IMPROVEMENTS IN 75-MEGACYCLE AIRCRAFT MARKER SYSTEMS

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Abstract.—The ground equipment consists of fan, Z, and instrument landing transmitters under the jurisdiction of the Civil Aeronautics Administration. The aircraft equipment consists of a receiver and a suitable antenna system.

The improvements described are an aircraft antenna mounted in the belly of the aircraft in a way that leaves the surface without projections of any kind, and an improved instrument for testing the complete aircraft installation before leaving the ground. The flush-mounted antenna has approximately the same electrical characteristics as the extensively used half-wave in-line wire antenna mounted underneath the fuselage. The marker tester is a portable, battery-operated unit. It is crystal-controlled, and uses a small motor driven switch for modulation frequency and output-level switching. In use, it is placed on the ground directly under the aircraft marker antenna and radiates a test signal into the aircraft system. The person testing the system need only watch the marker lights in the cockpit for a short period to know the condition of the system. This includes the over-all sensitivity.

I. INTRODUCTION

WHEN flying along an airway, it is necessary for an airline pilot to know his progress towards his destination with considerable precision. One of the more important methods used to accomplish this end consists of the Z, fan, and instrument landing marker stations maintained by the Civil Aeronautics Administration. These markers consist of transmitters operating on 75 megacycles with antenna systems of a type that concentrate the radiation upward.

The transmitter and antenna system at the range station is known as a Z marker. It has a vertical radiation pattern in the shape of an inverted tear-drop projecting above the antenna system. About 5 watts modulated continuously at 3000 cycles-per-second is radiated. The antenna system is designed to produce circularly polarized radiation so that an airplane flying through the marker at any heading will receive the same indication. The purpose of the Z marker is to indicate when the airplane is above the range station. This position indication is also given by the characteristics of the range signals, but several deficiencies in these signals when used for this purpose may result in the range station location not being successfully determined.

The size of the inverted tear-drop of signal is determined by the radiated power and the over-all pickup sensitivity of the receiving equipment aboard the airplane. Its shape is determined by the antenna system used on the ground and on the airplane. In practice the inverted tear-drop extends to 10 or 12 thousand feet and gives a 15 second indication at 800 feet above ground at a speed of 120 miles-per-hour.

Fan marker stations are located on the range courses and are used as position indicators along the course. The fan marker transmitter output is about 50 watts in magnitude. It is keyed in groups of dashes from one to four to identify the range legs. The pattern in space is fan shaped with the wide dimension of the fan lying across the airway. The pattern extends upward to more than 20,000 feet, it is approximately 16 miles across at its broadest point, and 4 miles thick parallel to the range course.

The instrument landing markers perform the same function during the approach procedure as do the fan markers during enroute flying. The pattern erected across the approach path is similar; the power used is considerably less. Modulation tones of 400, 1,300, and 3,000 cycles-per-second together with distinctive keying are used to identify the individual markers.

The marker receiver carried in the airplane is a crystal-controlled superhetrodyne with several specialized circuits to make it suitable for its intended job. It is stabilized so that its sensitivity does not change appreciably with changes in supply voltage, temperature, etc. The audio circuits contain 400,- 1,300,-and 3,000-cycle filters that select the audio modulation tone and direct it to one of three indicator lights mounted on the airplane's instrument panel. The 400-cycle tone illuminates the purple light, the 1,300-cycle tone illuminates the amberlight, and the 3,000-cycle tone illuminates the white light.

The aircraft marker antenna most used today is a half-wavelength wire mounted underneath the fuselage in the line of flight and about 6 inches from the skin of the airplane. The antenna is coupled to a coaxial transmission line by a wire tapped on the antenna a few inches off center. With such an antenna maximum pickup is downward from the airplane as is desired.

II. NEW MARKER ANTENNA

A new marker antenna has been developed and is coming into use that mounts entirely inside the bottom of the fuselage of an all-metal airplane and receives signals through a plastic window 12 inches by 20 inches in dimensions. Such an antenna is desirable since it does not project into the airstream to produce drag and to collect ice under bad weather conditions. A series of diagrams is shown in Fig. 1 to explain the operation of this flush-mounted antenna. Figure 1 (a) shows a half wave antenna fed by a single wire off center transmission line—a conventional arrangement. Figure 1 (b) shows the same antenna with its outer ends replaced by capacitances C_{-1} and C_{-2}. Figure 1 (c) shows the antenna placed in a half-cylindrical metal structure, and mounted behind a plastic window in the metallic skin of an airplane. The proper mounting location for the antenna is in the under side of the fuselage, on the centerline, and at a place where the skin is approximately parallel to the line-of flight. The antenna mounting must be such that the pickup rod is also parallel to the line-of-flight. There must be no obstructions, such as other antenna wires, across the plastic window.

Figure 2 shows the type ES-396 marker antenna that is now in service

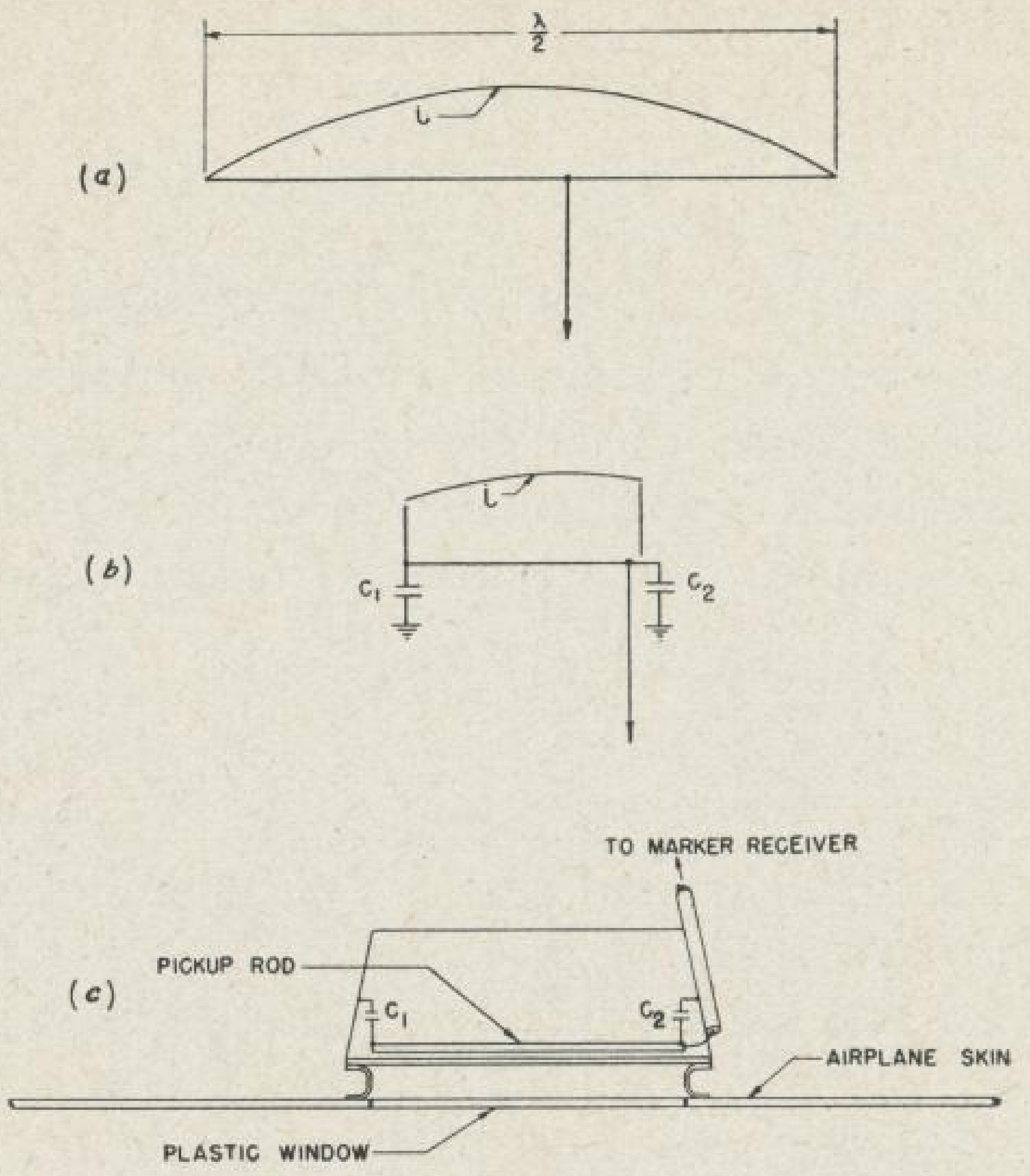

FIG. 1—Series of diagrams to explain the operation of the flush-mounted antenna.

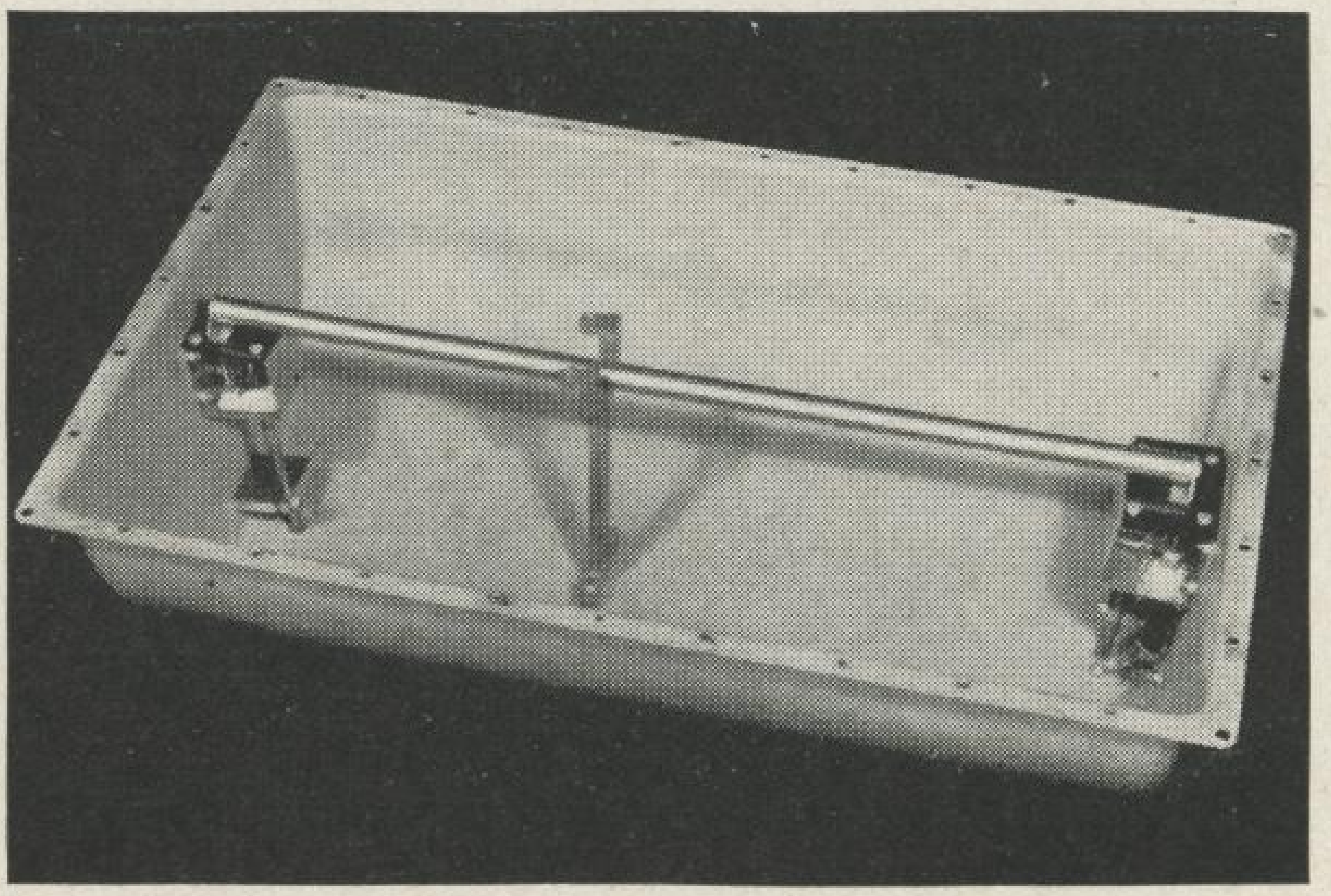

FIG. 2—The type ES-396 marker antenna in service on United Air Lines.

on United Air Lines. The bakelite cover has been removed to show the internal construction. Variable condensers are mounted in the small housings on the left and right. The condenser on the left is C_{-1} and has a capacity of approximately 7 micro micro farads. The condenser on the right is C_{-2} and has a capacity of approximately 130 micro micro farads. A short length of 52-ohm coaxial transmission line is connected across C_{-2} and is brought out to a suitable coaxial socket. The pickup portion of the antenna consists of the ½ inch diameter aluminum tube extending from left to right across the opening. Its length is 19 inches or $\frac{1}{8}$ wavelength.

The ES-396 antenna is tuned, with the bakelite cover in place, by fastening it in an opening in an aluminum sheet about 3 feet by 6 feet in dimensions in a manner that duplicates as nearly as possible the aircraft mounting. A small amount of radio frequency power at 75 megacycles is delivered to the antenna through a 52-ohm coaxial line. In series with this line is a three-voltmeter Z-meter. This device consists simply of three r-f voltmeters placed $\frac{1}{8}$ wavelength apart along the 52-ohm coaxial line. The impedance of the antenna can be computed if desired from the three voltmeter readings. A schematic diagram of this instrument is shown in Fig. 3.

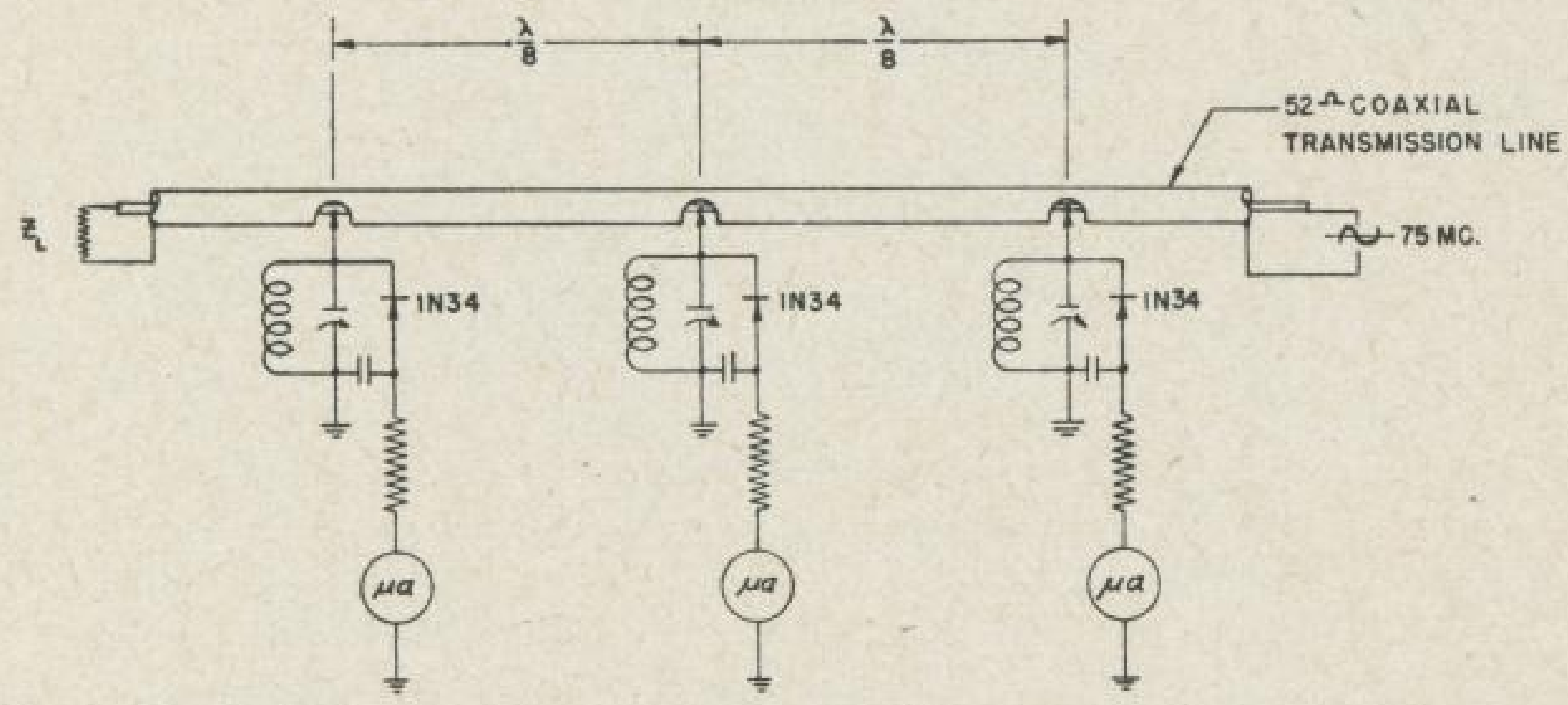

FIG. 3—Schematic diagram of three-voltmeter impedance-measuring system.

A mathematical analysis of this method of impedance measurement can be found in a paper by W. L. Barrow entitled "Measurement of Radio-Frequency Impedance with Networks Simulating Lines" in the July, 1935 issue of the Proceedings of the Institute of Radio Engineers. It will be observed that the three voltmeters will read the same only when the 52-ohm line is terminated by its characteristic impedance thereby producing a "flat" line. This condition is brought about by adjustment of condensers C_{-1} and C_{-2}. In practice the adjustment can be made to produce a standing wave ratio of 1.1 without difficulty. This is a completely satisfactory adjustment. The antenna is then installed in the airplane without further tuning.

Figure 4 shows the ES-396 antenna installed in a C-54 airplane currently being used by United Air Lines. The view shown is looking downward and to the rear through the door in the rear of the cabin. The antenna is mounted just aft of the bulkhead containing this door.

Figure 5 is an external view of the antenna mounting. A bakelite plate can be seen riveted flush with the aluminum skin so that the contour of the fuselage is preserved.

There are other characteristics of the antenna that are of interest. The pattern in a plane containing the pickup rod is shown in Fig. 6. This pattern was made with the antenna mounted in a flat metallic sheet and represents the characteristic of the antenna unmodified by the curved body of an airplane. It is believed, however, that this pattern is reasonably close to the one obtained in flight. A necessary condition for a marker antenna is that it have maximum pickup downward. This pattern indicates that the ES-396 antenna fulfills this requirement to a satisfactory degree.

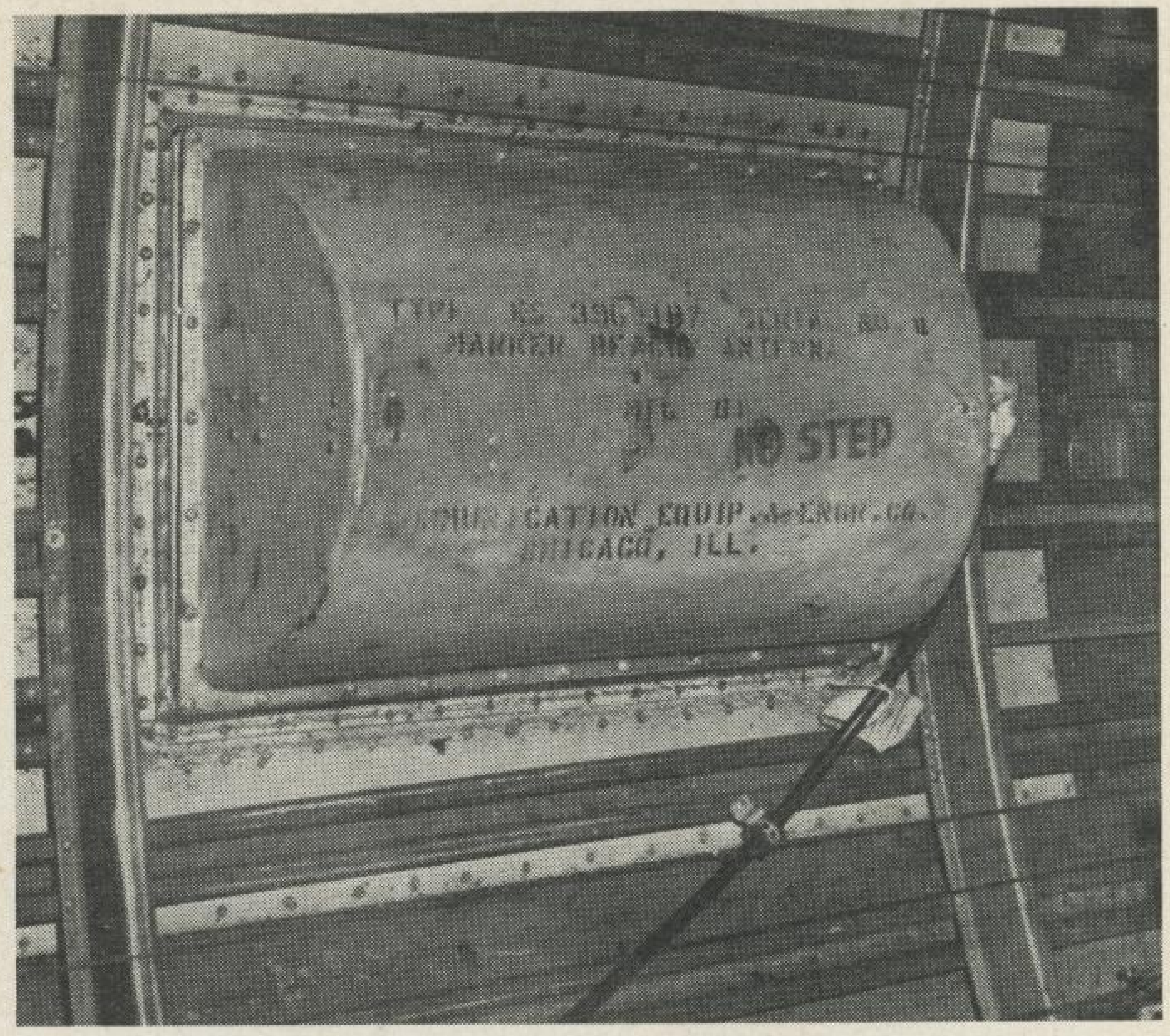

Fig. 4—Interior view of marker antenna installation.

Figure 7 shows the antenna pattern at right angles to the line-of-flight. The pattern in this plane would be expected to be completely symmetrical about the 90° radial. Any small deviation observed in Fig. 7 is believed to be due to irregularities in the test equipment and measurement technique.

The antenna was designed to be mounted with the bakelite cover flush with the skin of the airplane. It was found during the CAA certification tests, however, that water sprayed on the cover at the high impedance end of the antenna caused a considerable decrease in pickup. When the antenna was moved inward approximately 1¾ inches, it was found that this undesirable effect was reduced to a satisfactory degree. Since practically all aircraft fuselages are curved at the locations desirable for the flush-mounted marker antenna, it imposes no particular hardship to mount the antenna back of the bakelite window in the skin.

The C-54 antenna installation shown in Figs. 4 and 5 required the Bendix MN-61A marker receiver to be set at a sensitivity of 165 microvolts for proper timing of the Z marker. This sensitivity was measured with a Measurements Corporation Model 80 signal generator with the 6-decibel pad in use.

III. MARKER TESTING

It is necessary to periodically check the over-all performance of the aircraft marker installation to be sure that the system is working satisfactorily.

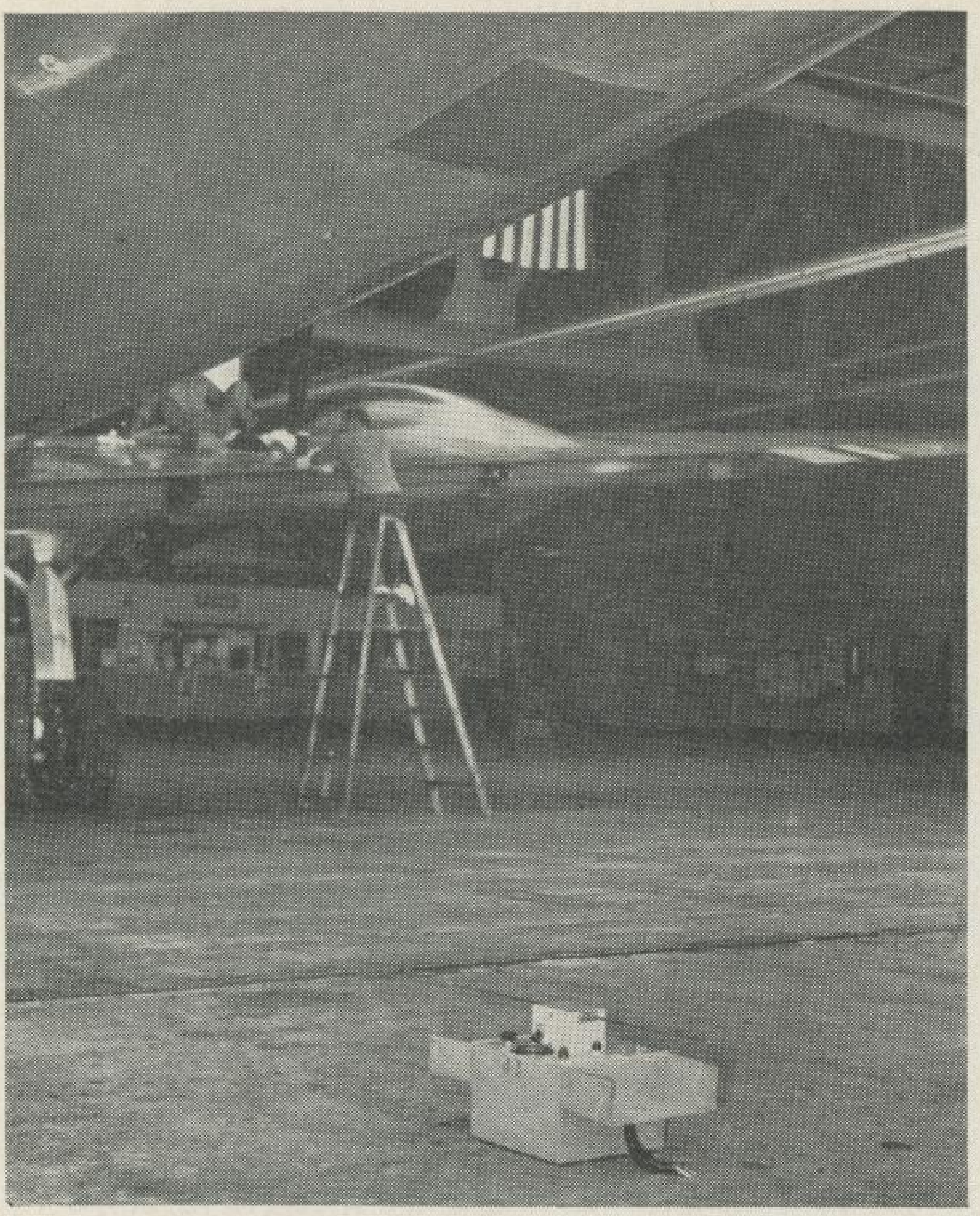

FIG. 5—Exterior view of marker antenna installation and marker tester.

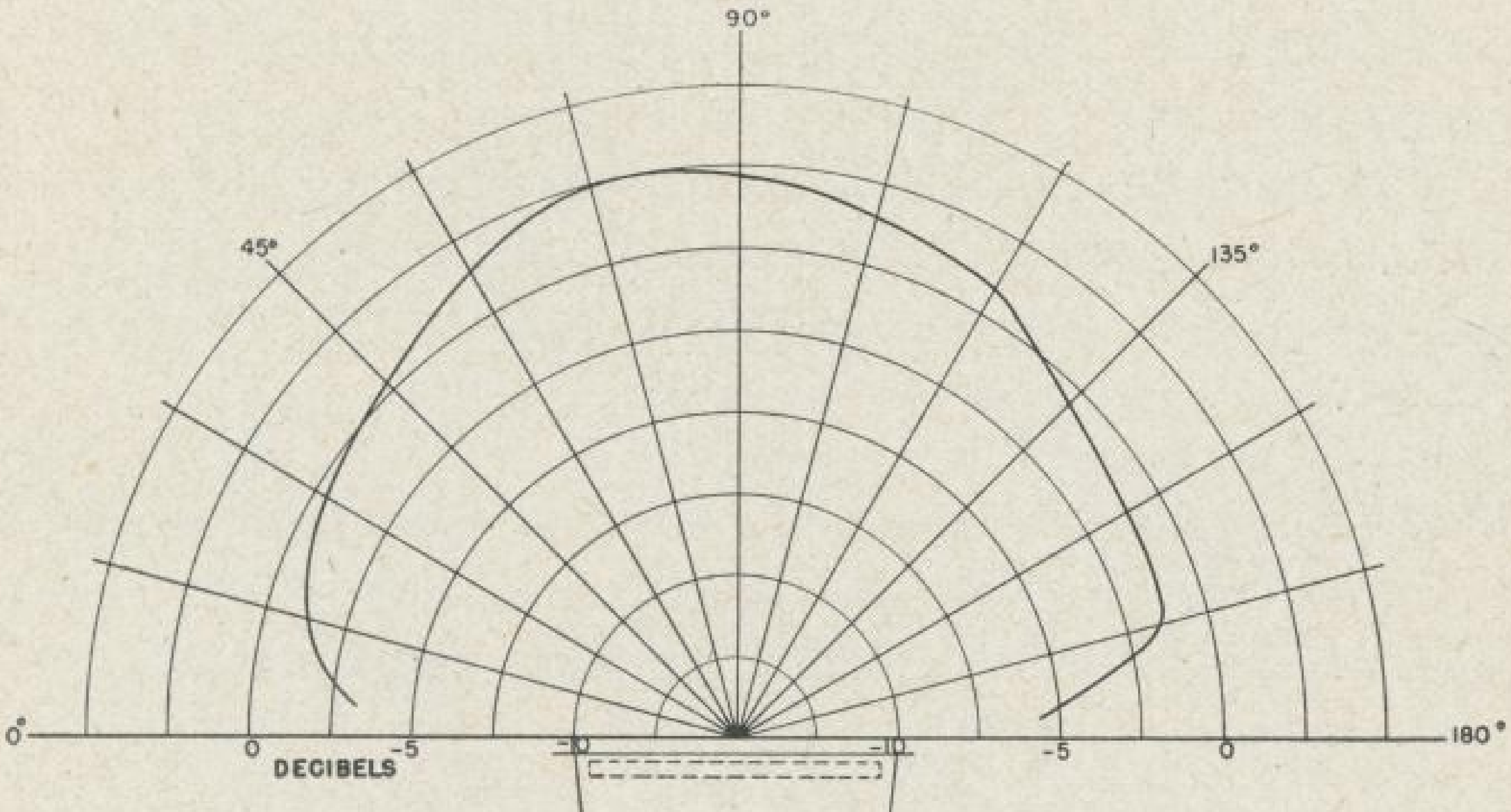

FIG. 6—Field pattern of flush-mounted antenna in a vertical plane containing the pickup rod.

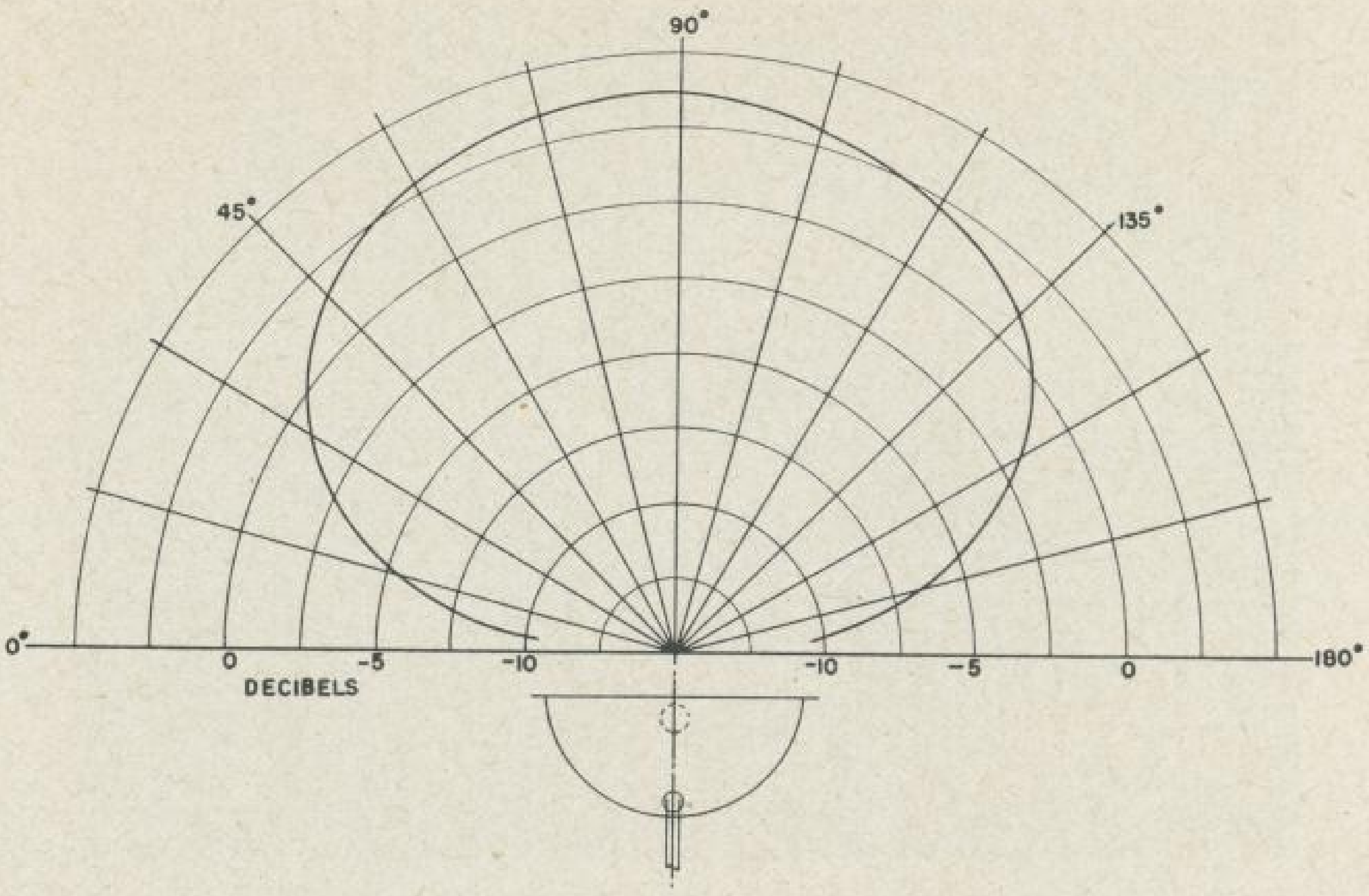

Fig. 7—Field pattern of flush-mounted antenna in a plane perpendicular to the plane of the pickup rod.

It is desirable to know that the over-all sensitivity of the system is correct and that the white, amber, and purple lights respond to 3000-, 1300-, and 400-cycle modulation. One test unit used is a portable, battery operated tunable oscillator whose audio modulation of 3000, 1300, and 400 cycles-per-second is selected by manually operated switch. A telescoping antenna is used to radiate the signal. The output is controllable and is indicated roughly by the radio-frequency oscillator grid current. Another test unit described by C. W. McKee in the November 1942 issue of Communications is crystal-controlled and has a motor driven modulation switch that automatically runs through the sequence of modulation frequencies. In the hands of a skilled radio mechanic these units give reasonably satisfactory performance.

A new marker tester has been designed that combines the good features of previous units. In addition some improvements have been added that almost completely remove the human element from the testing process. This new marker tester is a battery operated portable unit that is crystal-controlled and used automatic modulation frequency switching. Two important features are added to the unit that previous ones have not had however. A diode voltmeter is used to measure the voltage delivered to the antenna, and the automatic modulation switch also changes the radio-frequency output between two predetermined values. In the high output position the indicator light in the cockpit should be illuminated, in the low output position it should be dark. This procedure brackets the over-all system sensitivity and thereby determines whether the system is in satisfactory operating condition.

Figure 8 shows the ES-436 Marker Tester that has just been described. It is placed directly underneath the marker antenna. The motor driven switch rotates continuously through four positions: 400 cycles-per-second high output; 1,300-cycle high output; 3,000-cycle high output; and

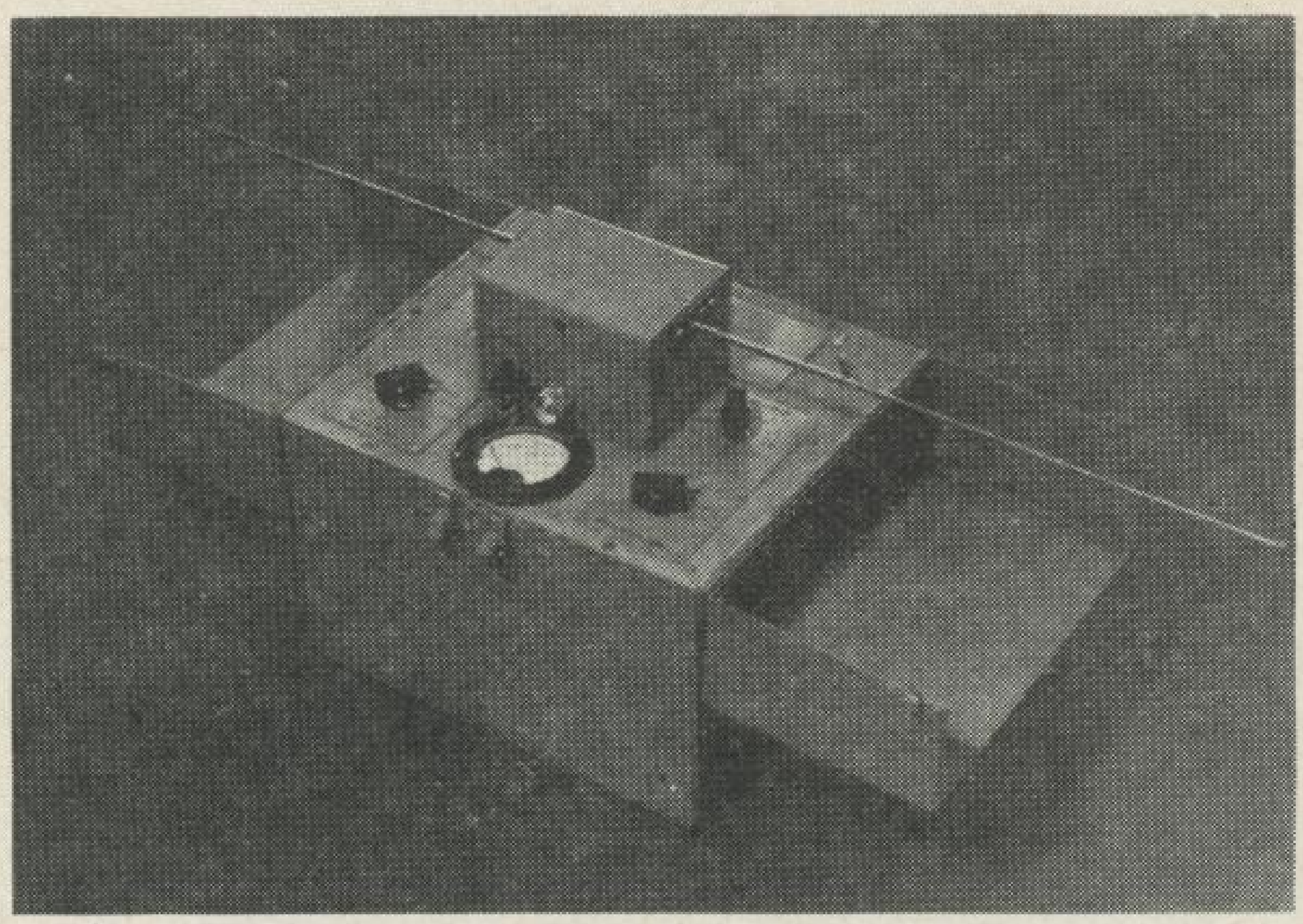

FIG. 8—The ES-436 marker tester.

3,000-cycles low output. In use the radio-frequency voltage at the antenna is set to a predetermined value on the meter in the high output position. With the Marker Tester so adjusted and placed under the marker antenna as shown in Fig. 5, it is only necessary to observe the white, amber, and purple lights in the cockpit to know the condition of the aircraft marker system.

Let us consider an airplane equipped with a marker system installation flying in a straight line that will pass directly over a marker station on the ground. This is shown in Fig. 9. The equation shown expresses the relation-

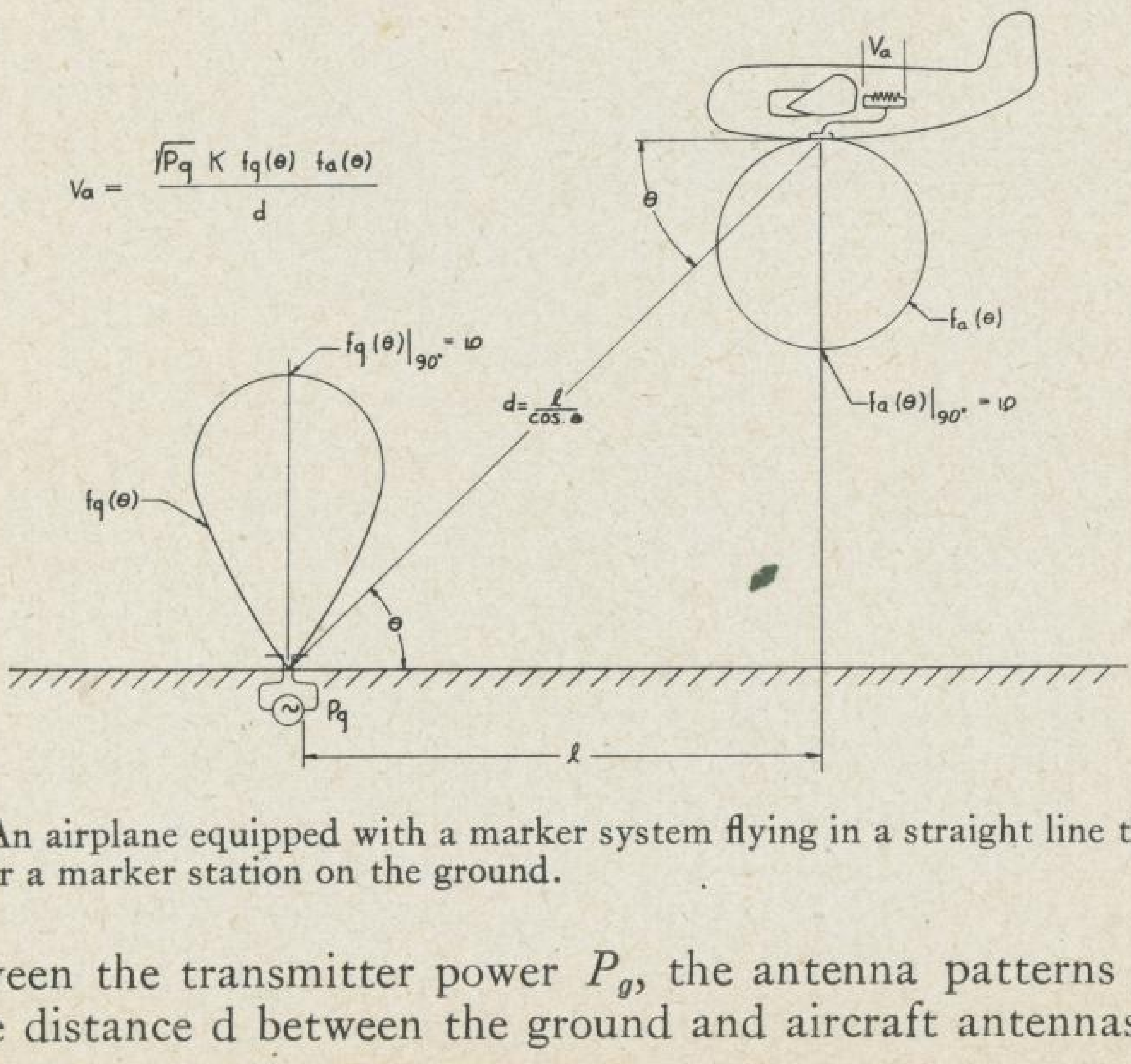

FIG. 9—An airplane equipped with a marker system flying in a straight line that will pass directly over a marker station on the ground.

ship between the transmitter power P_g, the antenna patterns $f_g(\theta)$ and $f_a(\theta)$, the distance d between the ground and aircraft antennas, and the voltage V_a delivered to the marker receiver antenna input circuit. The point to be brought out is that the pattern of the aircraft antenna and the pattern of the ground antenna play an equal part in determining the final space pattern. It must follow then, that it is desirable to know what the aircraft antenna pattern is. It can be seen, also, that it is desirable to place most of the required antenna directivity on the ground. The pattern of the aircraft antenna is fixed in relation to the aircraft. As the attitude of the aircraft changes its associated antenna pattern also changes. If this pattern is sharp, erratic marker indications may be obtained.

The work described in this paper was done while the author was employed at United Air Lines. Thanks are due United and the Director of the Aircraft Radio Laboratory at Wright Field for authorizing the publication of this material.