CIVIL AERONAUTICS AUTHORITY

Technical Development Report No 14

THE DEVELOPMENT ADJUSTMENT, AND APPLICATION OF THE Z-MARKER

By W E JACKSON and H I METZ
Radio Development Section

Formerly Report No 16, Safety and Planning Division, Bureau of Air Commerce, Department of Commerce, Reprinted by the Civil Aeronautics Authority

JULY 1938

UNITED STATES GOVERNMENT PRINTING OFFICE
WASHINGTON 1941

CONTENTS

The Development, Adjustment, and Application of the Z-Marker

SUMMARY

The Z-marker was developed to meet the need for a positive position indicator for aircraft operating under instrument flying conditions which would otherwise have to depend entirely upon the "cone of silence" as an indication of passage directly over a range station The marker consists of a low power transmitter and directive antenna array, operating on a frequency of 75 megacycles, which projects a vertical beam through which aircraft will pass when flying over the range station A special single frequency receiver, without tuning controls, provides both aural and visual indication

Ultra-high-frequency Z-markers were first installed experimentally at several radio range stations in 1934 and 1935 In 1936 and 1937, important improvements were made in antenna systems and transmitter frequency stability In April 1938, at Allentown, Pa , the first commercially manufactured Z-marker was installed and commissioned for regular service operation Based on the results of the experimental installations, these final markers have a simplified antenna system, and a dual automatic transmitter, designed to give continuous unattended service After conducting tests, several air lines prepared specifications and purchased an initial order of receivers suitable for utilizing these markers in routine scheduled flights

INTRODUCTION

There exists directly above every radio range station (Fig 1) a small zone known as the "cone of silence" in which no signal is present This zone was not considered of consequence in the early development of the radio range system, but it soon proved to be a valuable aid to airmen navigating entirely by instruments, as it gave a definite "fix" from which to start their let-down, or approach to the airport Dead reckoning is not sufficiently accurate for this purpose

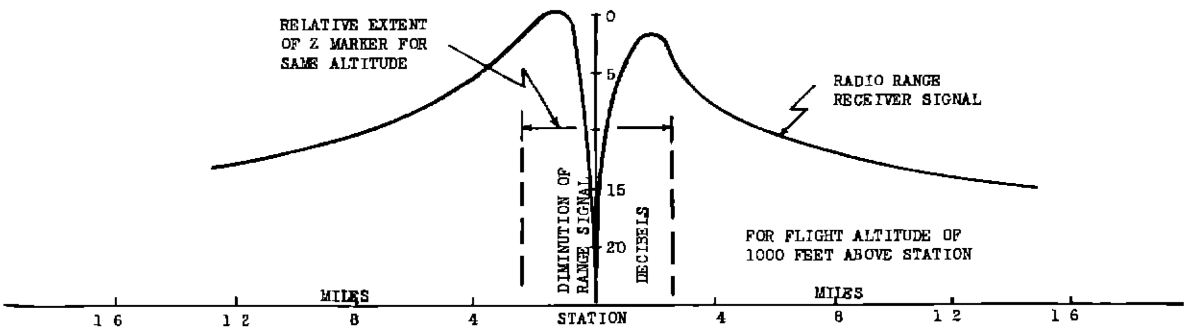

Figure 1 —Cone of silence data—Hartford radio range (operating nonsimultaneously)

Although the "cone of silence" is a fortunate byproduct of the radio range system, it is, after all, a negative indication so far as the aircraft receiver is concerned A result similar to that produced by the "cone of silence" may occur due to a faulty receiver, a drop in the aircraft battery voltage, a momentary failure of the transmitter, or by a "fade" caused by cancellation of a direct ray by an indirect ray reflected from mountains Furthermore, it has been found that at low altitudes the "cone of silence," as used in an approach to an airport, is so small in area, that it is difficult to locate. At high altitudes the "cone of silence" widens to such an extent that as a position check it becomes even less reliable. It has been considered desirable for many years to supplement the "cone of silence" with a positive signal.

In 1934, installations of experimental "cone of silence" markers, later designated as "Z" markers, were made at the following radio range stations:

Washington, D. C.	Pittsburgh, Pa.
Newark, N. J.	Oakland, Calif.
Chicago, Ill.	Salt Lake City, Utah.
Kansas City, Mo.	

The equipment consisted of a simple radio oscillator using only two tubes operating from the range station 110 volt a. c. power supply. The frequency was 93 megacycles and the modulation 60 cycles. The antenna system consisted of two "H" type arrays (Fig. 2) elevated ¾ wavelength above ground and arranged at right angles to each other. Originally parasitic reflectors ¼ wavelength below the antenna system were used. The transmission line length to the two arrays differed by 90 electrical degrees, so that reception in an airplane would be relatively equal, regardless of direction of approach.[1] The antenna used on the airplane to receive these marker signals is shown in Fig. 3.

In connection with the development of the Army Air Corps instrument landing system at Wright Field, location markers operating on 75 megacycles were used. In this development, special emphasis was placed on the simplicity of the aircraft marker receiver and marker transmitter. An output of approximately 20 watts was used in the marker transmitter, so that a simple, relatively insensitive and nonselective single tube receiver could be used on the airplane. A view of this receiver is shown in Fig. 4. The only vacuum tube, a detector,

[1] Cone of Silence Marker—*Penders Electrical Engineering Handbook,* III Edition, Sec. 16–42.

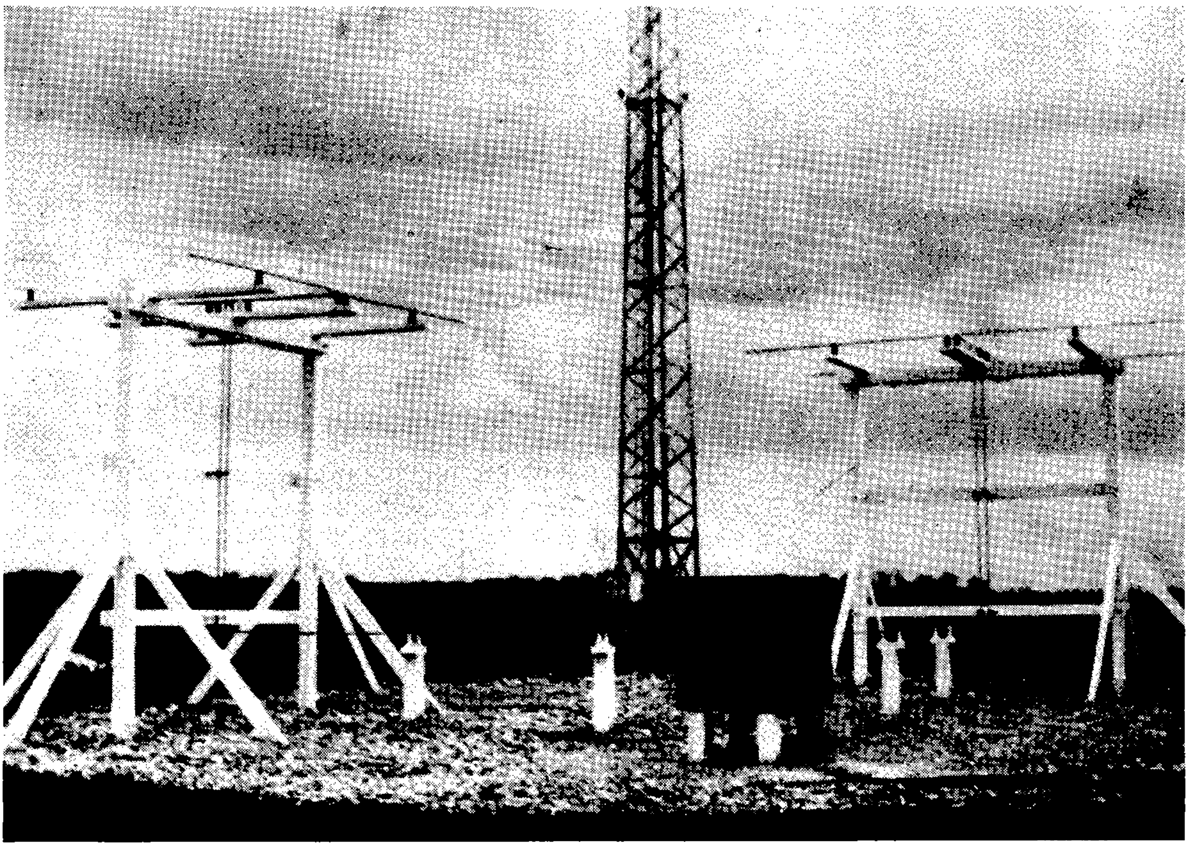

Figure 2.—Original H-type array.

is located inside the streamlined housing, which forms the central support of the doublet antenna. The indicator consisted of a small lamp mounted in an instrument case and covered normally by an electrically operated shutter or vane.

Simplicity of the receiving equipment for commercial transport and itinerant aircraft use was also considered of extreme importance; however, it was believed that a more sensitive and selective receiver was essential, in order to provide a more reliable indication, and to permit the development of a "fan type"[2] marker which would not require an unreasonable output power. A power up to about 100 watts was considered to be economically feasible for fan markers. It was also concluded that all markers should be operated on a single common frequency in order to permit the use of a single marker receiver. As a result, Z-markers, fan markers, and instrument landing inner and outer markers were all designed to operate on 75 megacycles.

In 1936, the Bureau continued work on the Z type marker. The results accomplished may be summarized as follows:

1. The frequency was changed from 93 megacycles to 75 megacycles.
2. The antenna system was simplified and and improved.
3. Correct transmitter power and receiver sensitivity, to allow use of both fan and Z-markers on a single fixed aircraft receiver, were determined.
4. A receiver suitable for both fan and Z-markers was provided.

[2] *Technical Development Report No. 5*—"The Development of Fan Type Ultra-High-Frequency Markers."

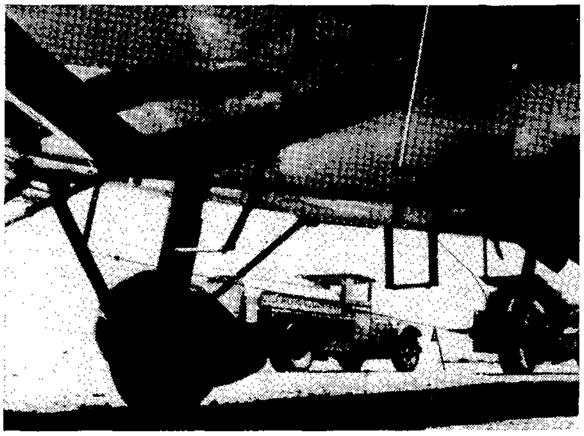

Figure 3.—Original airplane antenna for marker service.

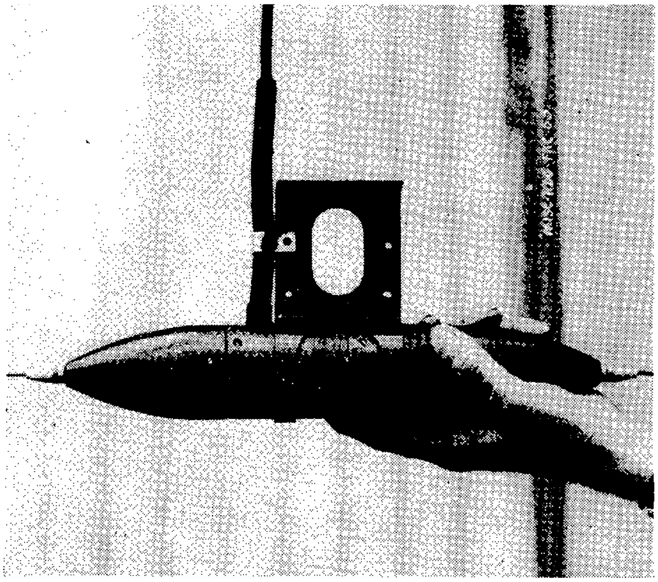

***Figure 4.—Original army marker receiver.* Stream-lined case contains detector tube and forms support for doublet antenna.**

In carrying out this work, a new and simplified transmitting antenna system was devised, and a counterpoise and radio transmission line was developed that would permit stable operation of the antenna under all weather conditions, including snow and sleet, which ordinarily make close supervision necessary. A suitable crystal-controlled transmitter was designed to work with the new antenna and, as a conclusion to the project, specifications were prepared from which a quantity of dual equipments were purchased for installation throughout the country. A suitable receiver was developed and used in all flight tests described in this report.

APPARATUS

The various types of antenna systems tried out in the course of the development are shown in the attached drawings. Fig. 5a shows the original H type array which operated on 93

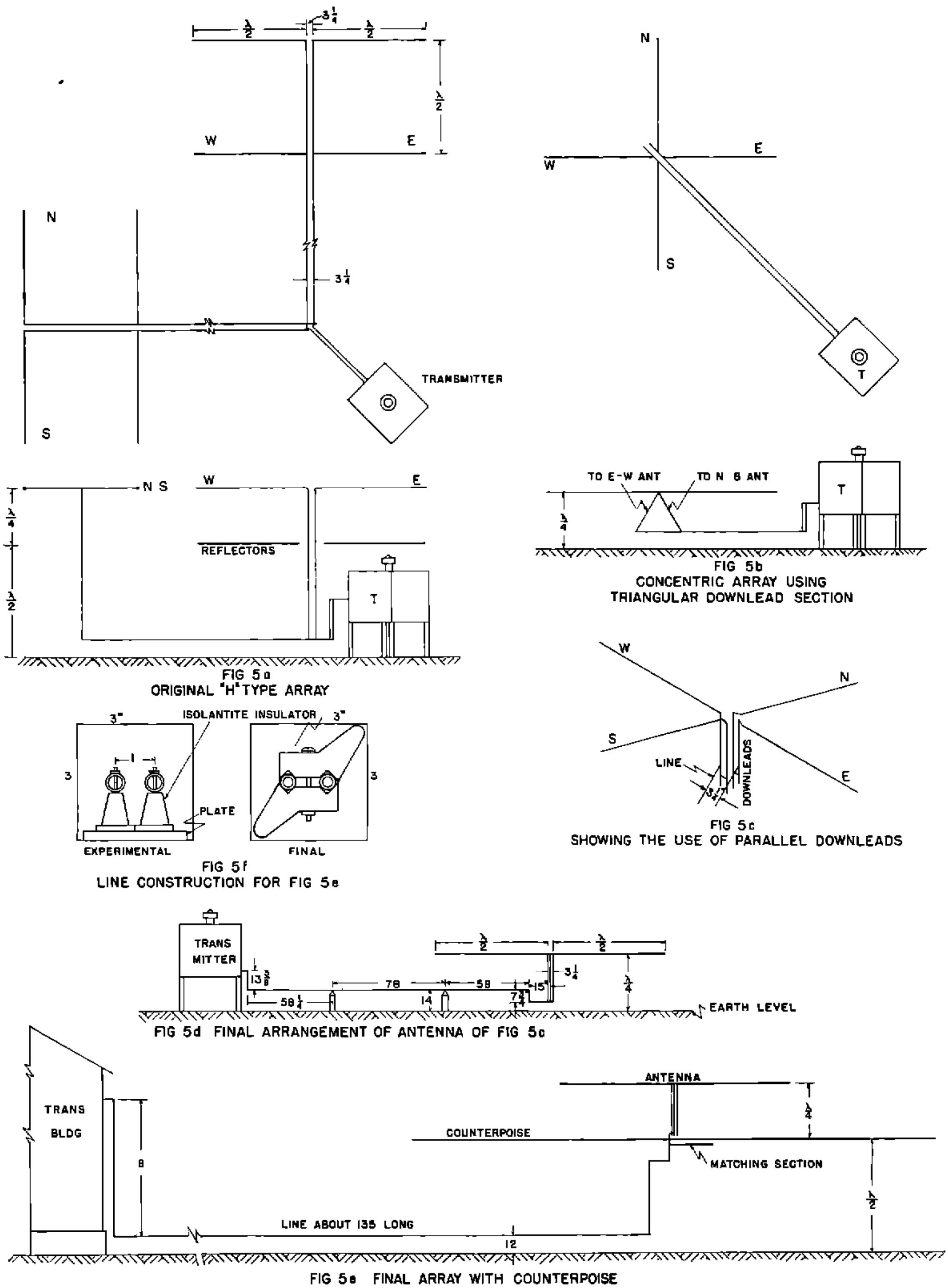

Figure 5.—Schematic diagrams of arrangements investigated

megacycles This type of antenna was also tested on 75 megacycles without parasitic reflectors, both at ¾ and ¼ wavelength above ground Fig 5b shows a simplified antenna designed to combine the electrical centers of the north-south and east-west radiators in an attempt to eliminate lobes that existed in space when using earlier types of physically spaced antennas A simplification of this last antenna is shown in Fig 5c This is the type that was finally adopted

Exposed copper tube transmission lines were used in the original tests These consisted of two half-inch seamless tubes, spaced 3¼ inches apart, and supported 10 to 14 inches above ground on Isolantite insulators The insulators were placed at points of zero voltage, as shown in Fig 5d, no attempt being made to terminate correctly the transmission line

The final array is as shown in Fig 5e The antenna is of the same type as in Fig 5d, but is erected ¼ wavelength above a coarse (3″×3″) mesh screen, and is connected to the remote transmitter through a shielded line that is correctly terminated The counterpoise provides an effective level reflector for the antenna, yet allows snow to fall through and vegetation to grow beneath, avoiding the change of pattern which these elements would otherwise produce The transmission line is a pair of half-inch seamless copper water pipes, spaced 1 inch apart and supported centrally in a 3″×3″ copper shield A cross section is shown in Fig 5f

The measurable features of the various antennas on which experiments were conducted are Frequency, antenna currents, line currents and field pattern shape and dimensions Frequency stability of a high order was not essential for the original market plans Accurately calibrated wavemeters, type AC–105, were used to set the frequency of the transmitter These wavemeters were similar to General Radio Company type 419–A, but were modified and accurately calibrated at the National Bureau of Standards The circuit is shown in Fig 6 When crystal-controlled transmitters were adapted to this marker service, the accuracy of these wavemeters was obviously inadequate, and accuracy of frequency was dependent upon the accuracy of the fundamental crystal frequency

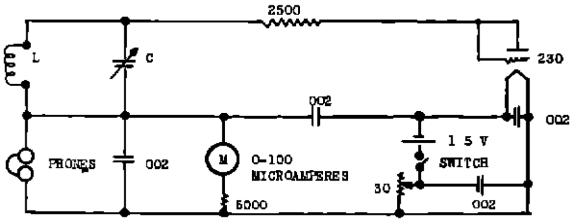

Figure 6.—Type AC–105 frequency meter

The antenna current required for final Z-marker service was found to be relatively low The actual current was never measured, because relative values only were required, and it is rather difficult to measure the actual current These relative values were obtained by clipping a low-reading (Weston 0–120 Model 425) R F milliammeter to the centers of the antenna rods It was found that the reading of the instrument could be increased about five times by series tuning The arrangement employed is shown in Fig 7

Rough ground checks of the radiated signal were made with an elevated rotatable pick-up antenna as shown in Fig 8

Relative line currents along the transmission line were measured on a tuned R F milliammeter, mounted on a carriage, as shown in Fig 9 A section of line shield, remote from the antenna, was opened at the top to allow use of this pick-up device

Relative patterns of the vertically radiated beam were obtained by flights in Bureau airplanes The receiving equipment consisted of a longitudinal wire below the belly of the ship, a short lead-in, and a receiver The receiver used is shown in Fig 10, its schematic diagram in Fig 11 General characteristics of this receiver were published in the Air Commerce Bulletin of February 1937 The receiving antenna in early tests consisted of a ½-wavelength wire with the lead-in tapped slightly off center Final tests were made with a doublet, using a concentric transmission line, as shown in Fig 12 Fig 13 illustrates an improved arrangement of the same type antenna A discussion of output indica-

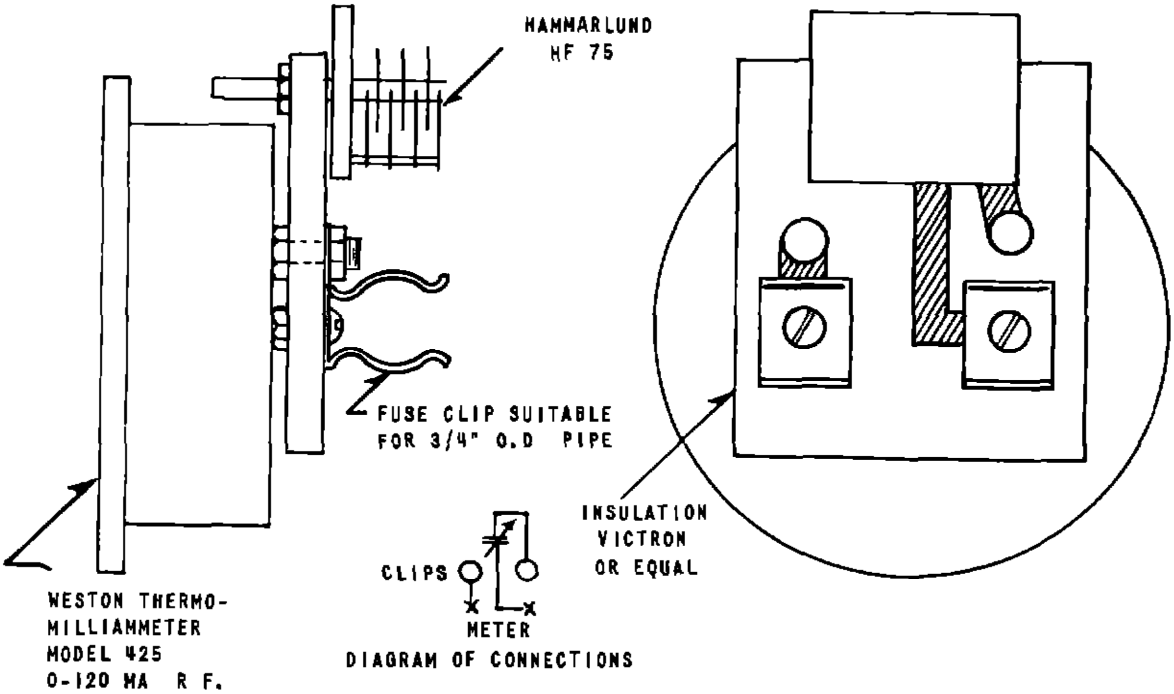

Figure 7 —Instrument for measuring marker antenna currents

tors developed for use with these receivers is contained in *Technical Development Report No 5*

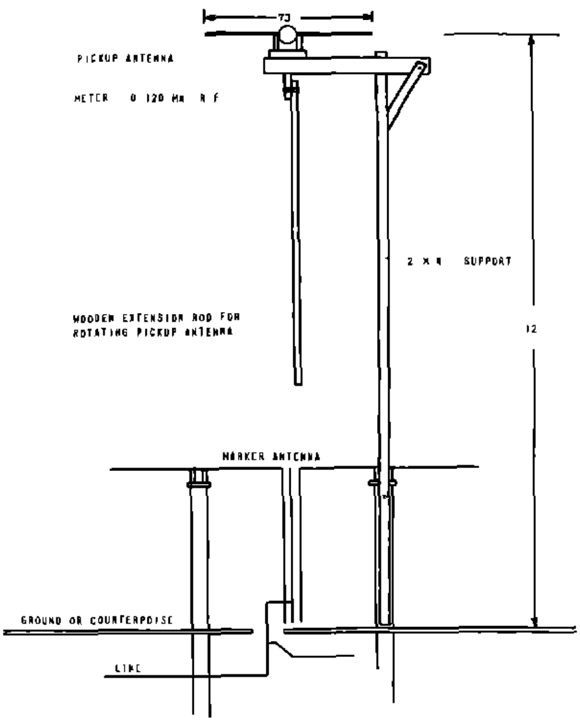

Figure 8 —Elevated rotatable pick-up antenna

TESTS

When tests were made to determine the characteristics of a given transmitting antenna system, flights were generally made at odd altitudes, starting at 1,000 feet, and in eight directions of approach toward the station Time was measured from the instant the marker light on the aircraft came on until it extinguished The duration of light for flights in opposite directions was averaged and the pattern dimension was taken to be the distance traversed during the mean lighted period In doing this, partial compensation was made for the effect of wind

On most flights, graphic records of receiver output were made directly on an Esterline-Angus recording milliammeter which had been equipped with an amplifier and rectifier for this purpose With this recording device, it was possible to detect and study irregularities in the pattern that were neither evident in visual checking with the indicator lamp nor in listening to variations in the aural output of the receiver

In all flights made when using the H type of antenna array shown in Fig 5a, dead spots or lobes were observed It was believed that these were the result of the physical displacement of the two north-south and east-west antenna elements at the transmitting station It appeared desirable to combine the elements so that they would occupy a common center, and yet produce the effective, nondirectional polarization of the signal

In order to obtain quadrature currents, the array shown in Fig 5b was set up The four radiating elements (north, east, south, and west) were each made approximately ½ wavelength, actually 73 25 inches, which is equivalent to

$$0\,93 \times \frac{\lambda}{2}$$

The value of 0 93 was found to be approximately correct for maximum current in the four doublets

The north and south doublets were connected to the transmission line through a length of line that was shorter than that connecting the east and west elements The correct difference in the lengths of these two lines was determined experimentally After adjustment of this array, the following antenna currents were observed

North	40
South	48
East	40
West	40

It was found that variation of antenna currents resulted from slight displacement of the downleads from the antenna elements Actually, the reasonably good current balance indicated above was obtained by slightly shifting the downlead positions While the mechanical arrangement of the antenna system did not ap-

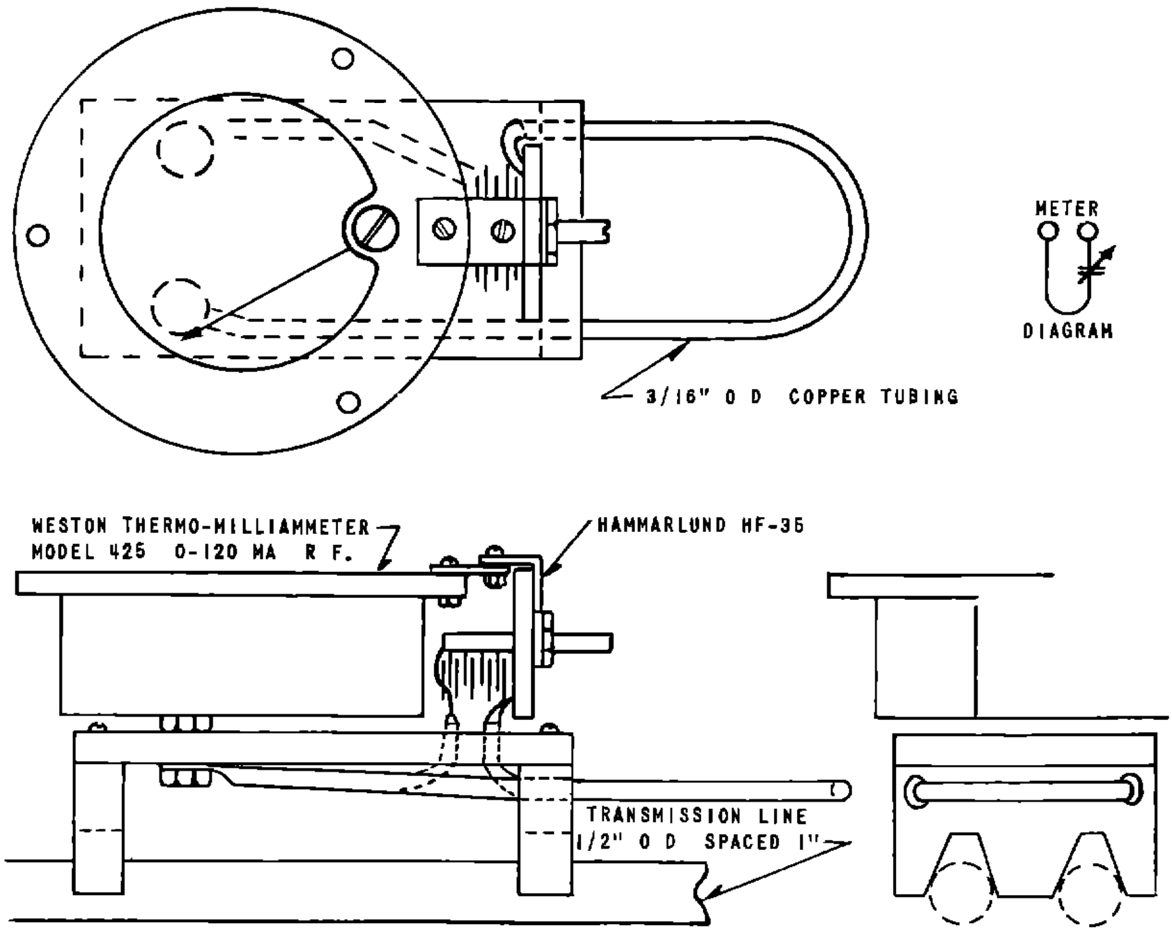

Figure 9 —Instrument for measuring transmission line current

pear entirely stable or desirable, flight checks were made which showed the relative pattern dimensions as plotted in Fig. 14. Two of the tory. The only objectionable feature was the awkward mechanical arrangement of the downleads.

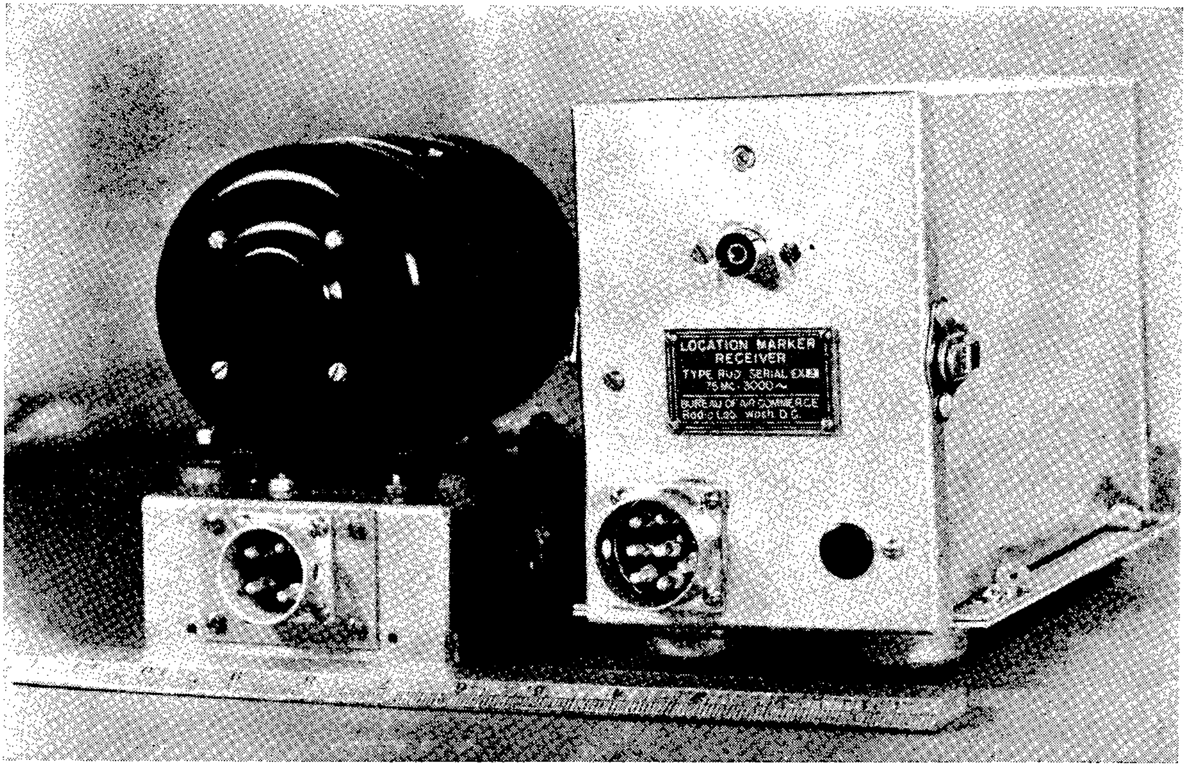

Figure 10.—Ultra-high-frequency marker receiver type RUD.

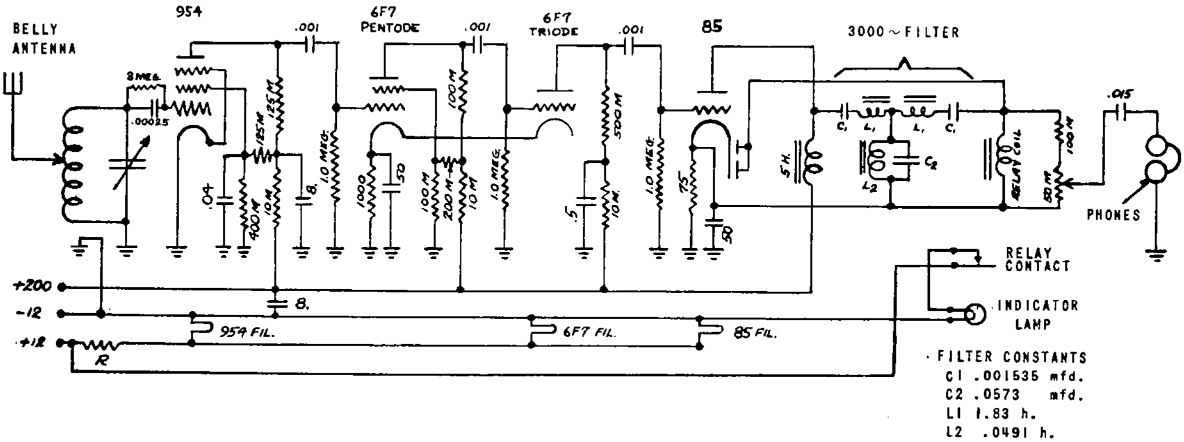

Figure 11.—Schematic diagram type RUD marker receiver.

amplitude recordings made during these flights are included in the same figure. It will be seen from the recordings that the results obtained from this antenna system were quite satisfac-

A new arrangement of the antenna system, shown in Figs. 5c and 15, was set up and adjusted. It was found possible to support the antenna and downlead system rigidly, and to

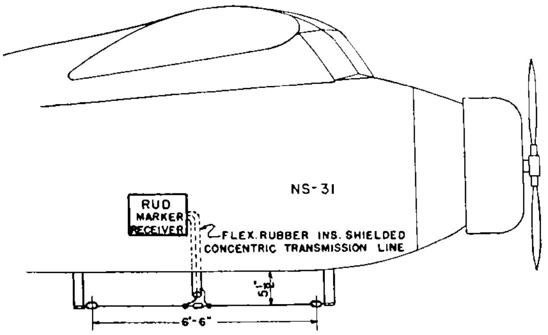

Figure 12.—Sketch of marker receiving antenna on NS-31.

perform all tuning adjustments on the system, by variation of the straps on the downleads and the position of the transmission line along the downleads. The former adjustment directly affects the balance of currents in the adjacent antenna rods, while the position of the transmission line along the downleads determines the relative phasing of currents. The actual operation of performing this adjustment is outlined later in the test and installation procedure. The adjustment is relatively simple, in that the links on the downleads are moved until the currents, as measured in adjacent antennas, are equal; then the transmission line position is varied until the current in an elevated

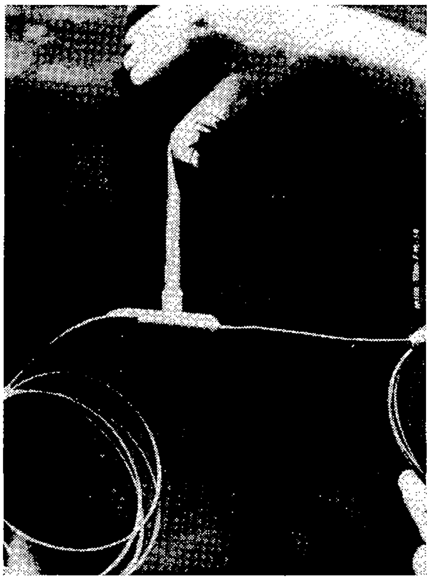

Figure 13.—Improved design marker receiver belly antenna. Rigid concentric line forms central support for doublet.

pick-up antenna is constant, regardless of its orientation.

Many flight checks were made of this final antenna system. The general results obtained are as indicated in Figs. 16 and 17. The graphic records made on one group of flights are shown in Fig. 18. It will be observed from these curves that the signal is relatively uniform, and contains no observable lobes that might cause erratic operation of the marker

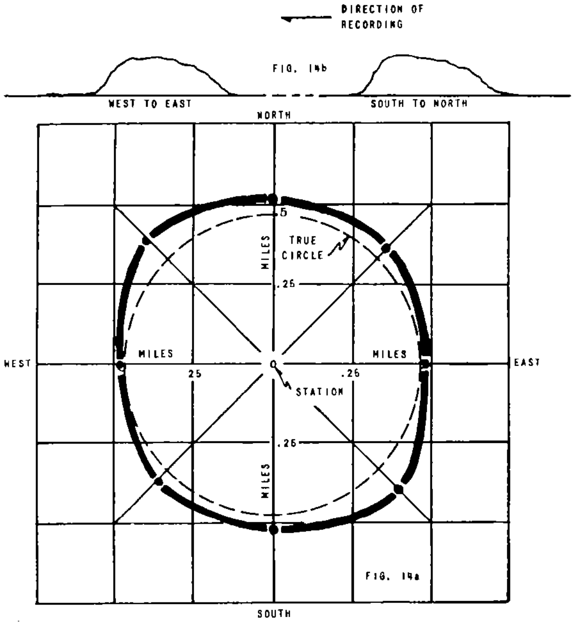

Figure 14.—Relative pattern of experimental marker signal and two of the graphic records.

signal lamp in the airplane. Three experimental installations (Chicago, Kansas City, and Newark) of this type of marker were made in November and December 1936, and comparable results were obtained in each case. All use 3000-cycle motor alternators for plate supply. Reliability of the transmitters has been demonstrated by satisfactory operation of these stations for approximately 16 months. The average tube life in the transmitters is about 5,000 hours.

All tests thus far described relate to an antenna system placed above smooth earth. The last mentioned antenna system was elevated ¼ wavelength (1 metre) above ground and connected to the transmitter through about 32 feet of open wire transmission line. The transmitter consisted of a simple 75-megacycle oscillator as shown in Fig. 19 (Schematic diagram in Fig. 20). A relay rack type of

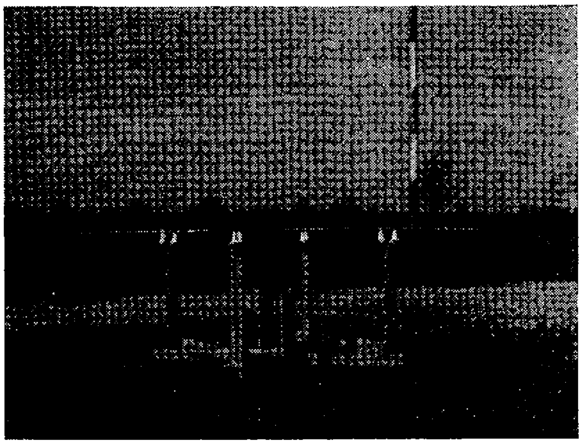

Figure 15a.—The final experimental antenna structure before being placed in the ground.

crystal-controlled transmitter, type TZA, was designed and built for further tests on these markers. A view of this transmitter is shown in Fig. 21, and its diagram in Fig. 22. It has an available output of approximately 25 watts, and derives its modulating frequency from a self-contained 3000-cycle vacuum tube oscillator. The original oscillator transmitter in Fig. 19, which was mounted in a small aluminum box, was replaced by the relay rack type crystal-controlled transmitter mounted in a 7′×7′ frame building. It was immediately found that irregularities existed in the pattern in flights made across the station parallel to the direction (northwest) of the transmission line feeding the antenna system. The irregularities did not appear in flights perpendicular to this direction. The presence of the tall relay rack, which measured approximately ½

Figure 15b.—The antenna of figure 15a after being installed and adjusted at the Washington radio range station.

wavelength in height, was suspected as a contributory cause of these irregularities When the equipment originally mounted on the relay rack was divided into two groups and mounted on a wooden rack having half the original height, as shown in Fig 21, it was found that the irregularities disappeared Graphic records made before and after the change in the relay rack are shown in Fig 23 It was obvious that the antenna must be removed from tall metallic objects a sufficient distance so that these reflections would not occur It was concluded that as long as the metallic equipment within about 50 feet of the antenna did not project above the level of the antenna system, no difficulty would be experienced from reflections It should be noted here that in subsequent tests of the Z-marker, in which the antenna system was placed on the radio range plot, in the proximity of five 125-foot steel radio range towers, no effect of consequence could be observed from reflections In this case, the marker antenna was centrally located with respect to three of the towers,

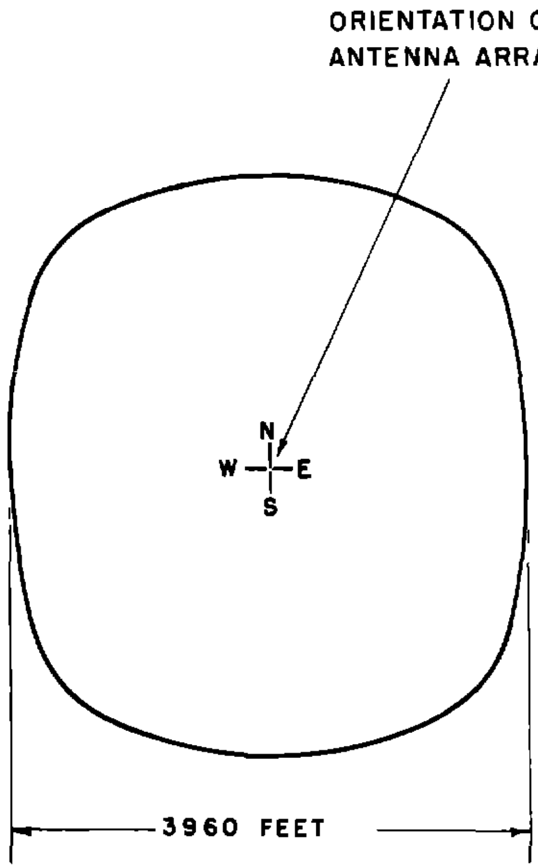

Figure 16—Z-marker horizontal pattern at 3,000 feet as obtained from transmitting antenna of figures 5c and 5d

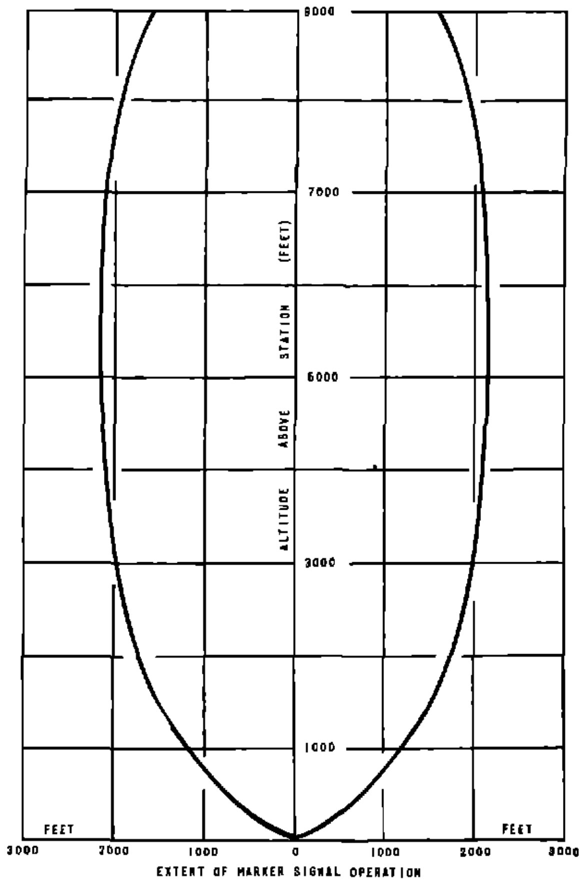

Figure 17—Relative vertical pattern of experimental marker using antenna as in figure 5d

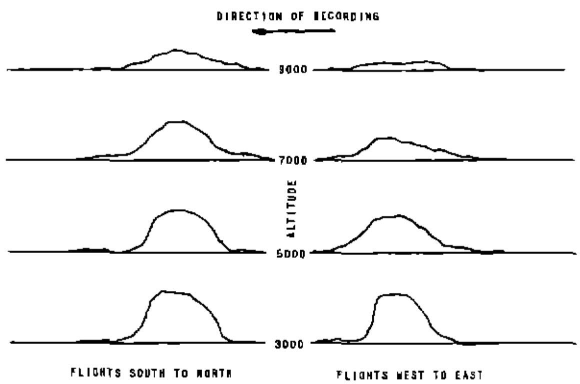

Figure 18—Copies of graphic records made on flight tests of array shown in figure 15 and used in preparing the pattern curves of figures 16 and 17,

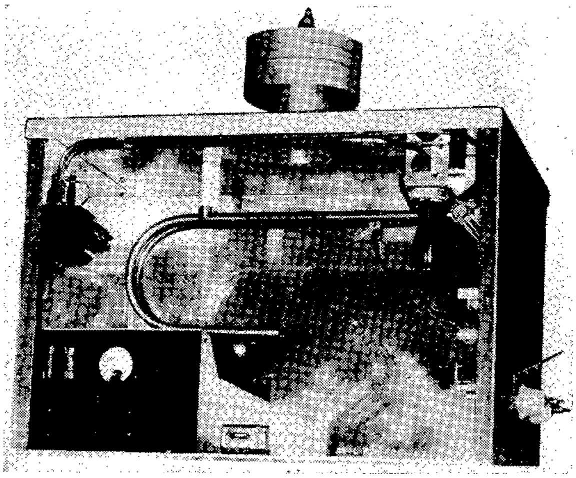

Figure 19.—Original ultra-high-frequency transmitter for marker service.

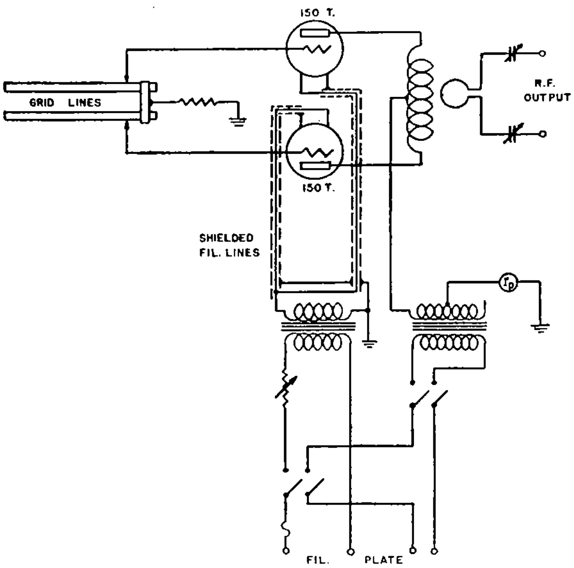

Figure 20.—Type THL 75 mc marker transmitter schematic diagram.

the distance to the towers measuring about 135 feet.

In order that the equipment would not be affected by snow and vegetation growth around the antenna system, two possible arrangements were considered and investigated. First, a small frame house was built over the antenna system in order that the antenna would be protected. The structure is shown in photographs, Figs. 24 and 25. Flights over the system, after construction of the shelter, indicated that the pattern was substantially the same as that when the antenna was exposed. Since this work was done in 1937, it has not been possible to observe the possible change of pattern with the accumulation of snow around and on top of the building, because snowfall has been negligible since its construction. The set-up is being retained for further observations.

A second method of avoiding these adverse conditions was to elevate the antenna system and erect a suitable large-mesh screen counterpoise which would provide a uniform reflecting surface through which snow would readily fall. A set-up of this counterpoise was made and is shown in the photograph, Fig. 26. The details of the counterpoise system are shown in Fig. 5e. In making the counterpoise installation, it was considered desirable to investigate operation of the array at a considerable distance from the transmitter, in order that in ultimate installation of these markers, the transmitter could be placed in the range station with the antenna sufficiently removed from the building and center tower of the range system to avoid pattern distortion. Accordingly, the counterpoise system shown in Fig. 26 was placed approximately 70 feet from the transmitter and

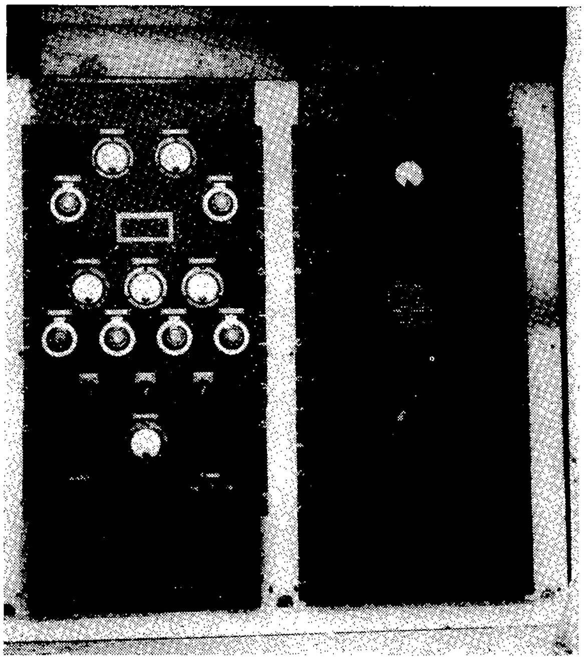

Figure 21.—Experimental crystal controlled Z-marker transmitter type TZA.

was connected by means of a two-conductor shielded transmission line spaced approximately one foot above the ground The line construction details are shown in Fig 5f

The same methods of adjusting the counterpoise antenna system were adopted as in the former antenna system The additional operation of correctly terminating the transmission line at the antenna was performed in order that standing waves would not be present in the line Details of the methods and results concerning this termination are given later under antenna adjustment Flight tests of the counterpoise antenna system gave results similar to those of the former array

RECEIVER SENSITIVITY ADJUSTMENT

Correct receiver sensitivity was considered to be very important in the proper operation of the marker system The greatest uncertainty in the operation of the system was the possible marker receiver response to signals other than those of the marker transmitter The pilot would then receive inaccurate or misleading information concerning his position The receiver originally developed for this marker service did not possess extreme selectivity inasmuch as it was considered desirable that the receiver be light, simple, and certain to respond to signals of the marker transmitters, which in their early form were not crystal controlled

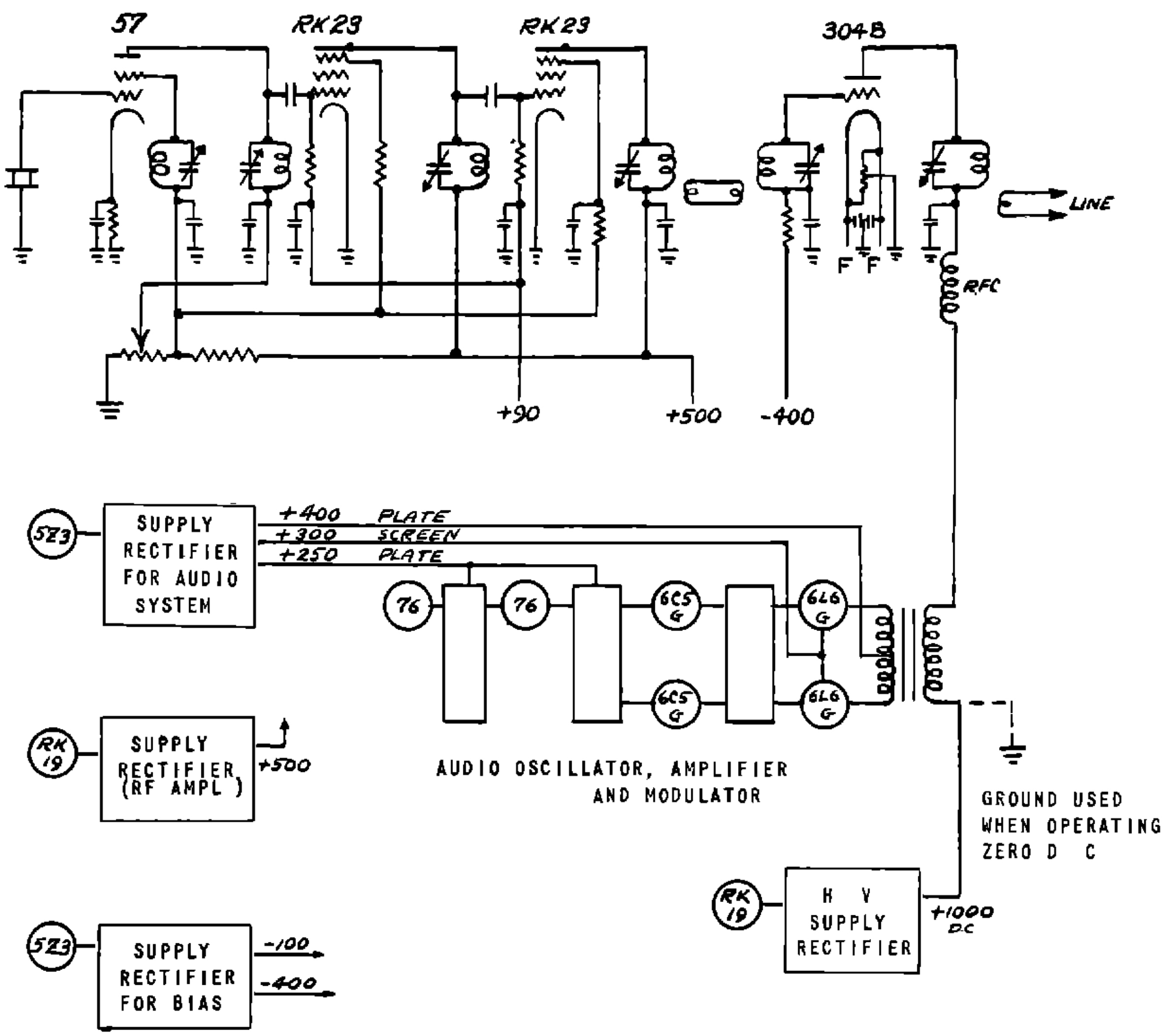

Figure 22—Schematic diagram of type TZA marker transmitter

Most of the receiver discrimination against undesired signals was obtained through the use of a modulation frequency of 3000 cycles, a frequency considerably removed from that of other classes of service, together with the insertion of a good 3000-cycle electrical filter in the output of the receiver. The remainder of the selectivity was obtained by means of a tuned radio-frequency input circuit. With this amount of audio and radio selectivity, the receiver sensitivity could be reduced considerably below that which would cause any flashing

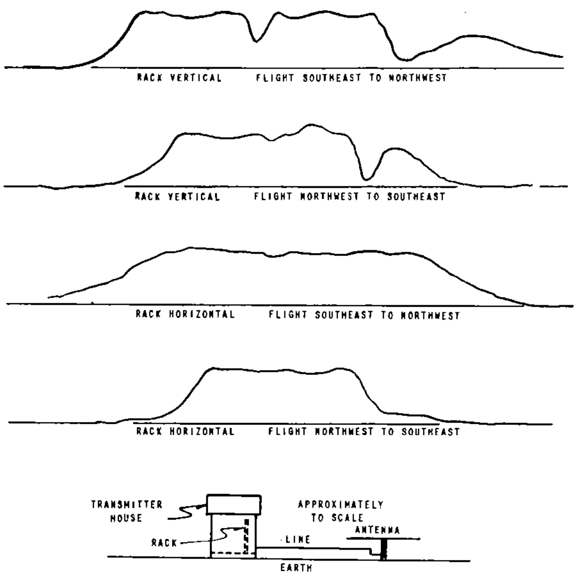

Figure 23.—Copies of graphic records showing the relative effect of the presence of the vertical relay rack in the vicinity of the transmitting antenna.

of the indicator lamp when flying directly over powerful ultra-high-frequency telegraph transmitting stations and over the 65-megacycle teletypewriter beam signals of the Bureau station at Silver Hill, Md. When the sensitivity had thus been reduced, it was found to measure approximately 1400 microvolts on the Ferris Type 18B signal generator. This sensitivity was then assumed to be the correct safe value, and the marker transmitter power adjusted to give the desired size of marker pattern with such a receiver.

In addition to the sensitivity investigation as outlined in the foregoing, it was necessary to

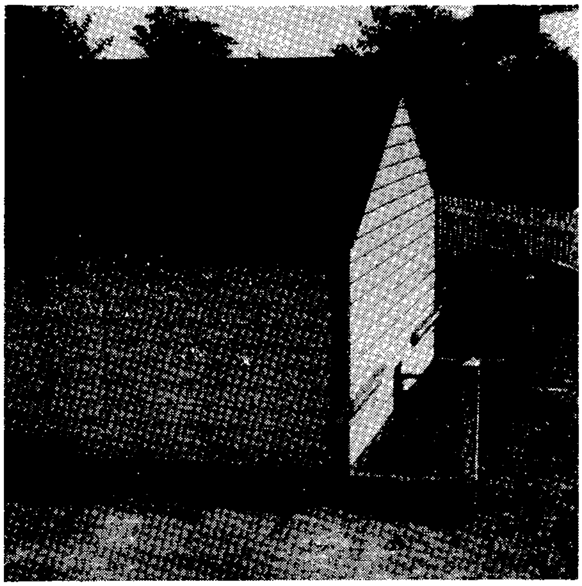

Figure 24.—The experimental shelter to protect the transmitting antenna from the elements.

arrive at a sensitivity that would accommodate operation of the receiver on fan marker signals of the type described in *Technical Development Report No. 5*, and a sensitivity that would not require too great a power at the fan marker station to provide the desired patterns. The

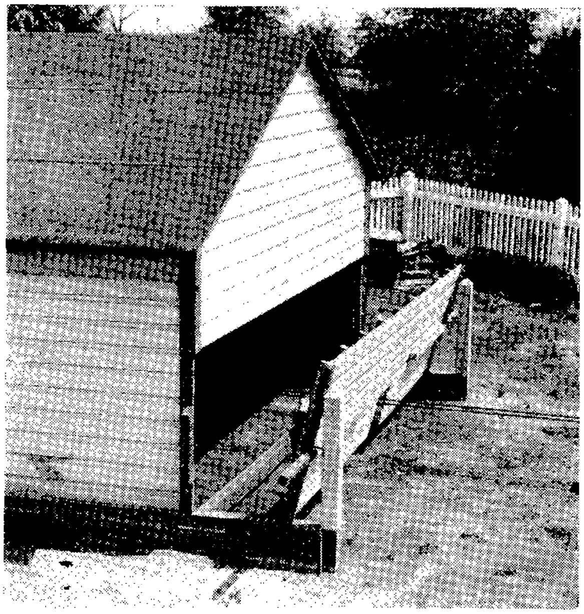

Figure 25.—The shelter showing removable section which allows the complete house to be withdrawn on its skids during adjustment of the antenna.

value of 1400 microvolts, as indicated, appeared to be satisfactory in all respects.

MARKER POWER ADJUSTMENT

In adjusting the output of the marker transmitter to provide the required pattern size in accordance with the receiver sensitivity outlined above, it was observed that an antenna current of approximately 10 milliamperes was required. This corresponded to a plate power input of approximately 7 watts at the transmitter, the plate supply to the power amplifier tube being 3000 cycles a. c., zero d. c. No d. c. voltage was used on the power amplifier stage in order that the percentage of modulation on the transmitter signal would remain constant. Final specification for this type of transmitting equipment, however, was made to include a d. c. plate voltage in order to avoid possible future difficulty from modulation harmonics, particularly after installation of approach markers which will operate with 400- and 1300-cycle modulation.

The antenna current referred to in the foregoing was measured by clipping the antenna meter directly on the antenna rods at their center. This method does not indicate the true current in the antenna, but is a relative value which is satisfactory for the adjustment of the marker pattern. In order actually to read a current value this low with the instruments available, it was necessary to series tune the meter with an arrangement as shown in figure 7, and as described under APPARATUS.

ADJUSTMENT OF THE ANTENNA SYSTEM

Considerable experience has been gained as a result of the adjustment of the four experimental Z-marker installations at Washington, Newark, Chicago, and Kansas City, and the adjustment of the first commercially made Z-marker installation at Allentown, Pa. As a result of this experience, precise procedure has been developed for the adjustment of this type of antenna as described herewith.

Adjustment of current balance.

Fig. 27 illustrates the factors involved, and the adjustments available for this type of antenna array. It will be noted in Fig. 27a that

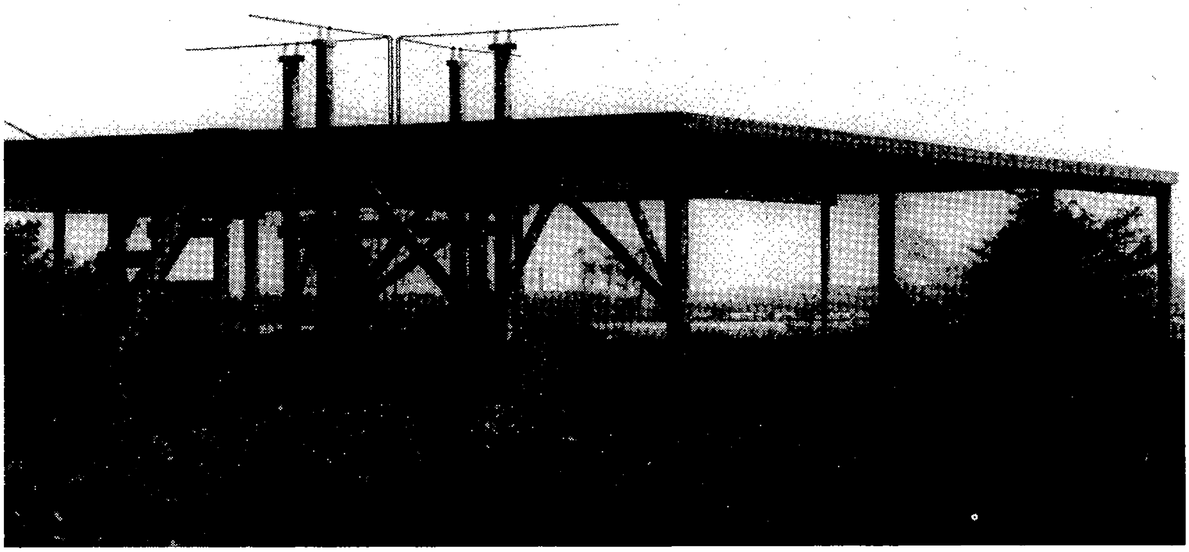

Figure 26.—The experimental counterpoise system as installed at Washington radio range station.

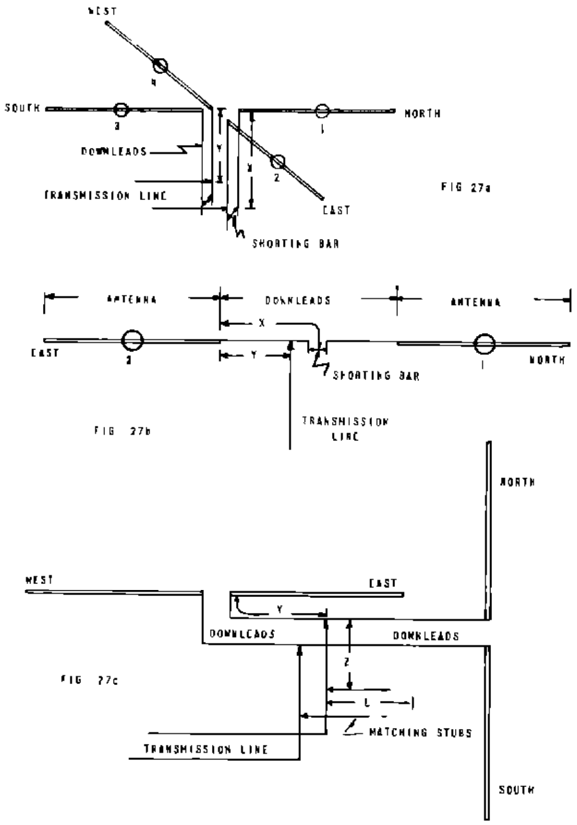

Figure 27—Schematic arrangement of transmitting antenna showing the factors involved in adjustment

there are four antennas, north, east, south, and west, with their respective downleads The north and east antennas are connected by means of a shorting bar The south and east antennas are also connected by a shorting bar The antennas are each ½ wave in length and the downleads are each ¼ wave long In Fig 27b, the north and east arrays have been drawn in a straight line with their respective downleads to illustrate the fact that the total over-all length is approximately 3 half-wave lengths The first adjustment involved is the making of this dimension exactly 3 electrical half-wave lengths for the north-east section and the south-west section

It was found by experiment that the correct length of the antenna rods for operation in this array is approximately 73 25 inches This dimension is measured from the end of the rod to the center line of the downlead Dimension X, as indicated in Figs 27a and 27b, is measured vertically from the center line of the antenna along the downlead to the center line of the shorting bar With the transmission line position (Y) remaining fixed, the position of the shorting bars (dimension X) is varied until approximately equal currents are obtained in the four antenna meters, 1, 2, 3, and 4 It will be observed from Fig 27b that when a correct dimension X is obtained, the antenna meters 1 and 2 will read equal values of current[3] in the north and east antennas respectively The same condition holds for the meters 3 and 4 on the south and west antennas, although the absolute values of currents in the north-east array and the south-west array may be different If the currents in the four antennas are plotted with respect to dimension X, curves resembling those of Figs 28a and 29a will be obtained The correct position for the shorting bar is that at which the respective current curves cross In

[3] *"Single Wire Transmission Lines"* Proc I R E vol 17 No 10 October 1929

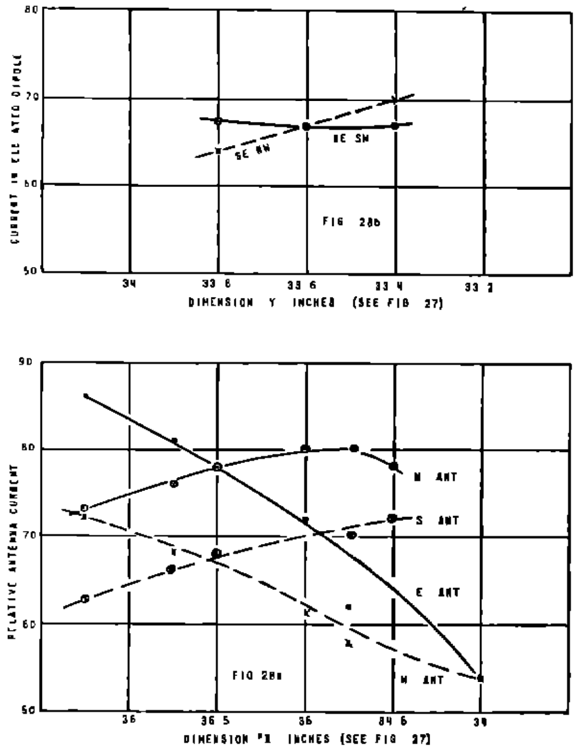

Figure 28.—Currents observed during adjustment of Chicago experimental Z-marker Antenna, downleads, and line were ½ inch outside diameter

Fig 28a, the dimension is 35 5 inches, and in Fig 29a, it is 37⅞ inches

In measuring the antenna currents, a meter, as illustrated in Fig 7, is used and it is clipped on the antenna rod approximately at the center of the rod It is believed that the correct position for this type of meter is that which gives equal current readings when attached to either side of the antenna rod Only a few tests are required to determine this position The exact position is not of very great importance, however, so long as the position of the meter is the same on the respective antennas The readings of the antenna current meters are changed by a person standing in the vicinity of the antenna and it is therefore necessary that the operator step back clear of the antenna system for each reading It has been found convenient and satisfactory to observe the adjacent antenna readings, for example, north and east from one position of the operator, and the readings for south and west antenna from a diagonally opposite position

A variation of the position of the downleads has considerable effect upon the relative currents in the four antennas It is important that the downleads be accurately spaced,

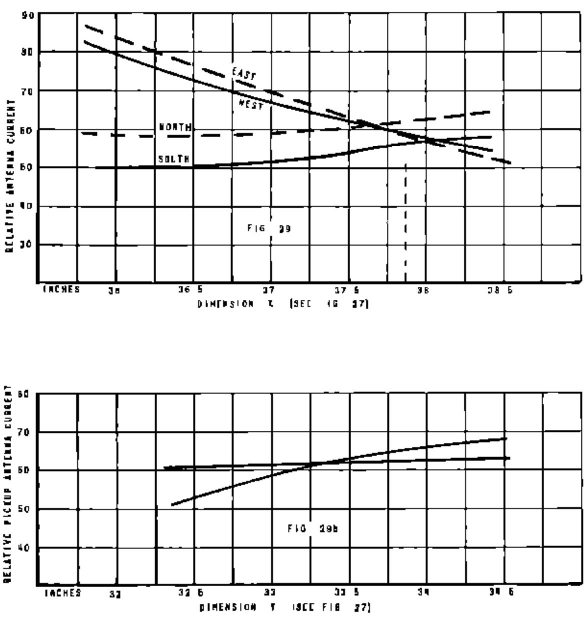

Figure 29—Curves of currents observed in adjusting Allentown Z-marker Antenna and downleads were ¾ inch outside diameter tubing Transmission line was ½ inch outside diameter tubing

parallel to each other, and perpendicular to the plane of the antenna system

The adjustment of phasing

The phasing adjustment is accomplished by variation of the position of the transmission line tap on the downlead system The effect of phasing is observed by means of a rotatable pick-up antenna as illustrated in Fig 8 and by actual flight check of the pattern after completion of antenna adjustments The phasing of currents in the antenna system directly affects the strength of signal that is received by the pick-up antenna in the quadrants defined by the respective antenna rods For example, in Fig 27a this would be in southwest-northeast and northwest-southeast directions The correct adjustment of phasing (dimension Y, Fig 27) can be obtained by observing the relative pick-up currents in these two directions If dimension Y is varied while observing currents in the pick-up antenna for these two directions, a curve can be plotted as shown in 28b and 29b The correct dimension Y is that where the two curves cross 33 6 inches for Fig 28b and 33⅜ inches for Fig 29b When the correct phasing position has been determined, relative pick-up in all directions can be observed and plotted as illustrated in Fig 30 It will be observed in Fig 30b, that while the phasing is correct as indicated by the equality of currents in the northeast-southwest and northwest-southeast directions, the north-south current is somewhat greater than the east-west current This is probably caused by the slight unbalance in the actual antenna currents as shown by the arrows in Fig 30 A difference of the magnitude indicated in Fig 30, however, is insignificant in the actual use of the marker

Termination of the transmission line

The third adjustment in connection with the antenna system is the proper termination of the transmission line so as to remove reflections and standing waves from the line This is accomplished through the use of matching stubs as indicated in Fig 27c

The position of the matching stubs Z from the point where the transmission line is connected to the downleads and the length L of

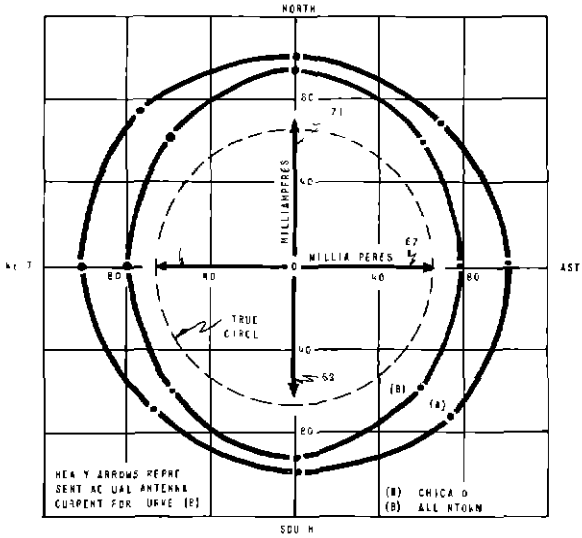

Figure 30—Relative patterns obtained on Chicago and Allentown Z-markers using rotatable pick-up antenna

the matching stubs are both critical The procedure in determining the correct dimensions Z and L involves first the measurement of standing waves on the line at a point on the line remote from the antenna system A section of the transmission line shield approximately 80 inches long must be removed to allow this operation A suitable meter to measure the line currents is shown in Fig 9 As this meter is moved along the line, currents are observed which if plotted will resemble the curve of Fig 31a This represents the condition existing with no matching stubs applied to the terminal end of the line The ratio of maximum to minimum current is approximately 10 1 As the correct adjustment for the matching stubs is approached, the currents observed along the line resemble those shown in Fig 31b The desirable termination is that which gives a straight line or equal current for all readings along the line Actually the best termination that has been obtained is that giving a ratio of maximum to minimum 1 05 1

In adjusting the matching stubs, the first procedure is to assume a given length L and, while holding this length constant, to vary the position Z along the line, observing for each position the ratio of maximum to minimum current on the line A typical curve of the results of this procedure is plotted in curve No 1, Fig 32a The best position, it will be observed, is for a dimension of Z equal to 13¼ inches The next procedure is to secure the dimension Z at this best value, 13¼ inches, and vary length L over a considerable range observing, for each dimension of L, the line current ratio For the series of adjustments of L, a curve resembling that of No 1, Fig 32b, will be obtained

Additional values of dimension Z must then be taken, and for each value the line ratio for several lengths of "L" must be observed From this information, a group of curves similar to curves 1 2 and 3 of Fig 32b can be plotted From curves 1, 2, and 3 a curve similar to curve 2 of Fig 32a can be plotted, this curve representing the minimum or best line ratio for each of the curves 1, 2, and 3 of Fig 32b It is apparent from curve 2 of Fig 32a that the optimum dimension Z is

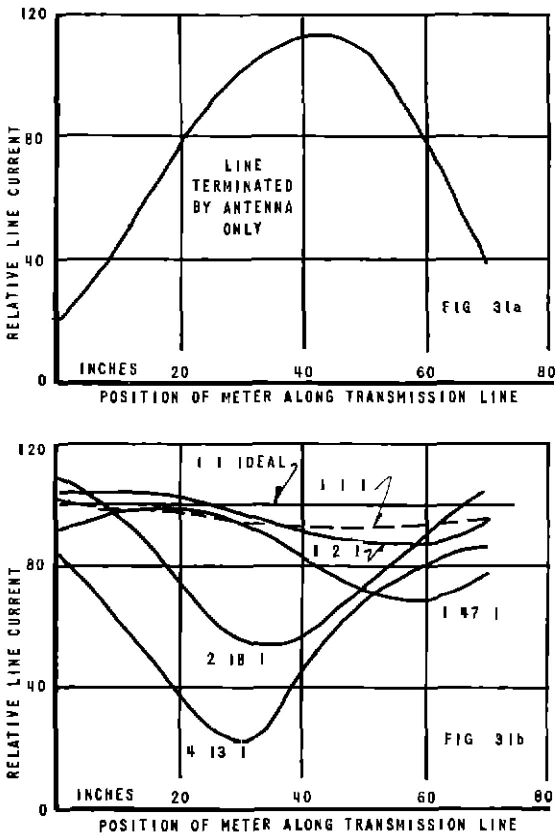

Figure 31—Curves of transmission line current readings

approximately 11½ inches for the antenna on which these measurements were made It will also be observed from the curves of Fig 32b that the optimum dimension from length L will be approximately 23¼ inches

In making the adjustments described in the foregoing procedure, it was noted that there was some reaction between the various adjustments When one adjustment was made, other adjustments had to be rechecked to insure that they were still correct A particular example of this occurred in the dimensions X and Y, in which considerable change in antenna current balance resulted from a change in dimension Y, when the dimension Y was changed to any great extent, after finding and setting dimension X at an optimum value

It also has been noted that in making adjustments for line termination, it is essential that the terminating stubs be supported during initial adjustments by the insulators that

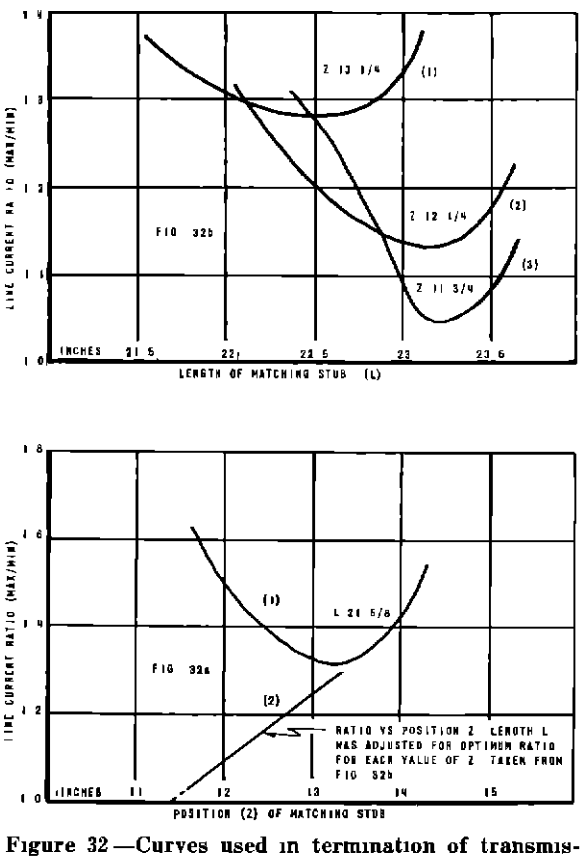

Figure 32—Curves used in termination of transmission line

are to be used after the final adjustment Unless this is done, the capacity of the end caps and clamps of the matching stub supporting insulators (see Fig 37), added to the matching stubs, will seriously upset the matching of the line impedance

RESULTS

Tests on first commercially made installation, Allentown, Pa

The first commercial installation made for the Bureau at Allentown, Pa , as shown in the photograph, Fig 33, illustrates the final form of this development The details of construction are shown in Figs 34 to 39, inclusive The transmitter is shown in the photographs, Figs 48 to 51, inclusive Notes have been added to each illustration to make it self-explanatory Figs 37 and 38 illustrate the parts of the antenna system on which the adjustments of current balance, phasing, and line termination are accomplished

Careful adjustment of the downleads (see Fig 40), to bring them exactly parallel and perpendicular to the plane of the antenna system, is essential The use of the elevated pick-up antenna illustrated in Fig 41 requires the use of a transit or surveyor's hand level for observing the current in the pick-up antenna instrument Observation of this current through a hand level from the outer edges of the counterpoise system was found to be convenient and satisfactory

Line current ratios were measured by means of a pick-up device shown in Fig 9 and photograph, Fig 42 It was observed that considerable inaccuracy of line current readings resulted when the sides of the transmission line shield were allowed to change position with respect to the loop of the pick-up device In cutting open a long section of the transmission line, such as is necessary for these measurements, it is obvious that side walls of the shield will not remain in their normal straight line It was necessary to use spacing blocks, as illustrated in Fig 43, to maintain the correct side wall spacing necessary for reliable readings Several blocks, with correctly spaced slots cut in them, were used along the opening of the line, as shown in Fig 44

It should be noted that some difficulty was experienced in obtaining a good balance of antenna currents, and a good ratio of line currents, with the transmitting equipment as originally delivered for installation at Allentown. It was necessary to rearrange the leads between the output coupling coil of the transmitter and the transmission line terminals so that these leads were short, straight, and of equal length. The original arrangement of

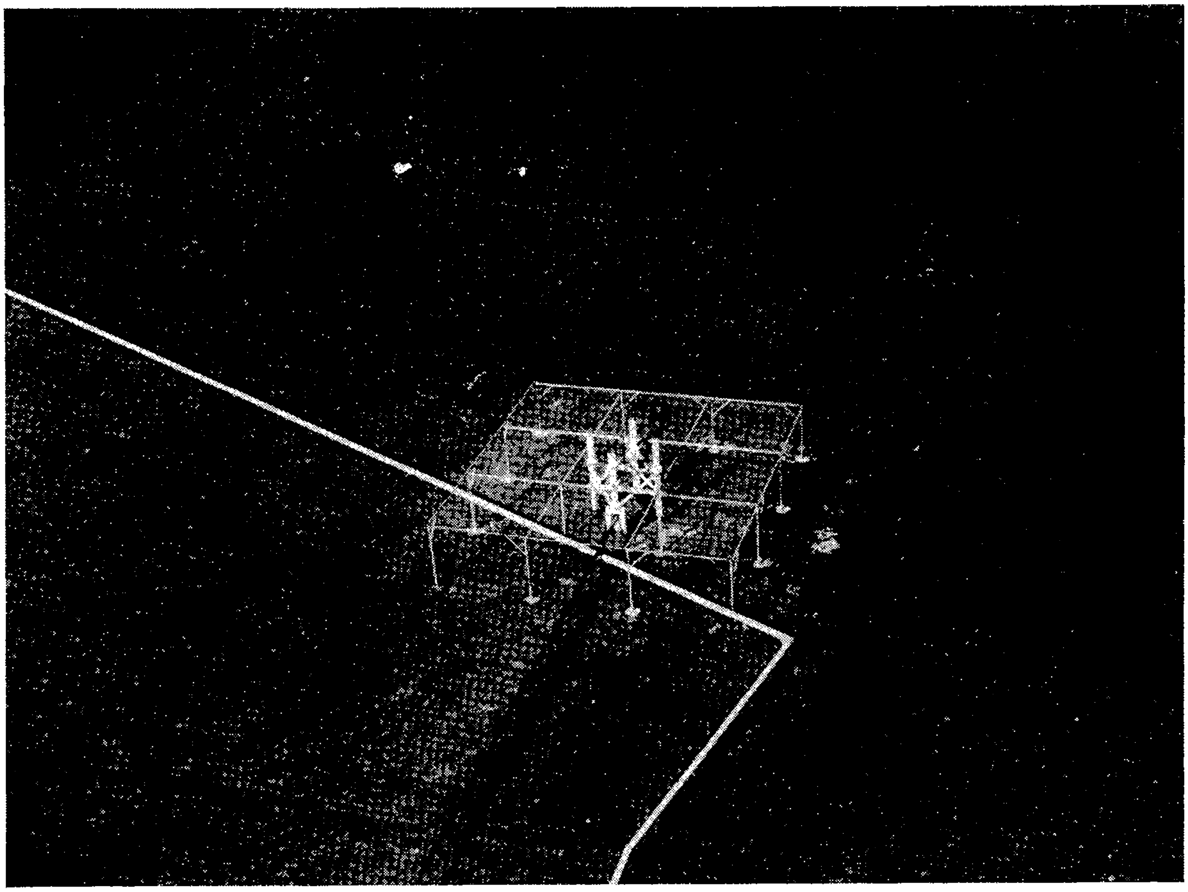

Figure 33.—Complete transmitting antenna at Allentown, Pa.

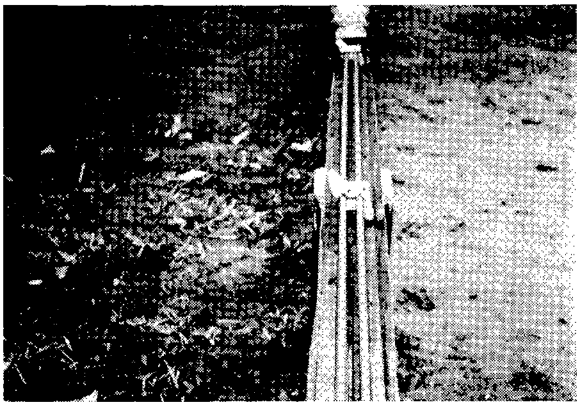

Figure 34.—Original arrangement of transmission line insulators at Allentown.

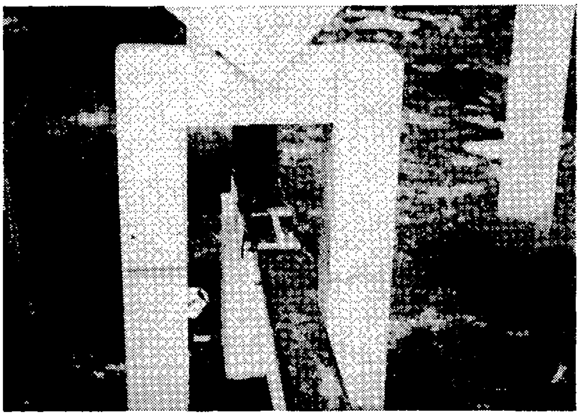

Figure 35.—Bridge arrangement over transmission line at Allentown.

leads is illustrated in Fig. 47a, and the modified arrangement in Fig. 47b. To obtain equal termination for both channels of the transmitter, it was necessary also to add an extra length of wire on the stand-by transmitter between its output relay terminals and the partition bushings, as indicated in Fig. 47b. This addition compensates for the length of line represented by the bushing length. The monitor unit could not be connected directly to the transmission line through condensers, as originally provided, without disturbing the conditions of current on the transmission line. It was necessary to inductively couple this unit, as shown in Fig. 47b. After making the

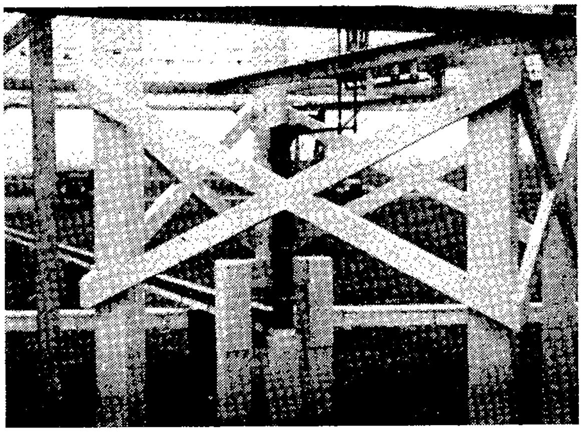

Figure 36.—Substructure of transmitting antenna system at Allentown.

modifications as indicated, it was observed that the antenna and line current conditions were approximately equal for both regular and stand-by equipments. The advantage of coupling the monitor to the transmission line, as originally provided, is that it is operative for both regular and stand-by channels. Although its primary function is to start the stand-by channel upon failure of the regular, it was considered valuable as a means of determining relative output and modulation for both channels. An attempt was made to inductively couple the monitor simultaneously to both power amplifier tank circuits, but it was discovered that, while identical monitor operation could be obtained from both channels, undesirable cross coupling existed that might cause confusion to operating personnel. Con-

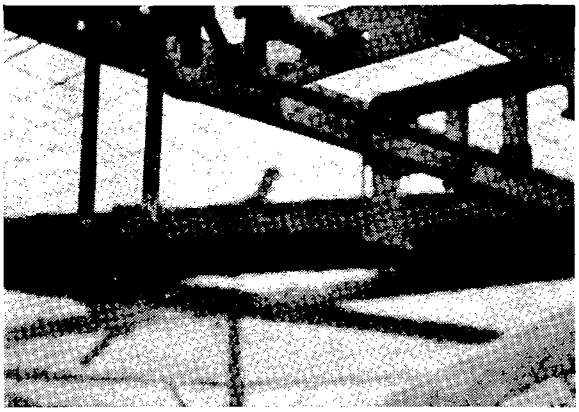

Figure 37.—Arrangement of matching sections.

sidering this, it was finally decided to couple only to the regular channel on the present equipment, and to provide an inductively coupled R. F. meter on the transmission line, on the top of the transmitter, to indicate relative output and modulation for both channels.

It is believed that if absolutely ideal termination were possible for the transmission line, some of the differences observed in the operation of the two channels (regular and stand-by) would not be present. However, since this ideal is not generally obtained, the only way in which identical operation can be expected from both channels is through strict adherence to mechanical and electrical symmetry between channels up to the transmission line terminals.

The final results of the adjustments for current balance phasing and line termination for

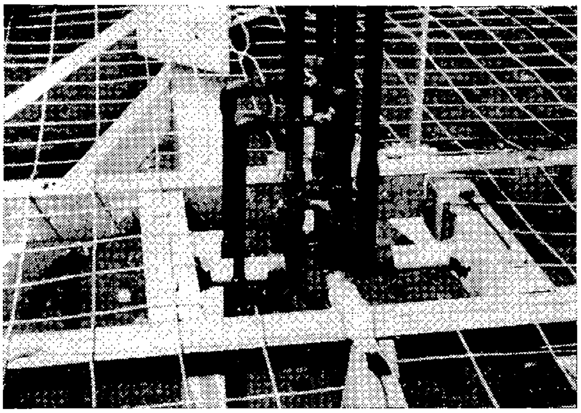

Figure 38.—The connections and adjustments on the antenna downleads.

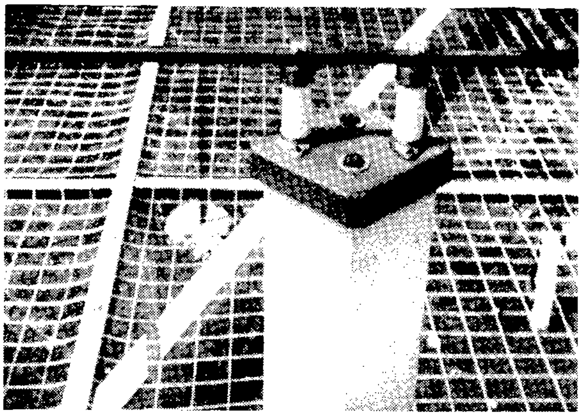

Figure 39.—Method of securing antenna rods.

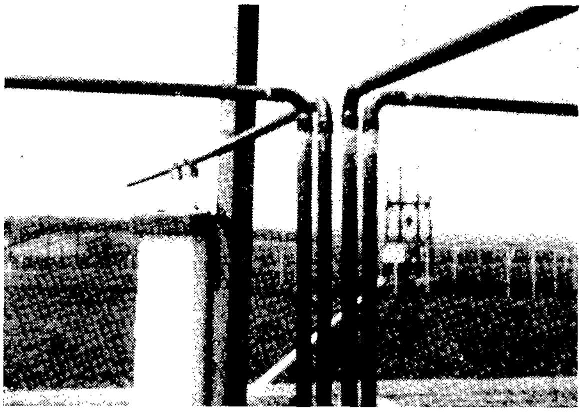

Figure 40.—Downlead section of antennas.

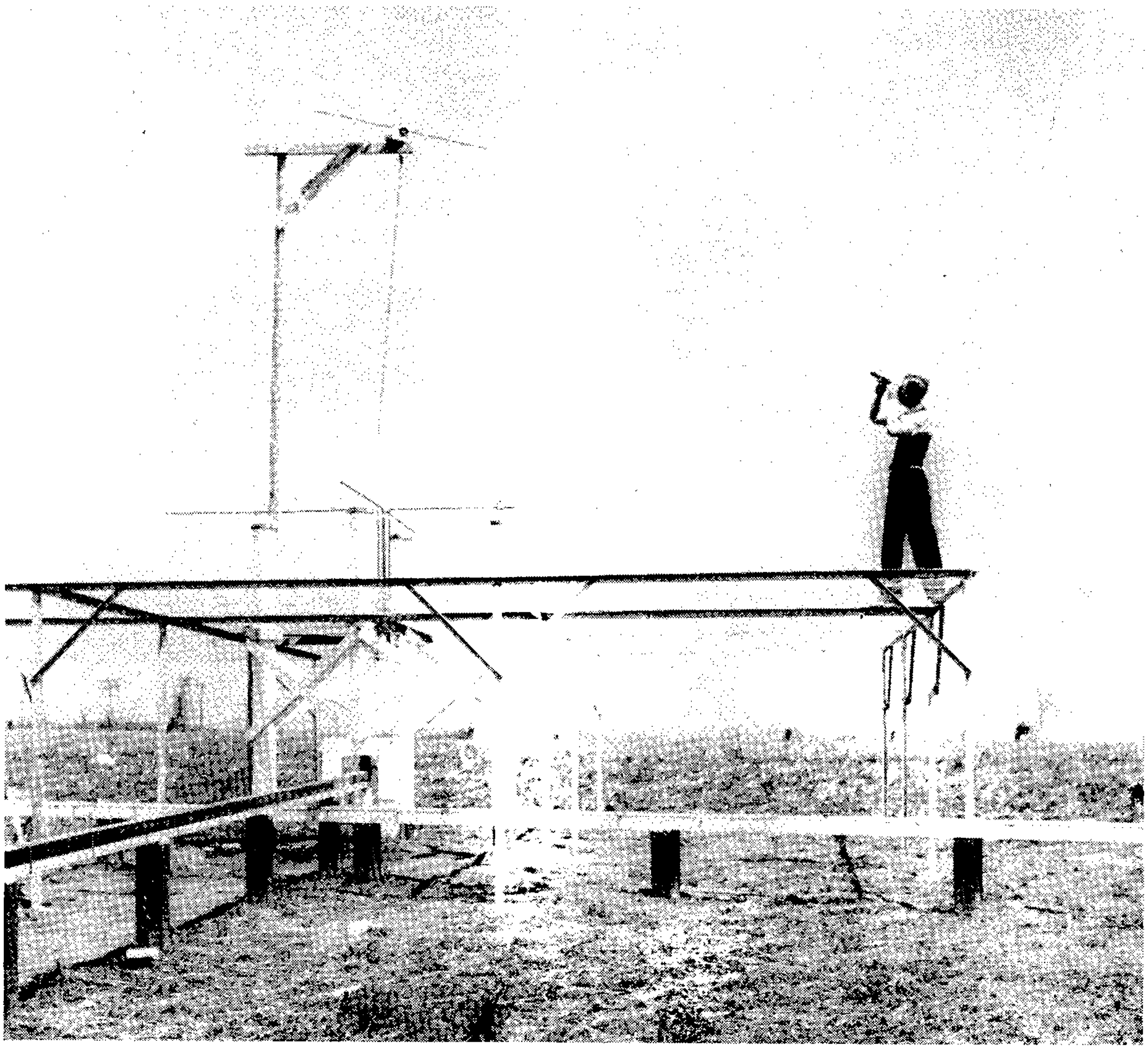

Figure 41.—Method of observing pick-up antenna current.

this installation are illustrated clearly in Figs. 29, 30, and 31. A flight check of the marker to determine the pattern of the transmitted signal was made in Bureau airplane NS-31, with

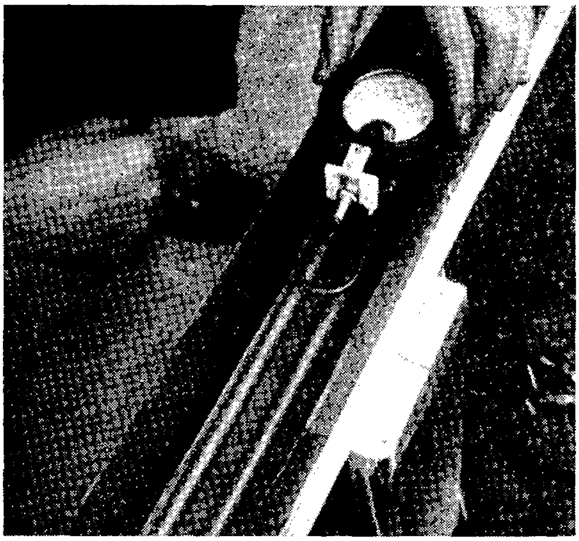

Figure 42.—Meter used in line current measurements.

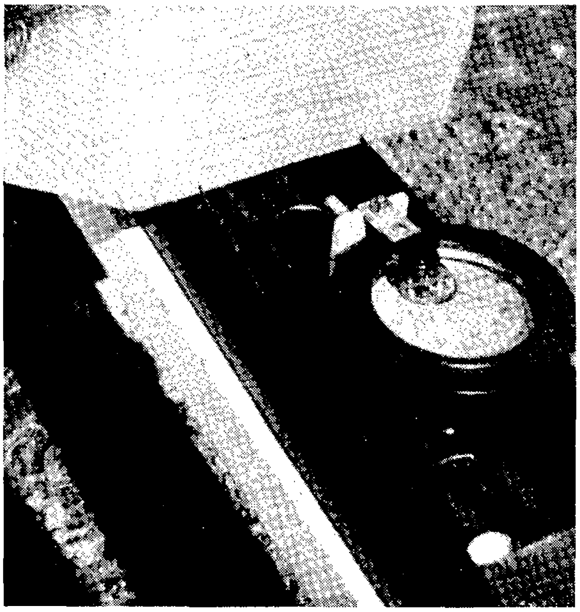

Figure 43.—Spacing block used to secure constant spacing of duct side wall.

its receiving antenna arranged as shown in Fig. 12, and with the RUD type receiver shown in Figs. 10 and 11. From the data obtained on these flights, the average curves of Figs.

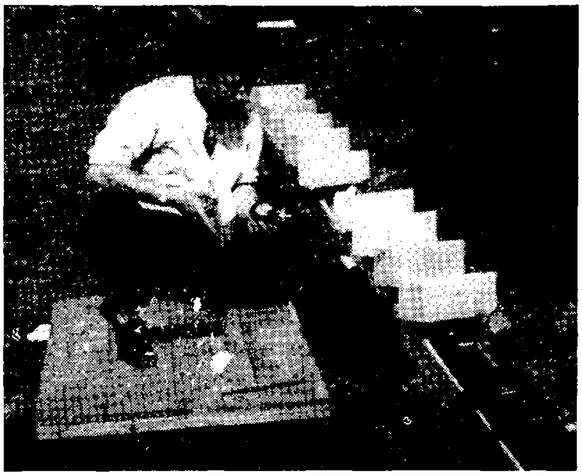

Figure 44.—Complete assembly of spacing blocks.

45 and 46 were obtained. Fig. 45 illustrates the approximate vertical pattern extending to an altitude of 9,000 feet, and useful slightly beyond this, for the finally adjusted transmitter power and the accepted receiver sensitivity. On this curve, a dotted line has been plotted to illustrate the approximate relative

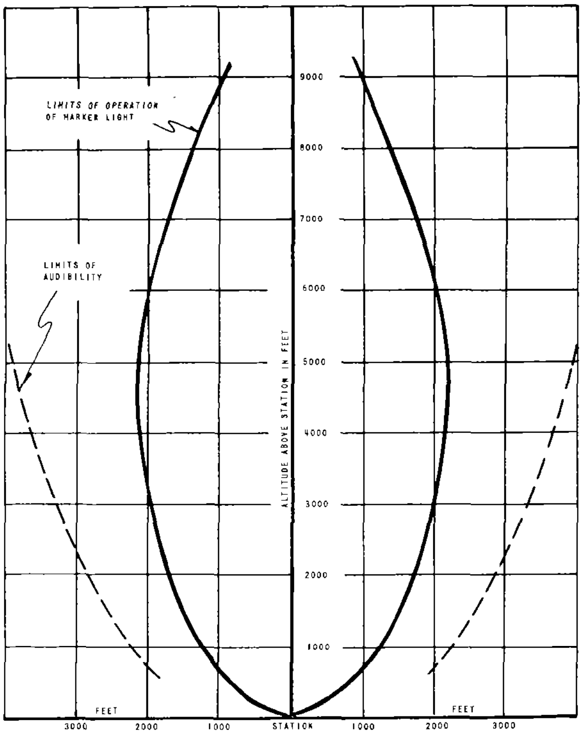

Figure 45.—Relative vertical pattern obtained by flight check of Allentown marker.

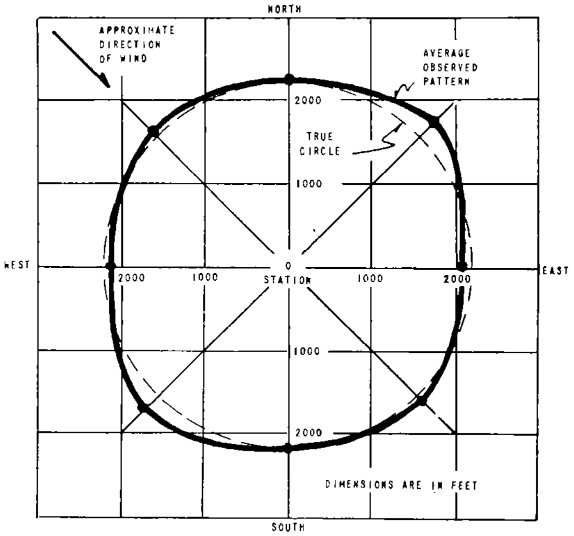

Figure 46.—Relative pattern cross section at 3,000 feet altitude for Allentown marker.

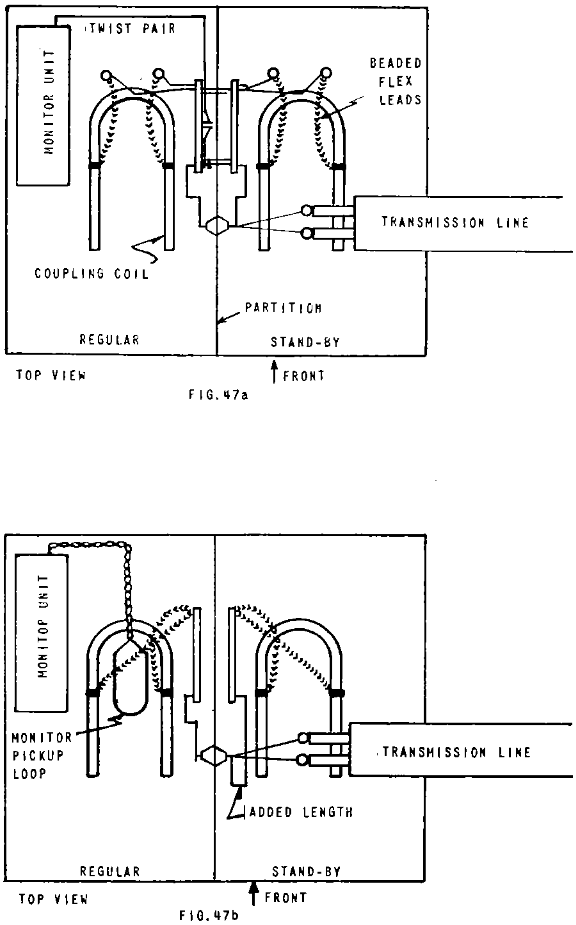

Figure 47.—Arrangement of transmitter output circuit.

limits of audibility for the marker signals. The inner solid curve, representing the actual marker pattern, is the pattern determined by the operation of the marker light on the airplane instrument panel. The marker signal is audible before and after operation of the marker light.

The curve of Fig. 46 was plotted from data taken in all directions over the station at an

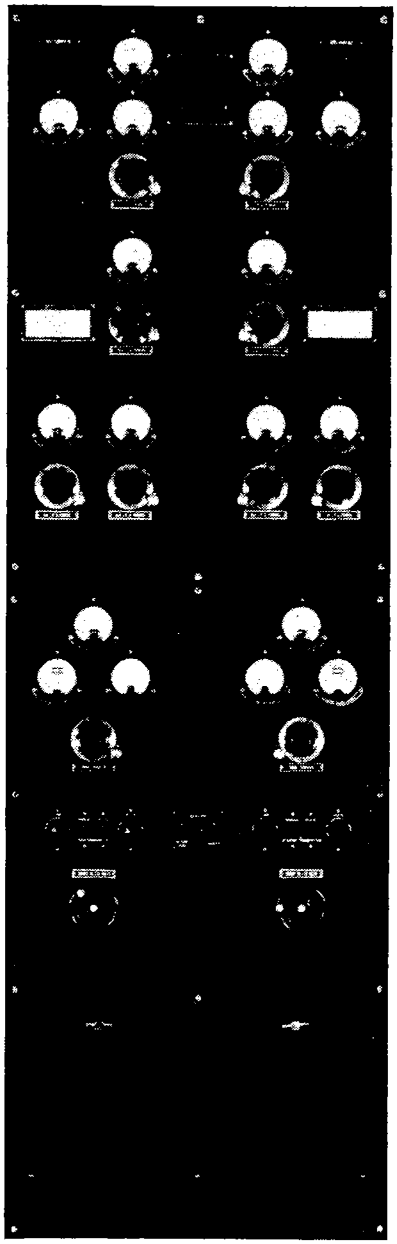

Figure 48.—Final type TZA marker transmitter.

altitude of 3,000 feet. It illustrates that the phasing of the antenna currents is approximately correct, since the signal received is approximately equal in all directions. The pattern is slightly larger in the northeast-southwest direction, probably because of direction of wind during the flights. The wind was in the approximate direction indicated by the arrow on the figure (from northwest). Flights in the northeast-southwest direction would naturally be made with considerable crab angle, resulting in a true ground speed much less than that for flights in other directions over the station. Consequently, this would account for the increased time of signal for this direction. Patterns of the experimental markers have, in general, been elongated slightly in a direction perpendicular to the wind direction. A true air speed of

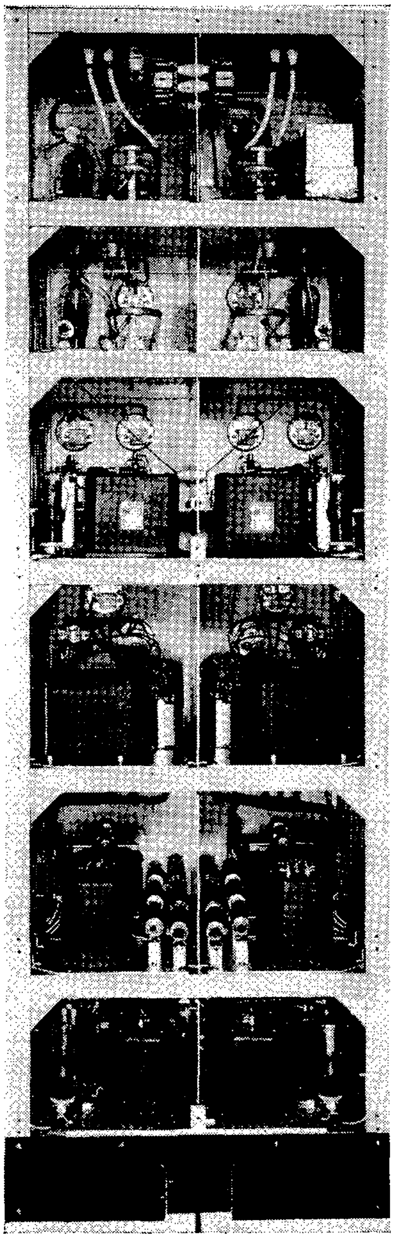

Figure 49.—Rear view of type TZA marker transmitter.

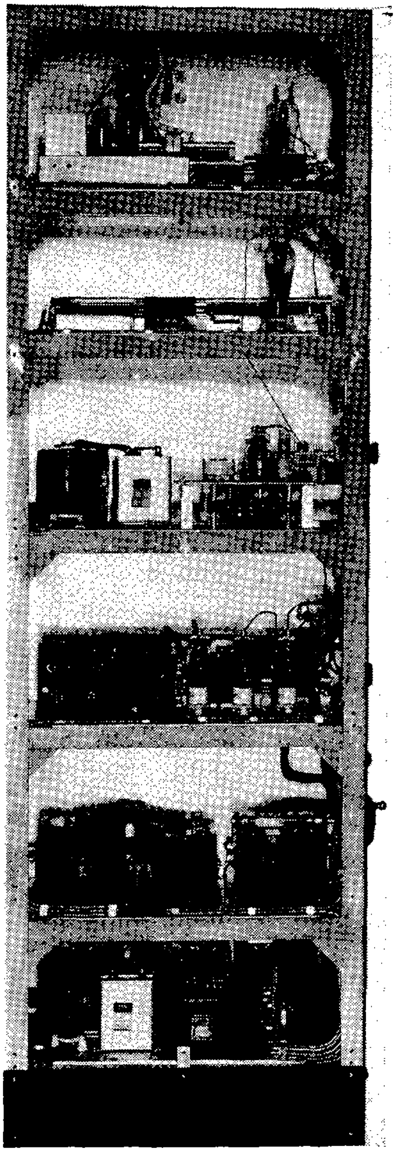

Figure 50.—Side view of type TZA marker transmitter.

100 miles per hour was maintained for all flights.

Final transmitter design.

The arrangement of the transmitter developed for this service is shown in Figs. 48 to 51, inclusive. A block diagram of the transmitter circuits is given in Fig. 53. The nominal output rating is 5 watts. The audio-frequency modulating voltage is derived from a stable 3000-cycle vacuum tube oscillator.

It will be observed from Figs. 48 and 49 that the transmitter consists of two identical units constructed vertically in a common frame. Controls and indicating instruments are provided for the tuning and adjustment of each channel, regular and stand-by. An elapsed time meter is provided for the filament circuit of each channel, so that a total number of hours of operation can be recorded.

The monitor unit provided with this equipment is shown in the upper righthand section of Fig. 49. This unit functions to disconnect the regular channel in event of its failure to deliver the required output, and starts up the stand-by channel, connecting it to the transmission line in place of the regular channel. In addition, the monitor unit with its two meters (rectified carrier current and rectified audio current) provides a means for setting the percentage modulation at approximately 100%. Curves of the audio and carrier currents have been plotted in Fig. 52 against relative percentage modulation. The monitor transfer system operates when the modulation has been reduced to about 45 percent, or when the carrier drops sufficiently to reduce the received rectified audio current more than about 30 percent.

Controls are provided, as shown in Fig. 51, to permit either manual or automatic operation of either channel of the transmitter. It is possible through the operation of these control

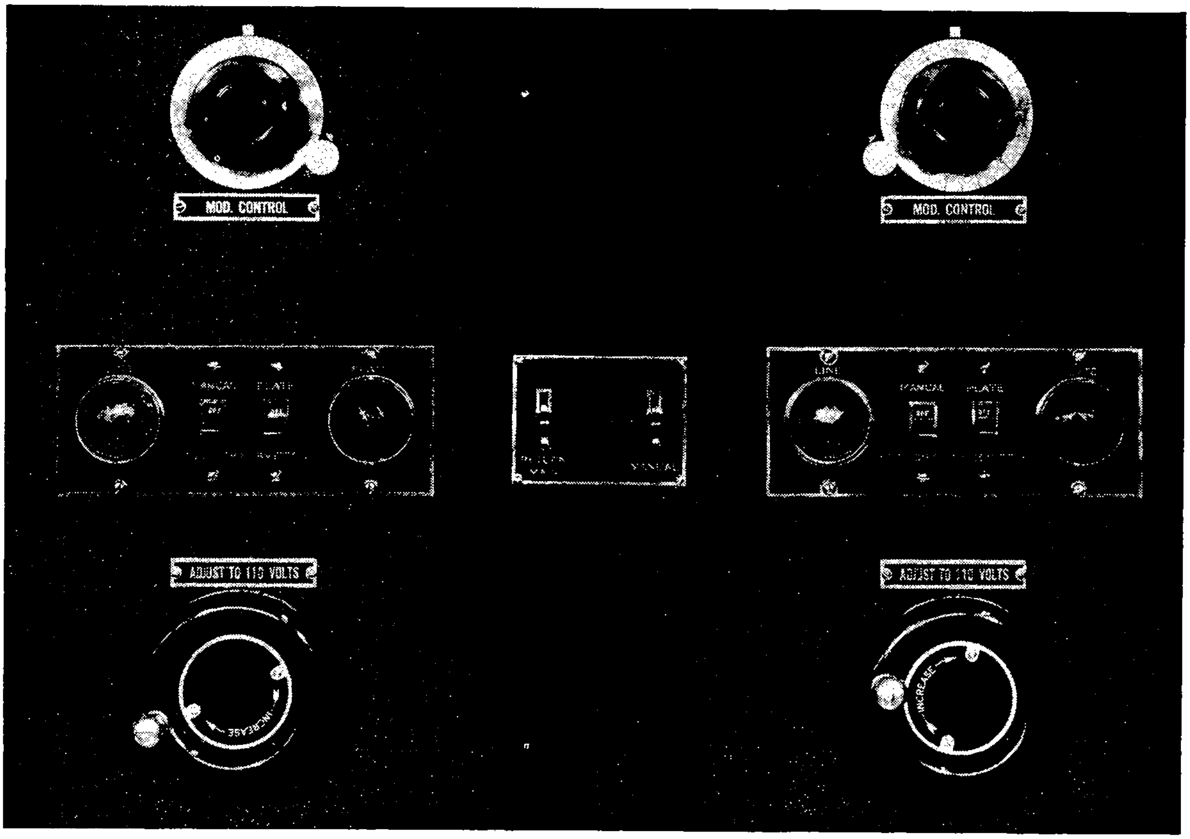

Figure 51—Control switches of type TZA transmitter.

switches for either channel to deliver power to the antenna system while repairs, adjustments, or tuning changes are being made on the other channel

Remote monitoring

Provision for remote monitoring of Z-marker equipment was not included in the final transmitter design although some experiments were conducted during the development period Remote monitoring was considered unnecessary for two particular reasons

1 The range station is visited daily by operating personnel and any irregularities of the Z-marker operation can be observed

2 There is a reliable stand-by equipment and automatic transfer device to operate in case of failure of the regular equipment

During development, small diode detector-amplifier units were coupled to the transmitter output circuits to provide an audio monitoring signal This signal was then connected through relays to the broadcast-control line which connects the range station to the remote control quarters An a c microammeter was used at the distant quarters to operate from this monitoring signal The relays were used to disconnect the signal for the line during broadcasting

A development project has been set up to study conditions and methods for monitoring all types of markers Considering the fact that good signals can be heard on a sensitive receiver at the Silver Hill (Md) experimental station

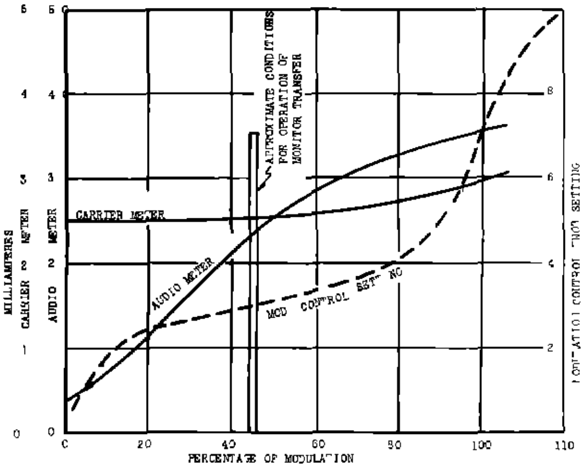

Figure 52 —Curves showing monitor current readings for various percentages of modulation

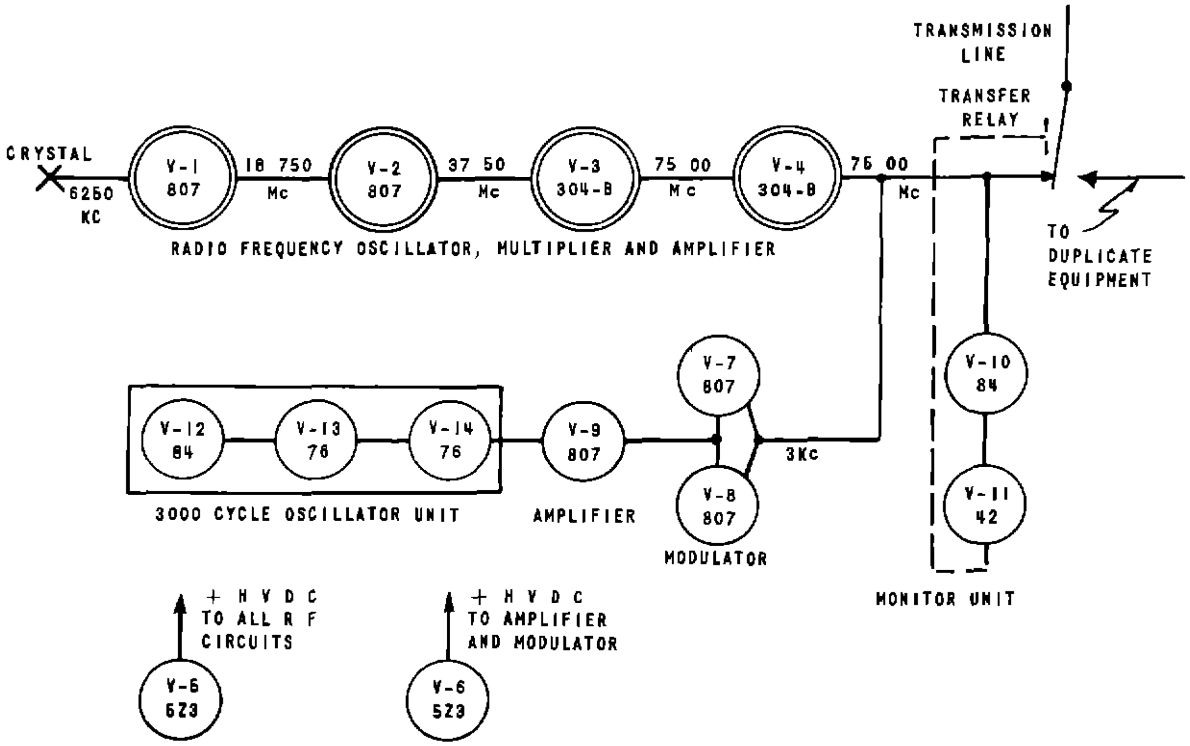

Figure 53 --Block diagram of type TZA transmitter circuit

of the Bureau from both the Bowie fan marker, 16 miles distant, and the Washington Z-marker, about 3 miles distant, it is possible that some method of remote monitoring, with the use of a receiver and directive receiving antenna, may eventually be provided at the centrally located quarters or airport

CONCLUSIONS

As a result of this development, it has been concluded that

1 The antenna system of the final design described in this report, and shown in Figs 5c and 33, is satisfactory for regular marker service

2 The average antenna current of 65 milliamperes in the four antenna rods, as measured by the instrument illustrated in Fig 7, is satisfactory for the present pattern dimensions These currents may vary 25 percent from one another without causing an appreciable change in pattern shape

3 The antenna system can be operated in the vicinity of radio range towers, provided these towers are not over 125 feet tall, and are placed at least 125 feet from the marker antenna Objects within a radius of about 50 feet of the antenna should not project more than about 6° above the plane of the antenna system

4 The use of an elevated antenna, with a counterpoise as shown in Figs. 5e and 33, is satisfactory and necessary The counterpoise may be supported on a grounded structural steel framework

5 The use of a two-conductor shielded transmission line, as illustrated in Figs 5f and 34, is satisfactory and is very convenient for this system

6 The termination of this line, using the matching stubs, as shown in Fig 37, is satisfactory

7 The dual transmitter of the type shown in Figs 48 to 51 is satisfactory for this service The rated output of 5 watts is adequate

8 The use of crystal control for the transmitter is satisfactory and desirable

9 The use of a monitoring device for the purpose of automatically changing from regular to standby transmitter in the event of failure of equipment is satisfactory as provided with the commercially-made equipments now being purchased

10 The use of the type RUD receiver, illustrated in Figs 10 and 11, is satisfactory for the checking of marker patterns, but a selective crystal-controlled superheterodyne receiver of the type described in Bureau specification BA–304 will be required for interference-free reception of marker signals under service conditions

11 The type of receiving antenna illustrated in Figs 12 and 13 is satisfactory for use on aircraft

12 The use of a small incandescent type lamp as an indicator is convenient and satisfactory

○