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THE DEVELOPMENT OF AN IMPROVED ULTRA-HIGH-FREQUENCY RADIO FAN MARKER

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SUMMARY

An antenna system, similar to the four-element array described in Safety and Planning Division Report No 5, except operating above a wire-mesh counterpoise, was installed and tested at the Bowie, Md, light beacon Improvements in the method of conducting energy from the transmitter to the antenna were incorporated in this installation The system was found to produce patterns equivalent to those measured for the former antenna and to be relatively free of variations caused by snow, sleet, or growth of vegetation

INTRODUCTION

The basic development of the fan-type marker, which began in 1936, was described in Technical Development Report No 5[1] In this report, experimental data were presented in which it was shown that a field pattern of suitable extent and shape could be produced by the use of four ½ wavelength antenna elements in line excited in phase and spaced ¼ wavelength above level earth The experimental results are in general agreement with the theoretical pattern produced

[1] Report No 5 'The development of a fan type ultra high-frequency radio marker as a traffic control and let down aid,' January 1938

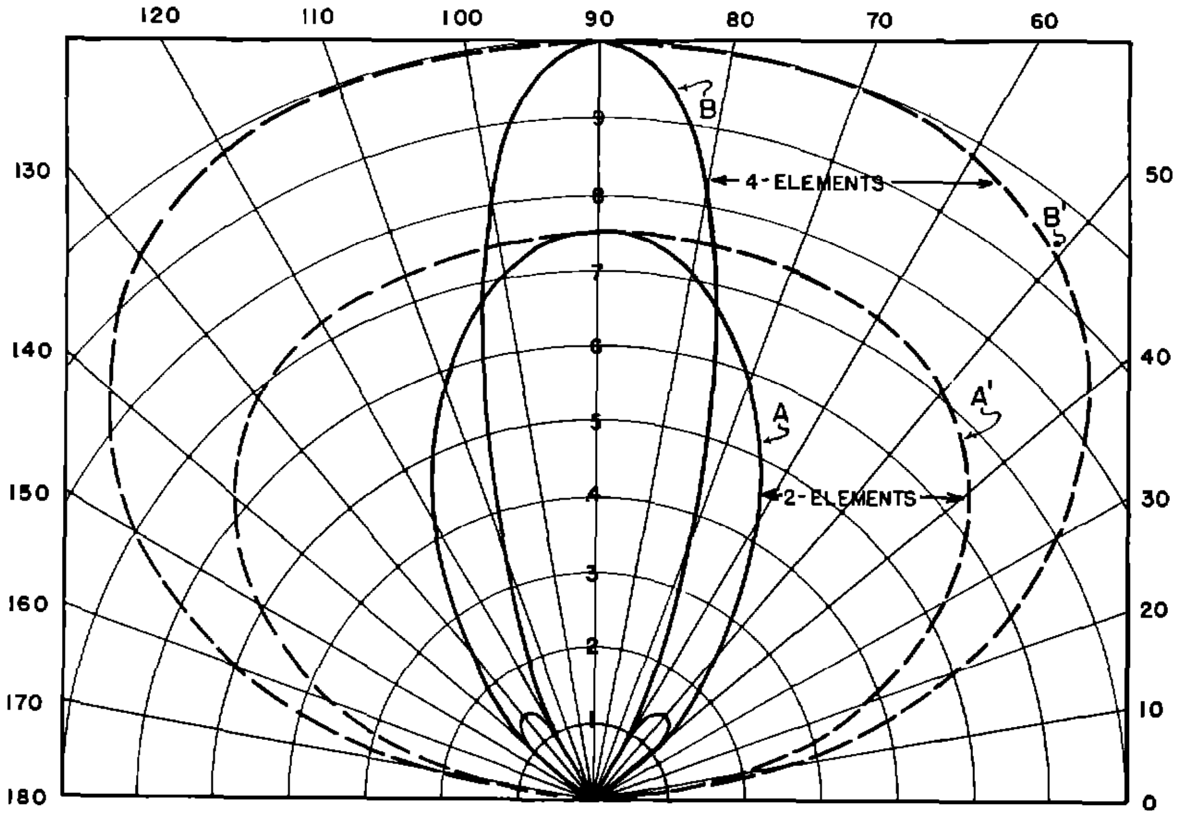

Figure 1—Calculated field patterns for two- and four elements arrays Horizontal ½ wavelength elements, ¼ wavelength above perfect ground, excited in phase Solid line—in line with antenna Dash line—at right angles to antenna

by an array of this type. The calculated radiation patterns for the four-element array and the simpler two-element array are shown in figure 1. Previous tests indicated that the power required for the desired pattern was between 100 and 150 watts. There remained, however, tests to be conducted on the use of a wire-mesh counterpoise which would act as a reflector for the antenna system and protect the radiated pattern shape from changes that might be expected as the result of the growth of vegetation and accumulation of snow. In addition to the antenna system, it was also necessary to develop and test means for conducting energy from the transmitter to the antenna system with protection from these same elements and with minimum loss. This report describes the tests conducted on the improved antenna system located at Bowie, Md., and illustrates with recordings and curves the satisfactory results obtained.

APPARATUS

A complete four-element antenna system was constructed using ⅞-inch (O. D.) rigid copper tubing supported by 6-inch stand-off insulators at the top of 6″ x 6″ wood posts. The height of the antenna elements above ground was made ¾ wavelength in order to allow convenient construction of the counterpoise at a distance of ¼ wavelength below the antenna. The height of the counterpoise above ground is determined by local conditions (growth of vegetation, snowfall, and natural slope of terrain), which for this locality demanded an elevation of approximately 6 feet or ½ wavelength. All insulators supporting the antenna system were placed at points of minimum voltage. The antenna posts were roofed away from the side containing the antenna insulators, to minimize sleet formation on that side of the post.

Two simple methods are available for exciting the antennas in phase. One is shown in Fig. 2 (A) in which the several antennas are fed in pairs. This necessitates a more complicated transmission-line structure than the final design shown in Fig. 2 (B), which takes the equivalent form of two antennas, each 3/2 wavelengths long, fed from a single line. The middle ½ wavelength section of each of the 3/2 wavelength antennas is folded to prevent radiation from the out-of-phase section, giving the effect of four ½ wavelength antennas in line, fed in phase. The direction of the instantaneous currents is indicated by the arrows in Fig. 2. Photograph, Fig. 3, shows the arrangement of the line at the antenna.

Counterpoise

The mechanical construction of the counterpoise is shown in the drawing, Fig. 4, and in the photographs Figs. 5, 6, and 7. Its orientation and position with respect to the beacon-light

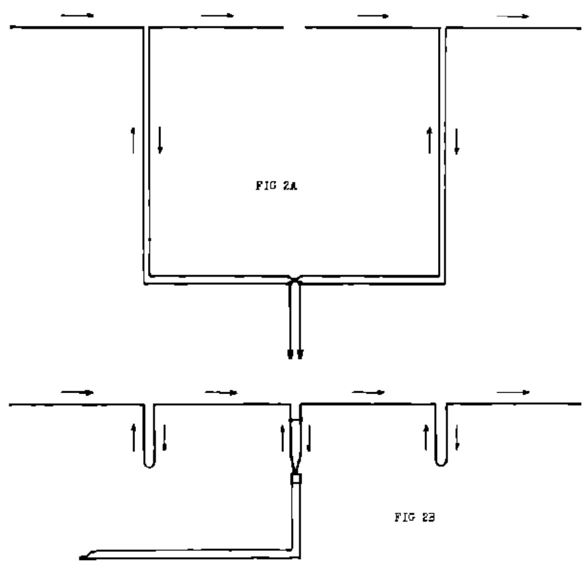

Figure 2.—Two methods of exciting four in-line antennas in phase.

tower is given in Fig. 8. The structure is made entirely of wood, the counterpoise supporting posts being 4″ x 4″, the antenna supporting posts 6″ x 6″, and all other framework 2″ x 4″. The 2 x 4's were placed on edge to minimize accumulation of snow or sleet on the counterpoise, and to provide minimum sag between supporting posts. The entire structure is covered with a 3″ x 3″ mesh of number 13 galvanized wire screen. The center of the system is placed ½ wavelength (78.74 inches) above ground. Due to the slope of the ground, this distance from counterpoise to ground varies from 4 to 8 feet. Copper ground straps one inch

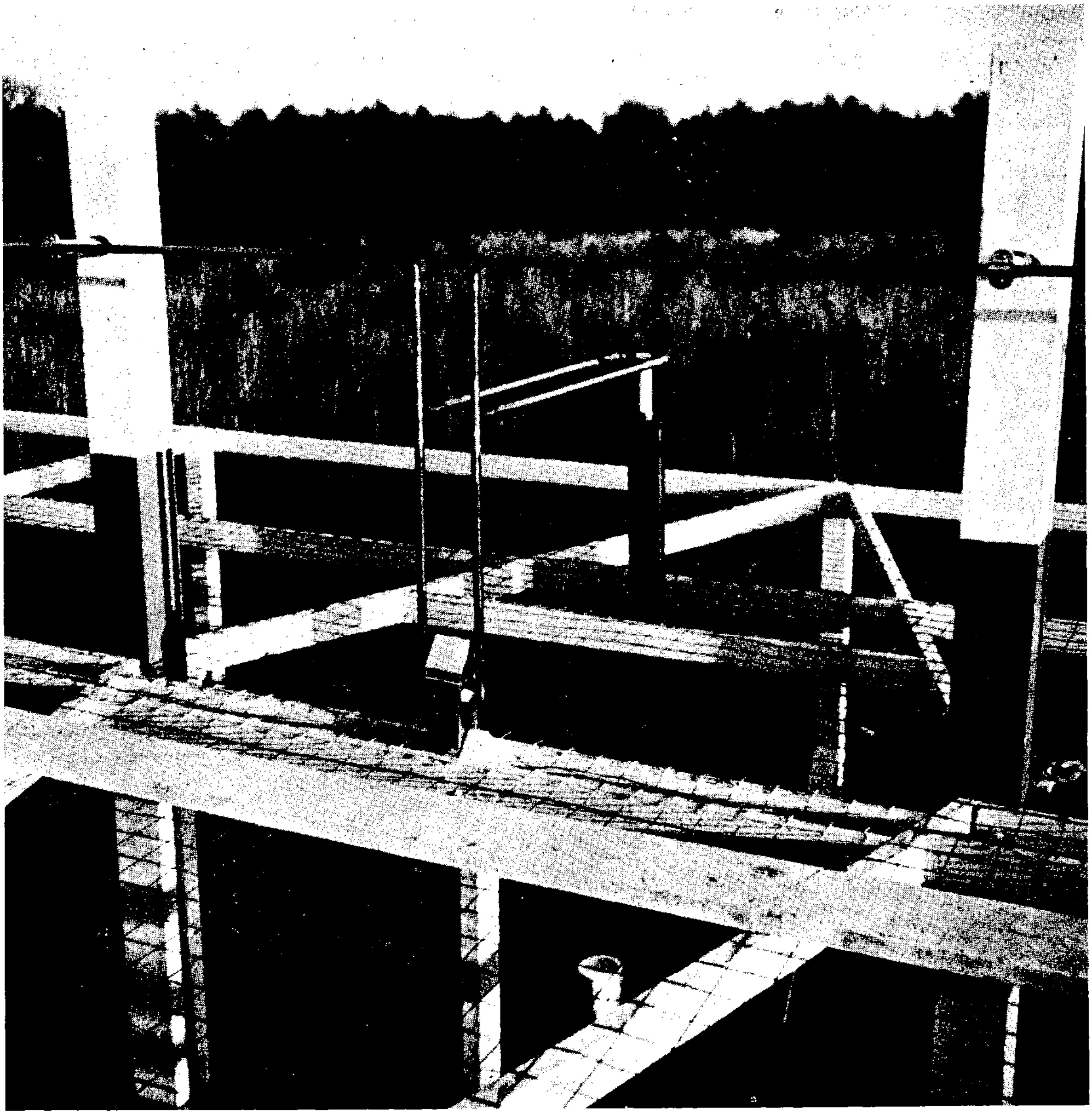

Figure 3.—Showing method adopted for exciting the antenna system, Bowie, Md.

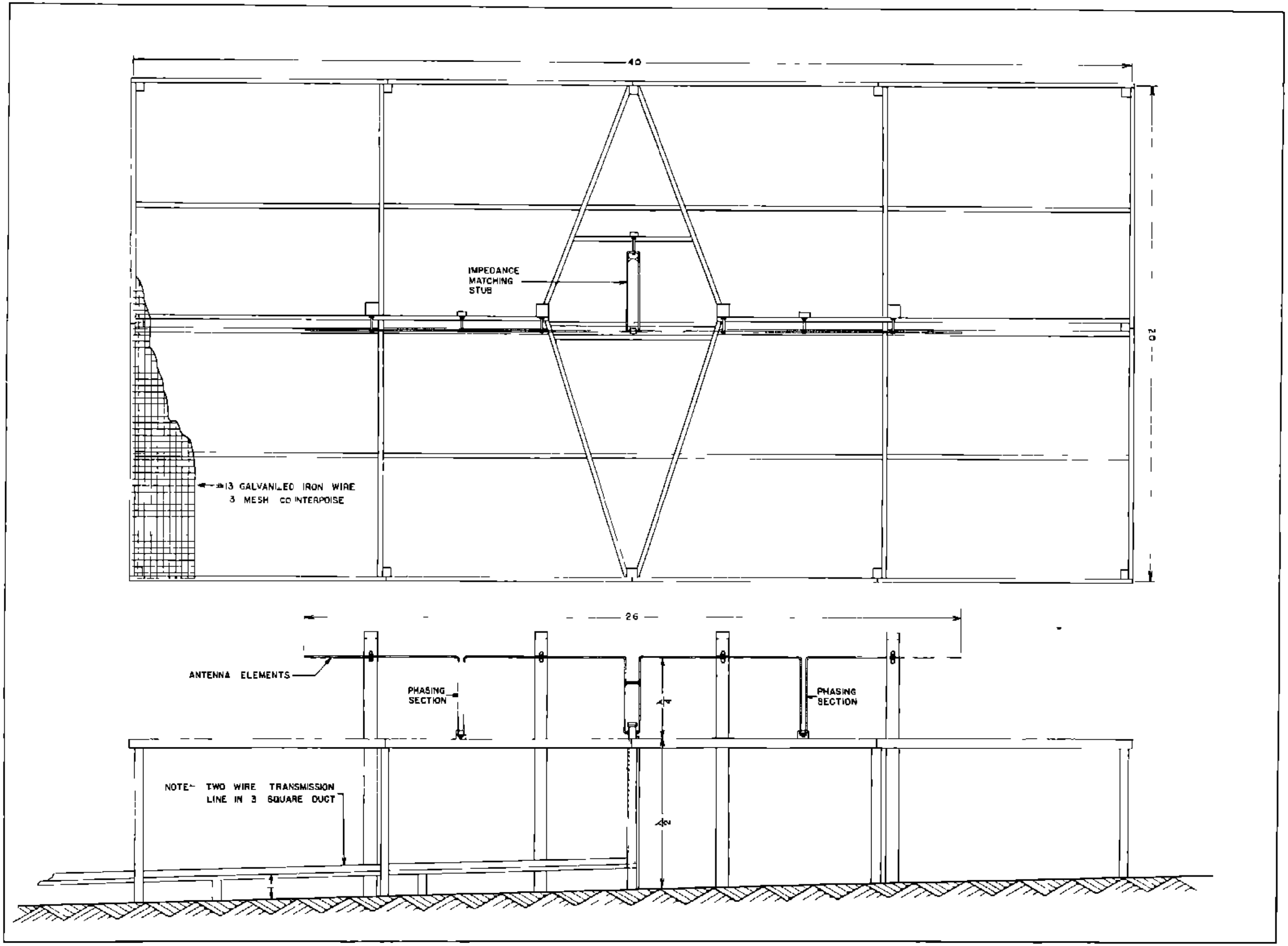

Figure 4—Antenna and counterpoise details

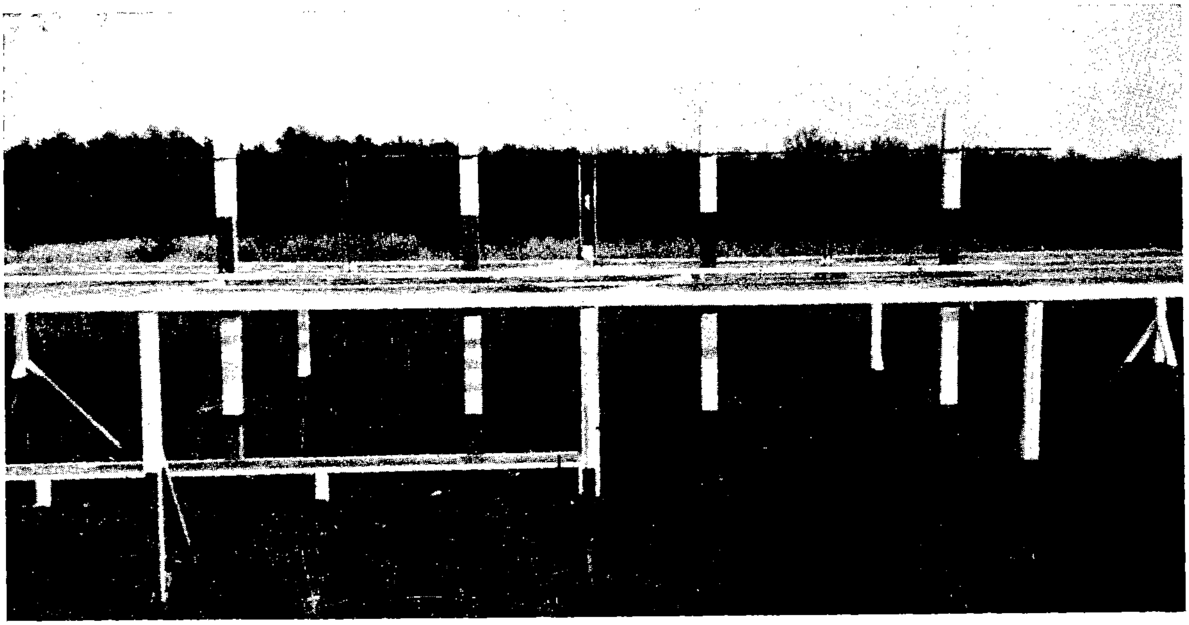

Figure 5.—Side view of Bowie, Md., fan marker antenna and counterpoise.

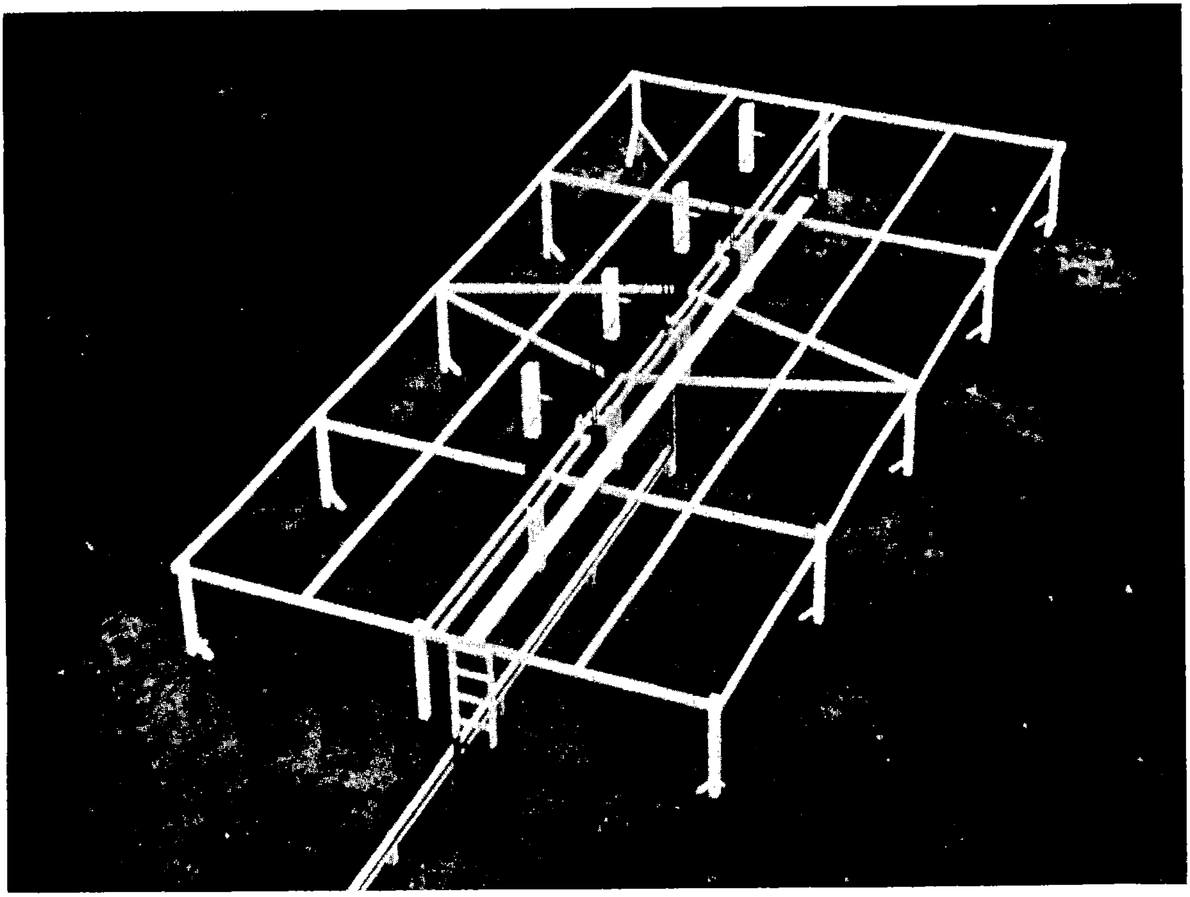

Figure 6.—Bowie, Md., fan marker antenna taken from beacon tower.

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wide by 0.020 inch thick were added to connect the counterpoise screen to ground at all posts (16), simulating a metal counterpoise framework.

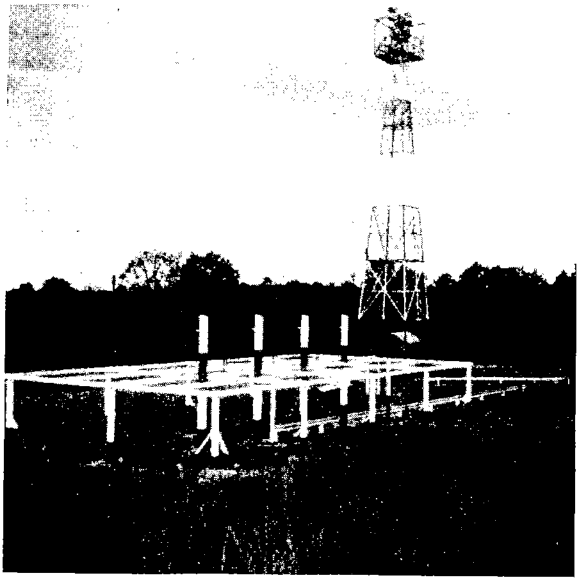

Figure 7.—Bowie marker installation, Bowie, Md.

Transmission line.

The two-wire transmission line is made of ½-inch outside diameter hard copper tubing, spaced one inch on centers, and enclosed in a 3″ x 3″ copper duct. The duct provides a shield for the line, and eliminates the effects of changing weather conditions and vegetation on the characteristics of the line. The lines are supported symmetrically in the copper duct by standoff insulators, mounted on 3-inch square bakelite bases, at intervals of approximately 6 feet. The transmission line duct is connected to the transmitter frame and to the counterpoise and is grounded every 8 feet throughout its length. The closure for the counterpoise end of the line is roofed to minimize the collection of snow and ice. The details are shown in Figs. 3 and 4.

Transmitter.

The transmitter used in these tests was the same one that was used for the concluding tests of the former antenna array and mentioned in Report No. 5. A block diagram of this transmitter is given in Fig. 9. The transmitter is a type TXI, crystal-controlled, 100-watt unit,

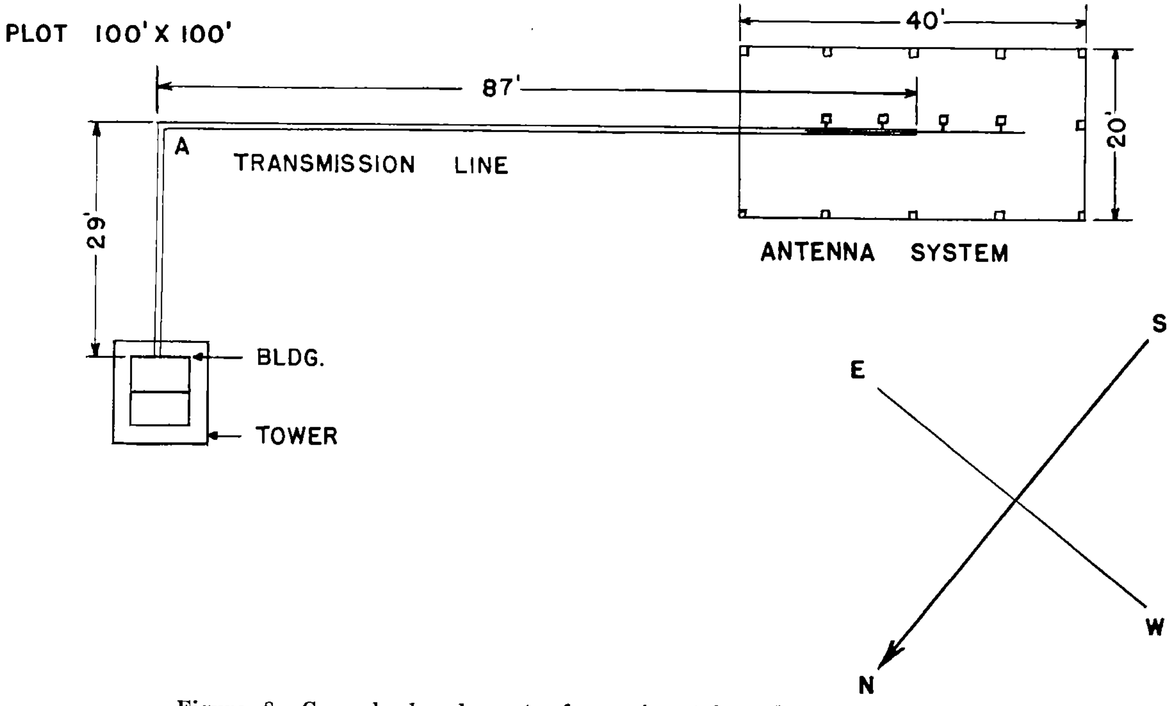

Figure 8.—Ground plan lay-out of experimental marker at Bowie, Md.

operating at 75 megacycles The crystal is of the low temperature coefficient type, operating in a crystal dynatron circuit The fourth harmonic (18 75 megacycles) derived directly from the 57 crystal circuit is then doubled again in an RK–23 tube, and is amplified by a second RK–23, which delivers sufficient power at 37 5 megacycles to excite the succeeding stage Following the 37 5-megacycle exciter stage, a type 304–B tube doubles the frequency to 75 megacycles, after which it is amplified in a second type 304–B tube to drive two type 304–B tubes in push-pull as a power amplifier High efficiency tank circuits, consisting of "hair-pin coils" tuned with "pie-plate" condensers, result in a power amplifier plate efficiency of the order of 60 percent when delivering 100 watts of power at 75 megacycles

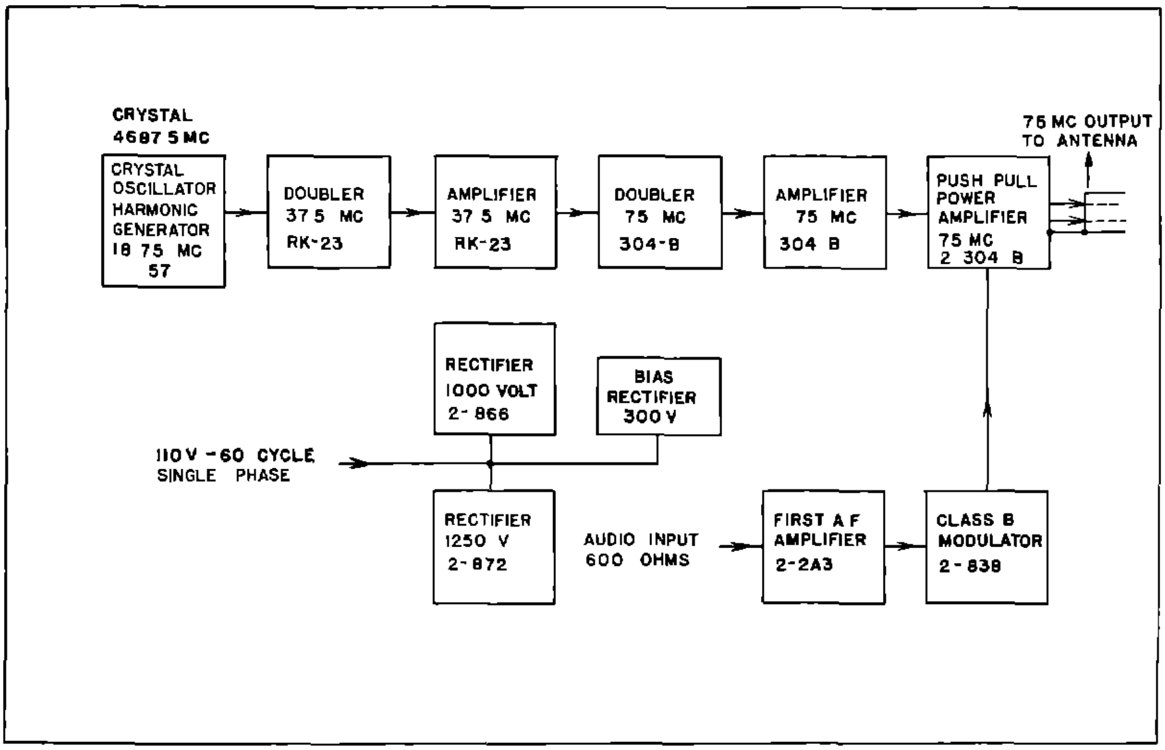

Figure 9—Block diagram of 75-megacycle transmitter—Type TXI

The modulator consists of two type 838 tubes in class B, excited by two type 2A3 tubes, and it delivers ample power to modulate fully the power amplifier A vacuum tube oscillator operating at 3000 cycles furnishes the tone used to modulate the transmitter This tone is keyed with the characteristic identification signal, which is a succession of dashes

High voltage direct current for plate power is supplied by two mercury vapor rectifiers The power supply to the transmitter is 110 volts, 60 cycle, single phase

A single transmitter was used in this experimental installation Its operation was studied to obtain information from which specifications for the final units could be written Six months of continuous operation have shown that, although more tubes are necessary in a crystal controlled transmitter, careful design and dual automatic transmitters will provide the necessary reliability for unattended operation

TESTS AND RESULTS

Method of determining antenna lengths

The measurement of current at ultra-high frequencies is a difficult problem, and this is especially true of the current in a conductor such as an antenna, where high potentials may be encountered. The meter may indicate a radiation current in addition to the desired current. If the meter is placed at a point of low potential the indications, however, are sufficiently accurate. Since it is not convenient to connect the meter directly in the antenna, a sensitive meter may be shunted across a section of the antenna, as illustrated in Fig. 10A, or coupled to the antenna as illustrated in Fig. 10B. The latter method is, of course, much more sensitive. The

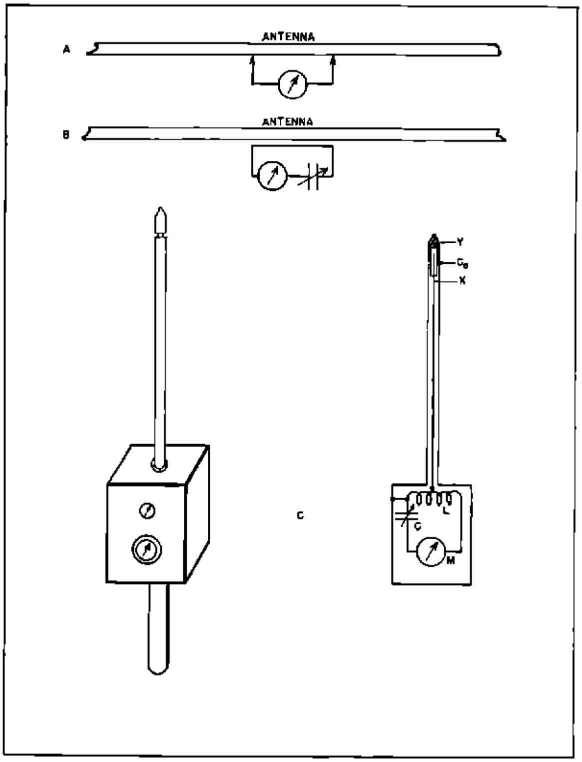

Figure 10.—Current and potential indicating devices

former method (Fig. 10A) is more rugged and was used for most of the readings presented in this report.

It was found that the position of the meter on the antenna had an effect on its reading. If the ground terminal of the meter was placed on the end of the antenna, a current indication resulted, while if the "hot" terminal of the meter was placed at the end, a zero reading was obtained. It was evident from this that the position of the minimum current could not be determined accurately. Since the high potential field was no doubt responsible for this discrepancy, all antenna measurements were based on the points of maximum current. Fig. 11 is a plot of the current readings taken on one of the antennas, curve (A) being taken from one side, and curve (B) taken from the opposite side. This curve indicates the displacement of the current maximum depending on the manner in which the meter was connected. The point of current maximum was taken as the point at which the meter would give the same reading from either side of the antenna, indicated as "x" in Fig. 11.

The point of current maximum for the end antennas was found to be 90 centimeters from the end, or 0.9 of a quarter wavelength. Due to the physical shape of the phasing sections (the folded ½ wavelength section), the current maximum on them could not be determined. The position of the current maximum on the inner antennas could be shifted by changing the length of the phasing section. The position of the current maximum on the end antenna was not affected by the length of the phasing section. It was felt that the antenna should act as a folded wire antenna, the length of the sections (aside from the ¼ wavelength section at the end) being full ½ wavelength. This was checked by stretching the complete antenna system into a straight line and determining the position of maximum current. Measurements thus taken bore out this assumption, and the elements were made full ½ wavelength except the end antennas, which were made 0.95 x ½ wavelength (¼ wavelength plus 0.9 x ¼ wavelength). Fig. 12 is a drawing showing the lengths of the various elements and the position of current maximums.

Line termination

When a transmission line is coupled to a load the impedance of which is other than the characteristic impedance of the line, reflections occur and standing waves are produced along the line. The impedance of the transmission line enclosed in a 3″ x 3″ copper duct as used in this installation is approximately 125 ohms. When this line is coupled to the antenna at a high voltage point or point of high impedance, a mis-match occurs and standing waves appear on the line. This will have several effects (1) loss of power due to the standing wave on the line, (2) inefficient transfer of power to the antenna if the transmission line is not tuned, (3) unstable line conditions which may damage tubes in the transmitter. The last item is the most serious in this installation. A line which has a standing wave on it may appear at the change, the power amplifier circuit will become detuned, and the tubes will be damaged due to excessive plate current. The detuning effects are more serious than the changes in transmitter loading since the effective capacity changes generally represent an appreciable proportion of the capacity necessary to tune the power amplifier tank circuits at these frequencies. Similar effects are obtained when the line appears as an inductive reactance. The transmitter may be

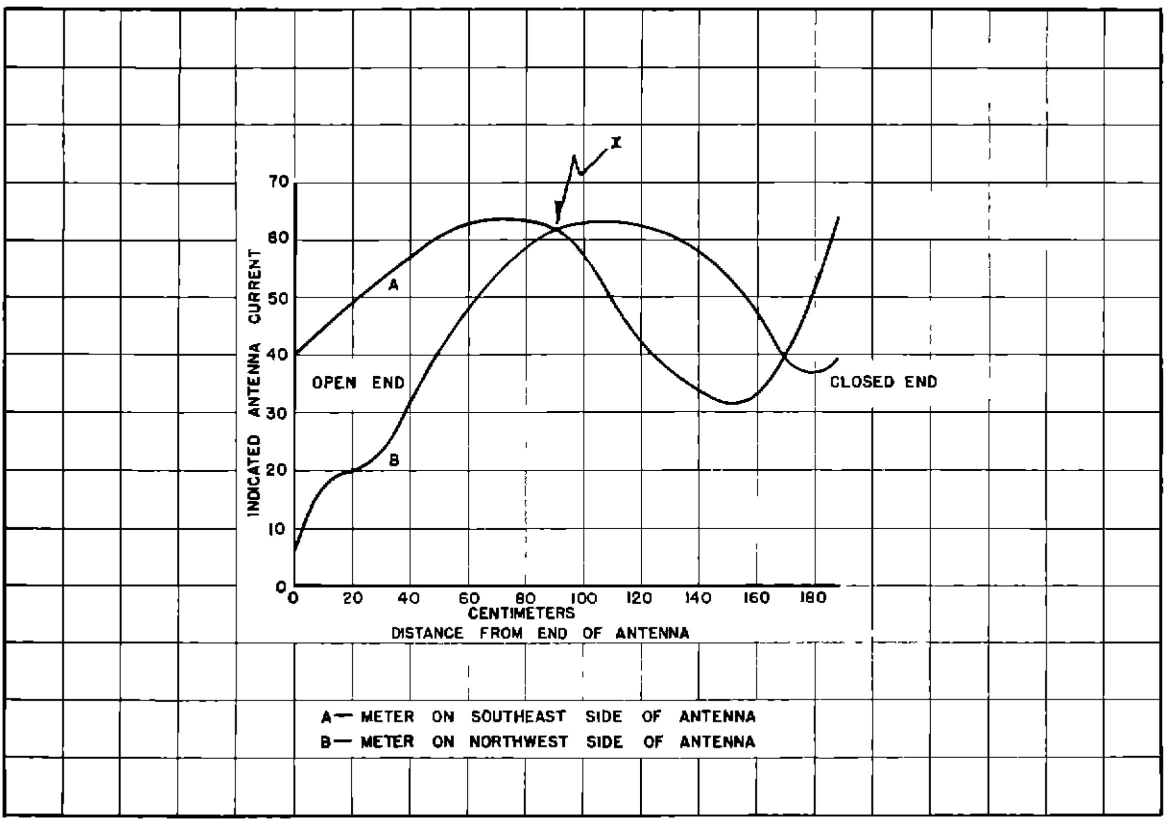

Figure 11.—Plot of meter readings along an antenna element, showing the apparent displacement of the current maximum by the position of the ground terminal of the meter

sending end as a resistance, inductive reactance, or capacitive reactance, depending on the position of the standing wave on the line. Assume, for example that the line appears at the sending end as a capacitive reactance. The effect on the power amplifier tank circuit will be that of adding a condenser across it. If the line condition should change as a result of a change in the load, the value of the capacitive reactance at the sending end of the transmission line will correctly adjusted for any one line condition, but since the line conditions may vary as a result of rain or snow on the antenna, the transmitter will require corresponding readjustment. These effects are particularly undesirable in the case of an unattended transmitter.

If the standing wave is removed from the line by proper termination at the antenna a more stable condition will result and normal changes due to weather will have little effect, and the transmitter will remain properly tuned and loaded

Several methods present themselves for establishing the proper termination between the line and the load

(1) A quarter wavelength section of the proper impedance may be used as a transformer, the ratio being dependent on the impedance of the line and load, and the characteristic impedance of the matching section

(2) The line spacing may be tapered at the point where it connects to the load by making the feeder section (line between the end of the enclosed section and the antenna) in the shape of a V

(3) The use of a reactance in the form of a shorted section of parallel line, connected to the feeders at the proper point

Method (1) could not be used in this case because the enclosed line ended several inches above the counterpoise, making it inconvenient to use a full ¼ wavelength section between the line and the antenna Method (2) was used with moderate success, however, the final matching was accomplished by use of method (3)

In attempting to match the antenna to the line by means of a V-shaped feeder section (method 2), the ratios of I_{max}/I_{min} on the line were observed for various separations at the top of the feeders The line current was measured by means of a meter and loop of wire coupled to both lines and maintained at a constant spacing from the lines These observations were repeated for several lengths of inner antenna rods These data are shown in Fig 13A For the several lengths of inner antenna, the minimum line current ratio obtainable was observed and plotted in Fig 13B This indicated that the best ratio would be obtained with an inner antenna length of 180 centimeters In order to keep the inner antenna length as near ½ wavelength as possible, a compromise was struck at 194 centimeters, which gave a line current ratio of 1 07 Changing the inner antenna lengths effectively changed the feeding point and there-

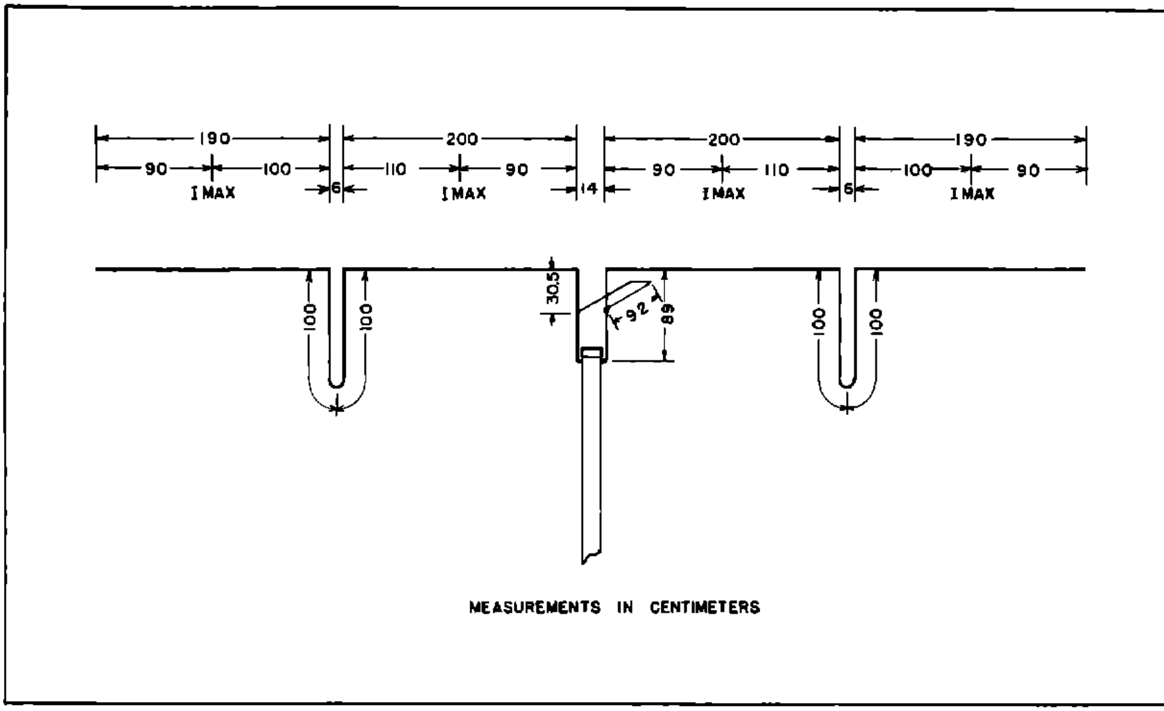

Figure 12—Antenna dimensions, showing the length of the various elements and the position of the current maximums

fore changed the impedance looking into the antenna

After termination, the currents in the several antennas were checked It was found that all four antennas had different currents (line 1 of Table I) This was considered undesirable, and an effort was made to determine the cause

Factors affecting antenna current

By means of a potential indicating device, as shown in Fig 10C, the position of the standing waves on each side of the two-wire line could be determined In this indicator the tuned circuit LCM is coupled to the line through a small capacity C_0, which is the capacity between the wire (X) and the metal cap (Y) If the circuit is tuned to be capacitive, then there will be little danger of the line (X) and the capacity C_0 acting to resonate the circuit The entire unit is enclosed in a shield and is provided with an insulated handle

It was found that the positions of the voltage nodes along the two wires of the line were not exactly opposite, being displaced about 3 centimeters This was found to be the same distance as the difference in the length of the lines due to the manner of turning the corner at (A) of Fig 14 The corner was turned in the original arrangement as in (A) of Fig 14, which made a difference in the length of the two lines Changing the construction of the corner to that of (B) of Fig 14 corrected the line lengths and the potential nodes then came opposite each other This also resulted in a better ratio of antenna currents as indicated in line 2 of Table I

It was reasoned that any capacity coupling from the power amplifier tank circuit to the line will cause in-phase currents to flow in the two lines The current caused by the inductive coupling between the power amplifier tank and

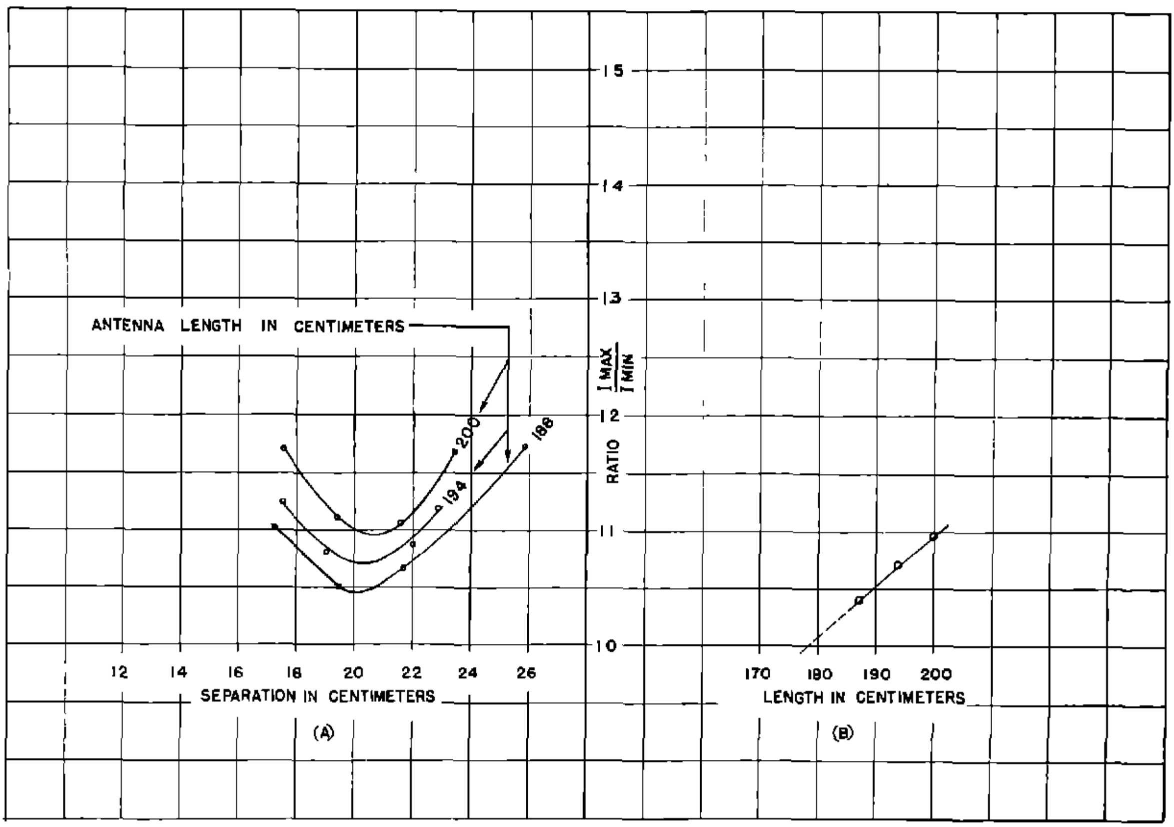

Figure 13—Line termination by means of a V-shaped feeder section A—Line current ratio plotted against separation at top of the V for various antenna lengths B—Best line current ratio plotted against antenna length

line acts between the wires, and is out-of-phase on the two conductors. The reaction between the in phase and out-of-phase current in the line tends to displace the nodal points, and causes an unbalance between the antenna currents. By grounding the voltage nodal point of the coupling coil this in-phase line current can be reduced. However, locating the exact nodal point is not very convenient. A simpler method of removing the in-phase currents is to connect a split stator condenser across the line and ground its rotor. The rotor will be at ground potential with respect to the out-of-phase currents and will act as a capacitive load across the line, the two capacities being in series. Grounding the rotor will have no effect on the out-of-phase currents but the in-phase currents will then be shunted to ground through the two sections of the condenser in parallel. Since the effectiveness of this path is dependent on the ratio of the impedances of the line beyond the point and that of the condensers, the impedance to ground can be reduced by connecting the midpoint of the condensers to ground through a coil of such inductance to tune to resonance with the split stator condenser. When properly adjusted this in-phase trap circuit has a tendency to provide a better balance between the antenna currents as shown in line 3 of Table I.

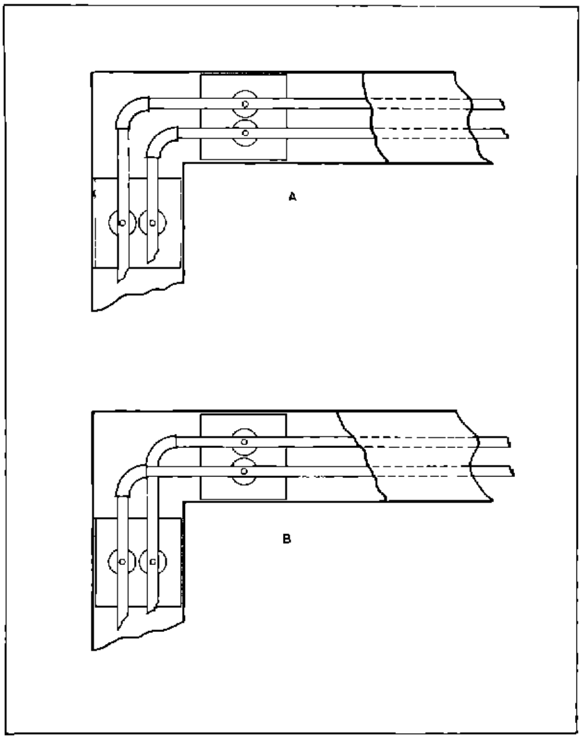

Figure 14.—Methods of constructing 90° bend in transmission line
A—Line lengths unequal
B—Line lengths equal

TABLE I

	Antenna				Ratio
	1	2	3	4	$\frac{I_{lowest}}{I_{highest}}$
1	80	104	108	93	0 74
2	76	92	95	78	792
3	84	106	106	86	792
4	96	106	106	99	90
5	93	109	109	93	85
6	115	142	140	115	82

A calculation of the radiation resistance of the antennas indicates that the resistance of the outer antennas should be less than that of the inner by 23 percent, the corresponding current, therefore, being greater. Measurements indicate a lower current in the outer antennas. This is no doubt due to the phasing sections and the method of feeding the antennas, since only the effect of the mutual coupling between the antennas was taken into account in the calculations.

In an effort to improve the ratio of the currents between the antennas, an interesting phenomenon was noted in connection with the phasing sections. It was found that changing the phasing sections so that they were vertical above the antennas improved the ratio by about 10 percent (line 4 of Table I), making the phasing sections horizontal was an improvement of about 5 percent (line 5 of Table I). When the phasing sections were horizontal, the indicated current maximum was at the center of the inner antenna. This was considered as the normal condition, since moving the phasing sections to a vertical position, either above or below the antenna, moved the indicated current maximum approximately ten centimeters either side of the inner antenna center. This indicated that possibly a current was being induced in the phasing sections in such a direction as to add to the inner antenna current and subtract from the outer Neither transposing nor reversing the feeders had any appreciable effect A folded ½ wavelength section in the shape of an **S** was substituted for the phasing sections This section had the same effect as taking up only a quarter wave, and the current maximum on the inner antenna moved to the outer end, or ¼ wavelength No explanation could be given for this result

and below as shown in Fig 4 The indicated antenna current maximum was displaced ten centimeters toward the feeders as shown in Fig 12 The final indicated antenna current maximums are shown in line 6 of Table 1

Final line termination

A shorted section of line was used for termination The curves of Fig 15A were obtained by plotting the line-current ratio against the length of the shorted section for several

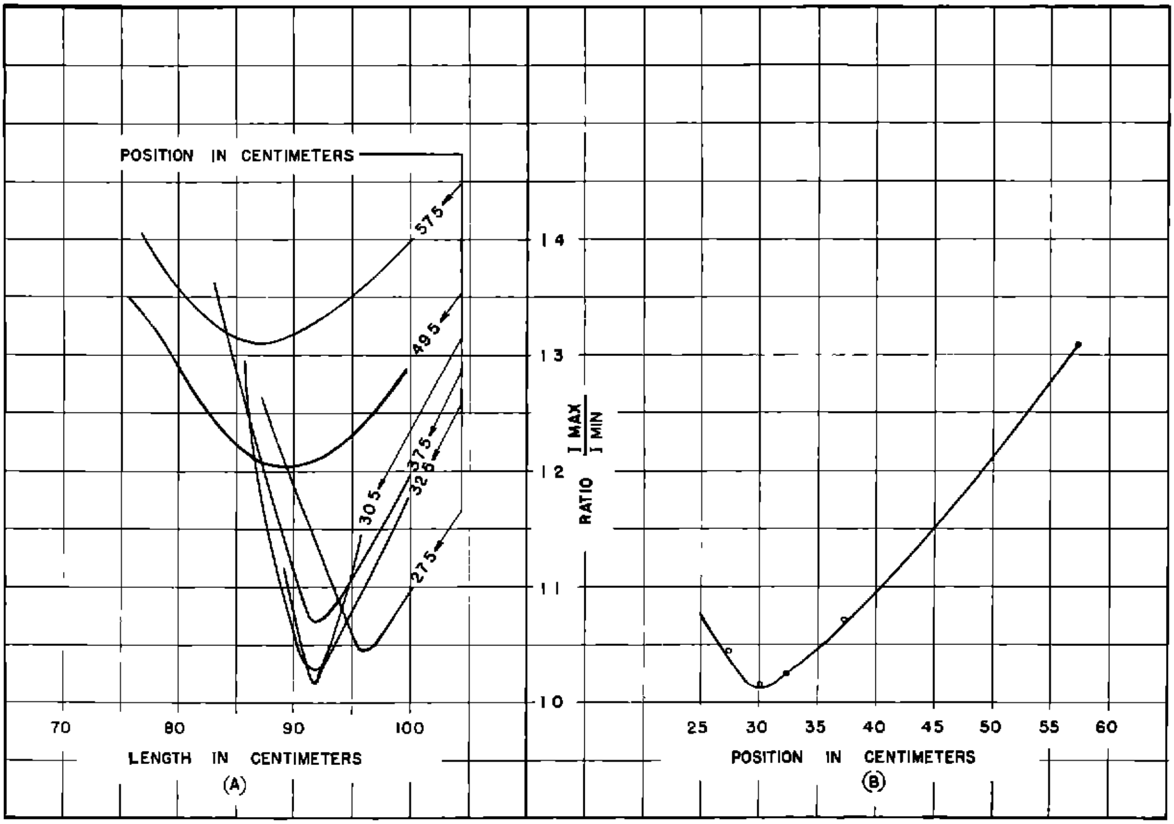

Figure 15—Line termination by means of shorted section of line A—Line current ratio plotted against length of shorted section for various positions Position is distance from the antenna to the matching section B—Best line current ratio plotted against position

Two different spacings for the phasing sections were tried one 5 4 centimeters, the other 12 centimeters The close spacing gave a slightly better ratio of antenna currents

Since it would not be practical to leave the phasing sections vertical above the antenna, due to the possible interference from the supporting structure, it was decided to make them vertical

positions of the matching section From the minimums of these curves is plotted Fig 15B, using the position as the variable From these two curves, it is seen that the matching section should be 92 centimeters long and placed 30 5 centimeters from the antenna Final check on the line gave a current ratio 1/1 as closely as could be measured

FLIGHT TESTS

After completion and adjustment of the antenna system, flight tests were conducted in Bureau airplane NS–31, a high wing fabric monoplane. The receiving antenna was a half-wave horizontal doublet stretched along the belly of the ship. A shielded coaxial line connected the antenna to the receiver. The installation is shown in Fig. 16. The receiver used

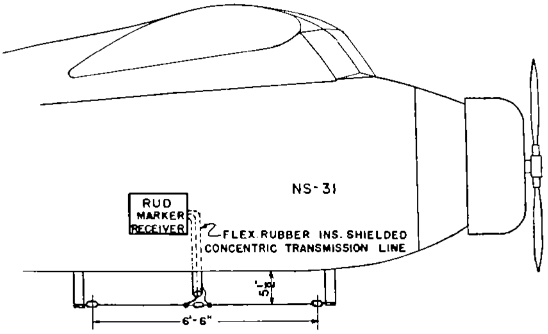

Figure 16.—Marker receiving antenna on NS–31.

was the type RUD, developed by the Bureau, and is shown in Fig. 17. Graphic records were made of the rectified audio output of the receiver, using an Esterline-Angus type AW recording milliammeter. This airplane and receiving equipment were used on many of the previous tests during the development of the fan and Z type markers. The receiver sensitivity is adjusted so that the relay will close and the indicator lamp will light when the signal input to the receiver is equivalent to 1300 microvolts (modulated 30 percent with 3000 cycles) from a Ferris Microvolter. Flights were made at altitudes between 3,000 and 11,000 feet, and for various positions to either side of the true "on course" over the station. From recordings and observations taken during these flights, it was possible to determine the relative shape of the field patterns at various altitudes.

Plan views of the pattern, based on average time of marker signal operation, are shown in Fig. 18. The relative thickness of the pattern obtained from flights directly over the station

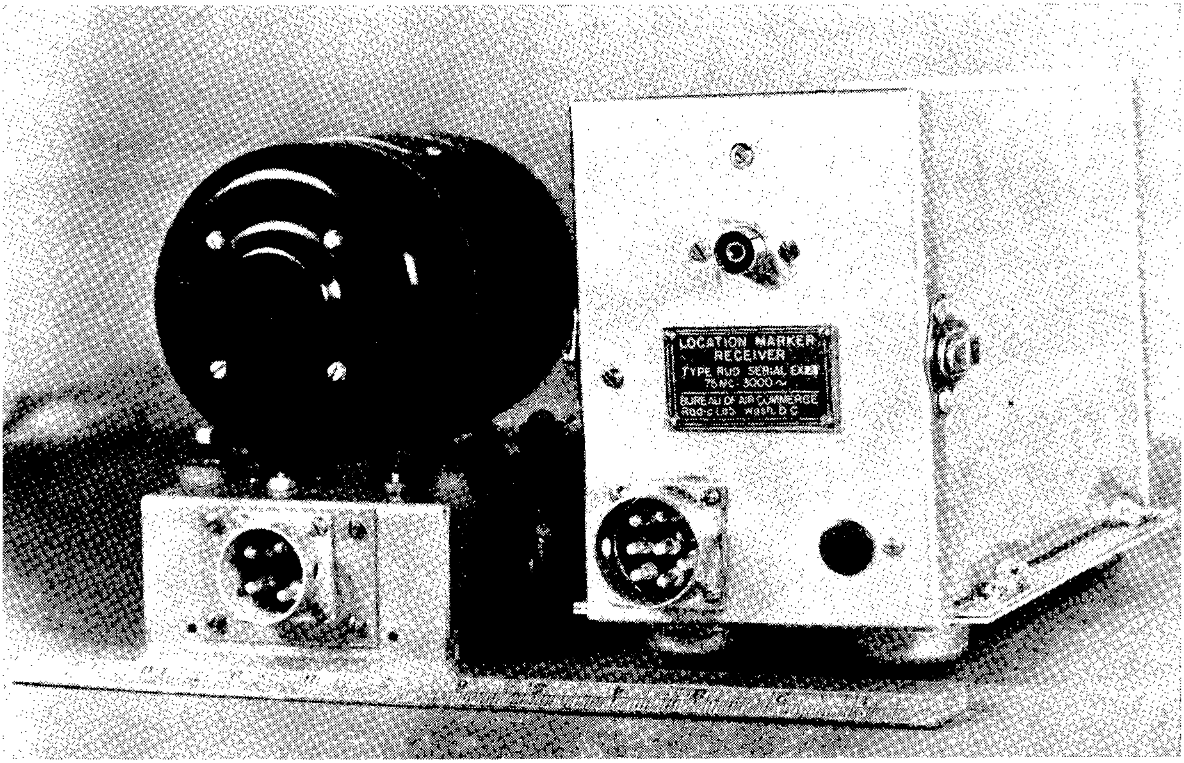

Figure 17.—Ultra-high-frequency marker receiver, type RUD.

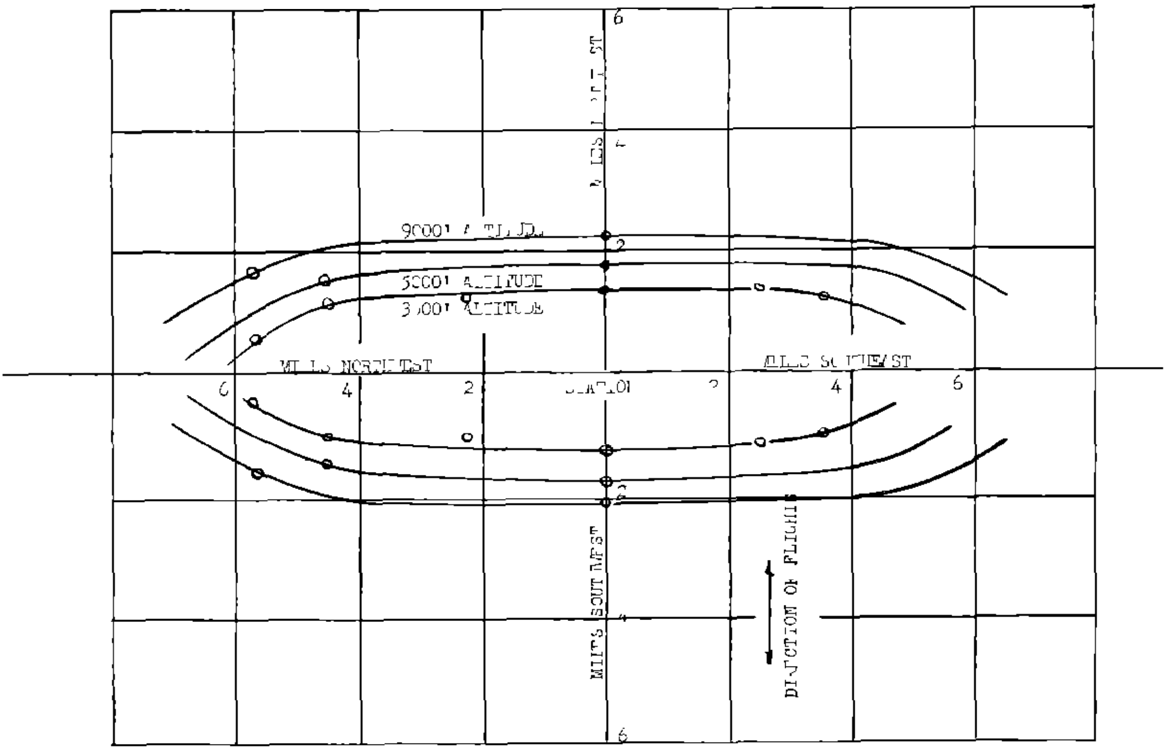

Figure 18—Patterns showing the approximate area over which marker signal operates

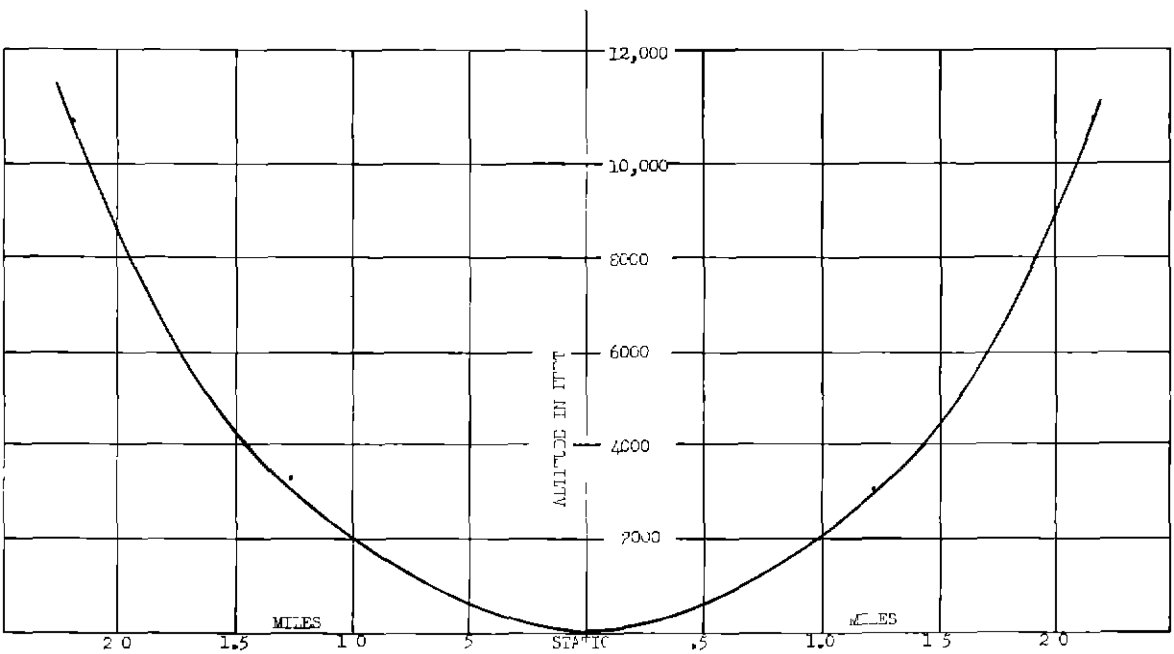

Figure 19—Thickness pattern up to 11,000 feet

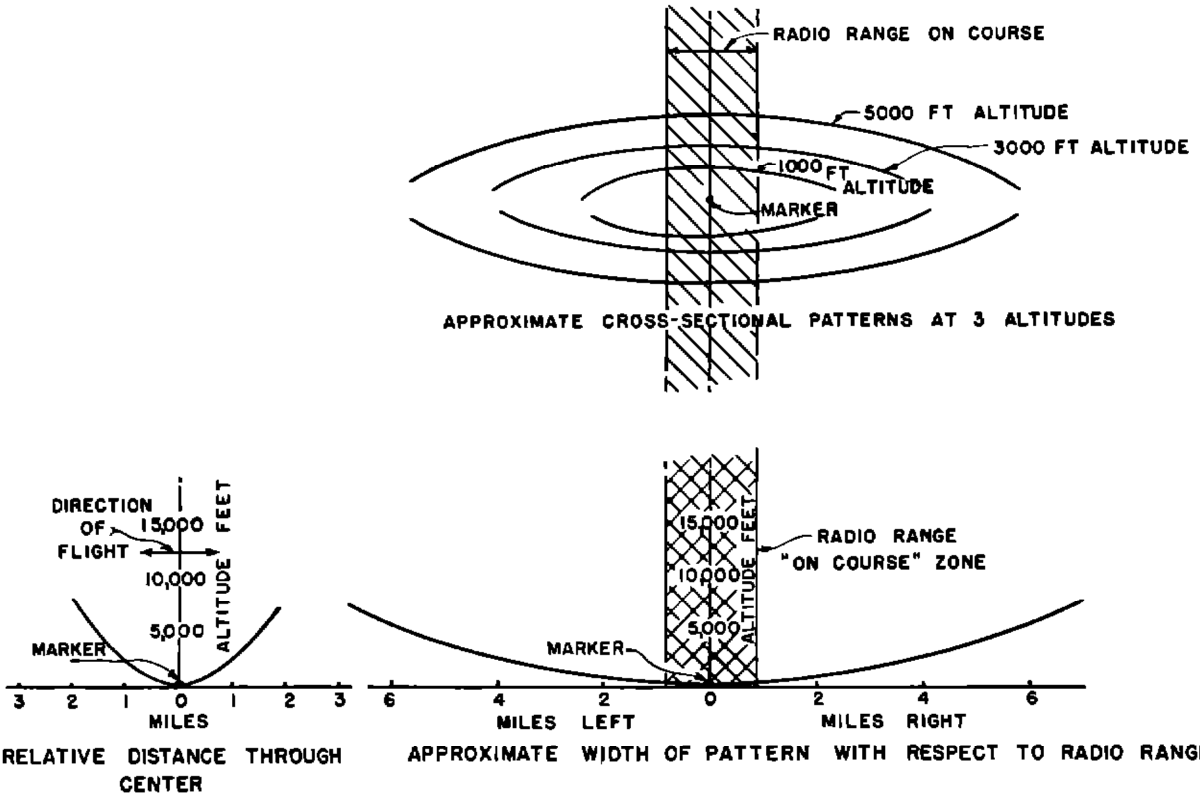

Figure 20—Fan-type marker patterns, based on earlier data without counterpoise system

along the true "on course" is shown in Fig 19 This pattern is also based on average time of signal operation In studying curves 18 and 19, it will be observed that for the 3,000-foot altitude, the pattern dimensions are approximately 12 miles wide and 2 5 miles thick The relative patterns obtained for the earlier antenna are reproduced in Fig 20 for comparison

From the recordings of receiver output taken during flights over this station, it is possible to determine the relative position of the two minor lobes existing on either side of the main lobe of the transmitted pattern This was done and the results are shown in Figs 21 and 22 Fig 21 represents flights made in a northeast direction directly over the station, for altitudes between 3 000 and 11,000 feet The irregularities of the recordings have been omitted in drawing the outlines of both Figs 21 and 22 to simplify the interpretation of the position of the two minor lobes In the central portion of the recordings, considerable irregularity was noted because of the overloading of the receiver from the strong signals of the major lobe These irregularities did not affect the determination of actual pattern dimensions or the position of the respective lobes Fig 22 shows the relative recordings and lobes over the station for flights made in the direction opposite to that of Fig 21 It will be observed that both figures are fairly symmetrical with respect to the station, although there is a noticeable leaning of the pattern for the northeast flights of Fig 21 This is less evident in the opposite flights of Fig 22 Such displacement can be accounted for partially by the directional characteristics of the

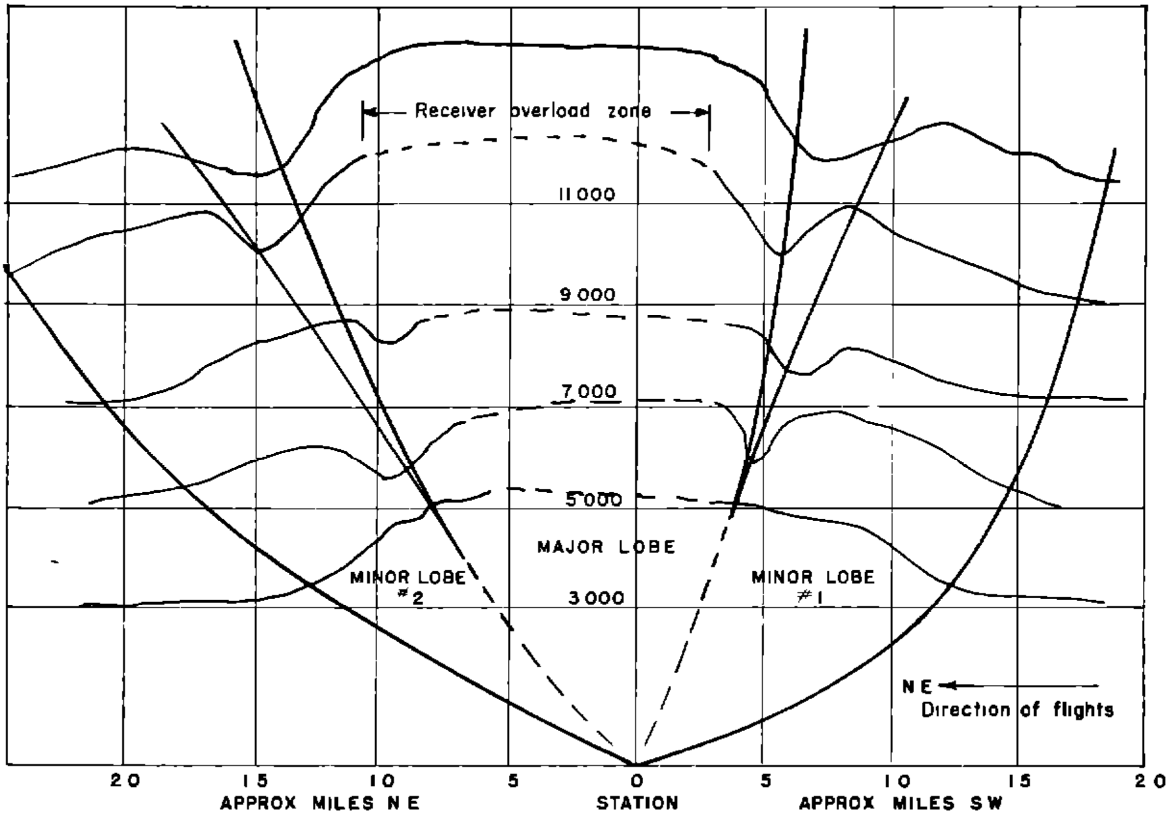

Figure 21.—Copies of graphic records of northeast flights, showing presence and position of lobes

receiving antenna on the airplane The receiving characteristic of the airplane antenna is known to point slightly toward the rear of the ship, rather than directly downward

According to Figs 21 and 22 it is believed that the effect of the minor lobe in lighting the indicator lamp on the airplane is lost at some altitude above 11,000 feet Since the amplitude of the minor lobes is only 15 percent of that of the major lobe, it can be assumed that the major lobe extends above any altitude at which flights of commercial aircraft are contemplated

CONCLUSIONS

In view of the results obtained, it is concluded that—

1 The vertical field pattern obtained is essentially the same as that obtained from calculations assuming a perfect reflector The sixty-foot high, steel beacon light tower at this site does not noticeably affect the field pattern

2 The use of a counterpoise consisting of 3″ x 3″ iron wire mesh is a satisfactory stable substitute for the actual ground and the dimensions of 20′ x 40′ are sufficient for the four-element array as used for this service

3 The counterpoise may be connected to ground at the several wood supporting posts, indicating that a metal supporting framework could be used for this service

4 Crystal controlled transmitters are practical at these frequencies, and when used in duplicate with automatic change-over, are capable of providing a reliable continuous service for unattended fan marker installations

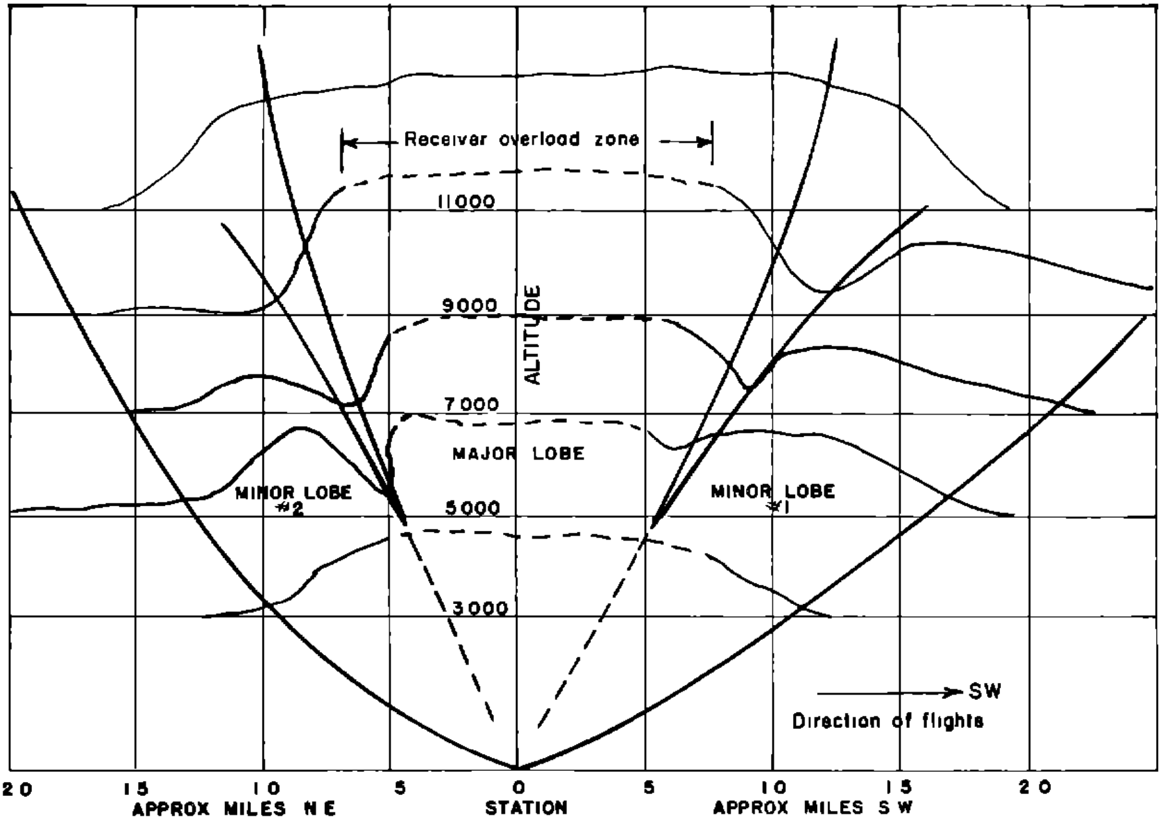

Figure 22—Copies of graphic records of southwest flights, showing presence and position of lobes

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