DEVELOPMENT OF A STRAIGHT-LINE GLIDE PATH

By

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THE DEVELOPMENT OF A STRAIGHT-LINE GLIDE PATH

SUMMARY

A constant intensity type of glide path was developed and installed at the Administration's Experimental Station in Indianapolis in 1935 In this system the resulting path was curved and parabolic in shape However, pilots indicated a preference for a straight-line type of path where the rate of descent remained at an essentially constant value The original curved constant intensity path was modified to provide a more nearly straight-line path but some degree of curvature still remained

Early independent studies by Mr H Diamond of the National Bureau of Standards and Mr D M Stuart of the Civil Aeronautics Administration indicated that a straight-line equi-signal type of glide path would be superior inasmuch as variations in receiver sensitivity or transmitter power output would not change the angle of the glide path The path would be caused by the overlapping of patterns in a vertical plane with each lobe modulated with a different frequency. This system was tested in 1938 and later developed to the extent shown in this report

It is concluded that a satisfactory straight-line glide path has been developed The glide angle can be varied from 2 to 5 degrees The glide angle of the Indianapolis system provided a 2 72 degree path Full-scale deflection was obtained at 0 51 degrees above the path and 0 65 degrees below the path The use of the present system is limited to altitudes below 3000 to 4000 feet because of the lack of sufficient receiver sensitivity or transmitted power The "fly-up" alarm circuit in the receiver is a very satisfactory device to warn the pilot of a failure of the glide path during an approach The circuit does not interfere with the path operation in any way as long as there is sufficient signal to keep the receiver within the limits of automatic volume control The path is satisfactory down to an altitude of approximately 100 feet where it becomes very sharp, irregular and difficult to fly to contact

INTRODUCTION

The history and status of the development of early instrument landing systems involving glide path equipment for guidance in a vertical plane has been discussed in previous reports[1,2,3] These reports cover the development completed prior to 1940 and deal primarily with the constant intensity type of glide path. For these systems, the glide path is determined by a locus of points of equal radiated field intensity. The shape of the path is parabolic conforming approximately to the equation $h = kd^2$ where h is the height of the path, d is the horizontal distance and k is a constant involving receiver gain and transmitter power A complete system containing a parabolic constant intensity glide path was installed and demonstrated at the Administration's Experimental Station near Indianapolis, Indiana, in October, 1939

The experience gained during the tests and demonstrations of the parabolic constant intensity glide path indicated that pilots preferred to make a landing

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[1] W E. Jackson, "The Status of Instrument Landing Systems", Technical Development Report No 1, October, 1937

[2] H I Metz, "The CAA-RTCA Instrument Landing System, Part I, Development and Installation", Technical Development Report No 35, October, 1943

[3] H I Metz, "The CAA-RTCA Instrument Landing System, Part II, Tests and Modifications", Technical Development Report No 36, October, 1943

approach at a constant rate of descent along a straight line to the airport. This type of approach was not possible using the parabolic path. Consequently, the curved path was modified to provide a more nearly straight-line path. However, some degree of curvature still remained. The modified glide path equipment was demonstrated to the Radio Technical Commission for Aeronautics, the Air-Line Pilots Association, the Air Transport Association and other interested agencies early in 1940.

Late in 1939 the National Academy of Sciences was requested by the President of the United States to review the instrument landing program and make recommendations for the standardization of such systems[4]. It was the general opinion of the committee that the system containing the modified constant intensity path was suitable for immediate installation at chosen points throughout the country. It was also agreed that the preliminary research resulting in a straight-line equi-signal type of path operating in the microwave region offered additional advantages over the partially curved glide path system. It was recommended that the equi-signal type of equipment be further developed.

On September 2, 1936, Mr. H. Diamond of the National Bureau of Standards prepared a report on a system that would produce an equi-signal type of glide path[5]. The proposed antenna system consisted of two antennas arranged at different elevations so that overlapping vertical patterns having different modulation frequencies were obtained. The glide path was produced by the intersection of these two overlapping patterns where equal intensity of modulation frequencies existed. Mr. Diamond suggested the use of 300 megacycles because this frequency would permit the use of a relatively low antenna system on the ground.

Early in 1938 Mr. Stuart of the Administration's Radio Development Section designed an equi-signal (straight line) type of glide path system operating at 109.9 megacycles which was installed at the Indianapolis Experimental Station. The two antennas were horizontal dipole radiators elevated at different heights - the uppermost being about twenty-seven feet above ground. Each antenna was modulated with a different audio frequency. A mechanical modulator was used to provide 90- and 150-cycle modulation. A straight-line path of approximately 4 degrees was obtained. Flight tests were conducted in July, 1938. A photograph of the antenna system for this glide path is shown in Figure 1.

In the Spring of 1940, the Administration conducted final flight tests at Boston, Massachusetts, on a 750-megacycle instrument approach system. This system was produced as a result of a development contract with the Massachusetts Institute of Technology. The system provided an equi-signal type of glide path formed by the overlapping patterns of two horn radiators. The tests revealed that a glide path of less than 4 degrees could not be produced with horn radiators of a reasonable size at the frequency used and that the technique of generation and measurement of micro waves was not known well enough to justify further development at that time.

As a result of the experience gained in the development of previous equi-signal types of glide path systems, the Civil Aeronautics Administration adopted a program to further develop an equi-signal glide path operating in the 300-megacycle band. This band was chosen because the measuring technique was known, the elevation of the antenna system would be low and reasonable crystal-controlled power output would be obtained with conventional tubes. This glide path would operate in conjunction with a 110-megacycle localizer and 75-megacycle markers to provide a complete instrument approach system. A contract for this development was awarded to the Federal Telephone and Radio Corporation on June 30, 1941. The project was undertaken immediately.

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[4] Civil Aeronautics Journal, Volume 1, No. 3, February, 1940.

[5] H. Diamond, "An Ultra-High-Frequency Equi-signal Beacon for Producing an Inclined Path in a Vertical Plane", Appendix I

Several months later, because of urgent military demands, the War Department decided to accelerate this development and make the glide path portable so that it could fulfill their requirements. The War Department participated in this development and tests were conducted jointly with the Administration at the Experimental Station as well as at the Pittsburgh and Cincinnati airports. A large quantity of portable straight-line glide path units were produced and some of these portable units are now being modified and installed by the Civil Aeronautics Administration as a fixed type glide path at civil and military airports It is one of these portable units that was modified for a fixed installation at Indianapolis that is described in this report

GROUND EQUIPMENT

The straight-line glide path system radiates two field patterns, one of which is modulated at an audio frequency of 90 cycles per second and the other at an audio frequency of 150 cycles per second. The equi-signal intersection of these patterns results in the straight-line glide path. These signals are received in aircraft and actuate the horizontal needle of a crossed-pointer instrument which instructs the pilot to "fly up" or "fly down" to keep the airplane on the path The vertical angle which the path makes with the ground can be adjusted from 2 to 5 degrees. A localizer equipment is used in conjunction with the glide path to provide lateral guidance The outer, middle and inner markers, provided for the complete instrument landing system, indicate distance from the point of contact. Figure 2 is a general view of the complete system.

Transmitter

The equipment used in these tests operated on a frequency of 335 megacycles. The transmitter equipment consisted of an exciter unit and a power amplifier unit. The exciter unit was crystal-controlled using a crystal having a frequency of 6203 kilocycles Following the crystal was an oscillator-tripler using a type 6SJ7 tube, a doubler using another 6SJ7 tube, a tripler using a type 832 tube and an amplifier using a type 829 tube. The exciter provided an output of 20 watts of 111 66-megacycle energy to the power amplifier unit Figure 3 is a photograph of the exciter unit.

The power amplifier consisted of a push-pull tripler stage followed by push-pull inverted amplifier circuit Each stage employed two type 8025 tubes. The power output was 25 watts at 335 megacycles Figure 4 is a photograph of the power-amplifier unit

Modulator and Bridge

It is the function of the modulator and bridge to divide the energy supplied by the transmitter into proper channels and modulate each with its respective audio frequency The bridge is used for the division of energy and for the prevention of cross-modulation, while the coupled sections in the modulator are used for modulating the energy. The general theory of operation of the mechanical modulator and bridge arrangement has been described in a previous Report[1] A schematic diagram of the circuits used in the glide path equipment is shown in Figure 5. Figure 6 is a photograph of the mechanical modulator and Figure 7 shows the bridge assembly.

Monitor Unit

Because of the nature of the glide path equipment, it is essential that complete reliability be maintained. Therefore, if any component of the equipment fails and causes the path to become shifted, or, if the amount of energy being radiated falls to an excessively low level, the transmitter must be turned off It is the function of the monitor unit to detect any undesirable change in radiation and,

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[1] Radio Development Section, "A Visual-Aural Ultra-High-Frequency Radio Range With Simultaneous Voice", Technical Development Report No 49, April, 1945.

having detected such a change, to turn the transmitter off and sound an alarm. When the glide path equipment is operating normally, a green light is energized. However, when the radiated field strength varies more than 50 percent or the glide path angle varies more than 10 percent, an alarm sounds and a red light is energized. A monitor meter on the unit provides a quantitative indication of the glide path signal strength and deviations of the glide path angle. Figure 8 is a photograph of the monitor unit.

Figure 9 is a general view of the complete transmitter equipment including power supply and control unit.

Radiating System

Figure 10 is a photograph of the building and antenna installation at Indianapolis. The lower antenna is a half-loop with a screen reflector. This antenna produces a uniform signal over broad regions to each side of the perpendicular to the screen reflector. The ends of an abruptly terminated screen tend to radiate considerably. However, the dimensions of the screen used for the glide path equipment have been selected and the ends tapered so that the tendency for radiation is appreciably reduced. While the physical length of each radiating element is 90 degrees, the electrical length is approximately 180 degrees with the current maximum located approximately at the center. The radiation resistance of the radiating elements is 350 ohms which is transformed to 125 ohms by means of a quarter-wavelength transformer inside the antenna tube. The monitor pick-up is a loop of copper strap. One end is grounded to the antenna frame while the other end feeds the coaxial line to the monitor equipment. The input impedance of the monitor pick-up is 50 ohms. The amount of signal picked up by the monitor loop is varied by rotating the plane of the loop. Figure 11 shows a close-up view of the lower antenna and screen.

The upper antenna is an array of two end-fed "V-type" antennas with dipole reflectors. The V antennas are fed in phase and are spaced 180 degrees vertically. The dipole reflectors provide a front-to-back ratio of about 5 to 1 and a sharper forward radiation pattern.

The lower reflector is also used as a pick-up antenna for the monitor system. An end-feed arrangement is used to extract energy from each end of the reflector. Figure 12 shows the upper antenna assembly for the glide path system.

The glide path antenna system makes use of the fact that the number of lobes in a vertical plane increase as the height of the antenna is increased. The top antenna being a number of wavelengths above ground produces a vertical field pattern having approximately 15 lobes for a 2.5-degree path. The lower antenna is placed much closer to the ground resulting in only three lobes. Thus, one antenna may be placed several wavelengths above a second antenna to produce overlapping vertical patterns as shown in Figure 13. The vertical angle shown in Figure 13 is greatly exaggerated to more clearly indicate the lobe intersection for the glide path. Consequently, not all of the high angle vertical lobes are shown. The intersection of these patterns which are each modulated with different frequencies produces the glide path. The vertical pattern of the antenna elements is expressed by $m = \sin (360\ h \sin b)$ where m is the magnitude corresponding to an angle b above ground and h is the height of the antenna in wavelengths above ground.

If the maximum magnitude of the lobes from the upper and lower antenna is equal, or, if the magnitude of the lobes from the upper antenna is greater than that of the lower, then multiple paths or low clearance exists. The lower antenna, therefore, receives twice the voltage over that supplied to the upper antenna. This insures against multiple path and low clearance. Actually, the clearance of the equipment tested was such that the needle of the instrument never indicated less than 4 dots in either direction (eighty percent of full-scale deflection) except in the vicinity of the glide path.

In operation, both the upper and lower antennas are energized by the 335-megacycle signal from the modulator The carrier fed to the upper antenna is modulated by the 150-cycle channel of the modulator while the lower antenna receives 90-cycle modulation. The airplane receiver detects the composite signal, measures the difference between the amplitudes of the two audio signals and indicates the result on the horizontal needle of the crossed-pointer instrument. When the 90-cycle signal exceeds the 150-cycle signal, the horizontal needle points down instructing the pilot to "fly down". An excess of 150-cycle results in a "fly up" indication. When the two signals are equal, the pointer is horizontal and indicates that the aircraft is at the center of the glide path.

The vertical field patterns of both the upper and lower antennas for a 2.5-degree path are shown in Figure 15. Up to this point all calculations have been based on single dipoles having no vertical directivity of their own Actually, the glide path antennas are designed to have low angle directivity to avoid wasteful radiation at high angles The radiation is uniform up to an angle of 8 degrees, falls off 10 percent at an angle of about 23 degrees and drops off rapidly at angles exceeding 23 degrees However, the equation $m = \sin (360° h \sin b)$, which is based on ground reflection only without allowance for the directivity of the individual antennas, may be applied to the glide path radiating system for angles below 20 degrees without the introduction of additional factors

Figures 13 and 15 show a false path at a vertical angle of approximately 16.5 degrees. An airplane below this path would receive a "fly down" indication which would direct the pilot toward the true path A plane above the "false path" would receive a "fly up" indication resulting in a climbing attitude thereby indicating to the pilot that the course is false In any case, the reverse indications combined with extreme steepness and sharpness of the path makes it impossible to fly this path at a normal rate of descent (400 to 500 feet per minute).

The most practical method of changing the glide path angle is by changing the elevation above ground of both antennas. This change will alter the configuration of the lobes and the intersection will occur at a different elevation. The glide path equipment is designed to operate at any of eleven path angles which are obtained by setting the antennas at suitable heights on the supporting mast. Calibration points are marked on the mast for glide path angles of 2, 2 25, 2.5, 2 75, 3.0, 3.25, 3.5, 3.75, 4.0, 4 5 and 5 0 degrees. A glide path angle of 2 5 degrees has been determined to provide the most satisfactory operation for fixed installations.

In the previous discussion, it has been assumed that the straight-line path terminated at the base of the antenna mast Actually the glide path transmitting equipment must be located at a safe distance to one side of the runway This distance has been determined to be approximately 400 feet. Therefore, another vertical section of the radiation solid must be used This requirement causes a slight modification of the horizontal radiation patterns The upper antenna is designed to have horizontal directivity, radiating its full power forward and only a part of its full power to the sides. The horizontal patterns of both the upper and lower antennas are shown in Figure 14. The upper antenna is rotated 12 degrees away from the horizontal antenna; the result is that the ratio of the upper and lower antenna fields is substantially constant for all azimuth angles along the glide path. Both antennas are designed to radiate negligible energy to the rear, thus increasing the efficiency of the antenna system The large ratio of front-to-back energy greatly reduces the effect of reflections from objects to the rear of the antennas which would cause irregularities in the glide path. At Indianapolis the glide path was located 400 feet from a point on the runway which was 1100 feet from the approach end. A general view of the installation is also shown in Figure 14

Test Equipment

A path detector, field intensity meter and single probe voltmeter are provided with the glide path equipment. The path detector is designed to obtain measurements of the glide path near the ground. It can also be used to measure the sharpness and clearance of the path. The circuit within the detector unit rectifies the carrier and compares the relative ratio between the 90-cycle and 150-cycle energy.

The field intensity meter is a portable self-contained instrument for measuring relative field intensity This instrument is used to measure radiation patterns of the individual antennas and to measure the phase difference between the antennas when they are operated together.

The single probe voltmeter is used for various radio-frequency measurements.

AIRCRAFT EQUIPMENT

Receiver

The receiver used in the tests was designed to operate at 332.6, 333 8 and 335.0 megacycles. The receiver is a crystal-controlled super-heterodyne which operates from a 24 to 28-volt battery power source and obtains its plate supply directly from the battery. Figure 16 is a block diagram of the receiver. A "fly up" alarm circuit is included as an integral part of the receiver and is designed so that the horizontal needle of the indicator will always remain in a full "fly up" position when the signal becomes less than 50 microvolts. This feature prevents the pilot from believing he is on the path if the ground equipment fails during the approach Some of the direct current is taken from the 24-volt supply and fed to the zero-center glide path indicator to cause it to deflect to the top of the scale. The alarm current is controlled by a sharp cut-off amplifier which obtains its control voltage from the automatic volume control circuit. A schematic diagram of the "fly up" alarm circuit is also shown in Figure 16 A general view of the receiver is shown in Figure 17 A group of automatic volume control characteristics of several receivers is shown in Figure 18

Antenna and Indicator

The receiving antenna consisted of a half-wave dipole which was mounted on the same pedestal that supported the localizer "U" antenna This combined localizer and glide path receiving antenna assembly is shown in Figure 19. The indicating instrument was a standard crossed-pointer meter as shown in Figure 20.

TESTS

The final tests recorded in this report were made in Administration Airplane NC-11, a Boeing type 247-D, during the period March 7 to 18, 1945, although numerous preliminary tests were conducted throughout a period of nearly two years.

Before taking final recordings, tests were made in an attempt to determine the overall operation of the glide path equipment. The antenna system was adjusted to provide a 2.5-degree path. These tests indicated that there was insufficient "fly up" indication during approaches to the path at an altitude of 1500 feet The "fly up" indication under these conditions did not exceed 2 dots (40 percent of full scale). This indication was believed to be insufficient. An investigation of this fault revealed that the lack of "fly up" indication was due to both a lack of sufficient radio frequency energy radiated from the ground antenna system and a lack of receiver sensitivity. The power output from the transmitter was found to be below normal and, upon rectification of this condition, a "fly up" indication of 4 dots (80 percent of full scale) at 1500 feet was obtained. However, a 4-dot "fly up" indication was not obtained at altitudes above 1500 feet because of receiver insensitivity, although it was actually the most sensitive of a group tested. Previous models of glide path receivers which tuned to only one radio frequency had much higher sensitivities and consequently, could be used to much higher altitudes.

The first group of final tests was made at constant altitudes of 500, 1000, 2000, 3000, 4000 and 8000 feet. These tests were made to determine the course width, the path angles, the amount of clearance provided and the general composition of the radiated field. The receiver was arranged so that the "fly up" alarm circuit could be used, de-energized or keyed on and off. The purpose of this arrangement was to determine what effect the alarm circuit had on the glide path. The results of these tests are shown in Figures 21, 22 and 23. The flight altitudes for the tests shown on these figures were 500, 1000, 2000, 3000 and 4000 feet above the transmitter. Figure 21 shows the results obtained without the alarm circuit, Figure 22 is similar except that the alarm circuit was operating; and, Figure 23 shows the alarm circuit being keyed on and off. The check points used were the towns of Hall, Monrovia, Mooresville, 5.42-mile point, outer marker and middle marker. The middle marker was located 1.13 miles from the point of contact. The worst clearance obtained was at 3000 and 4000 feet where the needle returned to approximately 3 dots. The lack of sufficient radiated power or the absence of receiver sensitivity is apparent on the figures, where the on-course receiver filter input voltage decreases appreciably with altitudes above 1000 feet. The voltages obtained are shown in the following table.

TABLE I

Altitude Above the Station	Receiver Filter Voltage
500 feet	12.5 volts
1000	11.5 to 12.0
2000	8.5 to 9.0
3000	4.0 to 6.5
4000	approx 4.0

The fact that the filter voltage decreases with increasing altitude indicates that the receiver is operating below the knee of the automatic volume control characteristics at the higher altitudes.

Since the check points were accurately noted on the records, the ground speed and miles per inch of chart can be computed. The chart speed for all recordings was 6 inches per minute. From this data and the five-dot deflection points of the instrument as well as the actual altitude at the on-course point, the glide path course width can be computed. The actual altitude at the cross-over is shown on each recording. Table II shows the course widths (full-scale up to full-scale down deflection) computed for each flight. Course widths were not computed on the recordings obtained at altitudes above 1000 feet because 5-dot "fly up" indications were not obtained and the course was broadened at those altitudes because of the decrease in filter voltage.

TABLE II

Altitude	Course Width Below Path Center (5-dot "fly up")	Course Width Above Path Center (5-dot "fly down")
1000 feet	0.70 degrees	0.46 degrees
	0.70	0.60
	0.68	0.53
500 feet	0.65	0.55
	0.60	0.50
	0.56	0.41
Average	0.65 degrees	0.51 degrees

The same data that is used to compute the course width can also be used to compute the actual path angle Table III shows the path angles computed for each recording.

TABLE III

Altitude	Alarm Circuit	Path Angle
4000 feet	Disconnected	2.80 degrees
	Keyed on and off	2.80*
3000 feet	Disconnected	2.73
	Connected	2.80
	Keyed on and off	2 83
2000 feet	Disconnected	2.70
	Connected	2 70
	Keyed on and off	2.76
1000 feet	Disconnected	2.70
	Connected	2.70
	Keyed on and off	2.63
500 feet	Disconnected	3.00
	Connected	2.60
	Keyed on and off	2.37
*Off connection used for computation		
Average		2.72 degrees

The recordings in Figures 21, 22 and 23 indicate that the alarm circuit causes the glide path to be pushed ahead of the true path at altitudes above 3000 feet. Above 3000 feet the alarm circuit has not become completely de-energized and the actual path center is displaced. Figure 23 shows this effect very well where the alarm circuit is keyed At an altitude of 4000 feet a difference of 0.3 degrees is noted between the alarm on and alarm off condition. The path angle is 2 8 degrees without the alarm circuit and 3.2 degrees with the circuit operating.

Approximately ten instrument approaches were made down the glide path from an altitude of 1500 feet. One approach was made from an altitude of 4000 feet. These descents were made along the center of the localizer course In addition, 3 approaches were made down each side of the localizer course with the localizer indicator maintained at a 4-dot deflection, i e , approximately 2 degrees off the center of the localizer course. A summary of these tests is shown in Figure 24. The two charts at the top of the figure show the descent along the center of the localizer course from 4000 feet. This is the maximum altitude from which a descent could be made since a 1-dot "fly up" deflection was barely obtained approaching under the path. The next three charts show one descent each along the center of the course, along a line off the localizer course with the indicator 4 dots to the right and along a line off the localizer course with the indicator 4 dots to the left. These recordings are representative of several obtained. All of these tests were made with the "fly up" warning circuit rendered inoperative. The recordings indicate that the glide path is completely satisfactory and easy to follow down to approximately 0 8 miles from the point of contact (approximately 200 feet of altitude). Beyond this point at an altitude of 100 feet and approximately 0 5 miles from the point of contact, the glide path levels off slightly with some irregularities and then dives into the ground. It is considered that the path is satisfactory down to 100 feet but difficult to fly below this altitude. In all cases it was noted that the filter voltage did not stabilize until a point approximately over the outer marker was reached. This represents a distance of approximately 4.45 miles. When the glide path was used along a line slightly to the left of the localizer course, the results were practically the same as those obtained along the center of the course However, when the glide path was used along a line slightly to the right of the localizer course, the path was very satisfactory down an altitude of 75 feet. Beyond this point the path dived steeply.

The difficulties encountered with the glide path below altitudes of 200 feet may be caused by the new hangar which has been recently constructed a short distance from the glide path. The path was fairly satisfactory to contact prior to the construction of the building. In any case, rotating the complete antenna system plus or minus 10 degrees from the normal setting did not improve the path when flown along the center of the localizer course. The elimination of a huge pile of dirt 10 feet in front of the base of the antenna mast did not improve the path noticeably.

The two short charts at the bottom of Figure 24 show the results of taxi tests along the runway. These tests were also made with the "fly up" alarm circuit disconnected.

The first three charts at the top of Figure 25 show a level flight test made at an altitude of 8000 feet above the station. No "fly up" signal was ever obtained at this altitude. The indicator remained at zero center until the course position was reached in the vicinity of Gosport, Indiana, and then started to indicate "fly down".

Another group of tests shown on Figure 25 indicates the directivity of the airplane receiving antenna. These tests were made by circling on the localizer course above the glide path at a distance of 6 miles from contact and at an altitude of 2000 feet. The airplane was flown in approximately a 20-degree bank and in a relatively small circle. The circles were made in both a clockwise and counter-clockwise direction with the "fly up" alarm circuit connected and disconnected. The results of this test indicate that the antenna which is mounted on the nose of the plane just ahead of the cockpit gives satisfactory performance within approximately plus or minus 30 degrees of the heading of the airplane. Beyond these points the pick-up drops off rapidly. The reception to the rear was so poor as to make it impossible to fly the glide path away from the station. This effect is shown on the recording at the bottom of Figure 25 where a level flight was made away from the station in the direction of maximum signal from the ground equipment. Figure 26 is a chart showing the general performance of the glide path including the path angle and width.

CONCLUSIONS

As a result of the tests conducted on the fixed glide path installation at the Indianapolis Experimental Station, the following conclusions may be reached

1. The path angle is 2 72 degrees when the antenna elements were adjusted for 2.5 degrees. This path angle is considered satisfactory.

2. The glide path course width is plus 0.51 degrees and minus 0.65 degrees for a 5-dot (full scale) instrument deflection on either side of the center of the path

3. The clearance is sufficient to provide indications of at least 80 percent of full scale and is considered very satisfactory.

4. The receiving antenna directivity is satisfactory since instrument approaches can be made with crab angles up to 30 degrees.

5. The glide path cannot be used above an altitude of 3000 feet with the alarm circuit connected and 4000 feet with the alarm circuit disconnected.

6. The path is satisfactory down to an altitude of 100 feet

7. The glide path can be made usable at much higher altitudes by the use of more sensitive receivers. Future receivers will have more sensitivity.

8. The glide path can be improved below an altitude of 200 feet by the addition of corrective measures to eliminate reflections from an extremely large hangar adjacent to the glide path site Previous tests prior to the construction of the building indicated that the path was fairly satisfactory down to contact with the runway.

9. An overall conclusion may be reached that the present equipment provides a satisfactory straight-line glide path below 3000 feet. The glide path may be further improved through the use of more sensitive receivers and the elimination of reflections from adjacent objects.

10. The "fly up" alarm circuit in the receiver is a satisfactory warning device to the pilot that the glide path equipment is not operating satisfactorily. When more sensitive receivers are made, the fly up alarm should operate at a much lower point than the present 50 microvolts. Another alternative to the receiver problem is to appreciably increase the transmitter power Although this method is not very practical due to the limitations of producing radio frequency power at this frequency.

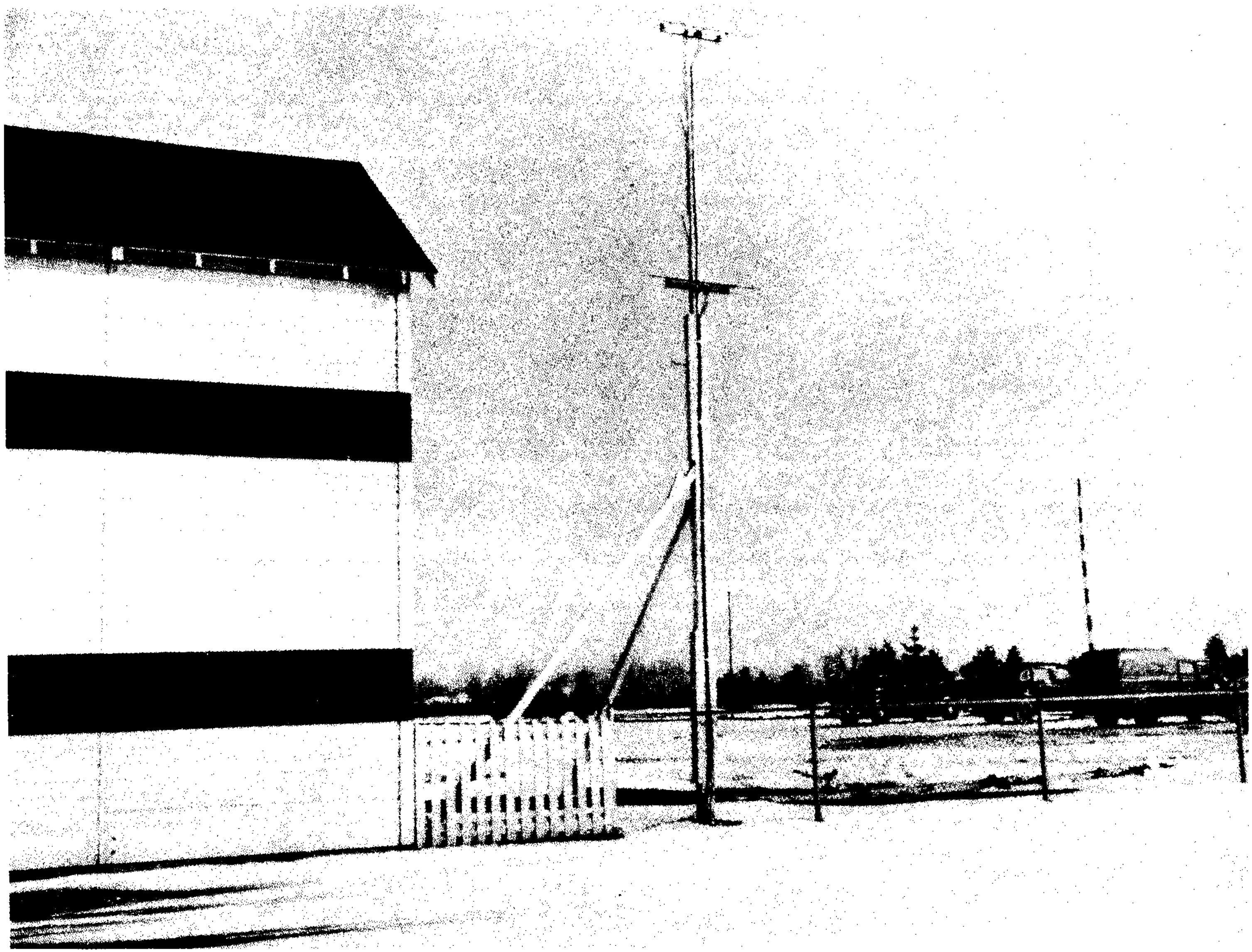

Figure. 1. Early 110-Megacycle Straight-Line Glide Path.

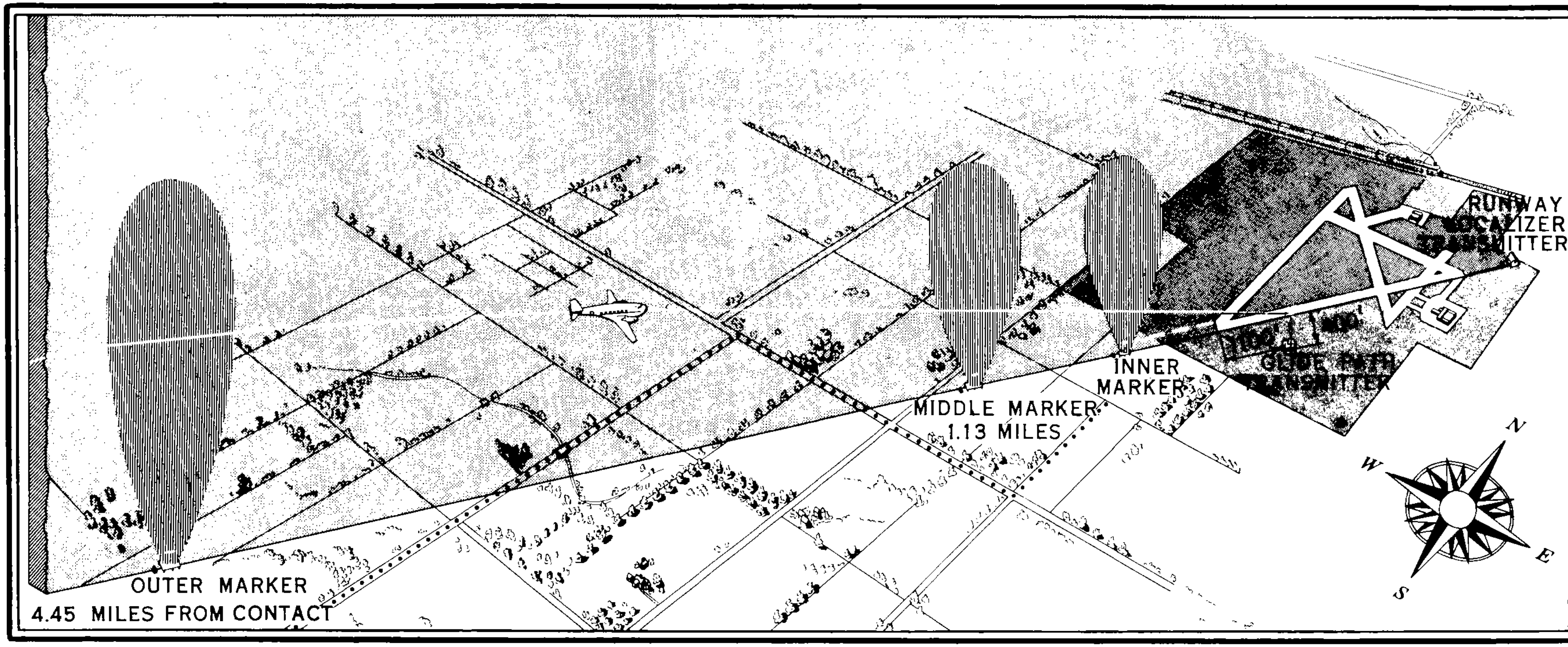

Figure 2. General View of Indianapolis Instrument Landing System.

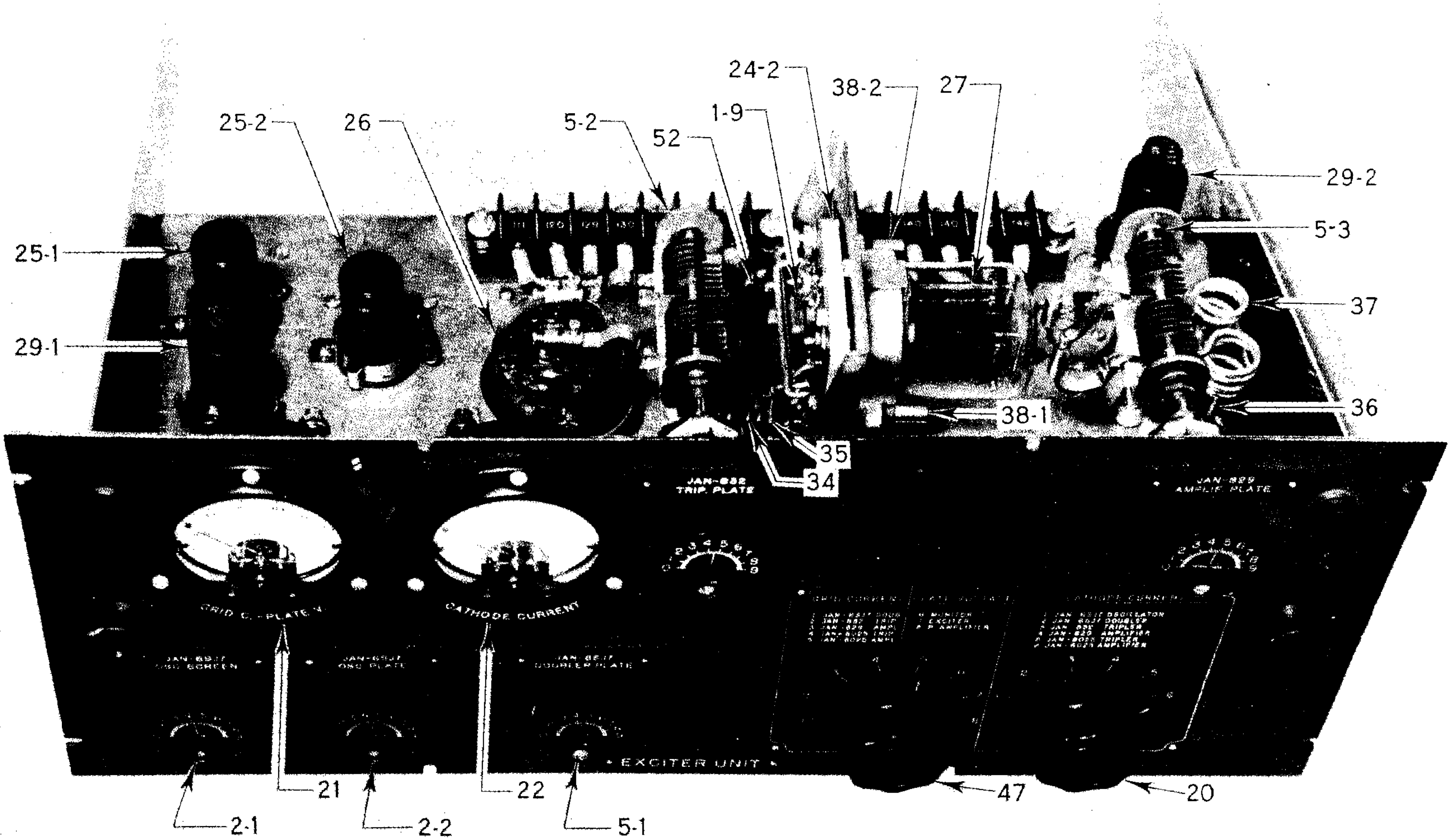

Figure 3. The Transmitter Exciter Unit.

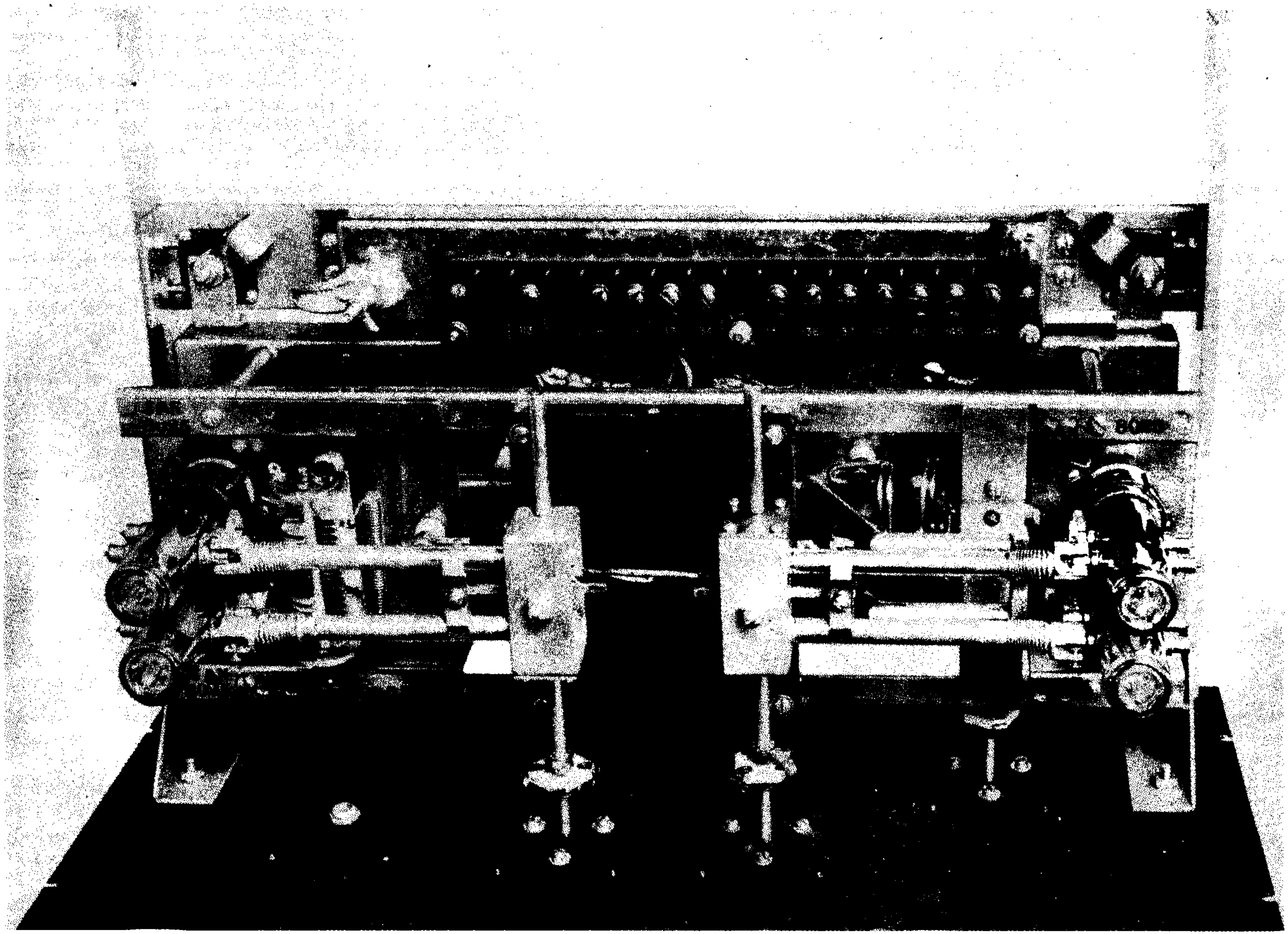

Figure 4. The Transmitter Power Output Unit.

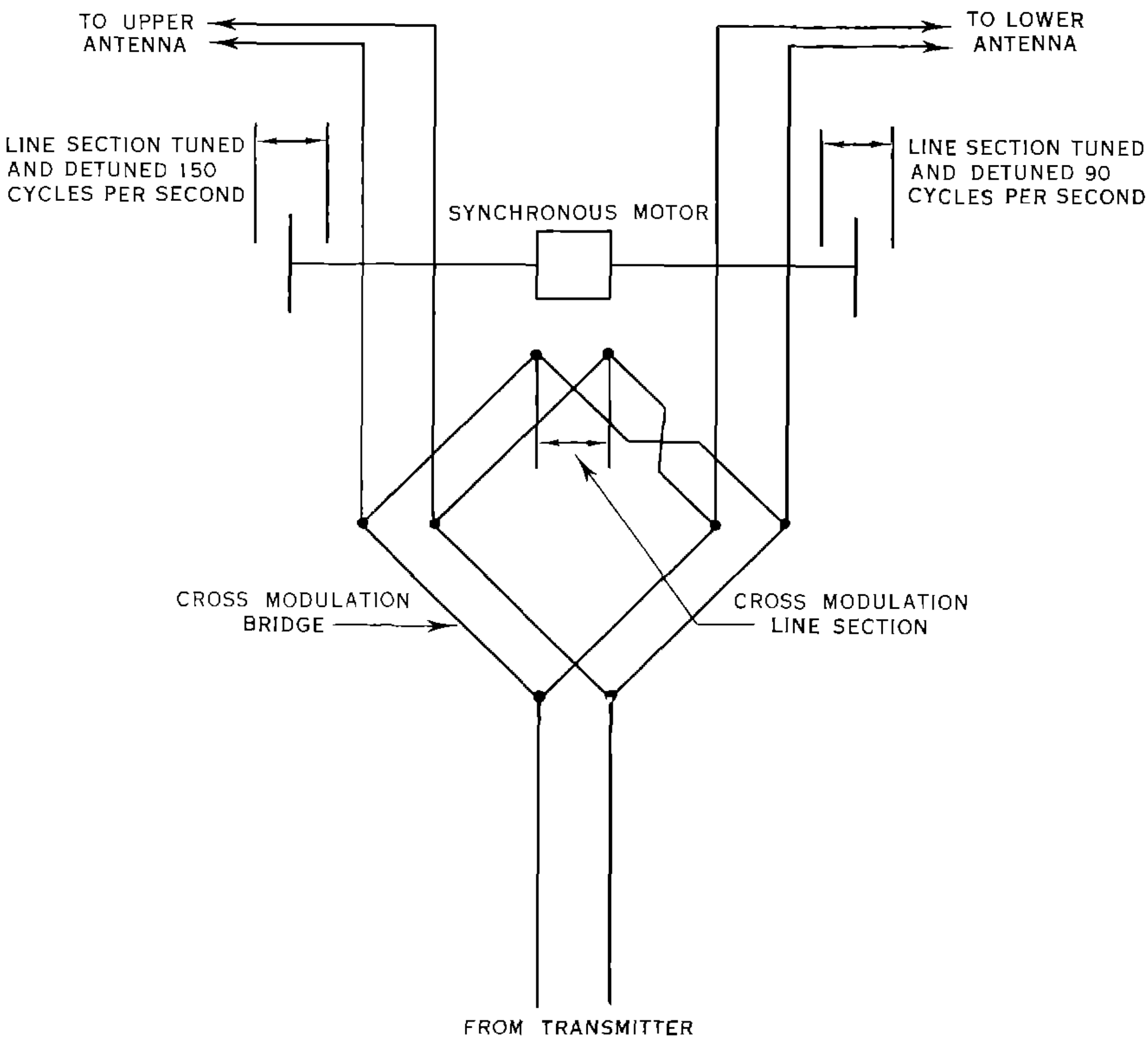

Figure 5 Schematic of Bridge-Mechanical Modulator Unit

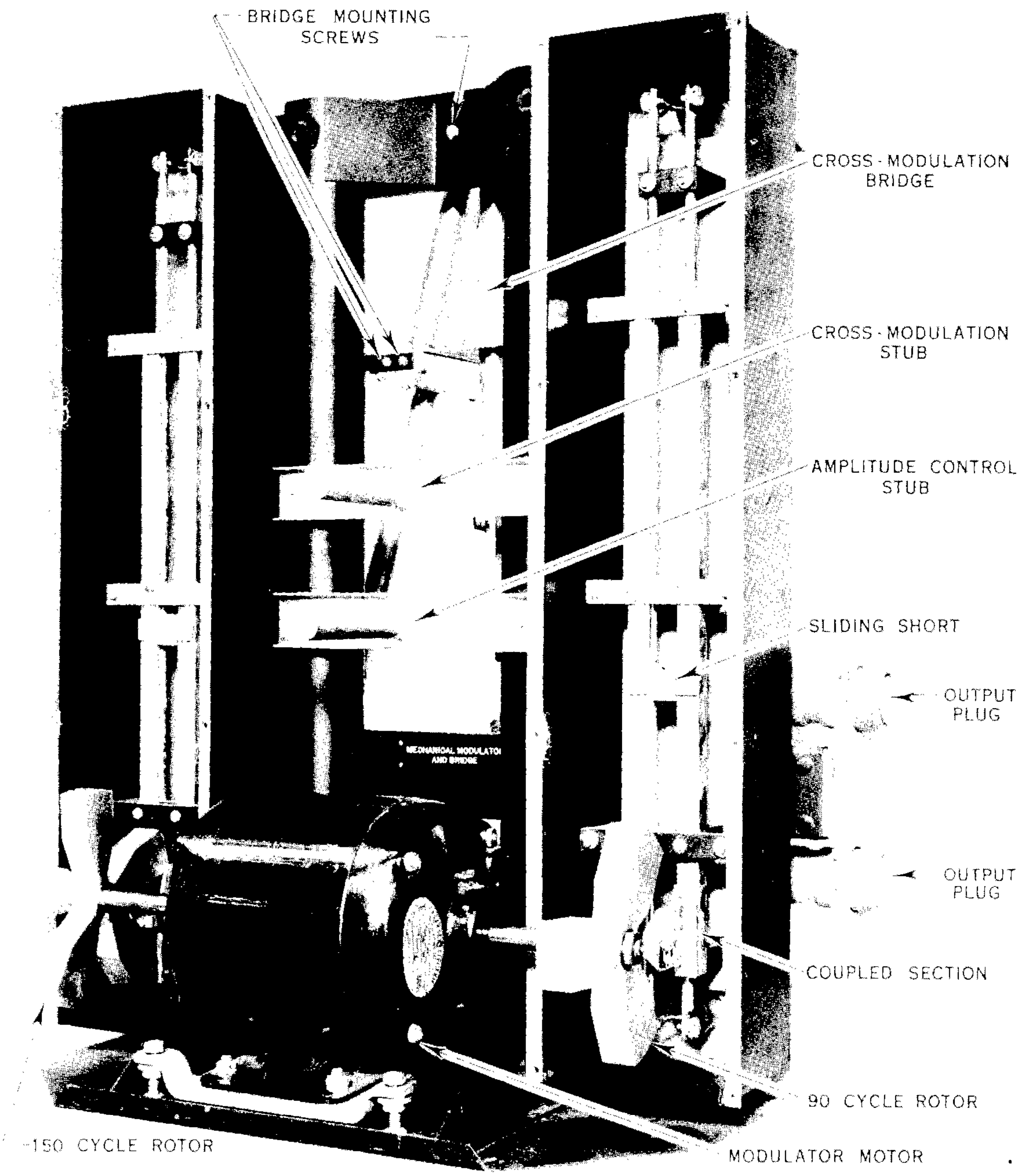

Figure 6. Mechanical Modulator.

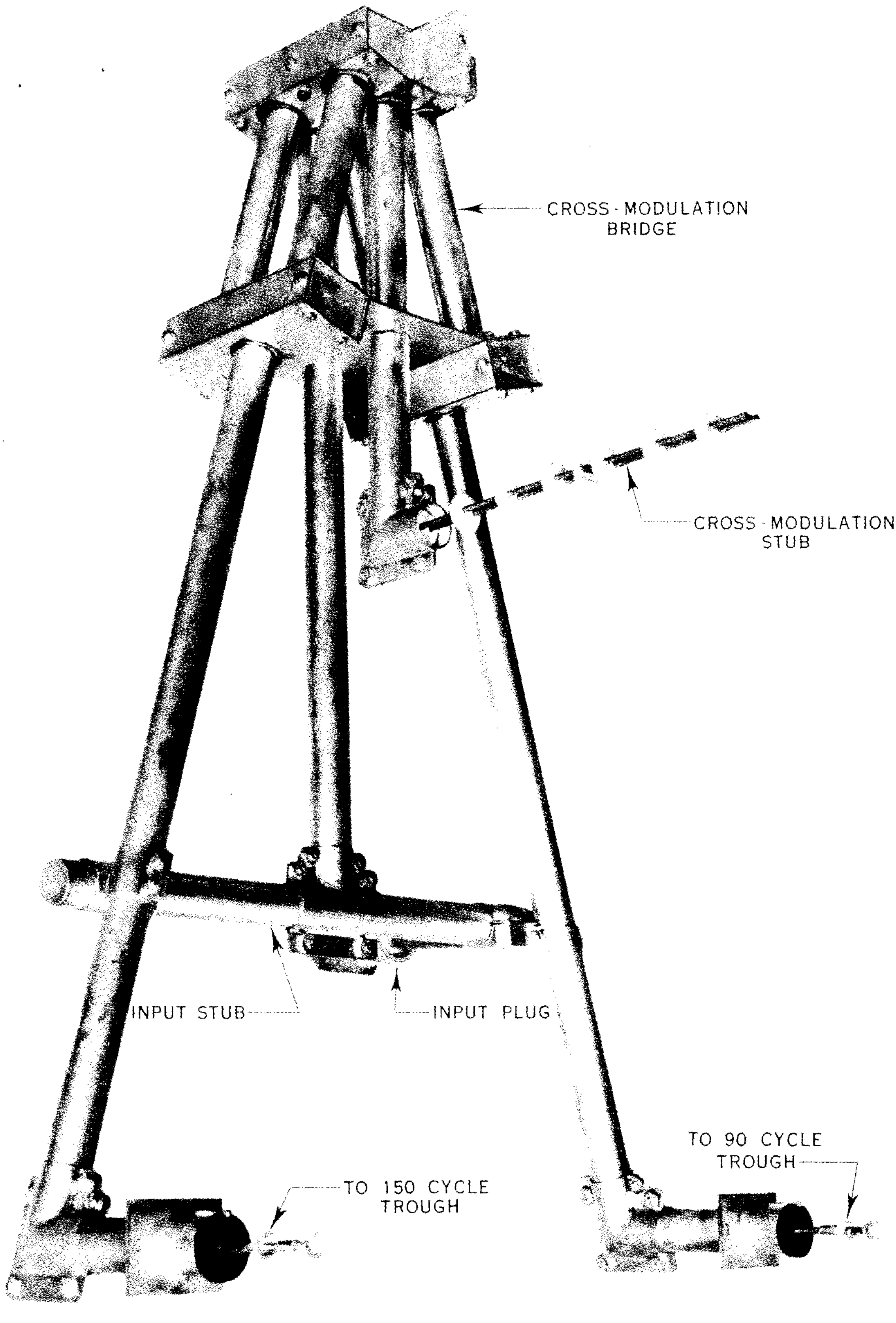

Figure 7. Mechanical Modulator Bridge Assembly.

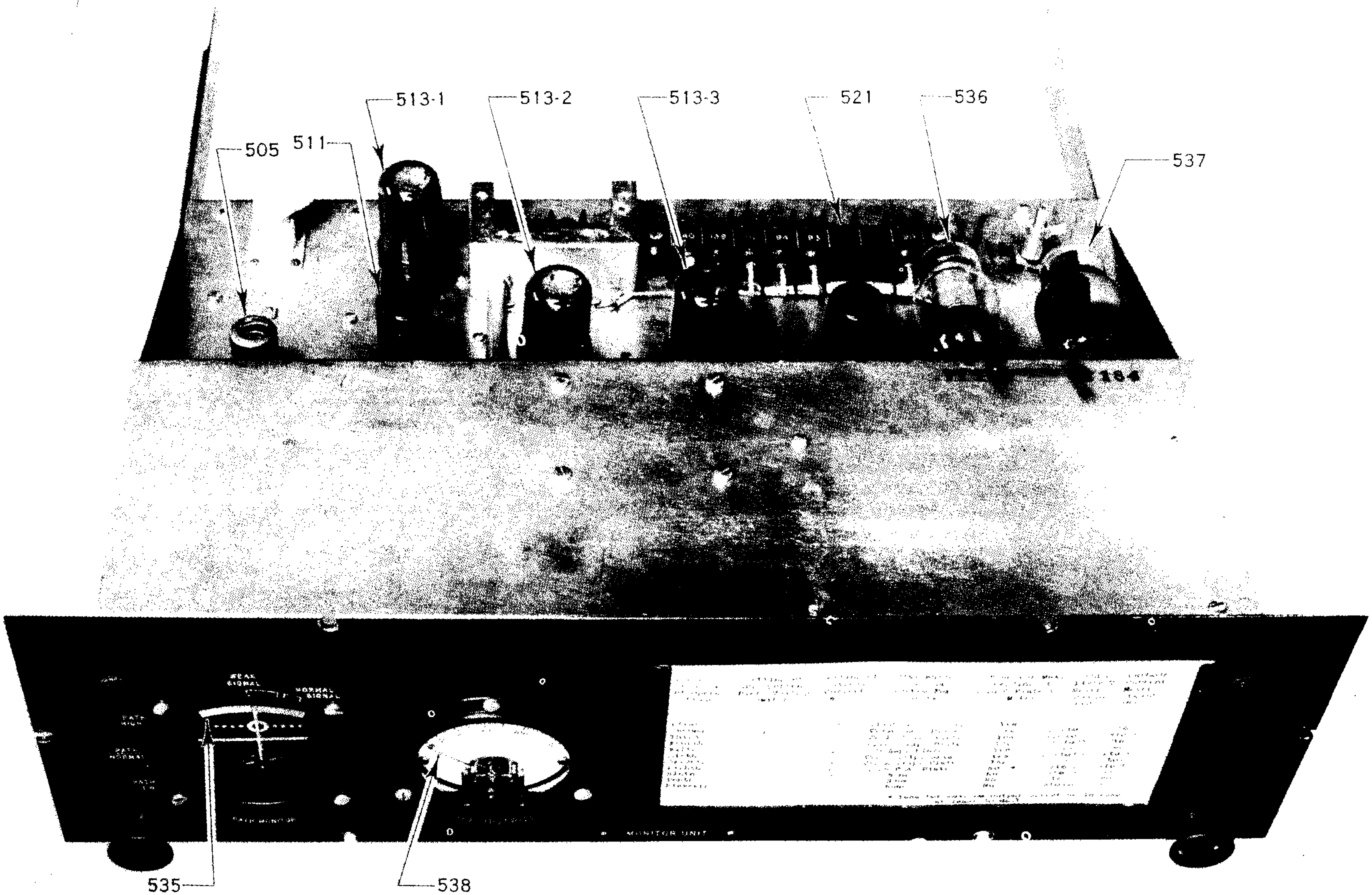

Figure 8. Monitor Unit.

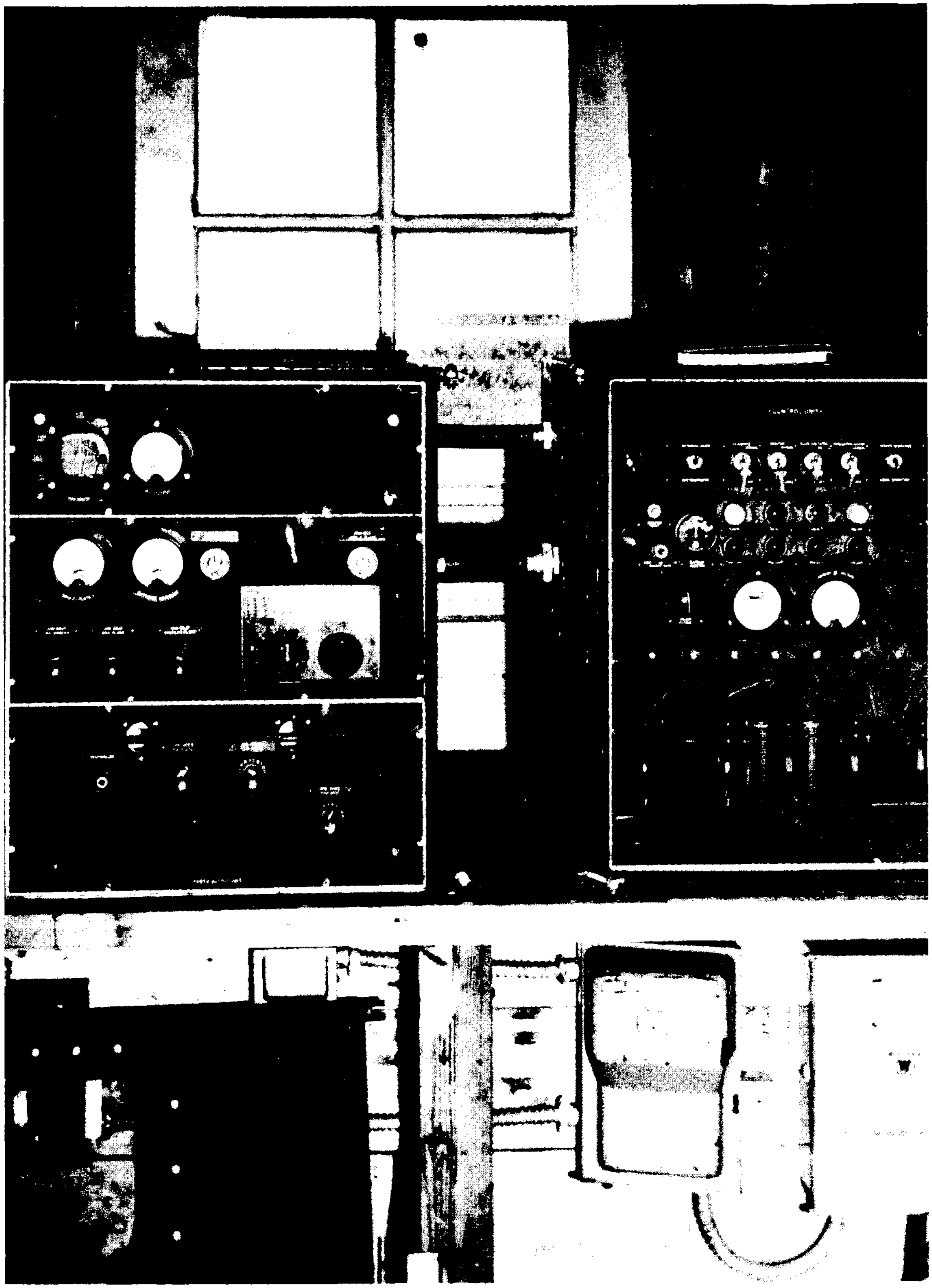

Figure 9. Complete Transmitter Equipment Installed at Indianapolis.

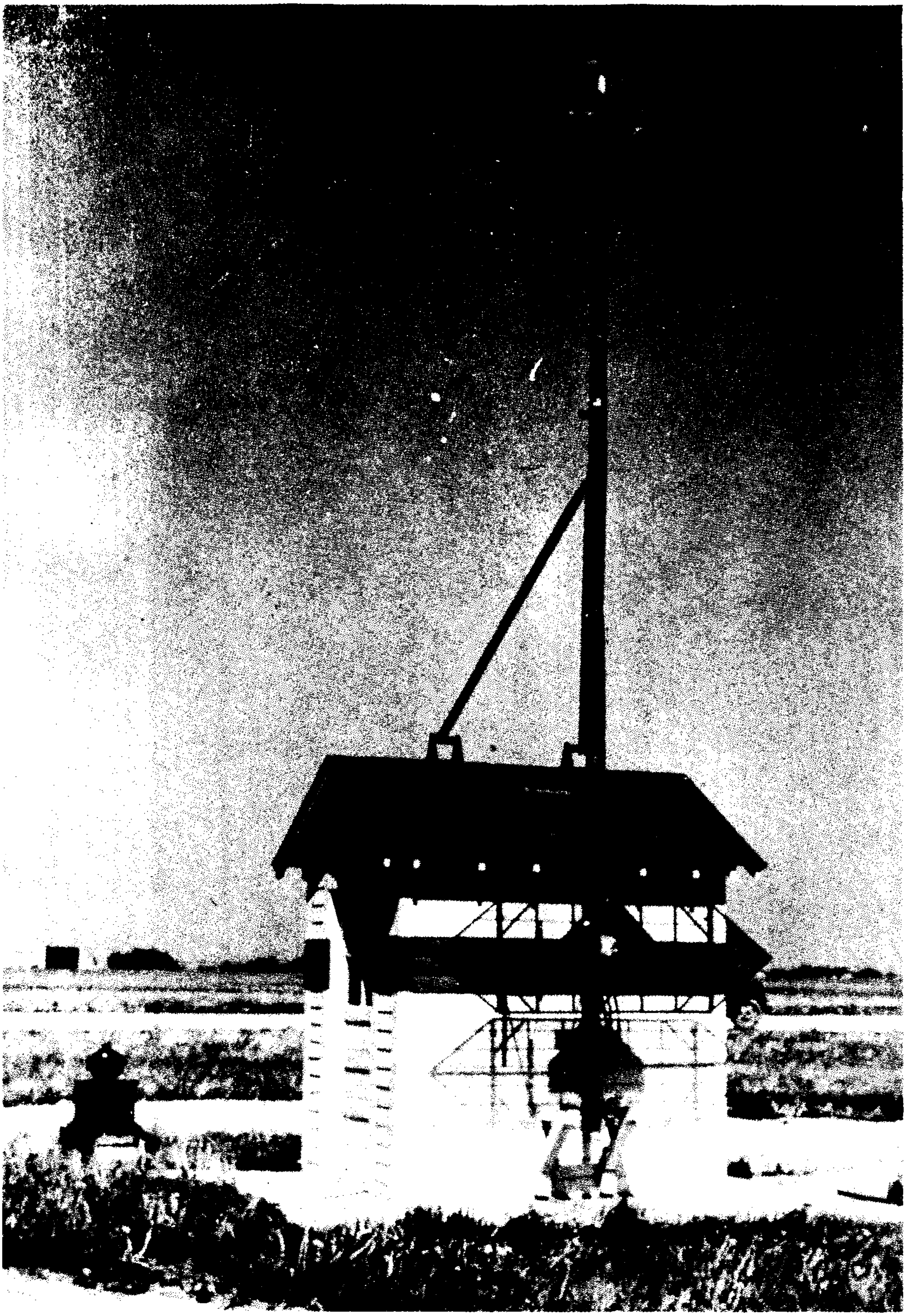

Figure 10. Transmitter House and Antenna Systen at Indianapolis.

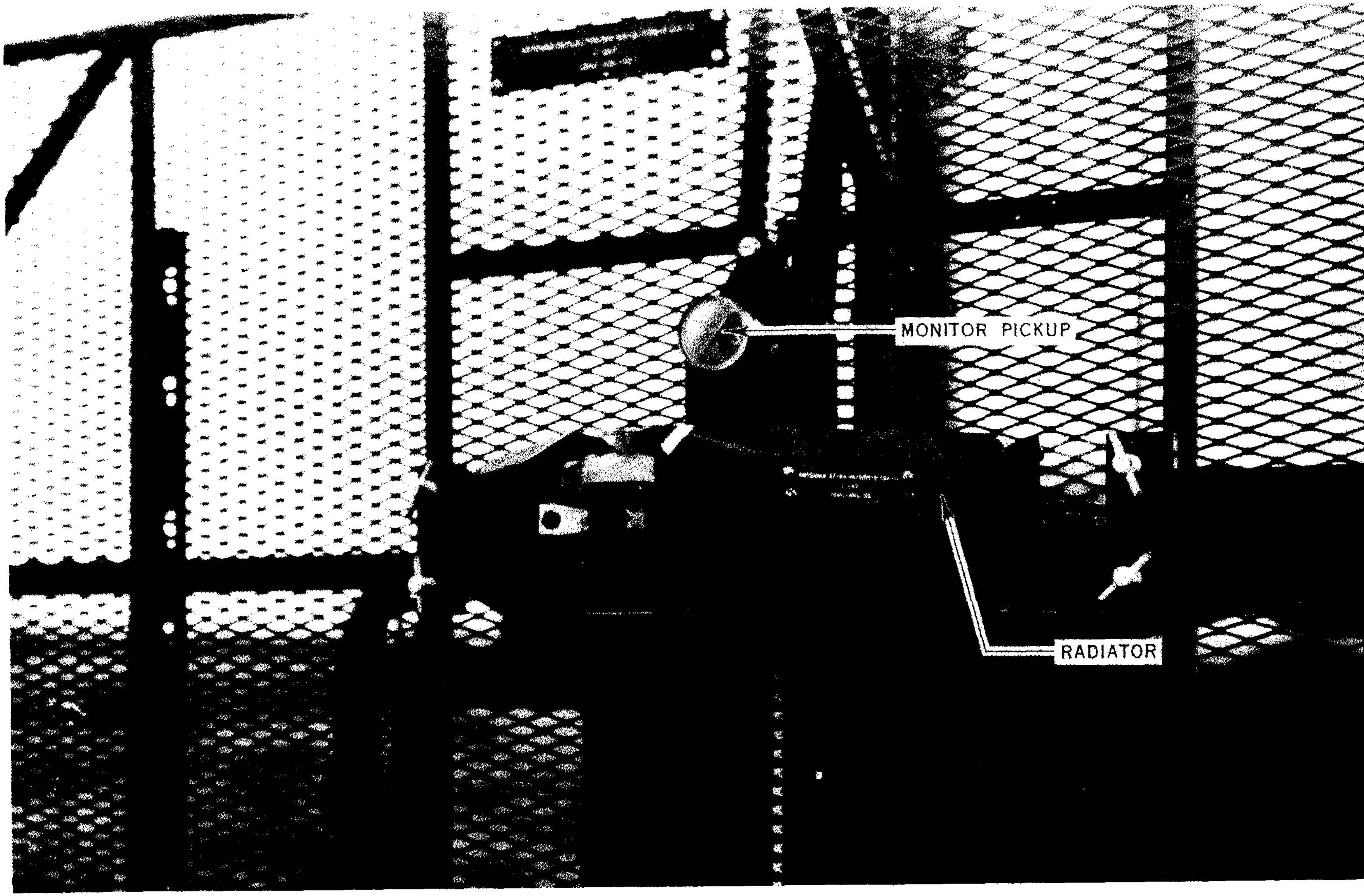

Figure 11. The Lower Antenna.

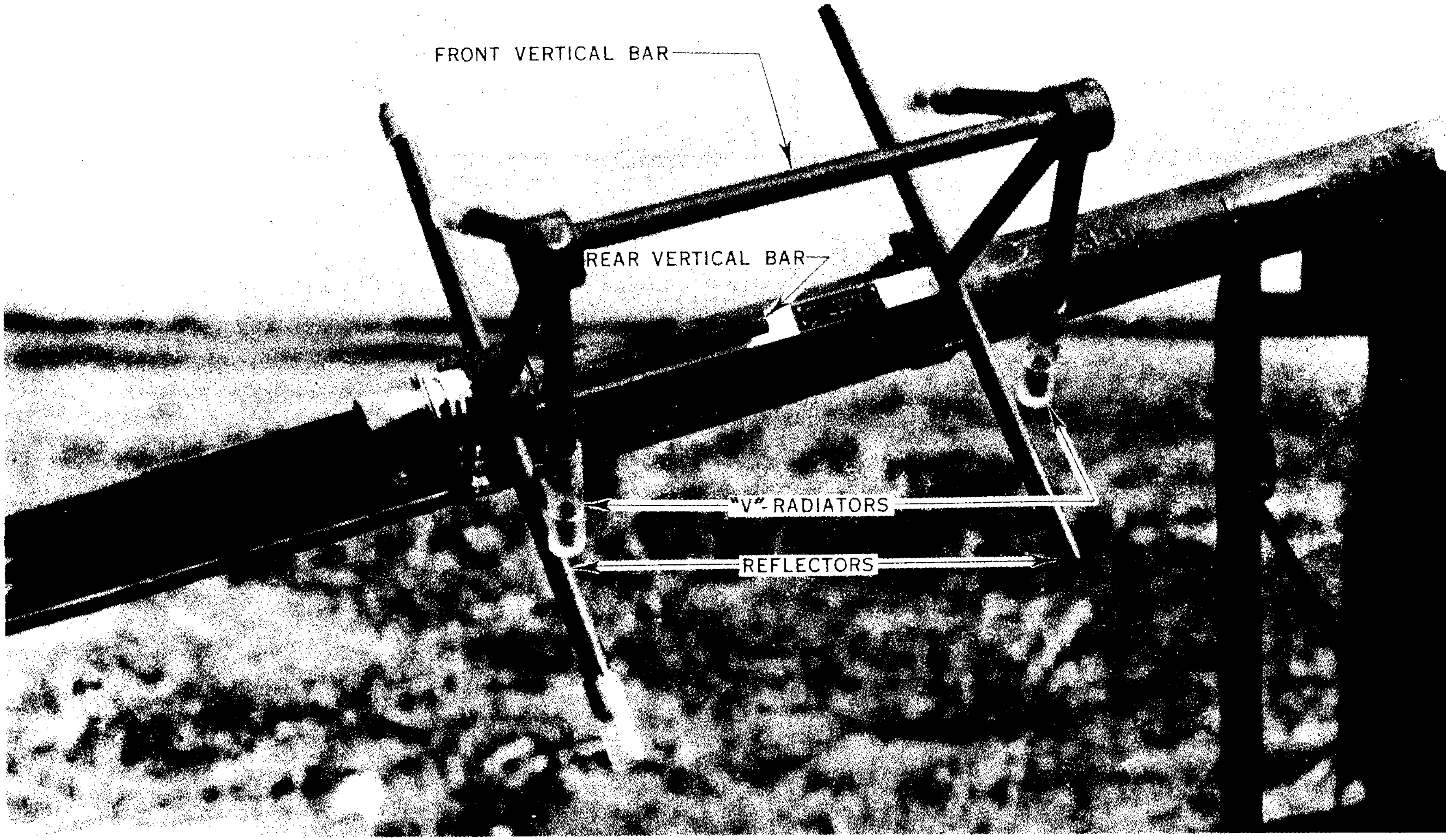

Figure 12. The Upper Antenna.

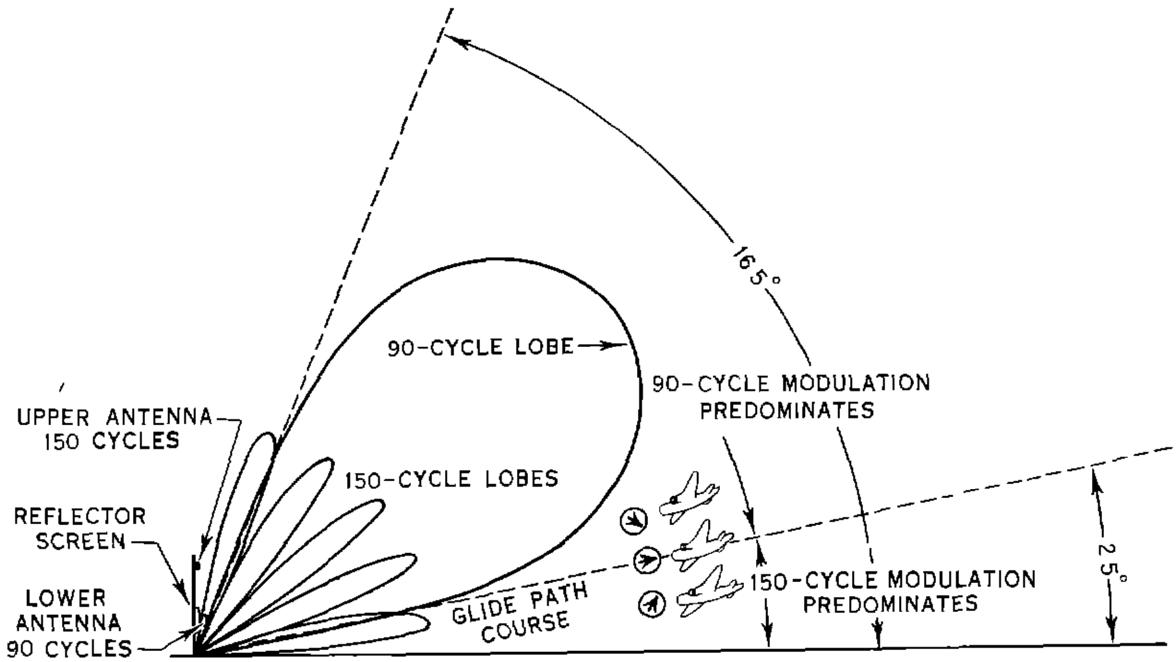

Figure 13 General Vertical Plane Radiation Patterns

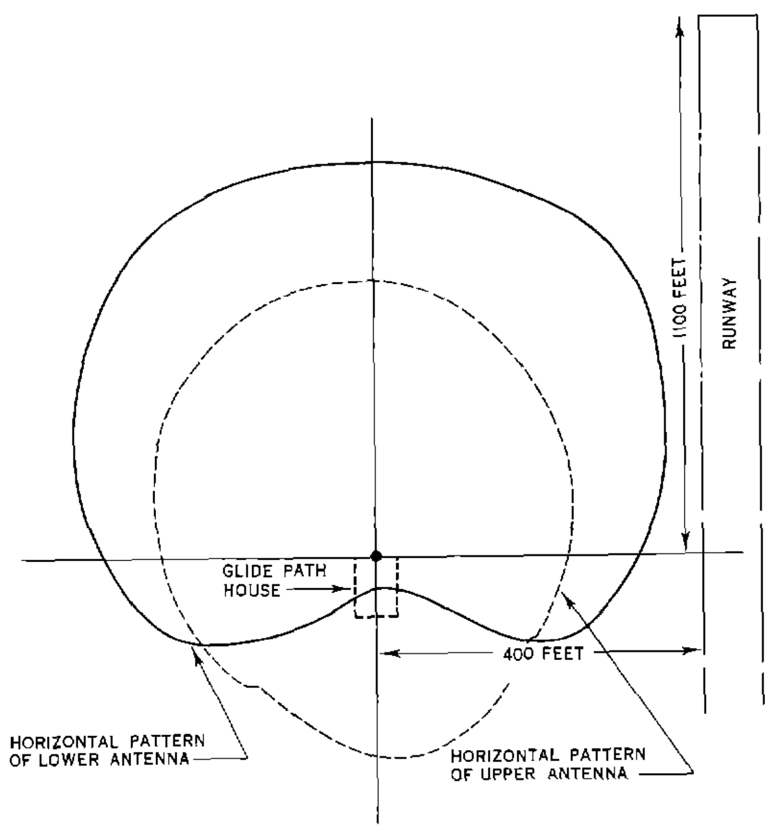

Figure 14 Horizontal Radiation Pattern

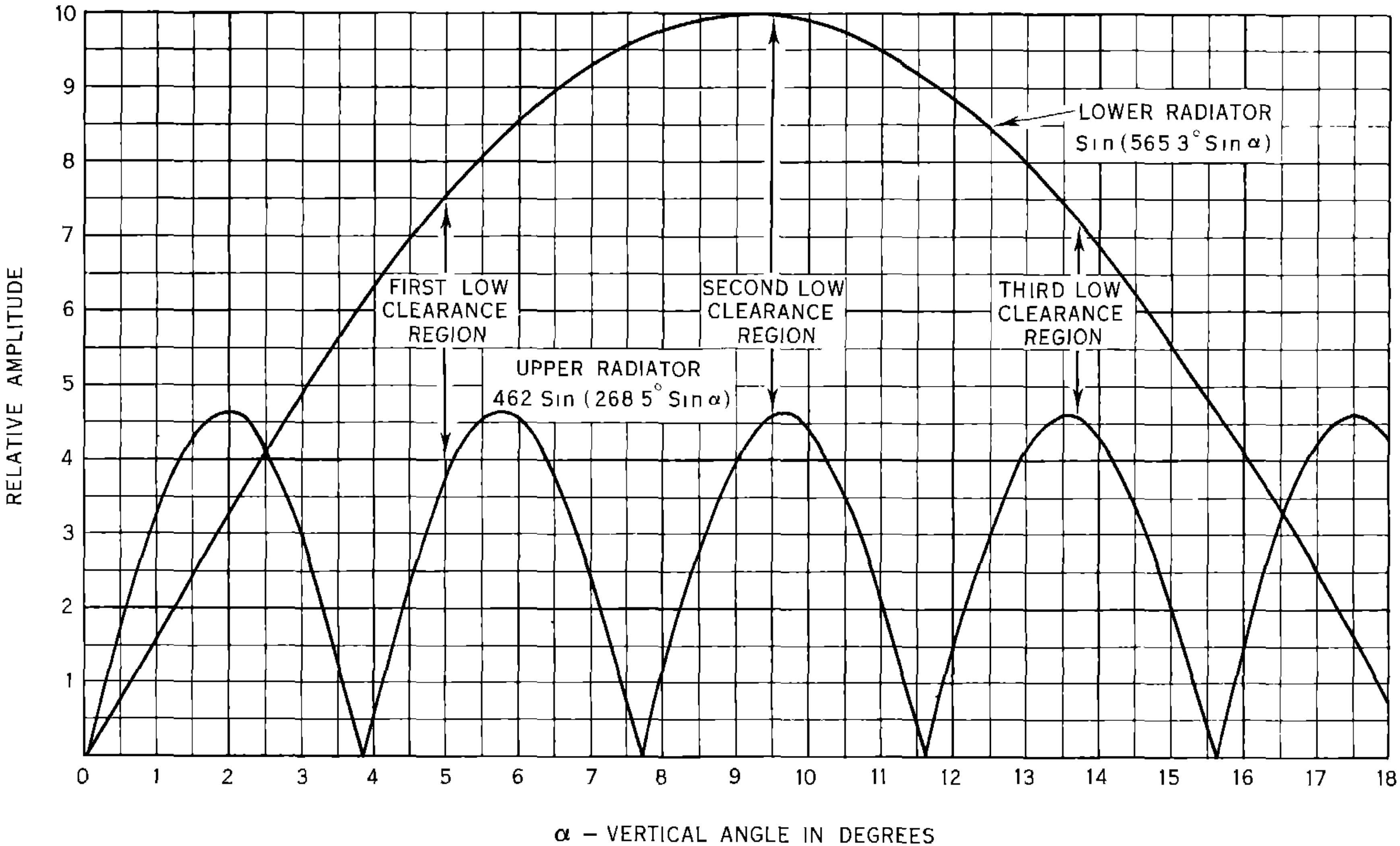

Figure 15 Actual Radiation Pattern for 2 5 Degree Glide Path

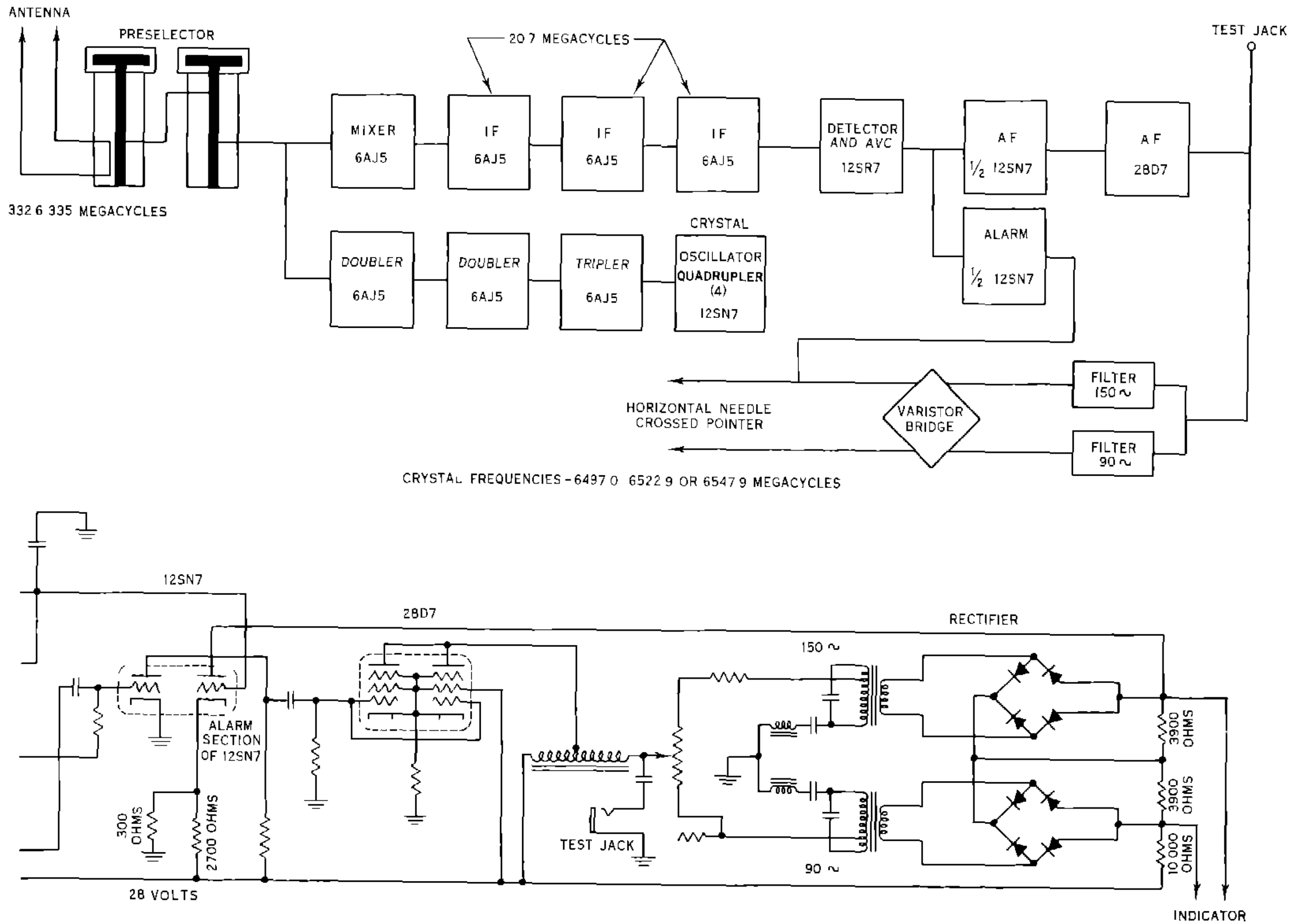

Figure 16 Block Diagram of Glide path Receiver and Schematic Diagram of "Fly Up" Alarm Circuit

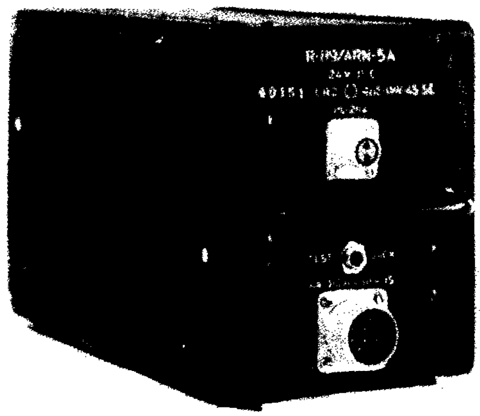

Figure 17. Glide Path Receiver.

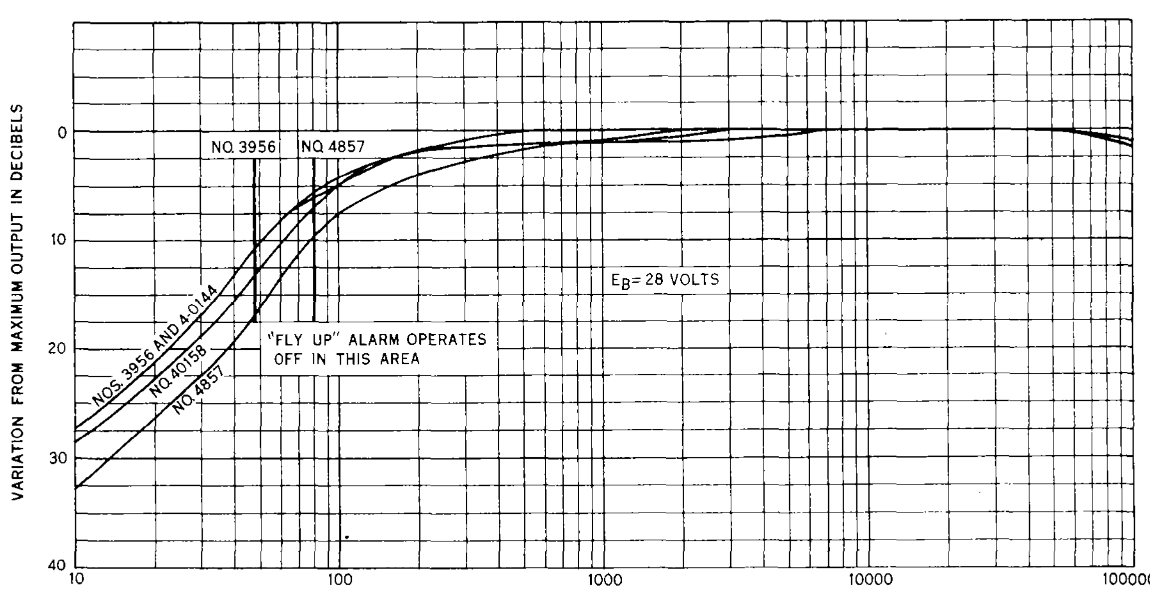

Figure 18. Automatic Volume Control Characteristics of Several Glide Path Receivers.

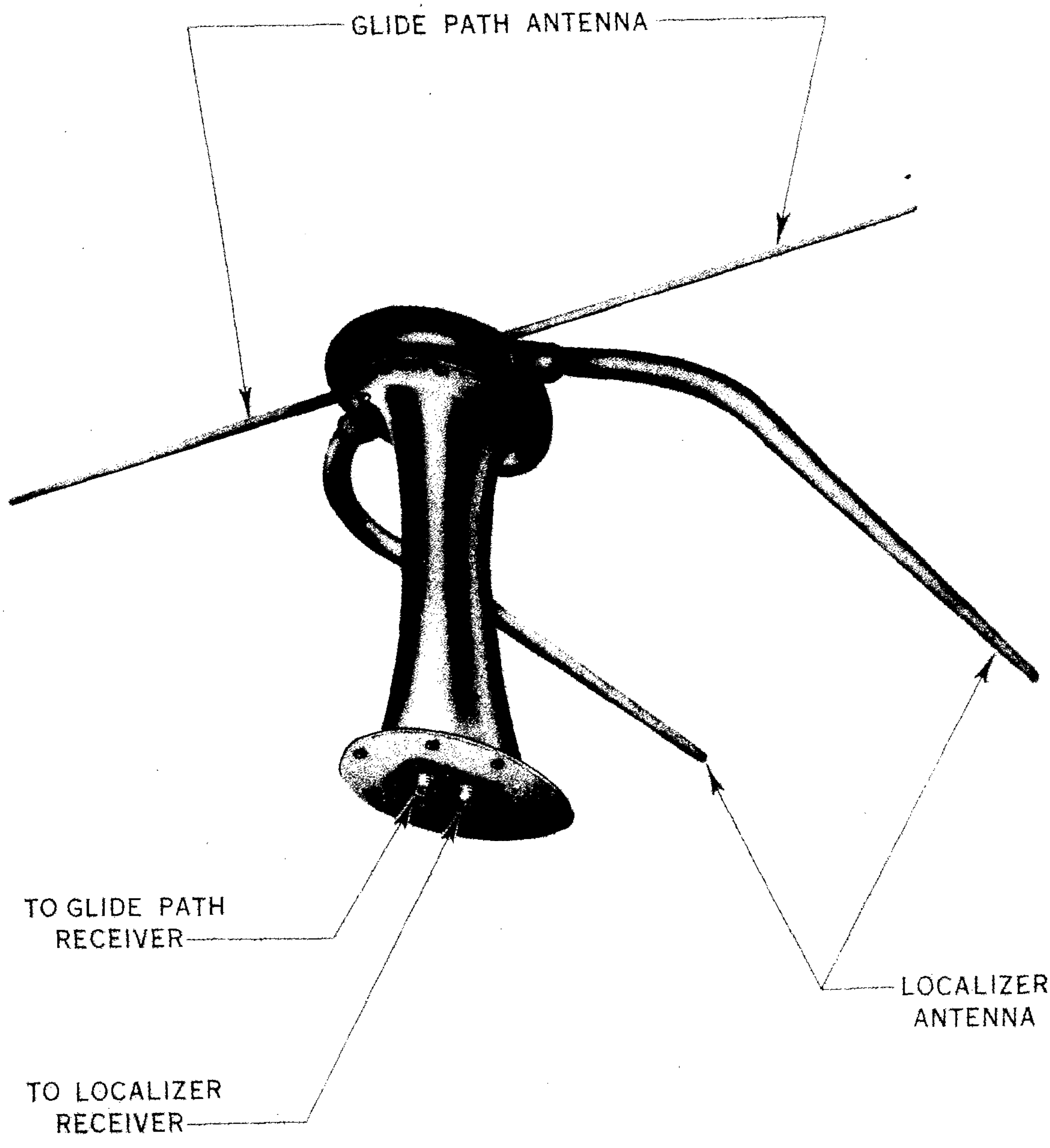

Figure 19. Receiving Antenna.

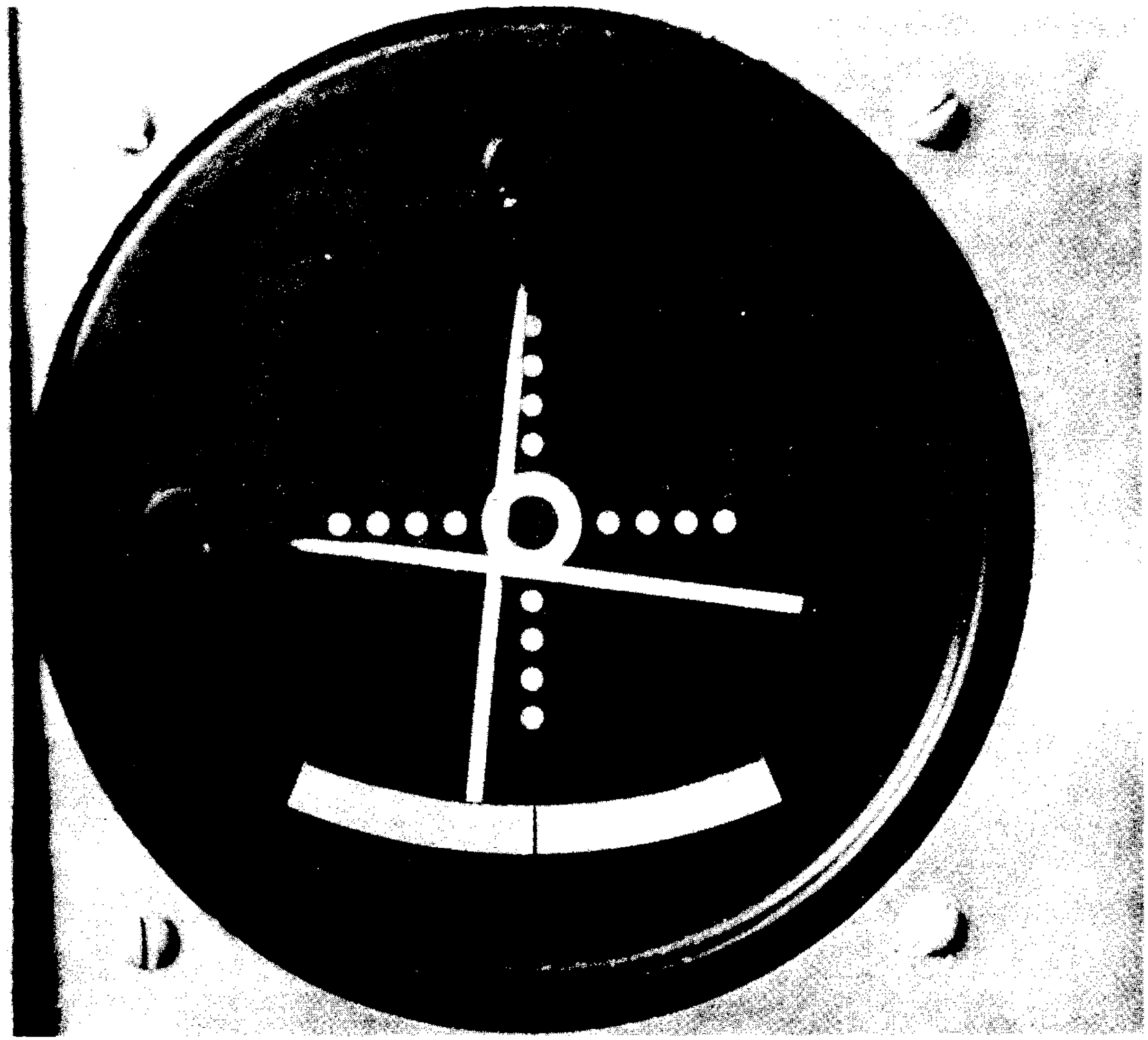

Figure 20. Crossed-Pointer Instrument.

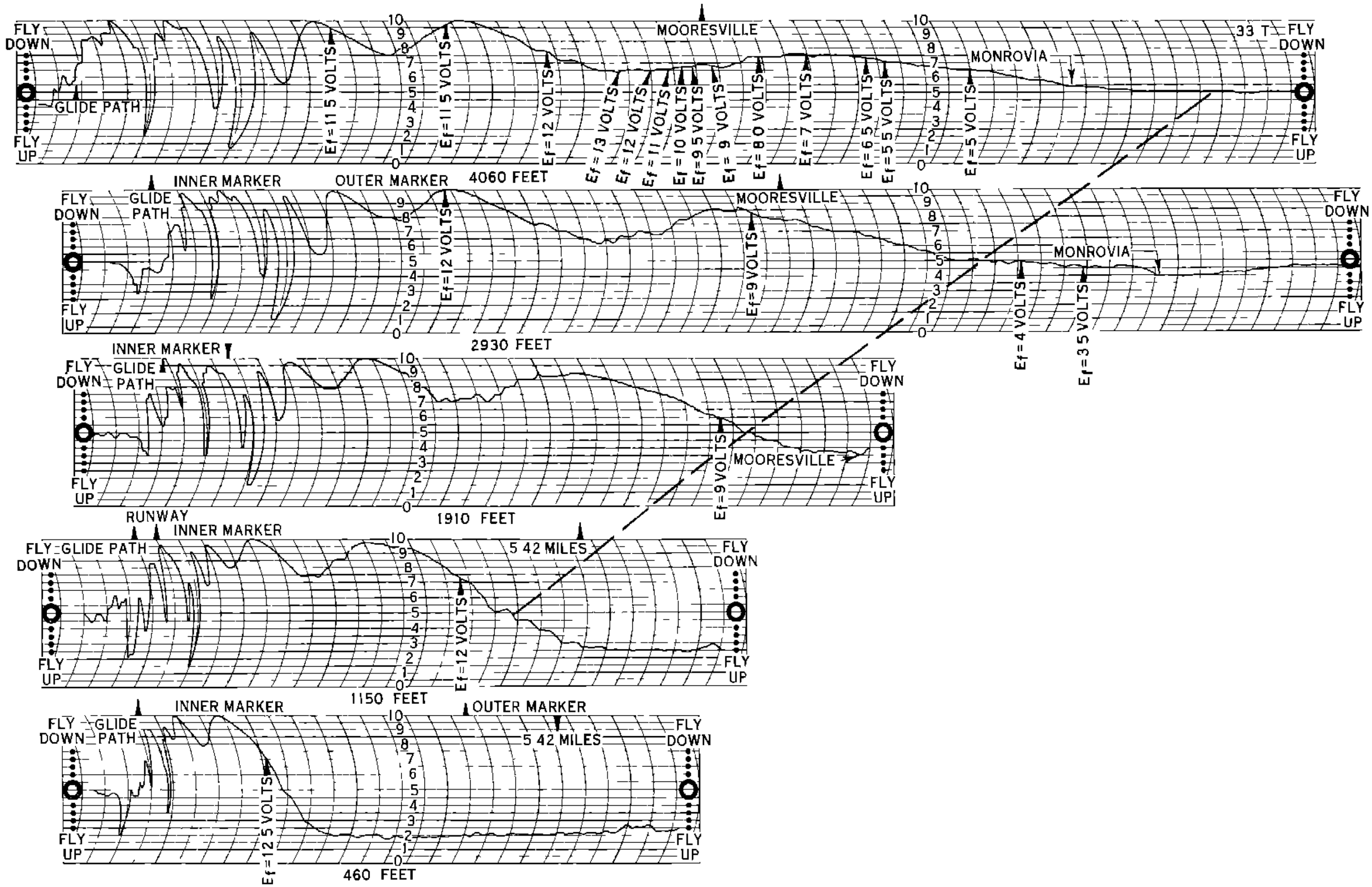

Figure 21 Flight Test Recordings Taken on the Glide Path Equipment During Flights Toward the Station Along the Localizer Course at Constant Altitudes of 500, 1000, 2000, 3000 and 4000 Feet with the Receiver "Fly Up" Warning Circuit Disconnected

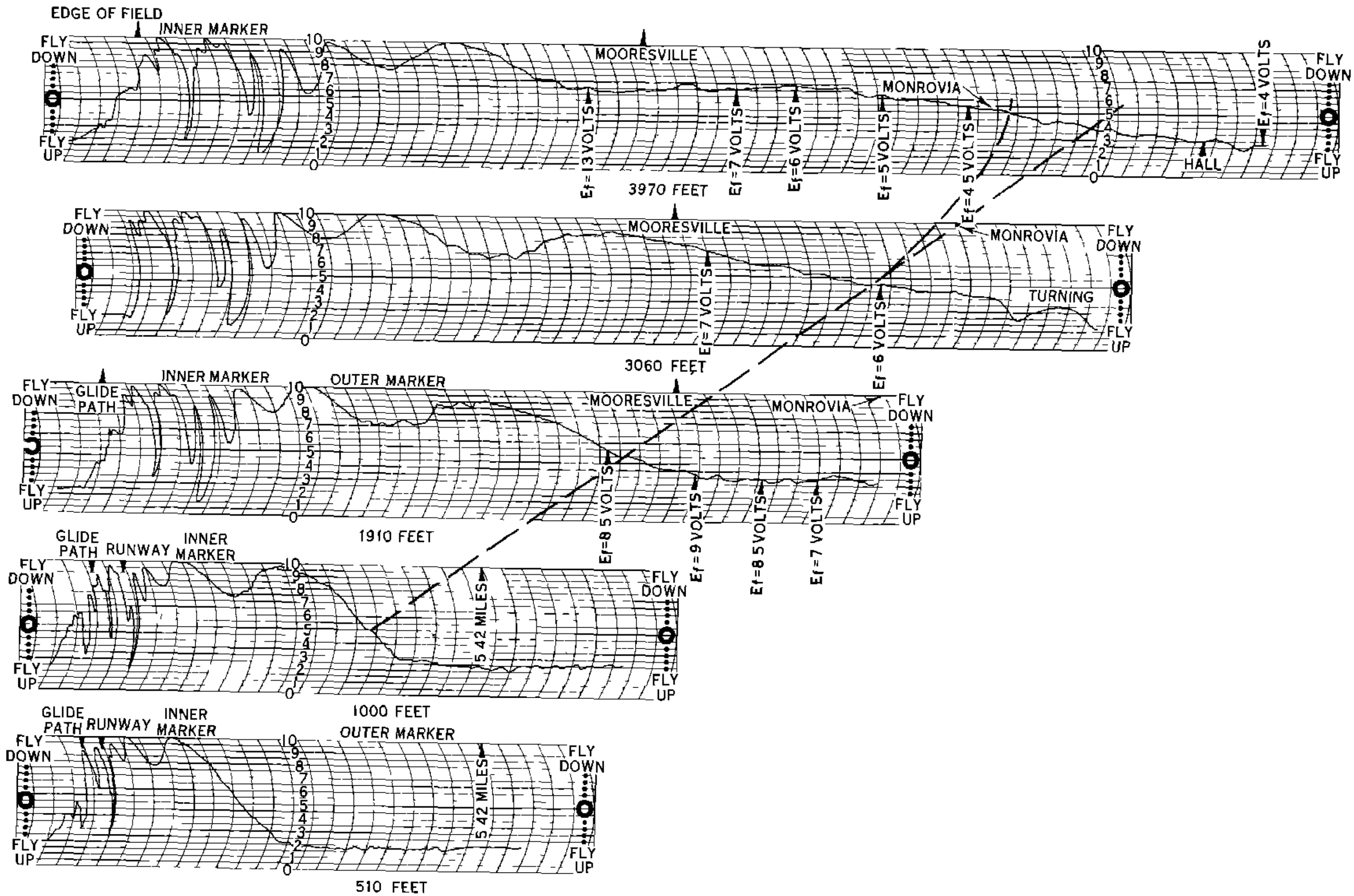

Figure 22 Flight Test Recordings Taken on the Glide Path Equipment During Flights Toward the Station Along the Localizer Course at Constant Altitudes of 500, 1000, 2000, 3000 and 4000 Feet with the Receiver "Fly Up" Warning Circuit Connected

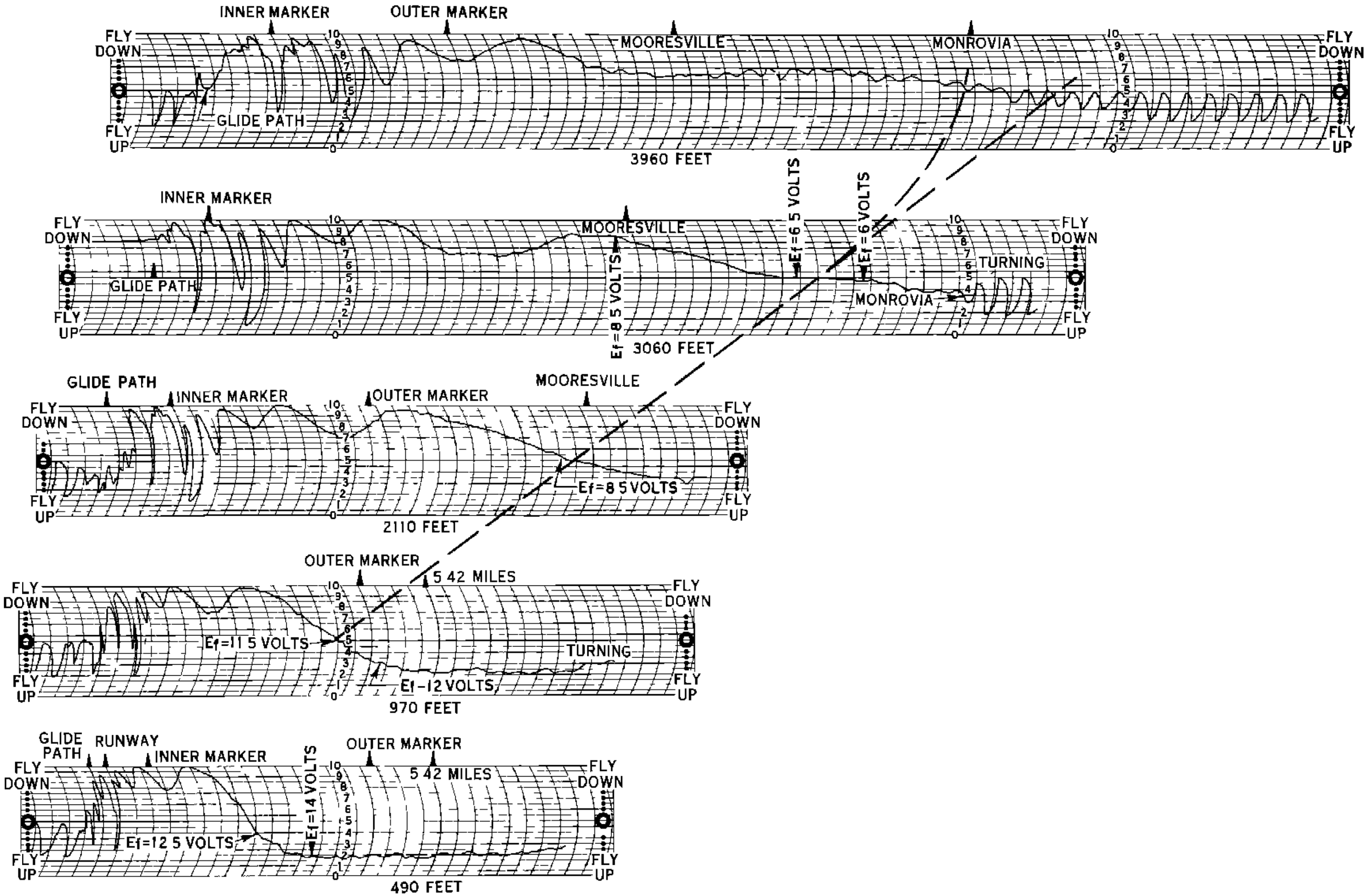

Figure 23 Flight Test Recordings Taken on the Glide Path Equipment During Flights Toward the Station Along the Localizer Course at Constant Altitudes of 500, 1000, 2000, 3000 and 4000 Feet with the Receiver "Fly Up" Warning Circuit Keyed On and Off

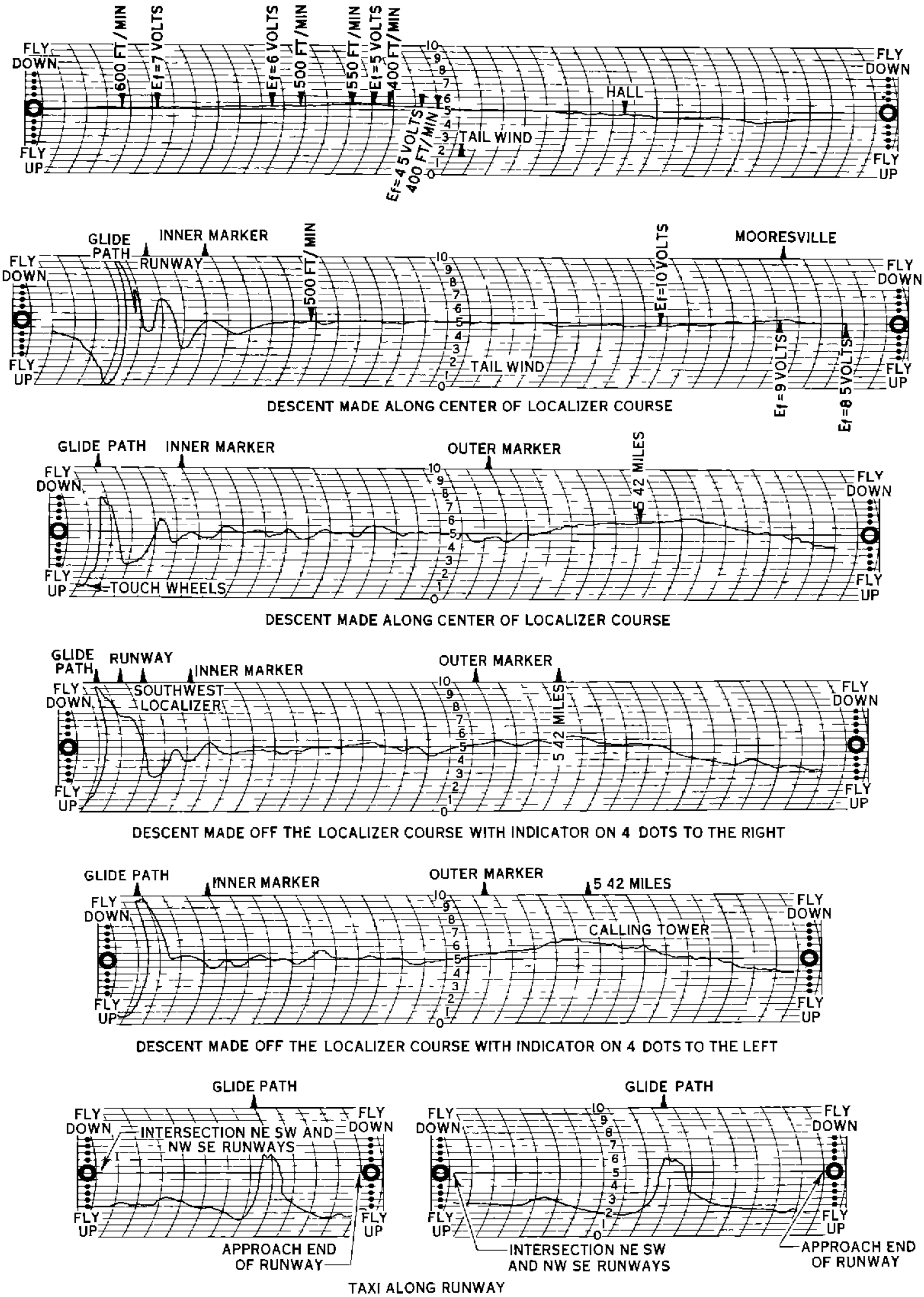

Figure 24 Flight Test Recordings Taken During Approaches Down the Glide Path and While Taxiing Along Runway "Fly Up" Alarm Circuit Disconnected

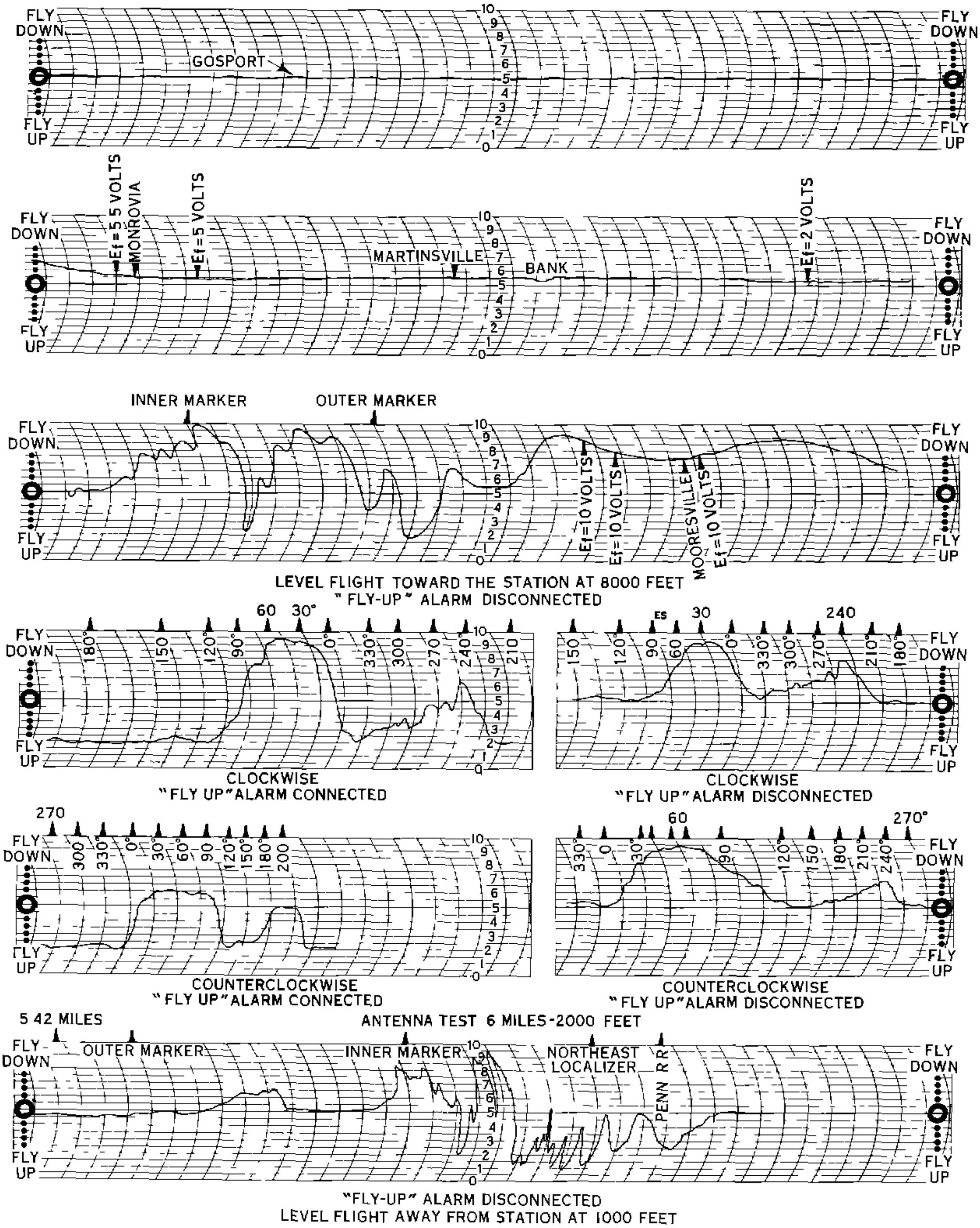

Figure 25 Flight Test Recordings Taken on the Glide Path Equipment During a Flight Toward the Station Along the Localizer Course at a Constant Altitude of 8000 Feet While Circling on the Localizer Course Above the Glide Path at a Distance of 6 Miles and an Altitude of 2000 Feet to Show Receiving Antenna Directivity, and During a Flight Away from the Station Along the Localizer Course at a Constant Altitude of 1000 Feet

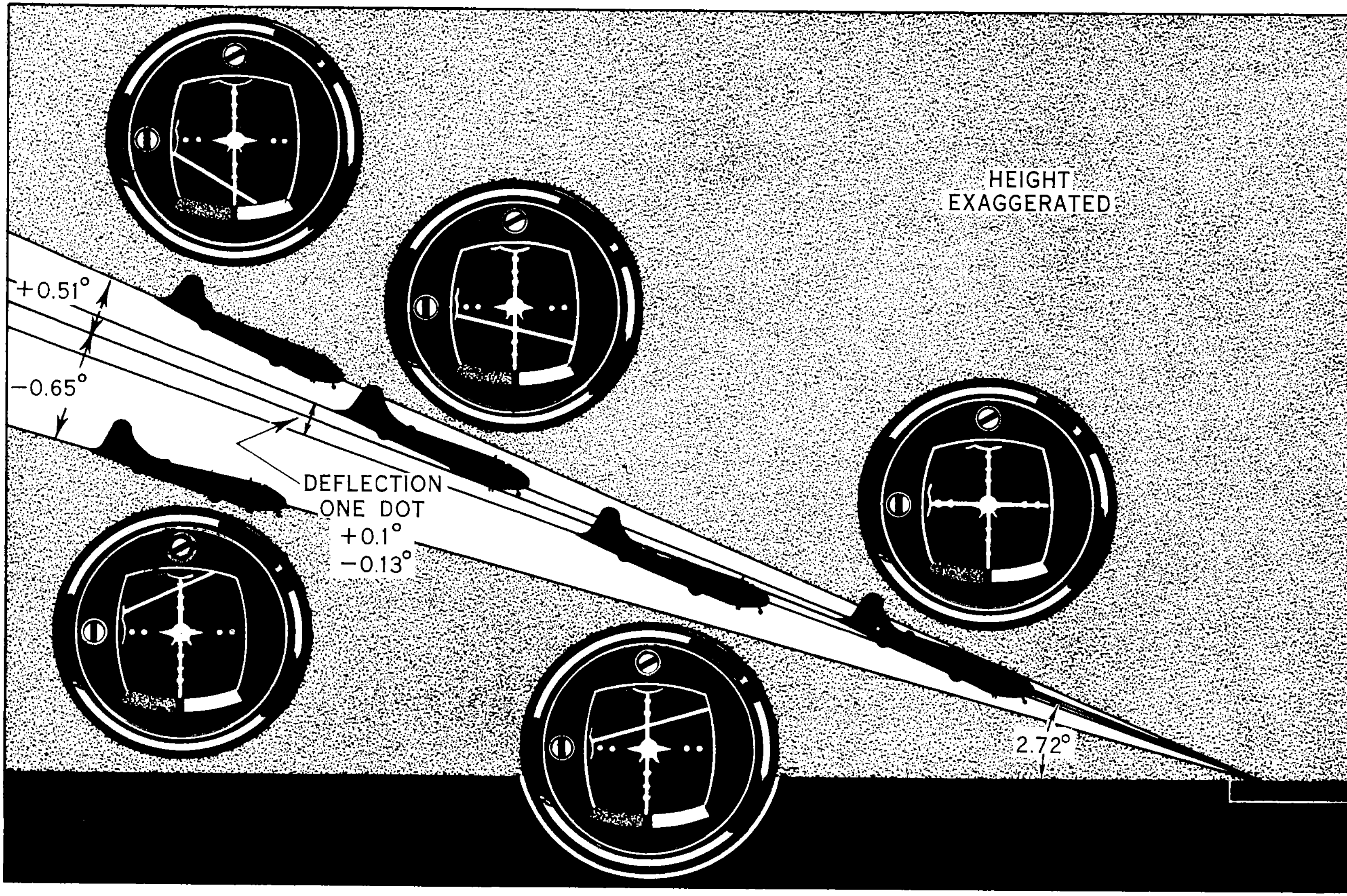

Figure 26. General Operational View of Glide Path System.