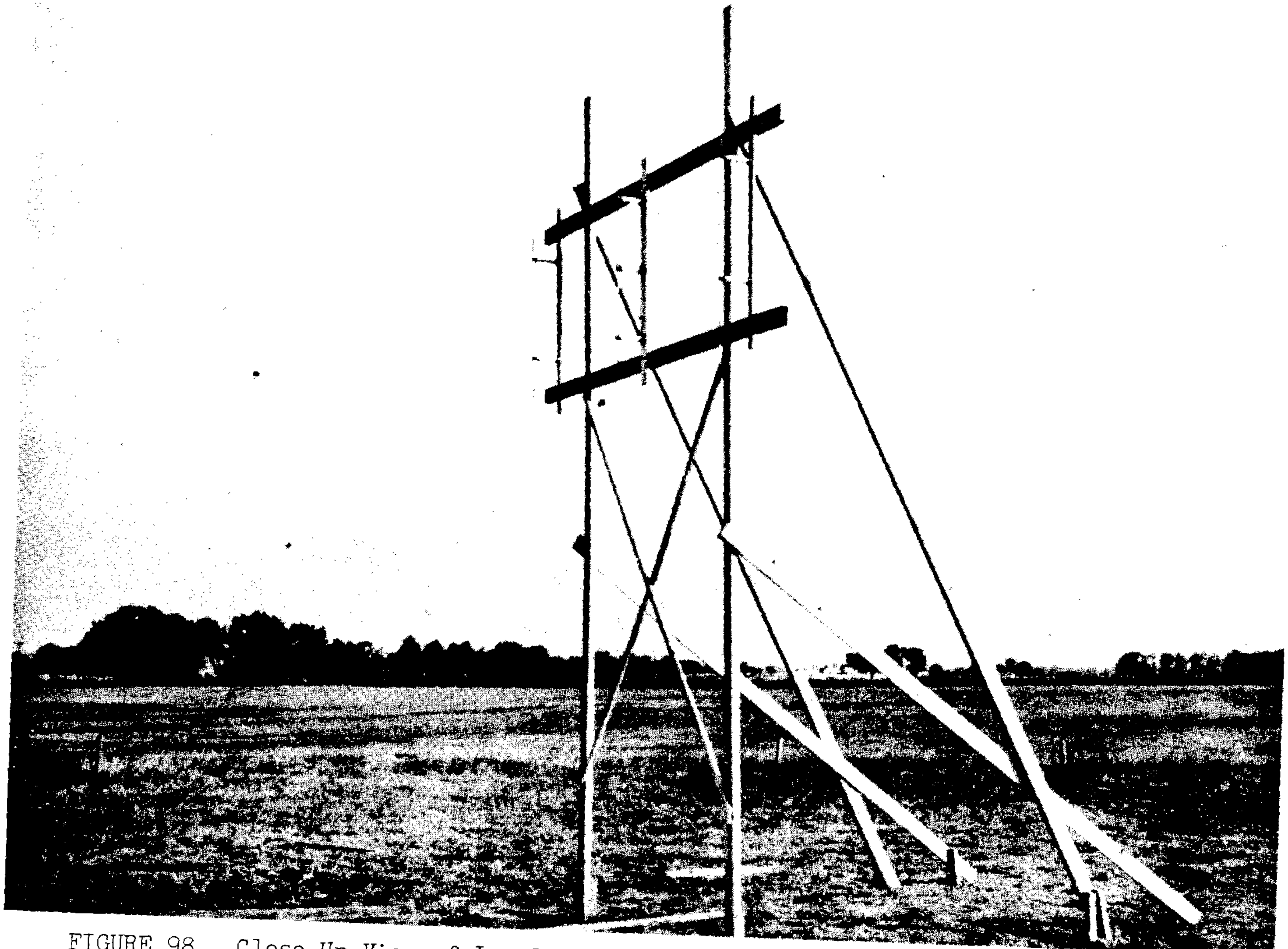

FIGURE 98. Close-Up View of Localizer Antenna Used in Vertical Polarization Test.

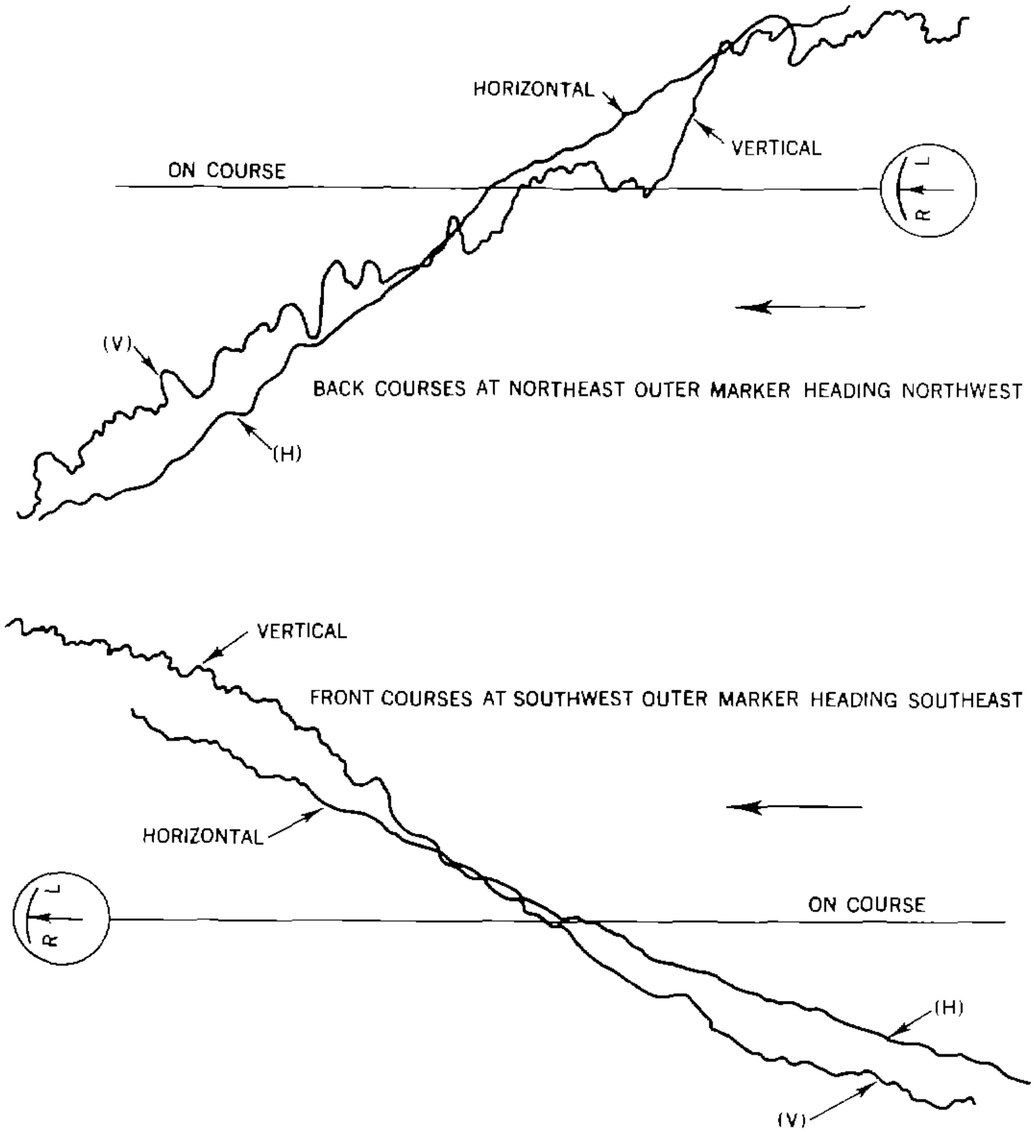

FIGURE 99. Vertical vs. Horizontal Polarization Graphic Records of Cross Course Flights.

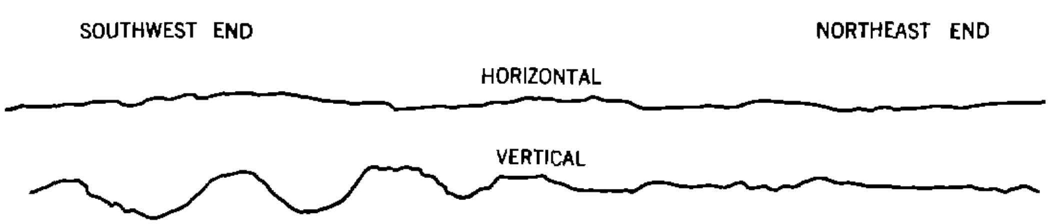

FIGURE 100. Vertical vs. Horizontal Polarization, Course Variations Along Runway.

APPENDIX 1

Theoretical Derivation of Localizer Patterns

The theoretical field patterns of the localizer in the horizontal plane are readily explained by reference to figure 26 Consider first the fields at any point P, distance from the station, due to radiators 2 and 3, figure 26B These fields are proportional to

$$F_2 = \sin (\omega t + 90 + s \sin \theta)$$

$$F_3 = \sin (\omega t - 90 - s \sin \theta)$$

in which

$$\sin (\omega t + 90) \text{ and } \sin (\omega t - 90)$$

are the phase advance and delay given the current in radiators 2 and 3, respectively, by virtue of their being excited 180° out of phase

s is the spacing between radiators 1, 2, and 3
θ is the angle measured from the course, the normal of the antenna array

The field at P due to both then is

$$\begin{aligned} F_2 + F_3 &= \sin (\omega t - 90 - s \sin \theta) + \sin (\omega t + 90 + s \sin \theta) \\ &= \sin \omega t \cos (90 + s \sin \theta) - \cos \omega t \sin (90 + s \sin \theta) \\ &\quad + \sin \omega t \cos (90 + s \sin \theta) + \cos \omega t \sin (90 + s \sin \theta) \\ &= 2 \sin \omega t \cos (90 + s \sin \theta) \\ &= -2 \sin (s \sin \theta), \text{ when } \sin \omega t \text{ is unity} \end{aligned}$$

Letting $\sin \omega t = 1$ the pattern due to 2 and 3 may be plotted from $2 \sin (s \sin \theta)$ as shown in figure 26C This is referred to as the "cloverleaf "

The field at point P due to the center radiator, 1, is a function of the direct radiation, $\sin \omega t$, of the center radiator and the parasitic reaction of radiators 2 and 3 The three vectors at P are

$$\text{Due to antenna } 1 = F_1 = \sin \omega t$$

$$\text{Due to antenna } 2 = F_2' = k \sin (\omega t + \phi + s \sin \theta)$$

$$\text{Due to antenna } 3 = F_3' = k \sin (\omega t + \phi - s \sin \theta)$$

k and ϕ have been experimentally determined as 0 55 and +113°, respectively, for the condition of resonance and a spacing of 165 degrees For the same spacing and with ϕ delayed to approximately 70° by readjustment of tuning on radiators 2 and 3, k has been observed as approximately 0 4 This adjustment gives maximum field strength on course The total field due to antenna 1 with 2 and 3 as parasitic antennas is

$$\begin{aligned} F_1 + F_2' + F_3' &= \sin \omega t + 2k \sin (\omega t + \phi) \cos (s \sin \theta) \\ &= \left[1 + 4k^2 \cos^2 (s \sin \theta) + 4k \cos (s \sin \theta) \cos \phi\right]^{\frac{1}{2}} \end{aligned}$$

This is referred to as the "dumb-bell" pattern because of its shape, as illustrated in figure 26D

Consider now the manner in which the dumb-bell and clover-leaf patterns combine. At any point P in the horizontal plane the 90-cycle side band radiated from antenna 1 is assumed to be in zero time phase and may be represented as vector 1 in figure 26E The 90-cycle side band energy present at P due to the clover-leaf pattern may be represented by vectors 2 and 3 in figure 26E, in which vector 2 is the 90-cycle minus 90-degree component from radiator 2 advanced $s \sin \theta$ and vector 3 is the plus 90-degree component from radiator 3 delayed $s \sin \theta$ The plus and minus 90-degree relation of the side bands in radiators 2 and 3 is achieved by the reversal ("F" in fig 26B) in the line to radiator 2 Obviously the resultant of the vectors 2 and 3 is in phase with 1 and therefore adds directly At point P' (fig 26F) on the opposite side of the course the advance and delay ($s \sin \theta$) of vectors 2 and 3 are reversed while the vector 1 remains unchanged The resultant of 2 and 3 therefore subtracts from 1 for all positions to the left of the course and adds for all positions to the right of the course, producing the right hand 90-cycle pattern (shown solid) in figure 26A This is commonly referred to as the "bean pattern" The 150-cycle side band component being opposite in phase to the 90-cycle component due to reversal "G" (fig 26B) in the "upper bridge" causes the opposite or 150-cycle "bean" pattern to be produced

Assuming that the side band power fed to the center antenna is twice the side band power fed to each side antenna, we obtain a current ratio 0 707 1 0 707

The equation representing the final "bean" patterns is the sum of the clover-leaf and dumb-bell patterns or

$$\begin{aligned} F_{(90-150)} = &\Big[\left\{1 \pm 1\ 41 \sin (S \sin \theta)\right\}^2 + \left\{2 k \cos (S \sin \theta)\right\}^2 \\ &+ 4k \cos (S \sin \theta) \left\{1 \pm 1\ 41 \sin (S \sin \theta)\right\} \cos \phi\Big]^{\frac{1}{2}} \end{aligned}$$

APPENDIX 2

Determination of Reflection Source

The determination of reflection sources involves first a study of the amplitude variation of the resultant received signal Generally, in this instrument landing system development, flights were made at about a 3-mile radius around each localizer station in which recordings of the signals were taken These recordings showed sinusoidal variations of the signal amplitude (see fig B) due to the addition and subtraction of the reflected wave to the main direct radiation The rate at which the addition and subtraction take place is a function of the position of the airplane around the station and the position of the reflection source with respect to the station For a given source of reflections, there are two positions 180° apart around the station where the rate of variation approaches zero, and two positions 90° displaced from these where the rate reaches maximum These are illustrated in figure B

Generally we are concerned only with the conditions on or near the localizer course It is therefore convenient and simple to consider the direction of the reflection source with respect to the outer marker, approximately 3 miles distant from the localizer station From the flight record made at this point, perpendicular to the course as illustrated in figure A, the distance X traveled by the airplane for a change of Δa in the path length of the reflected signal can be computed from the ground speed of the airplane The value Δa is determined from the record and may be taken as one-half wavelength, corresponding to one-half cycle of the recorded signal variation (Δa then equals 4 475 feet for 109 9 Mc) Referring then to figure A, the direction of the reflection source R from P is approximately

$$\theta = \sin^{-1} \frac{\Delta a}{x} = \sin^{-1} \frac{4\ 475}{x}$$

With this information it is possible to inspect the objects in the vicinity of the station along the calculated direction and arrive at conclusions as to which is causing the difficulty

It should be noted that the angle θ may be either plus or minus and still give the same value of x That is, the reflecting object may be R' Theoretically it could also be at R'' and R''', which are physically 180° opposite from R and R', but practically these objects are so distant from the station that the signal received and reflected by them is negligible The variation in direction of the reflecting object with values of "X" is given in figure C

The general location of reflecting objects with respect to the localizer station is summed up in the following flight observations

1 The spacing of multiple course or the rate of change (interference frequency) in received signal varies in proportion to the spacing "s" of the reflecting source from the localizer

2 Reflecting sources behind the station give rather widespread interference, while objects in the forward area produce interference in particular areas

3 The magnitude of the observed interference is proportional to the signal on the reflecting object and an inverse function of the course sharpness

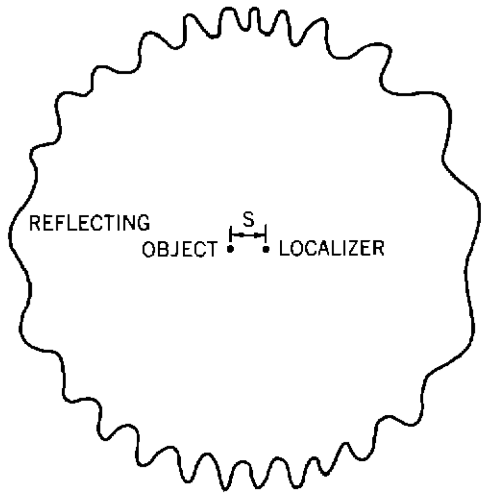

FIGURE B

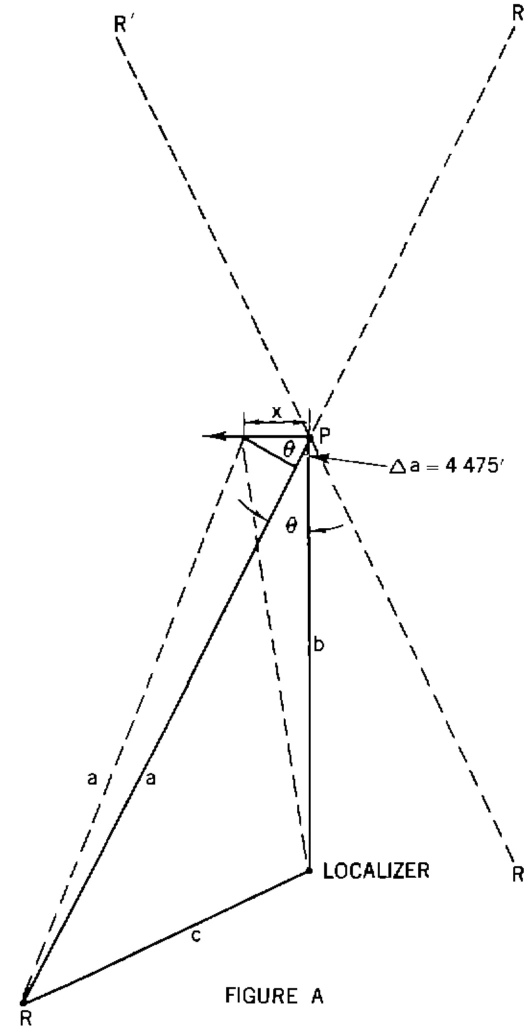

FIGURE A

FIGURES A and B   Determination of Reflection Source

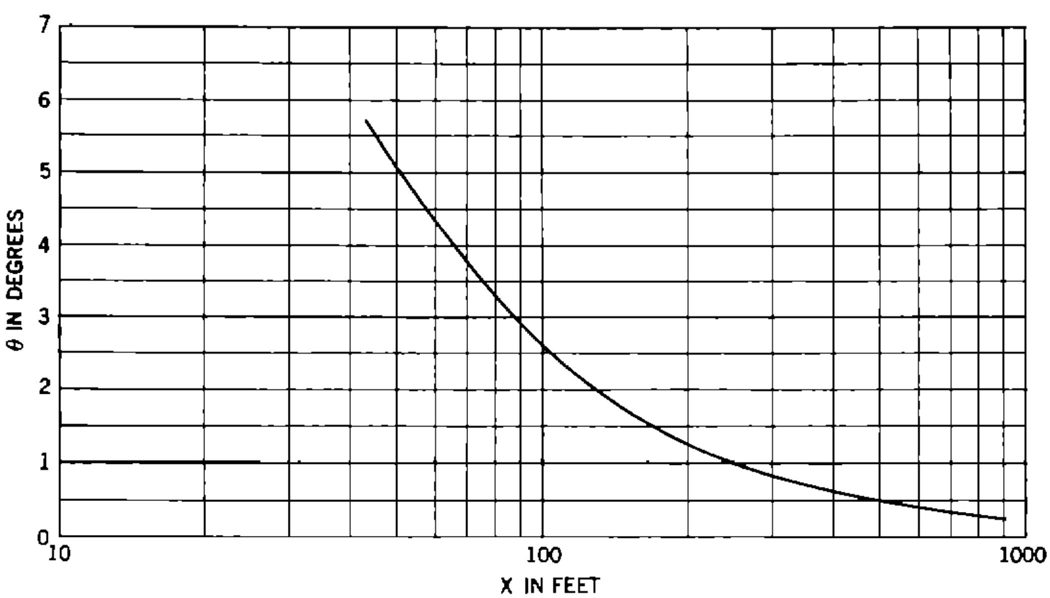

FIGURE C   Direction of Reflecting Object vs Distance.