CIVIL AERONAUTICS AUTHORITY

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PRELIMINARY INVESTIGATION OF THE EFFECTS OF WAVE POLARIZATION AND SITE DETERMINATION WITH THE PORTABLE ULTRA-HIGH-FREQUENCY VISUAL RADIO RANGE

By J M LEE and C H JACKSON
Radio Development Section

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CONTENTS

ILLUSTRATIONS

Preliminary Investigation of the Effects of Wave Polarization and Site Determination With the Portable Ultra-High-Frequency Visual Radio Range

SUMMARY

This report describes an investigation made to determine the effects of horizontal and vertical polarization on ultra-high-frequency radio range transmission, and to establish general site requirements for the installation of this equipment. Particular attention is devoted to the effects of polarization on the multiple course phenomenon. A description of the portable equipment used in the investigation is included. Copies of actual recordings taken during tests with transmission both from an open field and immediately adjacent to sources of reflection are also included in the report. It is concluded that site requirements are much less severe with horizontal polarization than with vertically polarized transmission.

INTRODUCTION

The Civil Aeronautics Authority has been engaged in study and development in the field of ultra-high-frequency radio range systems for the past two years. During this time a large amount of the work has been centered in the investigation of the possibilities of both horizontal and vertical polarization at both 63 and 125 megacycles.

An important consideration in developing any radio range system is the provision of a facility free from multiple courses. In general, it was found more difficult to eliminate multiples from ranges operating on 125 megacycles than from those operating on 63 megacycles, and that vertical polarization was more susceptible to the multiple course phenomenon. Although no attempt will be made to describe the tests made to arrive at this conclusion, it was found extremely difficult to predict the operation of a radio range at various types of sites and it was sometimes necessary actually to make an installation before it could be said that a given site was suitable for ultra-high-frequency range operation.

All of the tests at Indianapolis and Pittsburgh were made with an aural type (A-N) range. Recordings were taken in order that an analysis could be made after the flights to determine whether there were tendencies toward multiples present that were not distinguished at the time of the flight test. At this time it was felt that much more definite analyses could be made from a visual type radio range where the two audio modulation frequencies blend smoothly from an OFF-course signal in which one frequency only is recorded on one side of a zero-center record, through the center of the record when the two signals combine equally to form a course, to the other OFF-course signal where the second frequency only is recorded on the other side of the zero-center record. When the patterns radiated from the antenna system are uniform, then the record will show a smooth line from one side of the record to the other. When the patterns are nonuniform, a jagged line will show on the record and the results can be analyzed with ease.

With these advantages in mind, a portable visual radio range system was purchased from the Washington Institute of Technology. The equipment was housed in a trailer to provide a self-contained mobile unit that could be towed to any site so that tests could be made without any requirements other than those provided for in the trailer. With this equipment, it was felt that suitable sites for future ultra-high-frequency radio ranges could be selected in advance of the actual installation and that further study could be made of the causes of multiples in given locations.

EQUIPMENT

The trailer equipment.

The trailer equipment consists of a gas-engine-powered generator, a frequency and voltage regulator, an ultra-high-frequency transmitter, a transmission line modulator, and three different types of antenna systems. The weight of the trailer and equipment is 5,140 pounds. A three-quarter-ton truck is provided for towing the equipment.

The trailer.

The trailer is of the general house-type construction with well-insulated walls and complete metal shielding. Two compartments are provided; one for the gas-engine-powered generator and voltage regulating equipment, and the other for the transmitter and the storage cabinets. Both compartments have forced ventilation and protection against dust is provided. Because of the door seal between compartments, the blower in the engine room creates less than atmospheric pressure in that compartment thereby insuring against danger from carbon monoxide gas in the transmitter compartment. The gasoline storage tank located in the engine room has a capacity of 20 gallons and provides for approximately 15 hours of full load operation. Storage cabinets are available in the transmitter room for antenna rods, transmission lines, antenna structure, and miscellaneous material. The downward weight of the trailer at the coupling to the truck is 325 pounds. The coupling and jack systems are so constructed as to make it easily possible for one man to couple the trailer to the truck in approximately five minutes. Fig. 1 is a photograph of the truck and trailer.

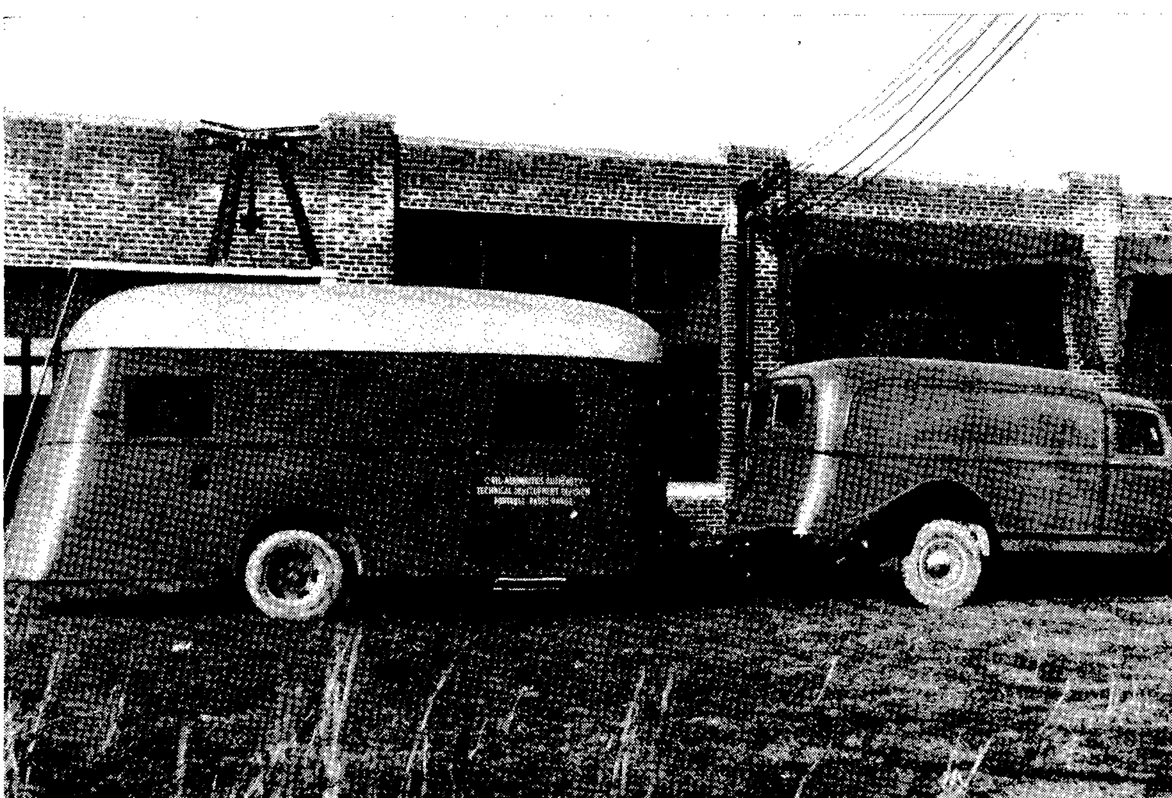

Figure 1.—Portable 125-megacycle radio range.

The power equipment.

The power source equipment consists of a 4-cylinder air cooled type gas engine driving an alternator capable of delivering 4 kilovolt-amperes at 115 volts, 60 cycles. Since the modulation frequencies of 90 and 150 cycles are quite critical and are dependent on the exact frequency of the 60-cycle power source, a governor is installed on the engine to provide for frequency regulation at or near full load. Provision is made for adjusting the frequency at loads other than full load. A voltage regulator maintains the line voltage within 5 percent of the specified 115 volts. An outlet on the outside of the trailer provides for the connection of external 115-volt, 60-cycle power when available. Fig. 2 is a photograph of the engine room.

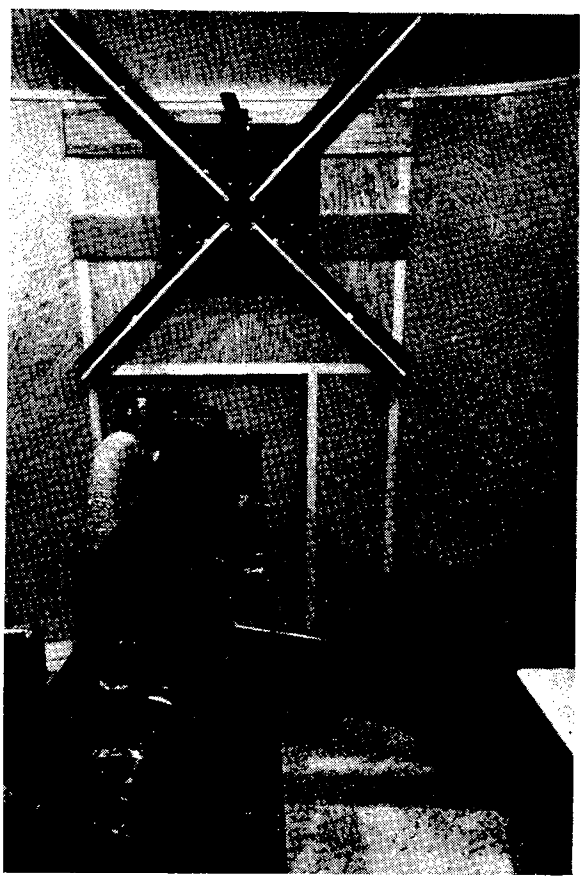

Figure 2.—Trailer engine room.

The transmitter.

The transmitter is constructed in two units, one containing the filament supply and radio-frequency stages and the other for the high voltage power supply and control circuits. The transmitter is crystal-controlled, using a 5208.333-kilocycle crystal. One type 802 tube is used as an oscillator-tripler, one type 807 tube doubling, another type 807 tube doubling, two type UH-51 tubes doubling, two type 100TH tubes amplifying, and a final power amplifier stage consisting of two type 250TH tubes with a final frequency of 125 megacycles and an output power of 200 watts. The transmitter is built up in sections with each section individually shock mounted for protection against vibration. A centrifugal blower provides ventilation for both units of the transmitter with spun glass filters for protection against dust. Fig. 3 is a photograph of the transmitter and Fig. 4 a photograph of the power and control unit. In addition to furnishing the high voltage supply for the transmitter, the power and control unit contains all the necessary protective devices and control switches. Fig. 5 is a block diagram of the transmitter.

The modulator.

The 90- and 150-cycle modulation required for visual operation is furnished by means of a transmission line modulator. This equipment consists of two rotating condensers (one in each transmission line) driven by a synchronous motor. One condenser modulates the carrier in its transmission line at the rate of 90 cycles per second and the other modulates the carrier in its transmission line at the rate of 150 cycles per second. Percentage modulation is controlled by the spacing between the rotor and stator plates; the frequency by the speed of the motor and the number of rotor plates; and the wave shape by the shape of the condenser plates and the setting of the tuning stubs. Coaxial transmission lines are used to connect the transmitter power amplifier stage to the modulator and the modulator to the antenna system.

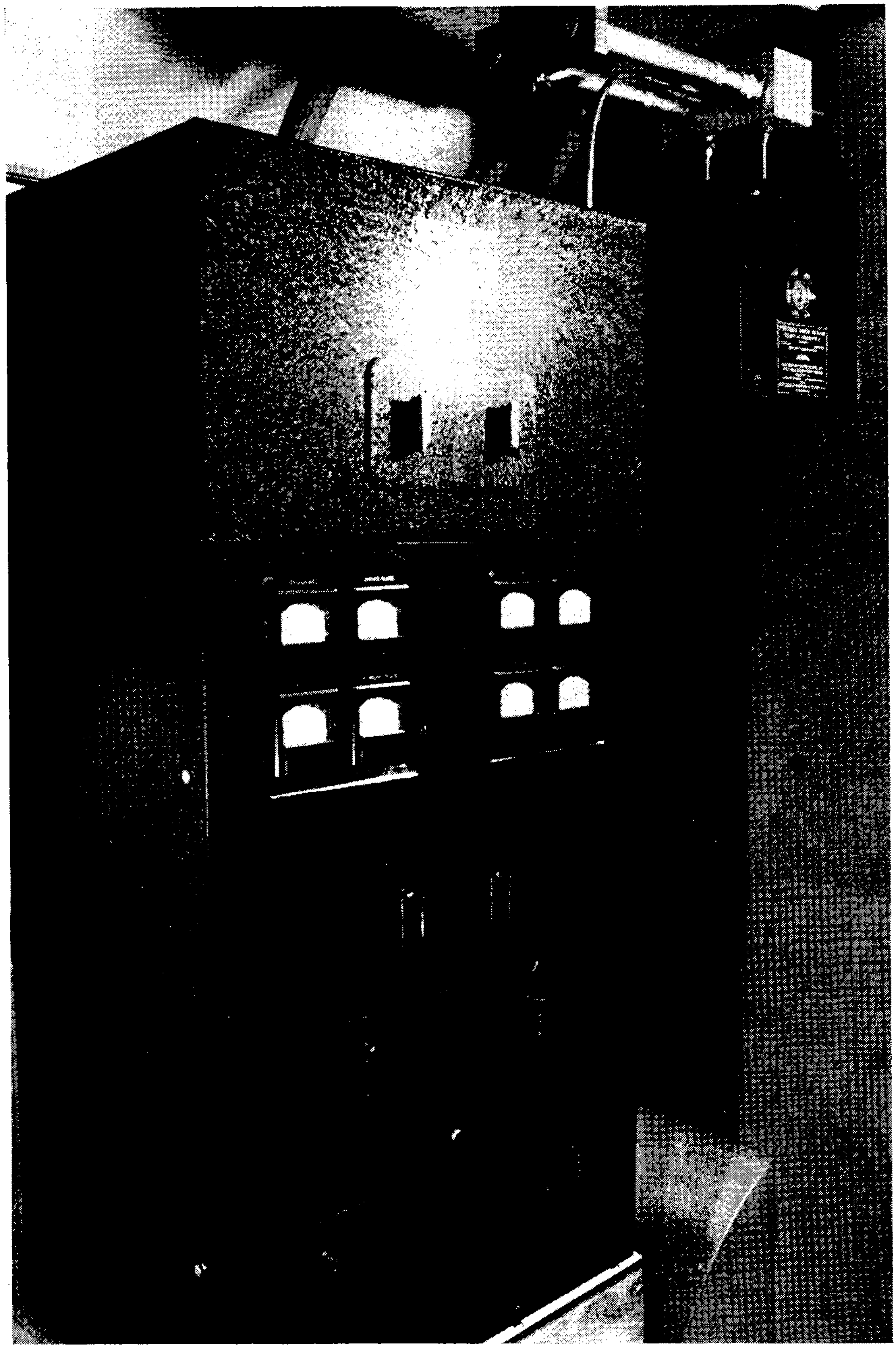

Figure 3.—Transmitter and beacon converter.

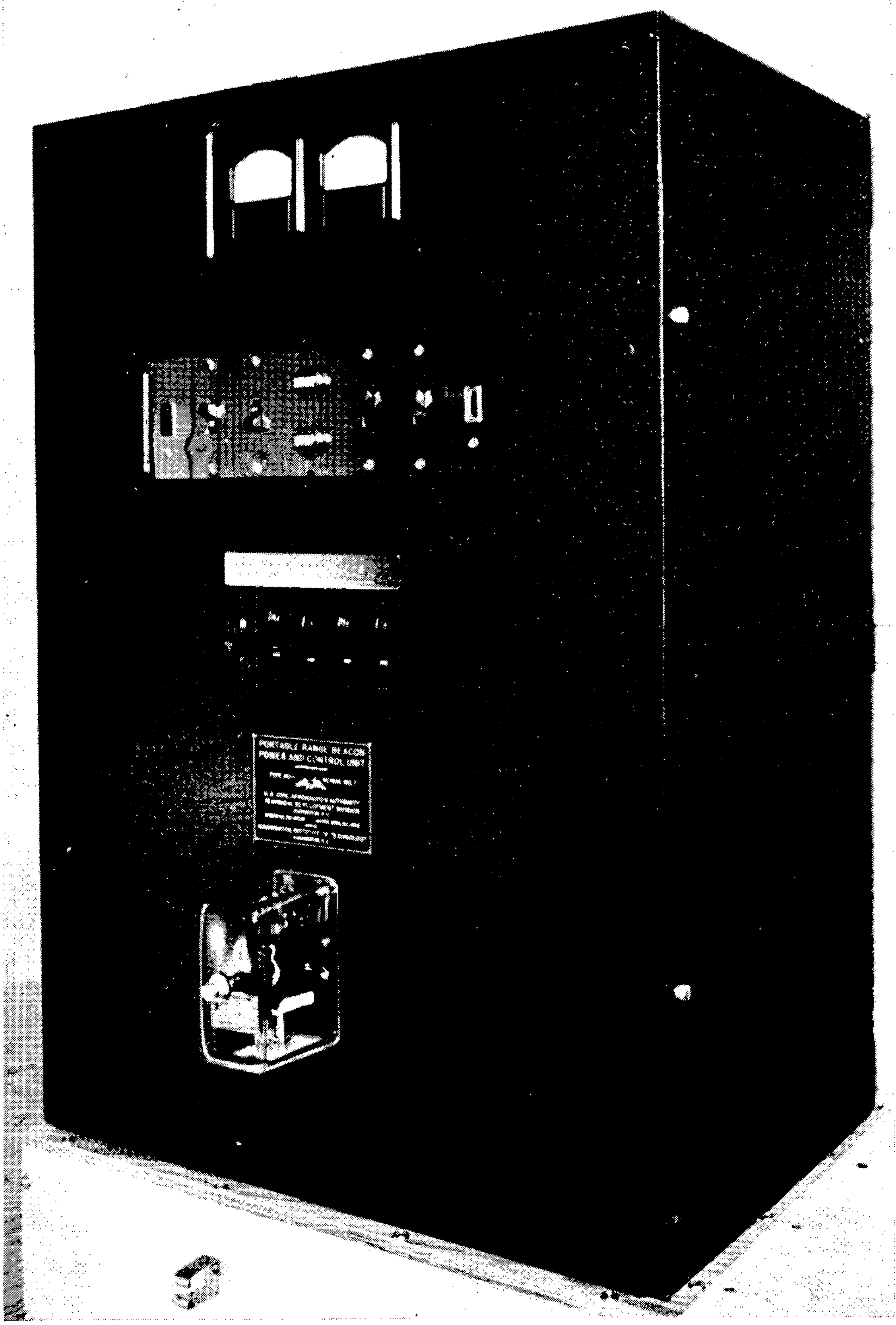

Figure 4.—Power and control unit.

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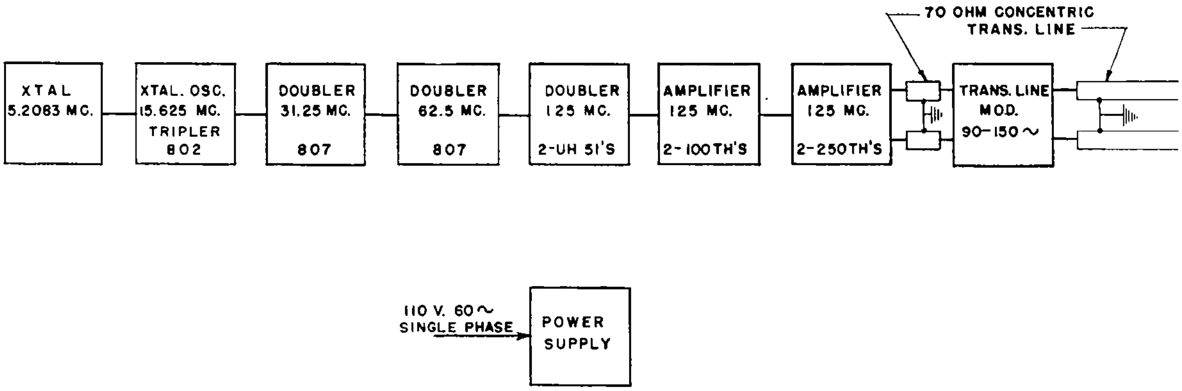


Figure 5.—Block diagram of 125-megacycle transmitter, portable radio range.

The antennas.

Three different types of antennas are provided, one for vertical polarization tests, and two for horizontal polarization tests.

The vertical antenna consists of four vertical one-half wave doublets placed in a square with 0.42 wave length separation between diagonally opposite elements. This array then provides two figure-of-eight patterns at right angles to each other in a horizontal plane with four courses approximately 90° apart. This antenna and its associated coupling device are shown in Fig. 6.

The two horizontally polarized antennas employ the same antenna elements but use different coupling systems. In the case of the two-course range, the carrier frequency is fed in phase to two horizontal half-way doublets at right an-

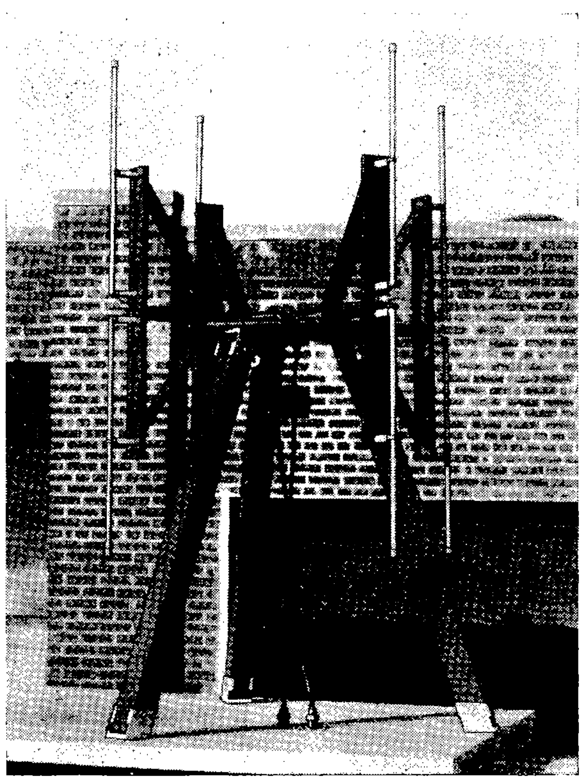


Figure 6.—Vertical four-course antenna.

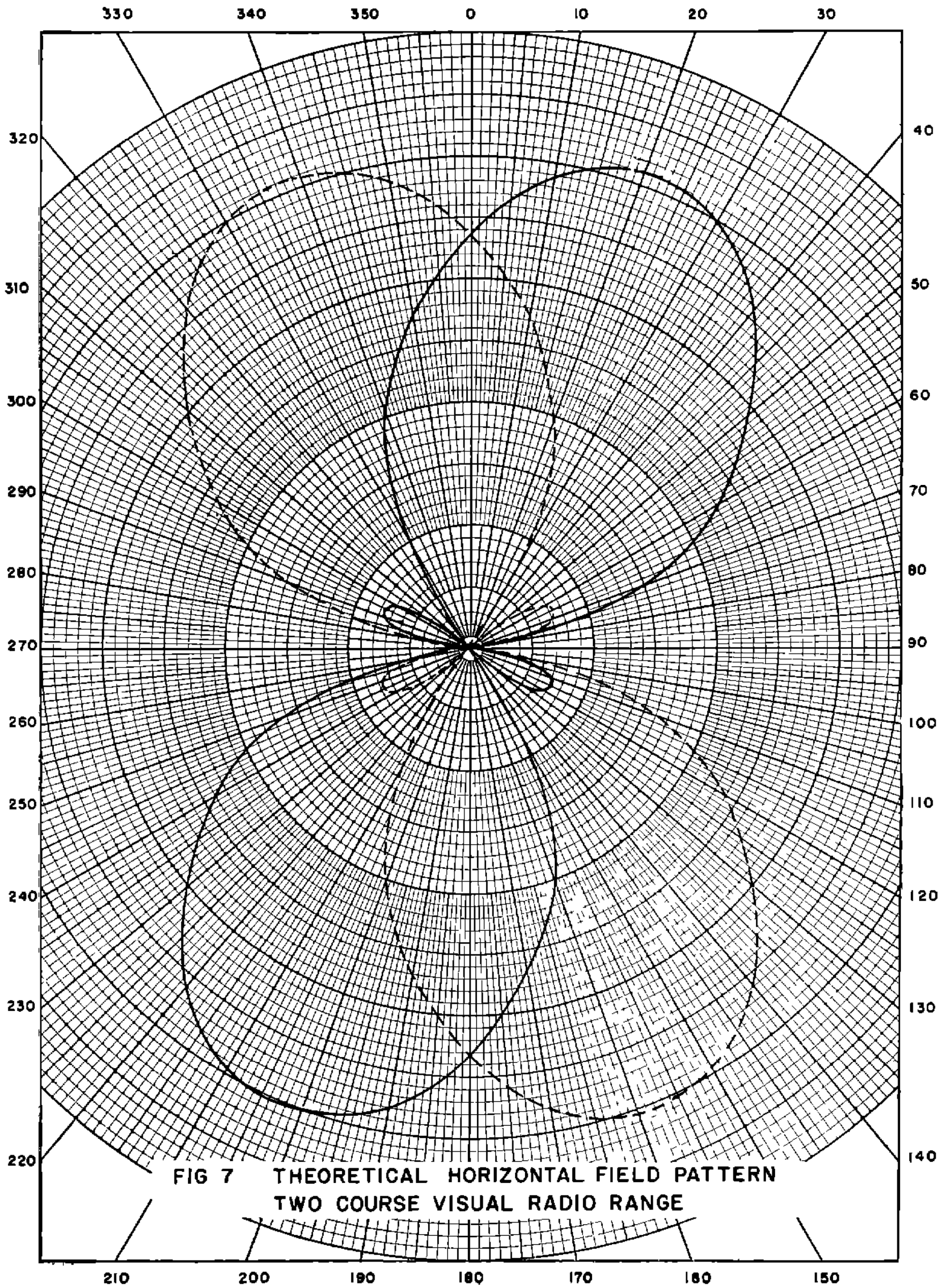


FIG 7 THEORETICAL HORIZONTAL FIELD PATTERN
TWO COURSE VISUAL RADIO RANGE

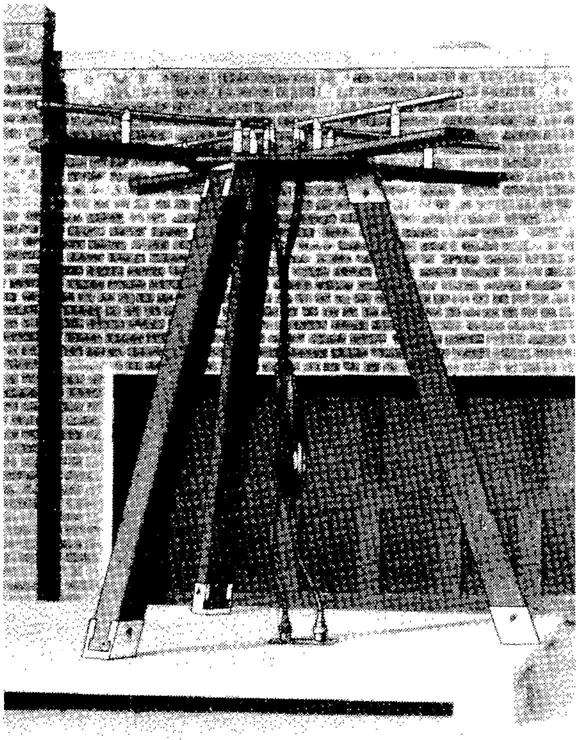


Figure 8.—Horizontal two-course antenna.

gles to each other on the same axis. The theoretical field pattern obtained by this type of array is shown in Fig. 7. In this case, the lobes of the figures-of-eight become elongated and squeezed so that only two courses are produced approximately 180° apart. Fig. 8 is a photograph of this antenna system.

In the case of the four-course horizontally polarized antenna, the carrier frequency is fed 90° out of phase to the same antenna elements as are used in the two-course range. This array then provides two figure-of-eight patterns at right angles to each other in a horizontal plane just as in the case of the vertically polarized antenna. A photograph of the four-course horizontally polarized antenna is shown in Fig. 9.

The aircraft equipment.

The aircraft equipment used in the tests consisted of a 125-megacycle crystal-controlled aircraft receiver, a two-channel audio amplifier and detector unit, an Esterline-Angus type AW recorder, a 75-megacycle horizontal marker receiver antenna, a 125-megacycle horizontal antenna and a 125-megacycle vertical antenna. Flight tests were made in Civil Aeronautics Authority airplane NC–17, a Waco model "N" with a tricycle landing gear.

The receiver.

The receiver is a crystal-controlled superheterodyne using a 6N7 tube for the crystal and harmonic generator stage and a 955 tube for the second harmonic generator stage. The crystal frequency is 9416.7 kilocycles. The twelfth harmonic of the crystal frequency is used to feed the first detector suppressor grid. The radio-frequency amplifier and first detector are type 956 tubes. Three stages of intermediate-frequency amplification at 12 megacycles are provided by three type 6K7 tubes. Following is a 6Q7G tube used as the second detector, automatic volume control and first audio amplifier; a 6C8G tube used as a noise suppressor and second audio amplifier; and a 6K6G tube used as a final audio

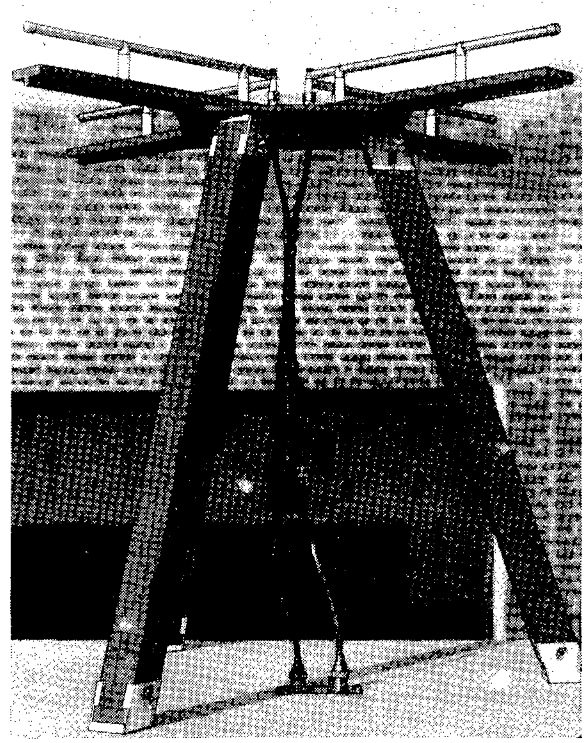


Figure 9.—Horizontal four-course antenna.

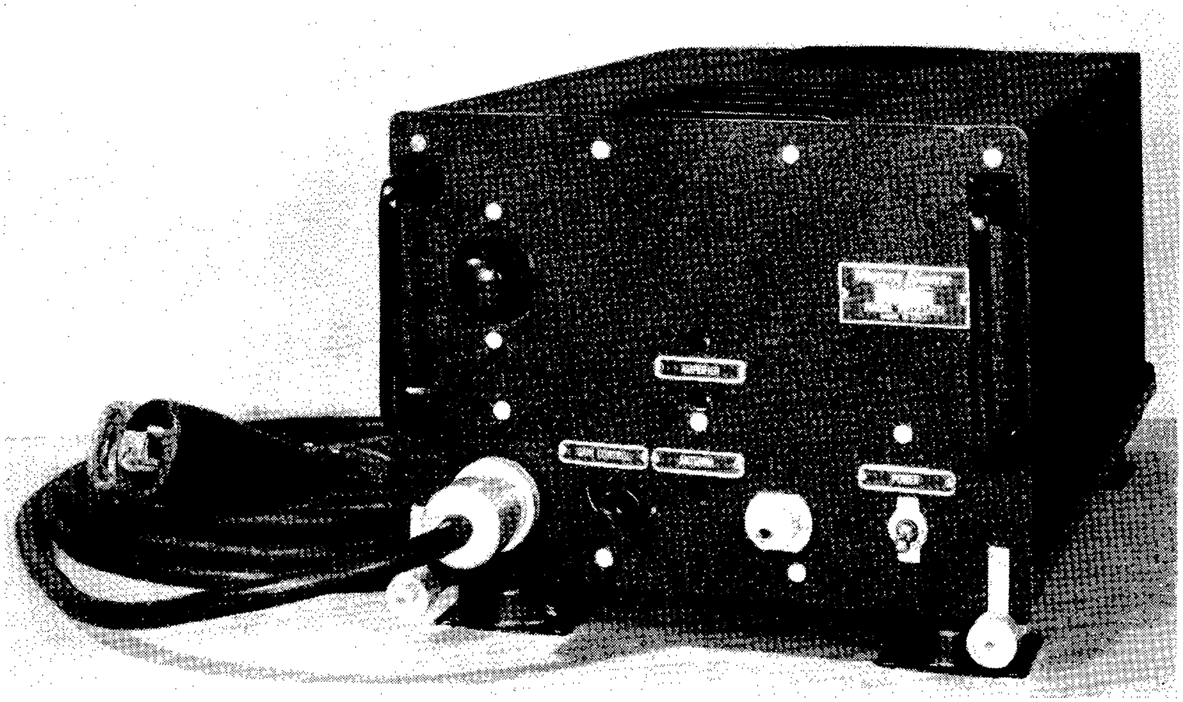


Figure 10.—Aircraft receiver for 125 megacycles.

amplifier. Types 0Z4 and 6ZY5G tubes are used as plate and bias rectifiers. Fig. 10 is a photograph of the receiver and Fig. 11 is a block diagram of the unit.

The recording equipment and visual indicator.

An Esterline-Angus, Model AW, zero to five milliampere recorder was used for the recordings taken during the tests. The paper feed

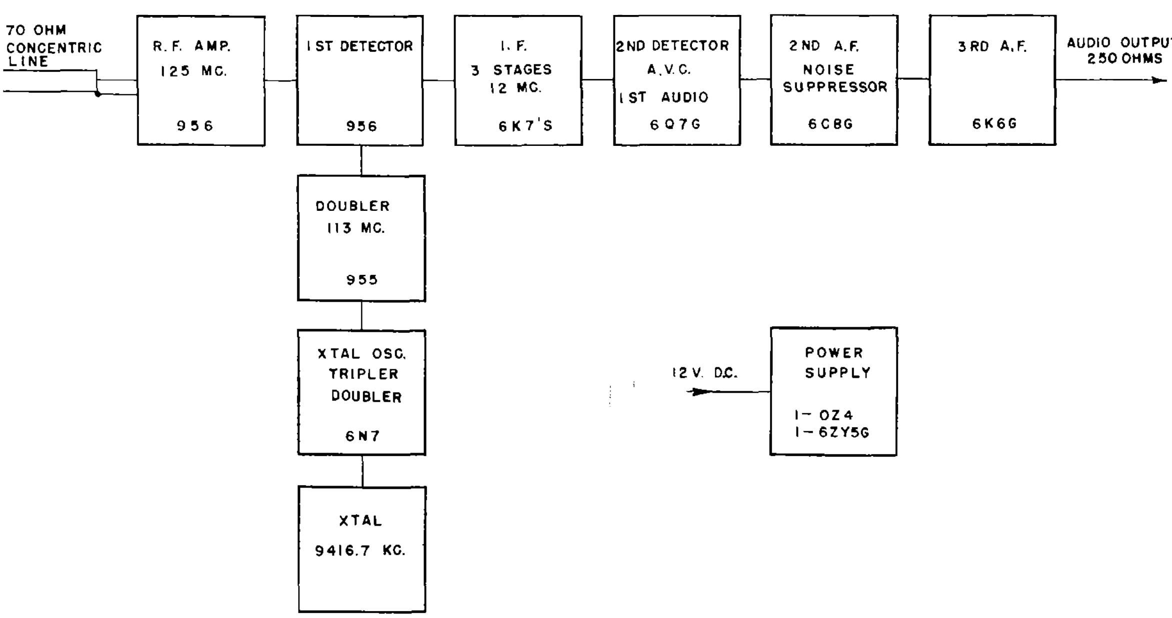


Figure 11.—Block diagram of 125-megacycle receiver.

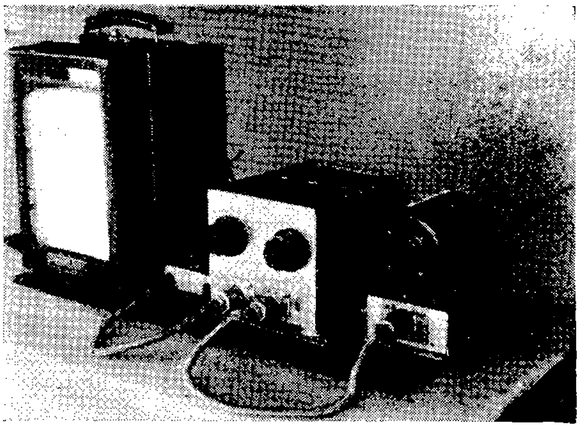


Figure 12.—Recorder, amplifier-rectifier and dynamotor.

was set to operate at the rate of 6 inches per minute. The pointer was set to read mid-scale with zero signal so that any positive signal recorded on one side of center and any negative signal recorded on the other side.

A filter-amplifier-rectifier unit was designed which would separate the 90-cycle modulation frequency from the 150-cycle modulation frequency; build up the normal headphone output of the receiver for each frequency individually; and rectify the audio output of the two channels individually so that the final resultant direct-current output could be applied plus or minus to the recorder. Fig. 12 shows a photograph of the filter-amplifier-rectifier unit used in the tests and Fig. 13 is a schematic diagram of the equipment. Since a standard 125-megacycle receiver was used which had no provision for 90–150-cycle filters, it was necessary to include the filters in the amplifier-rectifier unit. Inasmuch as the filter used was not capable of handling over 50 milliwatts, it was necessary to place the filter at the input to the amplifier to prevent overload. It was then necessary to amplify the two signals individually in two type 6F8G tubes so that there was sufficient signal on the grid of the rectifier to swing the recorder needle to its maximum in either direction with one milliwatt signal out of the receiver. Another 6F8G tube was used as a rectifier with the Esterline-Angus recorder across a potentiometer connecting the two cathodes of the double triode. The center of the potentiometer was grounded. A fixed bias was applied to the grids to provide for a maximum plate current change with signal. The potentiometer was used to adjust the recorder pointer for mid-scale with zero signal. Then with equal signals of 90 and 150 cycles, the drop across the two halves of the potentiometer remained the same and the recorder still read mid-scale. However, with unequal or OFF-course signals, the drops across the two halves of the potentiometer were unequal and the recorder read right or left of mid-scale

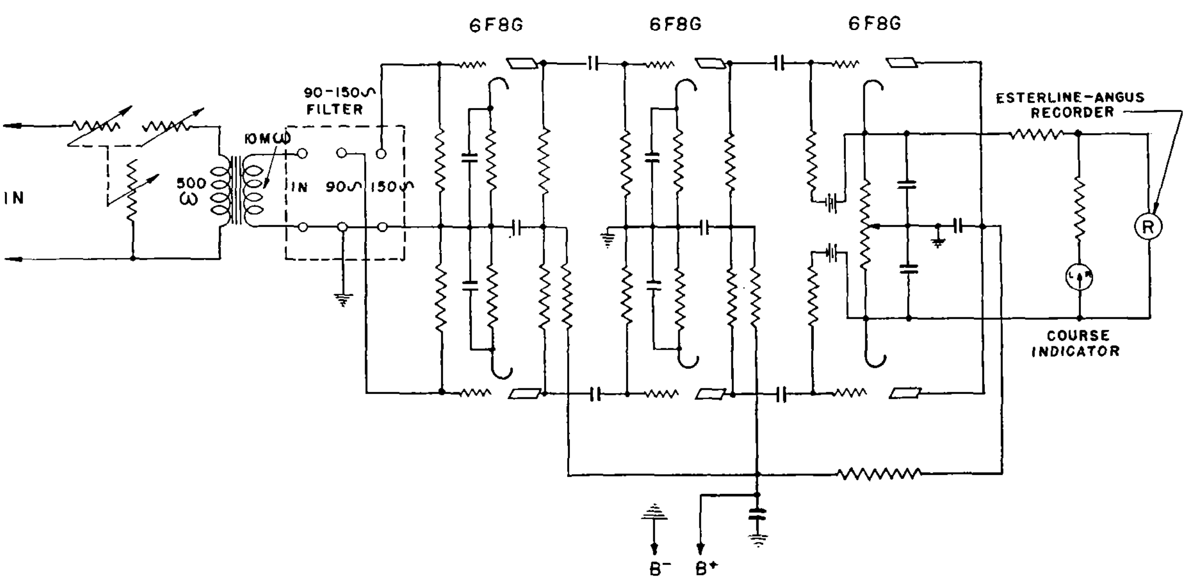


Figure 13.—Schematic diagram of 90–150-cycle amplifier-rectifier.

depending on which signal predominated. The zero center course indicator meter which was actually used to fly the system was connected across the recorder line.

Some tests were made previous to the flights with a separate copper-oxide rectifier for the course indicator connected in the circuit at the output of the filter. With this connection, it was found that unless the output of the copper-oxide rectifiers was carefully filtered, the ON-course indications of the recorder and course indicator did not coincide.

Airplane antennas.

The standard 75-megacycle marker receiving antenna was used for circling the station on tests of horizontal polarization. This antenna provided ample signal since its location on the airplane provided maximum received signal from the sides. For flying toward or away from the station ON-course, on the horizontal polarization tests, a special horizontal doublet was mounted on the plane just over the cockpit with the elements of the antenna parallel to the wings. This antenna was accurately tuned to 125 megacycles.

A 125-megacycle vertical fish pole was used for receiving all vertically polarized signals. This antenna was mounted on the fuselage to the rear of the radio cabinet. The two horizontal receiving antennas were also used to receive the vertically polarized signals to check the amount of horizontal component present. Figs. 14, 15, and 16 show the position of the receiving antennas on the plane.

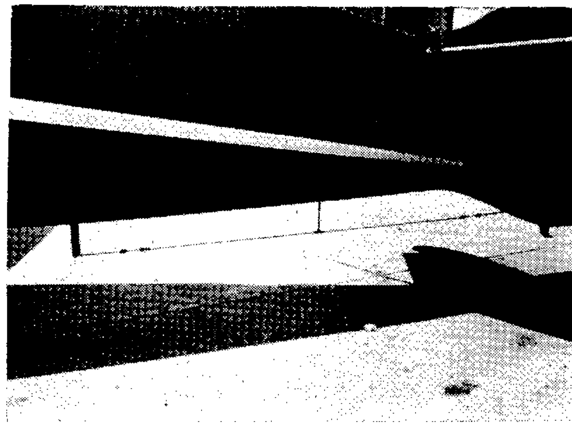


Figure 14.—Horizontal receiving antenna for 75-megacycle markers.

TESTS

Preliminary flight tests were made with this equipment at the Civil Aeronautics Authority Experimental Station, Silver Hill, Md., during the latter part of April 1939. The trailer equipment was located in front of the Silver Hill station in the largest open space available. The tests indicated that satisfactory operation could not be obtained at this location because of the proximity of other ultra-high-frequency antennas, and towers and woods. One 125-foot radio tower located approximately 150 feet from the trailer contained one 61-megacycle horizontal transmitting array and one 80-megacycle diamond receiving antenna. Slightly farther away, a 141-megacycle vertical receiving antenna was mounted atop a 60-foot pole. Another 125-foot radio tower located approximately 500 feet from the trailer contained a 125-megacycle horizontal radio range antenna located on top of the tower ½ wave above a 24-foot square counterpoise. Thick woods, houses, and other poles were all located within 200 feet of the trailer equipment.

Although no recordings were taken during preliminary flight tests, it was definitely determined that proper operation could not be obtained with the equipment at this location principally because of the number of multiple courses encountered. An aerial photograph shown in Fig. 17 indicates the approximate loca-

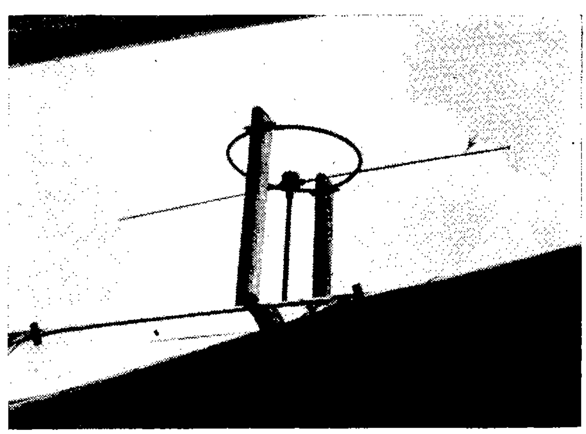


Figure 15.—Special horizontal doublet receiving antenna for 125 megacycles.

tion of the equipment at Silver Hill and the proximity of the sources of interference.

At this time, it was decided that a new site should be obtained which was as nearly perfect as possible so that the results of tests made at an ideal location could be compared later with the results of tests made at less favorable sites. Such a site was finally located near Forestville, Maryland. Fig. 18 is an aerial photograph showing the site, the surrounding territory and the two locations of the trailer equipment at the site. Fig. 19 shows the general location with respect to Washington and Silver Hill and the type of terrain over which transmission was made. As shown on Fig. 18, the field was approximately 1,750 feet long by 1,000 feet wide. For the first tests, the trailer was located near the center of the field 650 feet from the woods at the rear. The nearest trees were approximately 480 feet away and the nearest power line, telephone line, and buildings were about 1,500 feet removed. The location used was approximately the highest point in the field.

The first tests to be made at this location were ground checks to determine whether the proper field patterns were being radiated from the various antenna arrays. These ground tests were made with receiving equipment furnished by the Washington Institute of Technology. This equipment used reed filters rather than electrical filters as are used in all the flight tests with the Civil Aeronautics Authority test equipment. Sufficient information was acquired during these tests to substantially check the ground patterns as published in the instruction books furnished with the equipment. These ground patterns are reproduced in Figs. 20, 21, and 22.

After flight tests had been made with transmission near the center of the field, the equipment was moved to a position immediately adjacent to the trees on the northeast side of the field. Flight tests were again made to compare the results of tests in the center of the field to the results obtained with the trailer near the trees. At both locations, flight tests were made on all three types of transmitting antenna arrays and using all three types of receiving antennas individually.

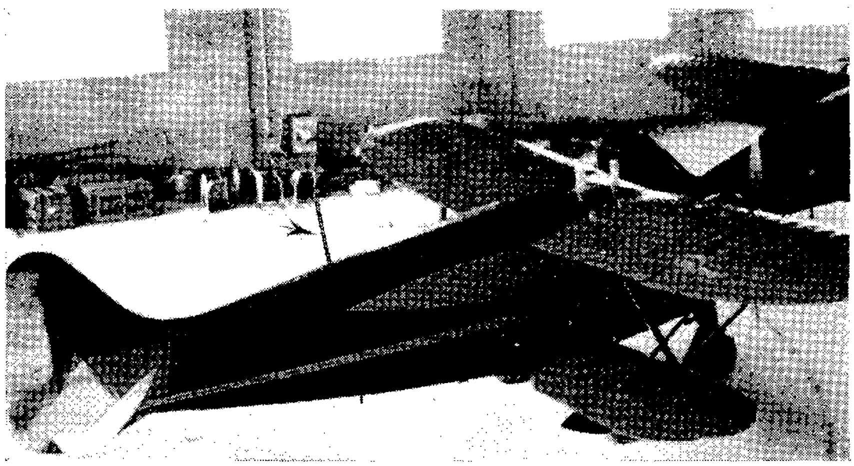


Figure 16.—Vertical receiving antenna for 125 megacycles.

RESULTS

The copies of the recordings taken of all the flights are shown in Figs. 23 to 35, inclusive. Figs. 23 to 27, inclusive, show the results obtained on the four-course horizontally polarized antenna. The first four figures showing the recordings taken using the 75-megacycle receiving antenna contain two recordings each—one with the transmitter in the middle of the field and one with the transmitter near the woods. Each of these four recordings shows the results obtained on each individual course in the two locations on flights cross course at a distance of 2 miles from the transmitter. On all the recordings, there is a difference between the amplitude of OFF-course readings at 90 cycles and readings at 150 cycles. The 90-cycle OFF-course amplitude is considerably less than the 150-cycle amplitude. This was caused by the additional loss at 90 cycles over that at 150 cycles in the audio response of the receiver.

A survey of the recordings indicates that all the courses were excellent with the equipment in the open field. The radiated patterns were free from scalloping or any other irregularities. With the transmitter located near the woods, however, less favorable results were obtained. Many scallops appeared and there were actual indicator reversals on the south and west courses. The most serious condition was on the south course where there were indicated reversals of large amplitude. It is believed that, in the case of this antenna, the cause of the serious multiples on the south course was the reflection from the trees north of the transmission point.

Fig. 27 shows a reproduction of a recording taken on a flight toward the station on the east course, over the station, and out on the west course. This recording shows clearly the high angle lobes encountered directly over the station. All antennas on the trailer equipment were approximately ½ wavelength above the screened roof of the trailer and 3/2 wavelengths above ground.

Figs. 28 and 29 are copies of recordings taken on the two-course horizontally polarized transmitting antenna using the 75-megacycle marker receiving antenna. The same arrangement of figures is used here as in the previous antenna, the top section of a given figure being a graph of results with the equipment in the open field

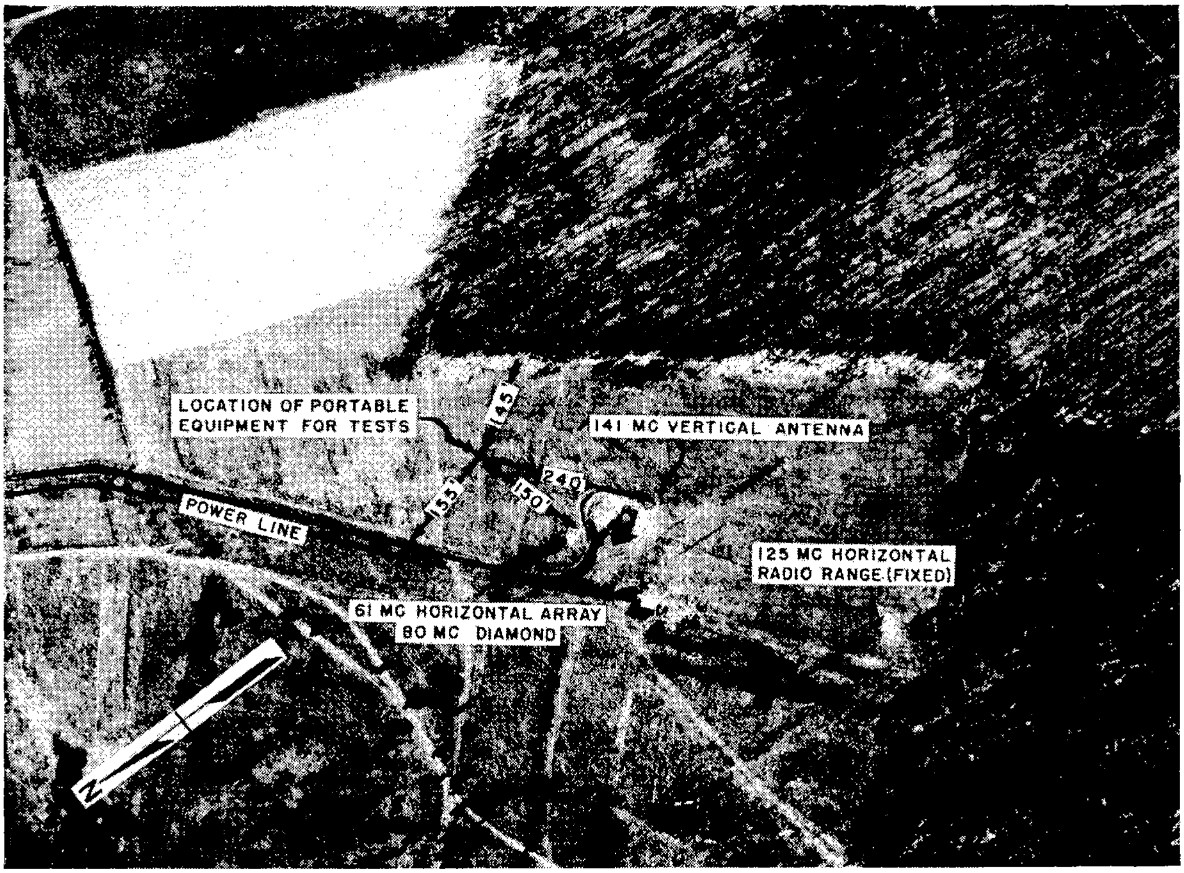


Figure 17.—Aerial photograph of Silver Hill, Md.

and the bottom section being results obtained with transmission near the trees. It can be seen that the courses using this type of transmitting antenna are much broader than the four-course antenna and much easier to fly, as shown by Fig. 30a, as compared to Fig. 27 for the four-course antenna. In fact, the course was probably much too wide for accurate flying. Analysis of the recordings shows that and the ground field pattern. As shown on the recording, there is actually an indicated course at this point as well as the area 180° removed.

The results obtained on tests of the vertically polarized array using the 125-megacycle vertical antenna for receiving are shown in Figs. 31 through 34. In this case, the recordings taken in the open field contain almost as much scalloping as the recordings taken on horizontal polar-

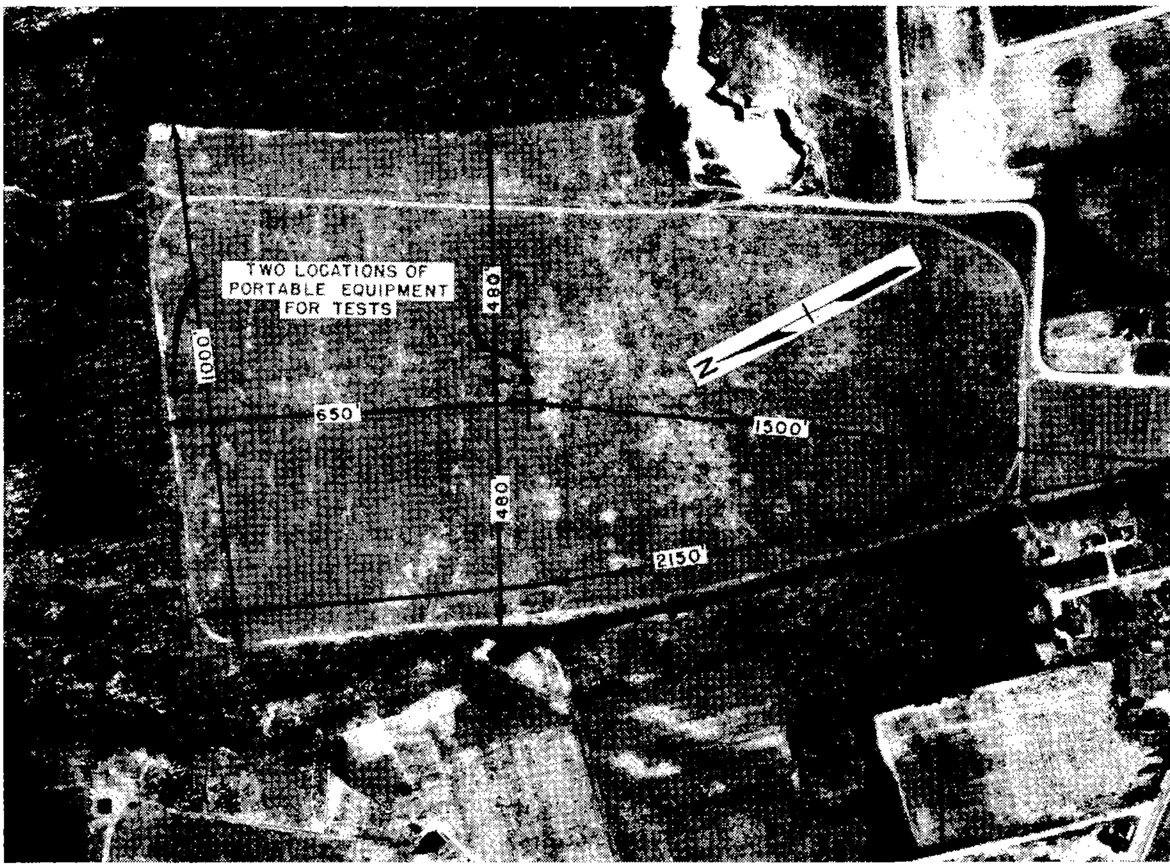


Figure 18.—Aerial photograph of Forestville, Md.

ization with transmission near the woods. It is interesting to note that the best course was probably the north course and that the thickest trees and obstructions were located north of the station. The east course was definitely the worst course encountered, as shown in Fig. 32. Multiples there are so numerous as to make it difficult to judge where the course should be located. The thick trees to the east were only 480 feet removed from the antenna while the

although there was very slight scalloping OFF-course with transmission in the open field, the ON-course was very smooth with no indicator reversals. When transmission was made near the trees, however, the ON-course signal showed slight indicator reversals on both courses.

Fig. 30b is a recording taken in the carrier suppressed zone shown between 70° and 120° on Fig. 20. A comparison of these two figures indicates agreement between the flight recording

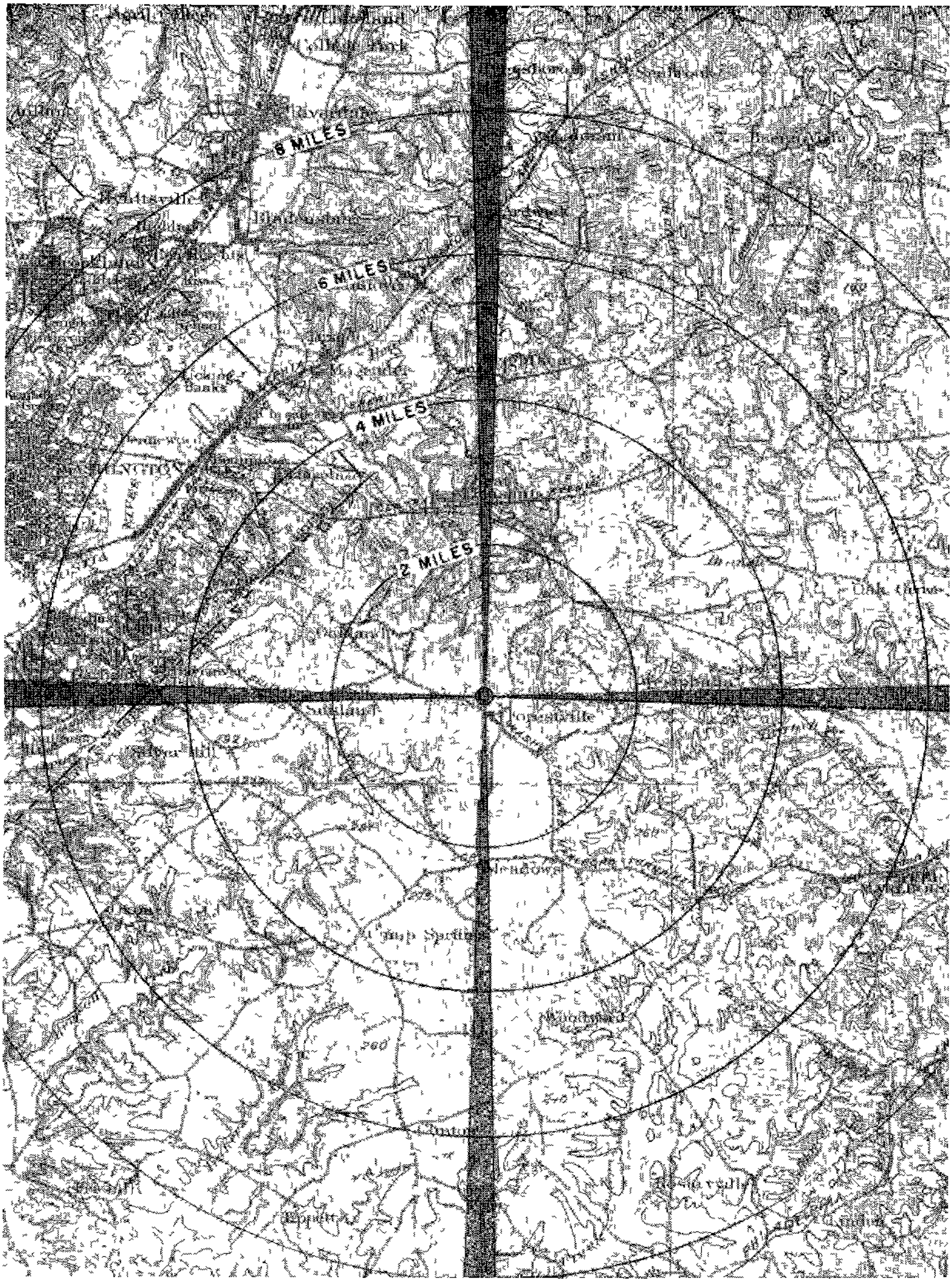


Figure 19 — Map showing location of portable equipment and surrounding terrain

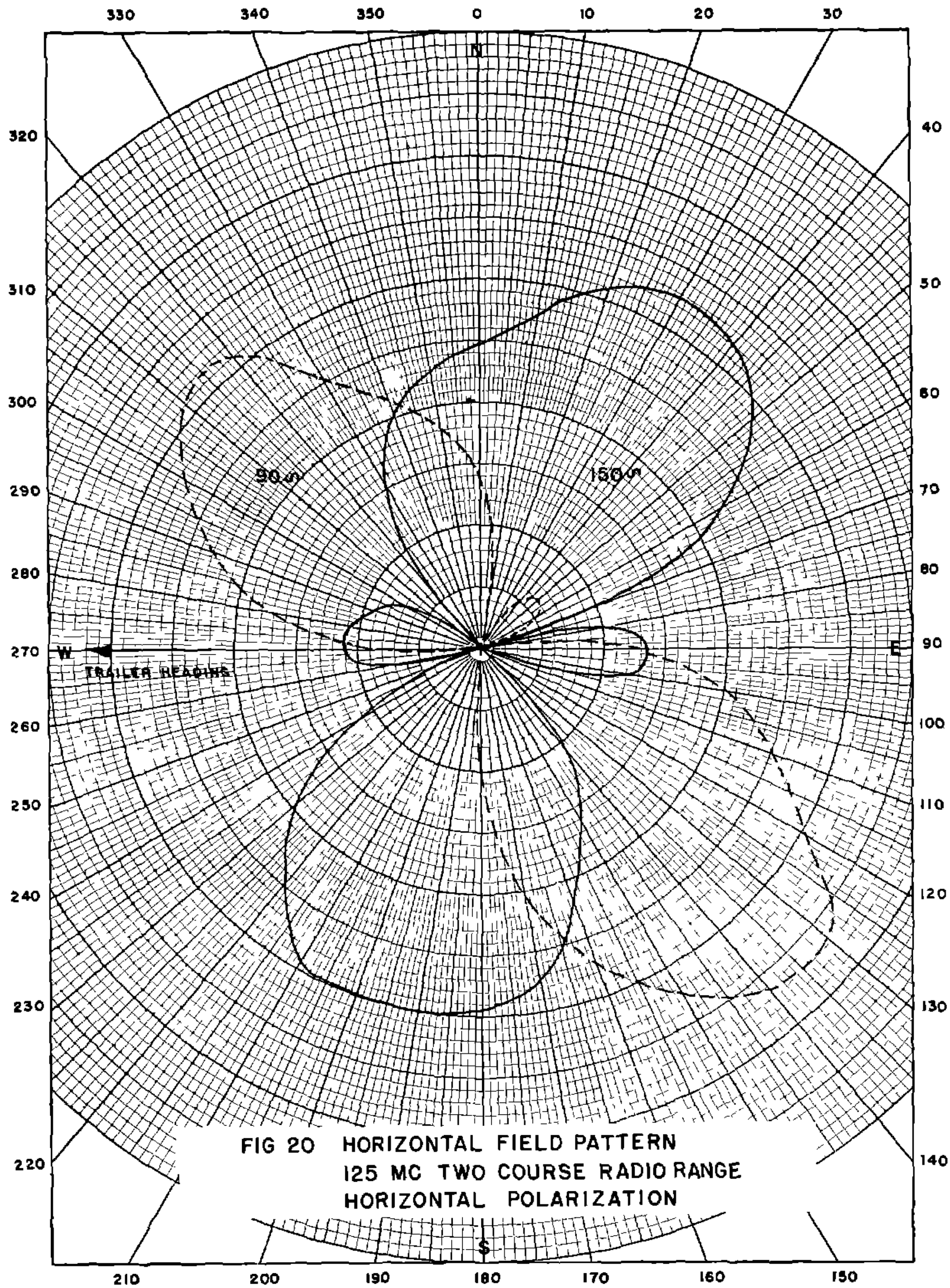


FIG 20 HORIZONTAL FIELD PATTERN
125 MC TWO COURSE RADIO RANGE
HORIZONTAL POLARIZATION

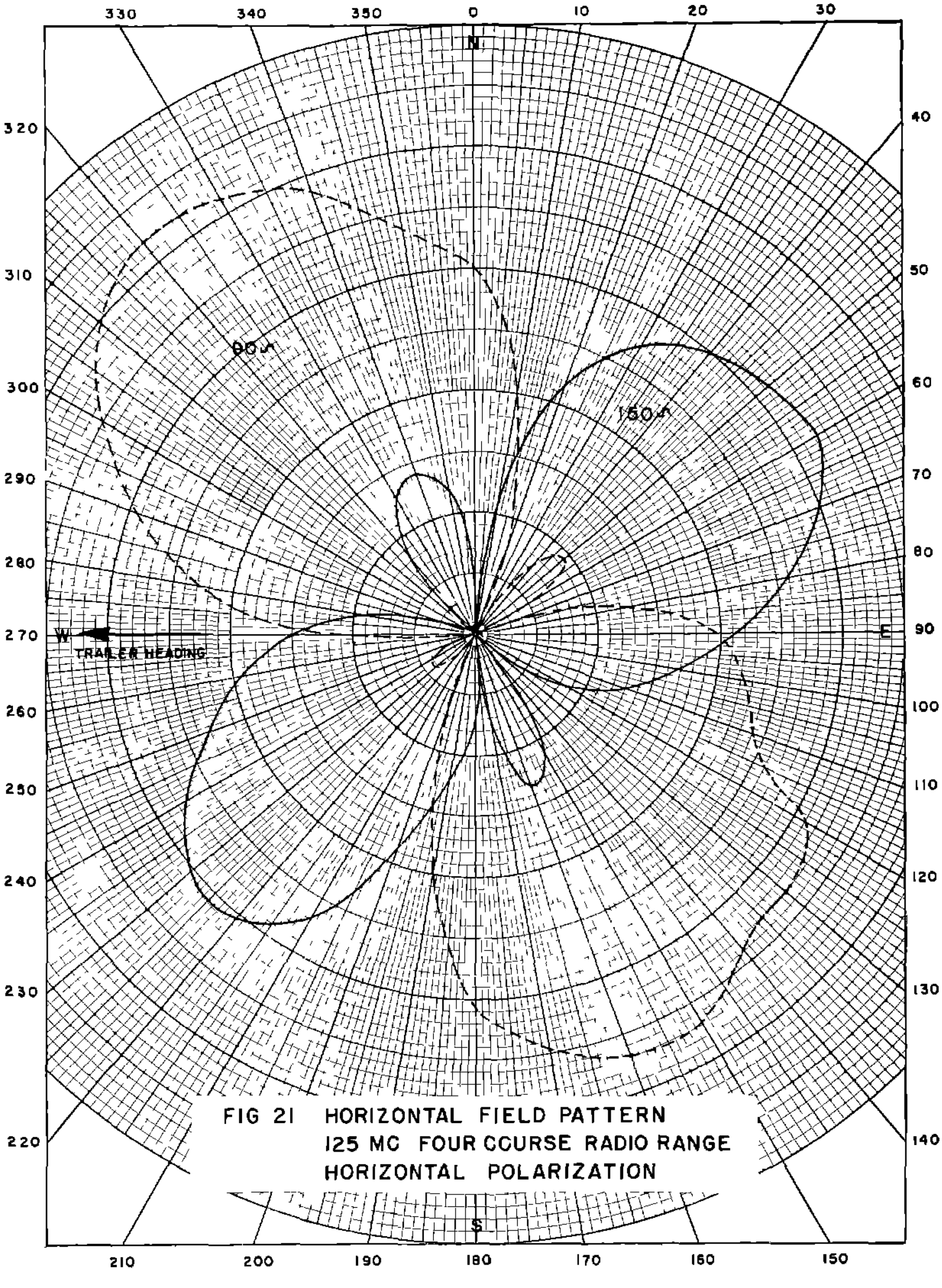


FIG 21 HORIZONTAL FIELD PATTERN
125 MC FOUR COURSE RADIO RANGE
HORIZONTAL POLARIZATION

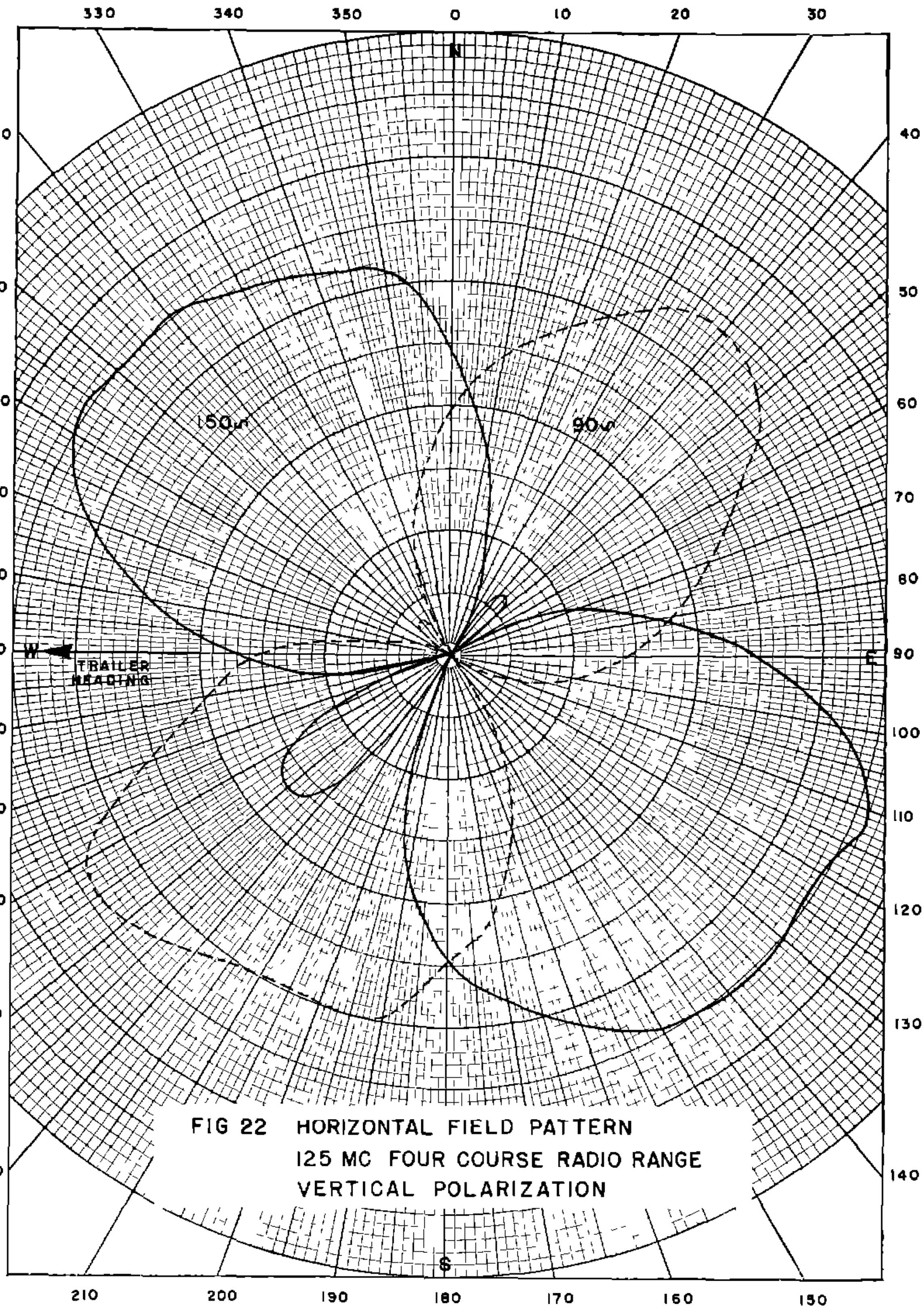
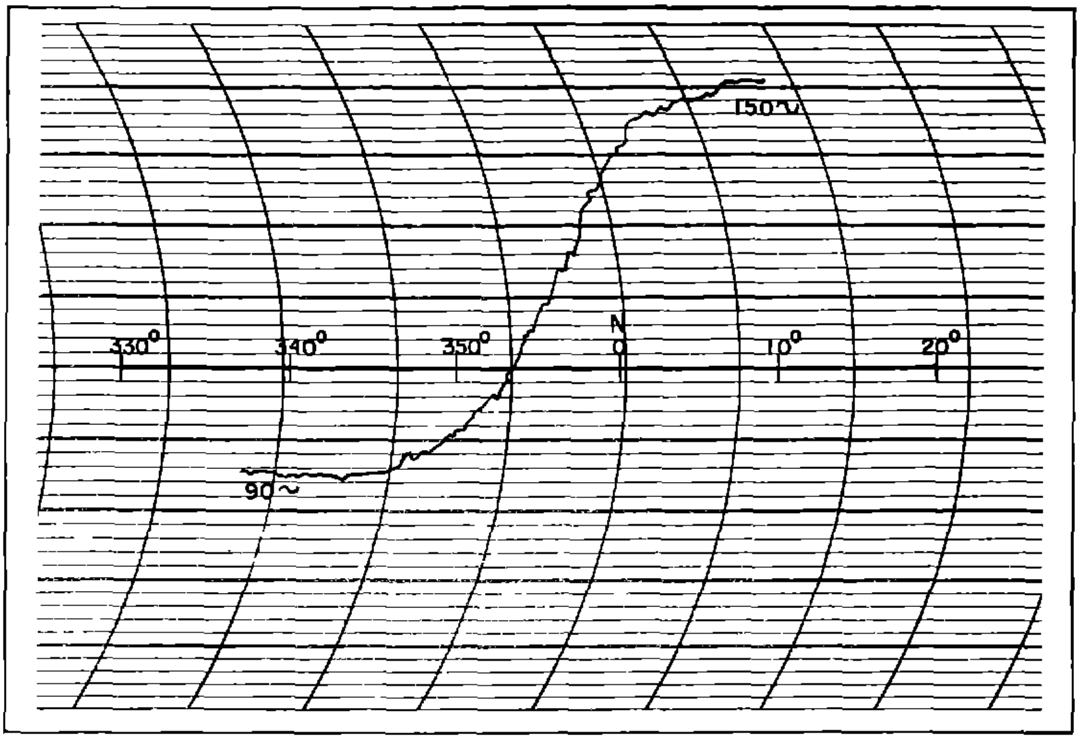
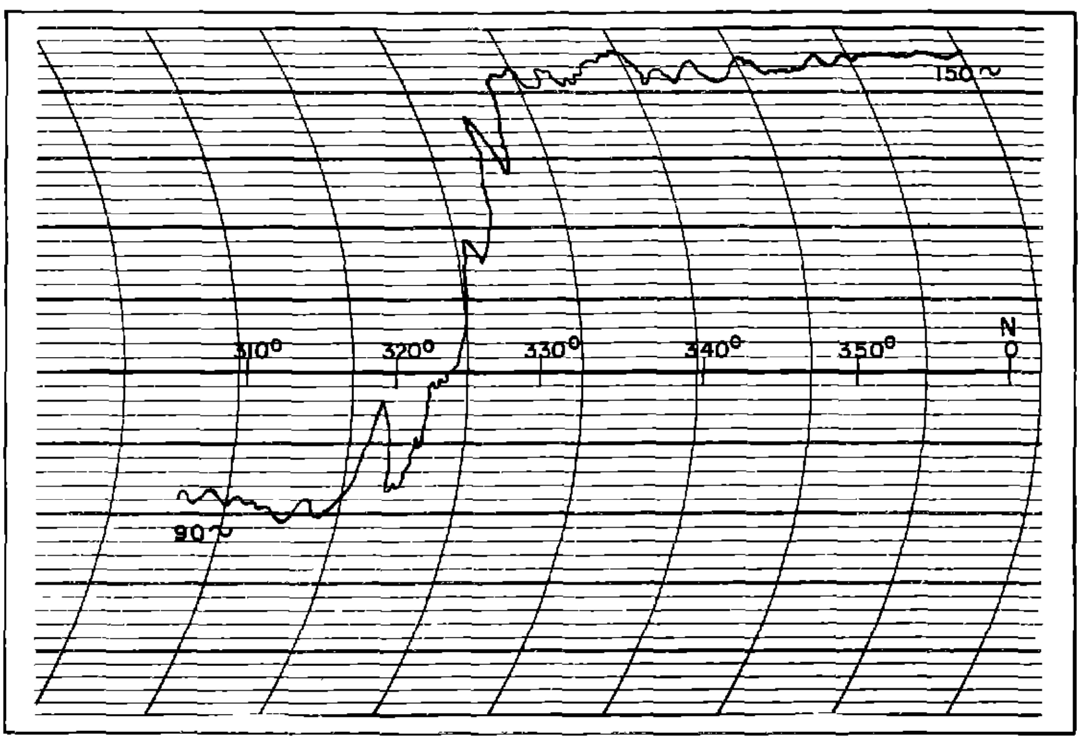


FIG 22 HORIZONTAL FIELD PATTERN
125 MC FOUR COURSE RADIO RANGE
VERTICAL POLARIZATION

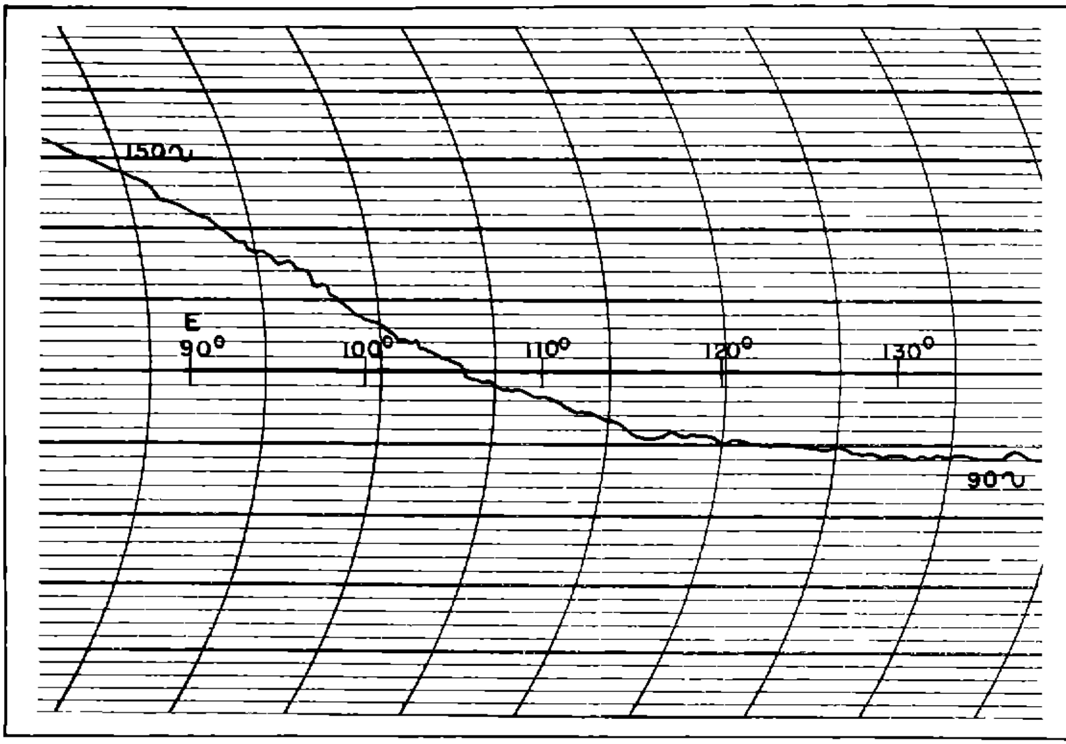


(A) NORTH COURSE, TRANSMISSION FROM OPEN FIELD

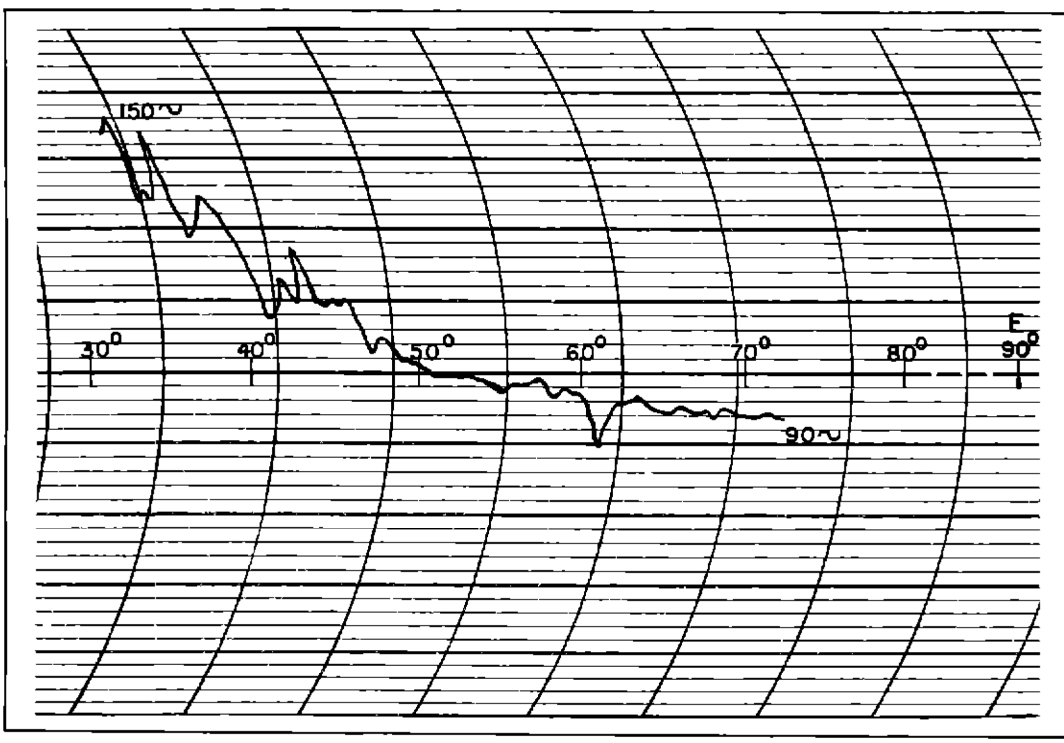


(B) NORTH COURSE, TRANSMISSION NEAR WOODS

Figure 23.—125-megacycle, four-course radio range, horizontal polarization (a) North course, transmission from open field (b) North course, transmission near woods

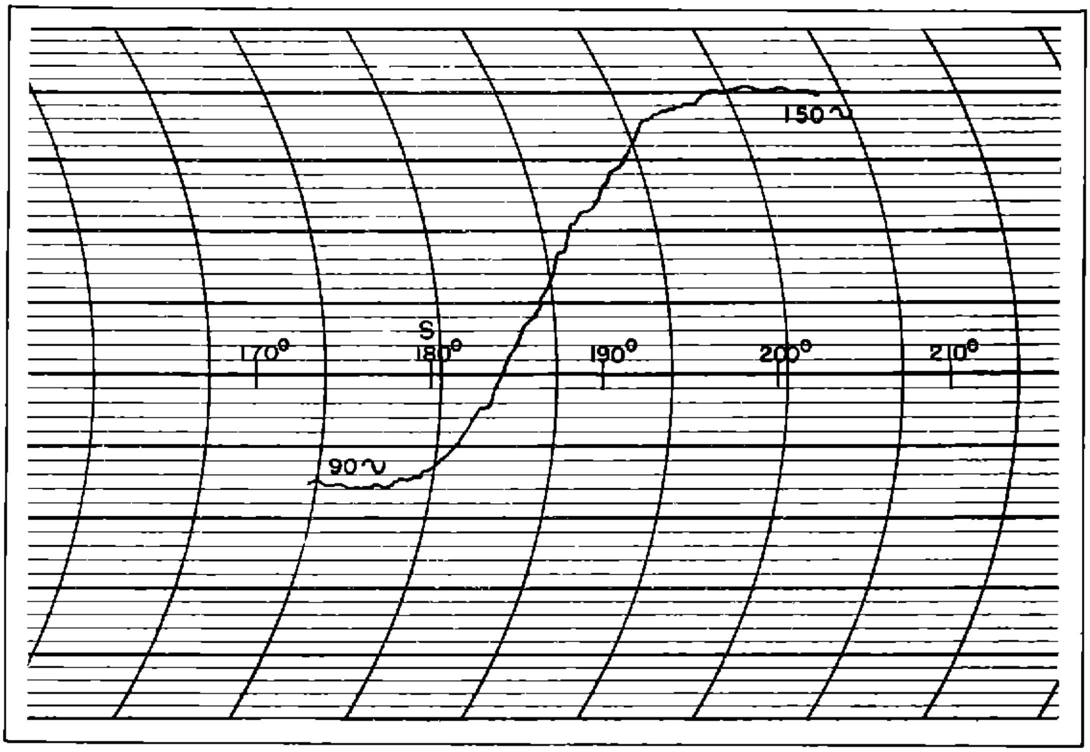


(A) EAST COURSE, TRANSMISSION FROM OPEN FIELD

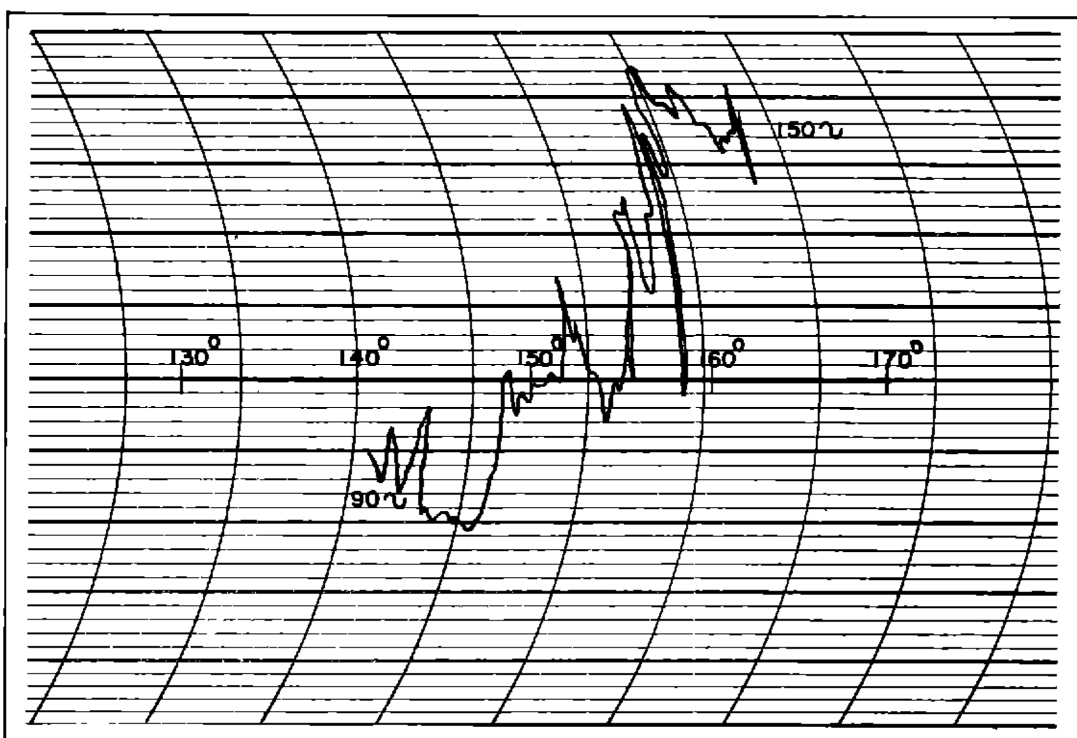


(B) EAST COURSE, TRANSMISSION NEAR WOODS

Figure 24—125-megacycle, four-course radio range, horizontal polarization (a) East course, transmission from open field (b) East course, transmission near woods

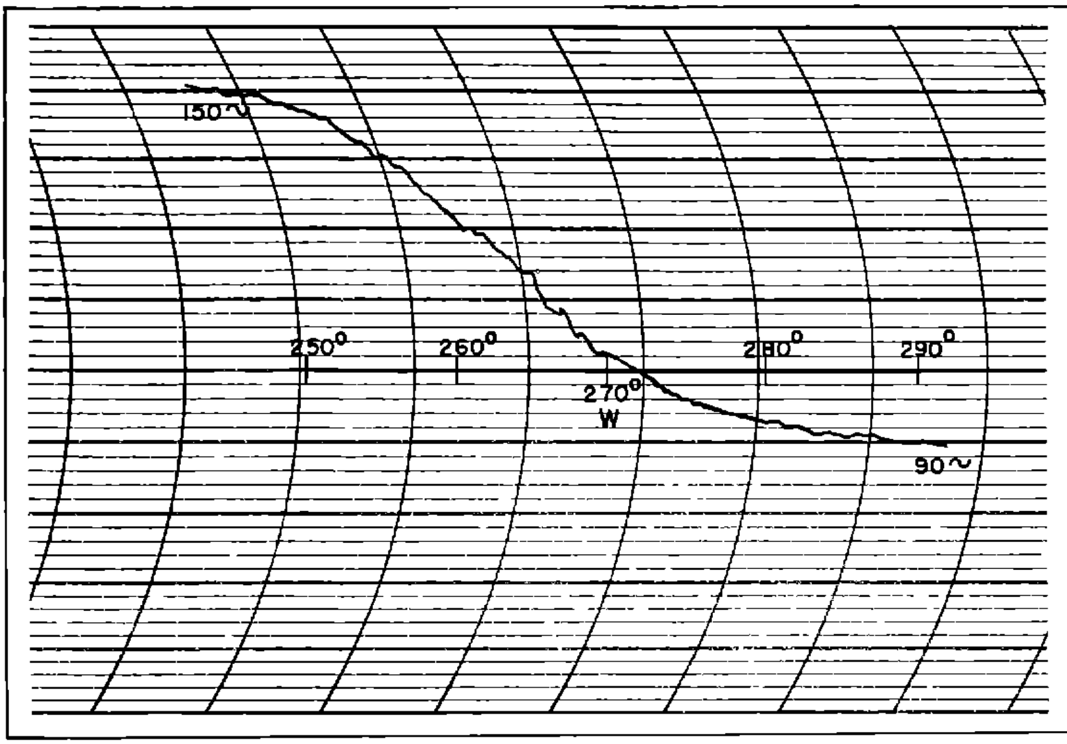


(A) SOUTH COURSE, TRANSMISSION FROM OPEN FIELD

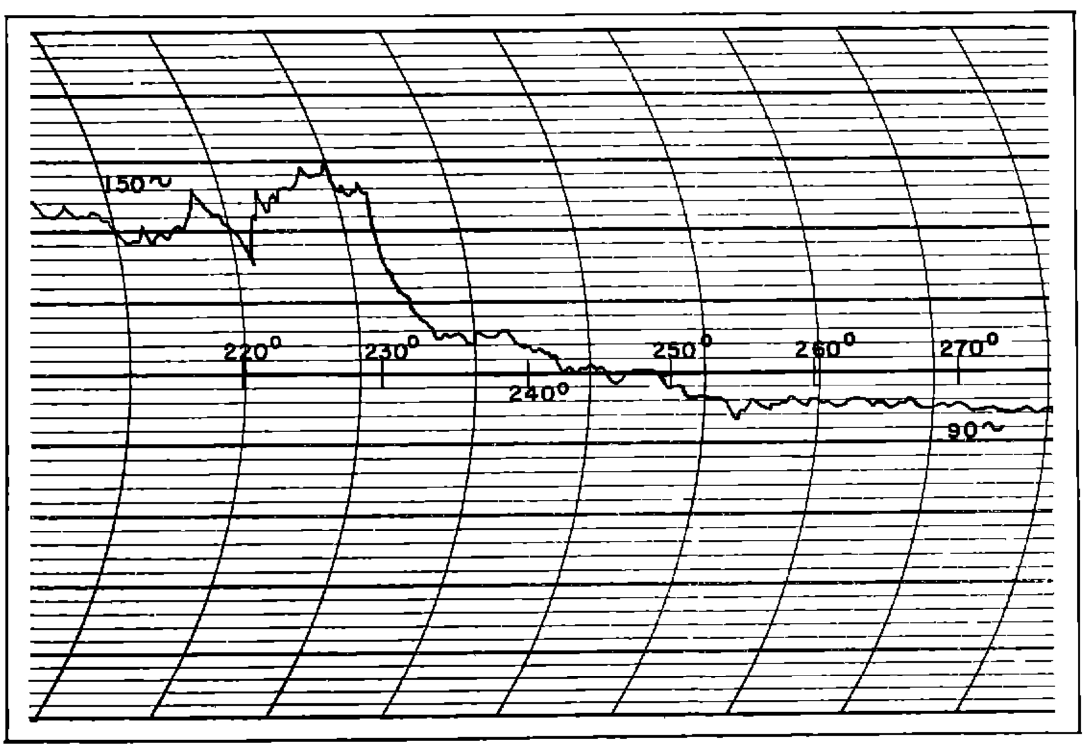


(B) SOUTH COURSE, TRANSMISSION NEAR WOODS

Figure 25—125-megacycle, four-course radio range, horizontal polarization (a) South course, transmission from open field (b) South course, transmission near woods



(A) WEST COURSE, TRANSMISSION FROM OPEN FIELD



(B) WEST COURSE, TRANSMISSION NEAR WOODS

Figure 26.—125 megacycle, four-course radio range, horizontal polarization (a) West course, transmission from open field (b) North course, transmission near woods

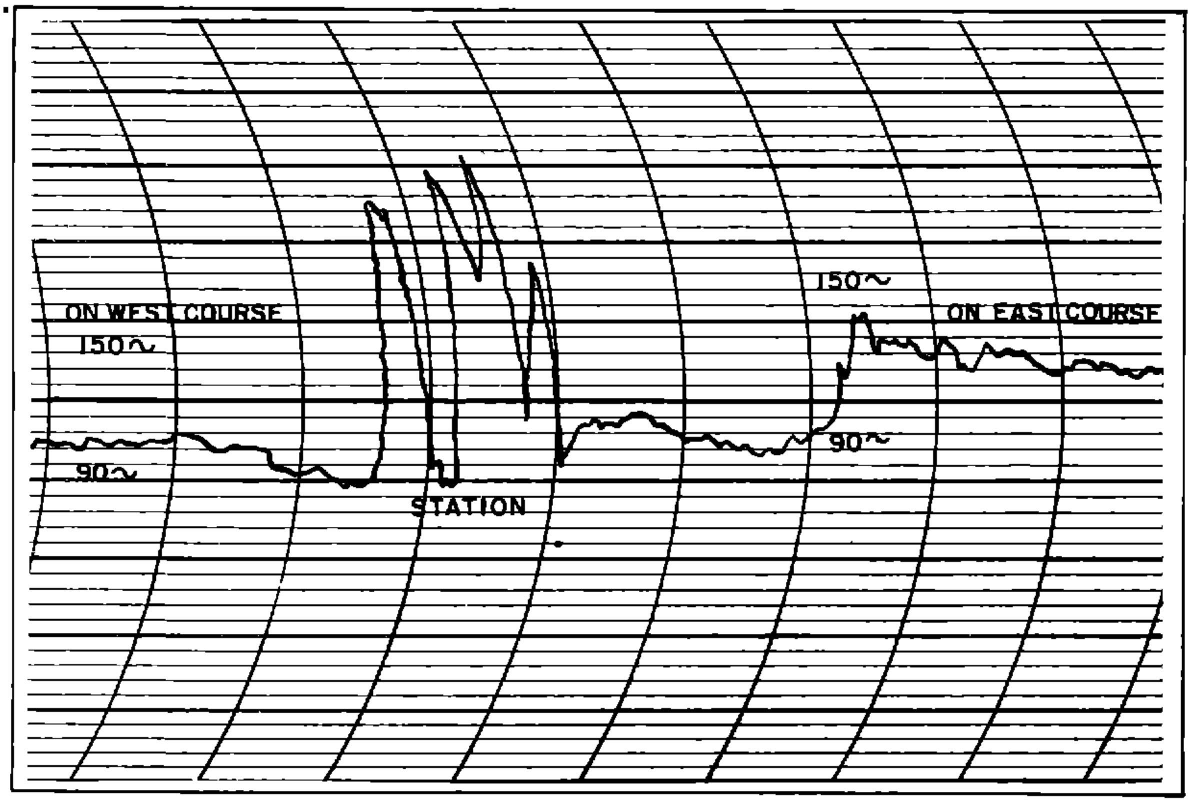
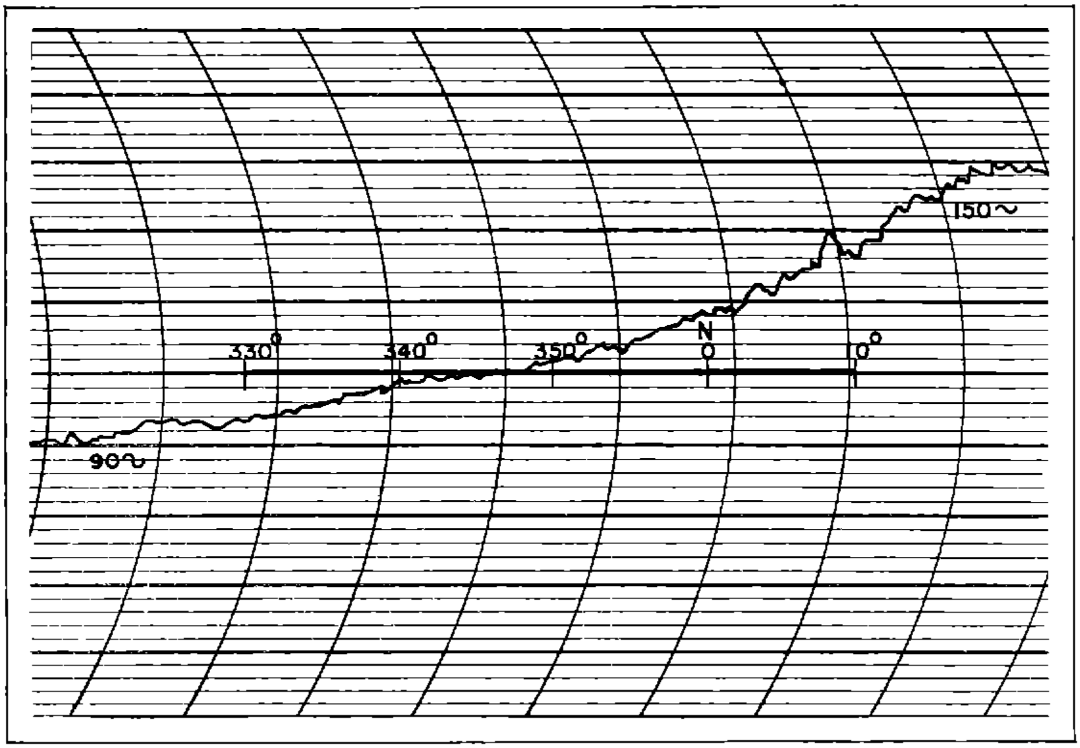
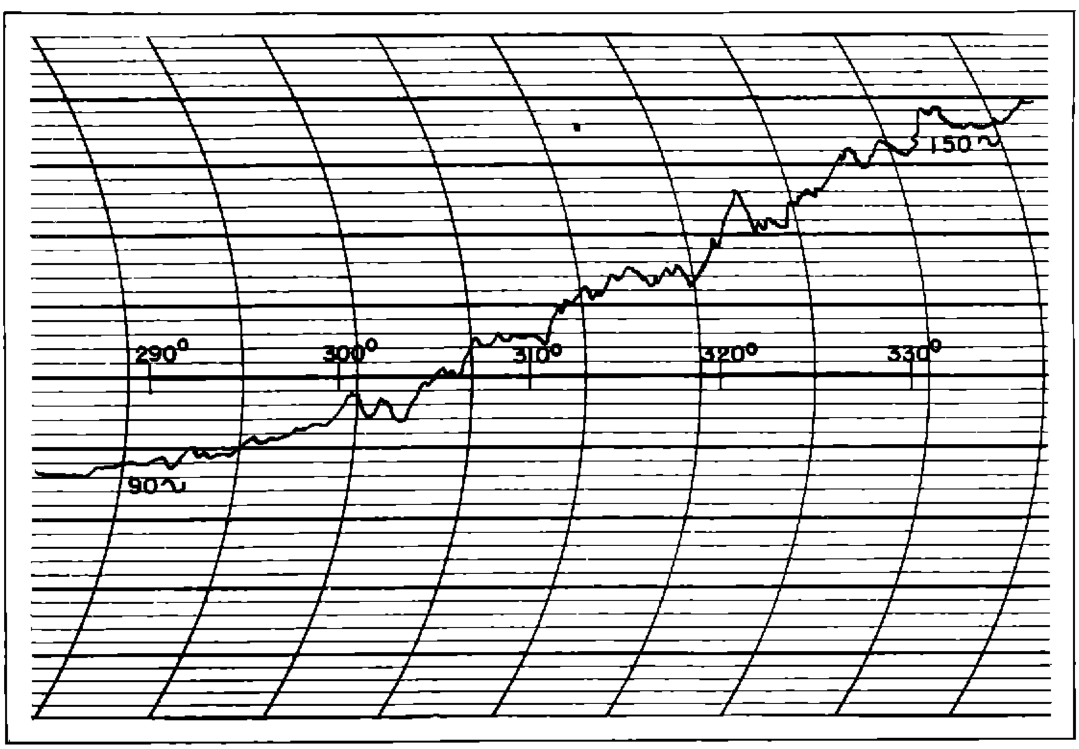


Figure 27 —125-megacycle, four-course radio range, on-course flight over station, horizontal polarization

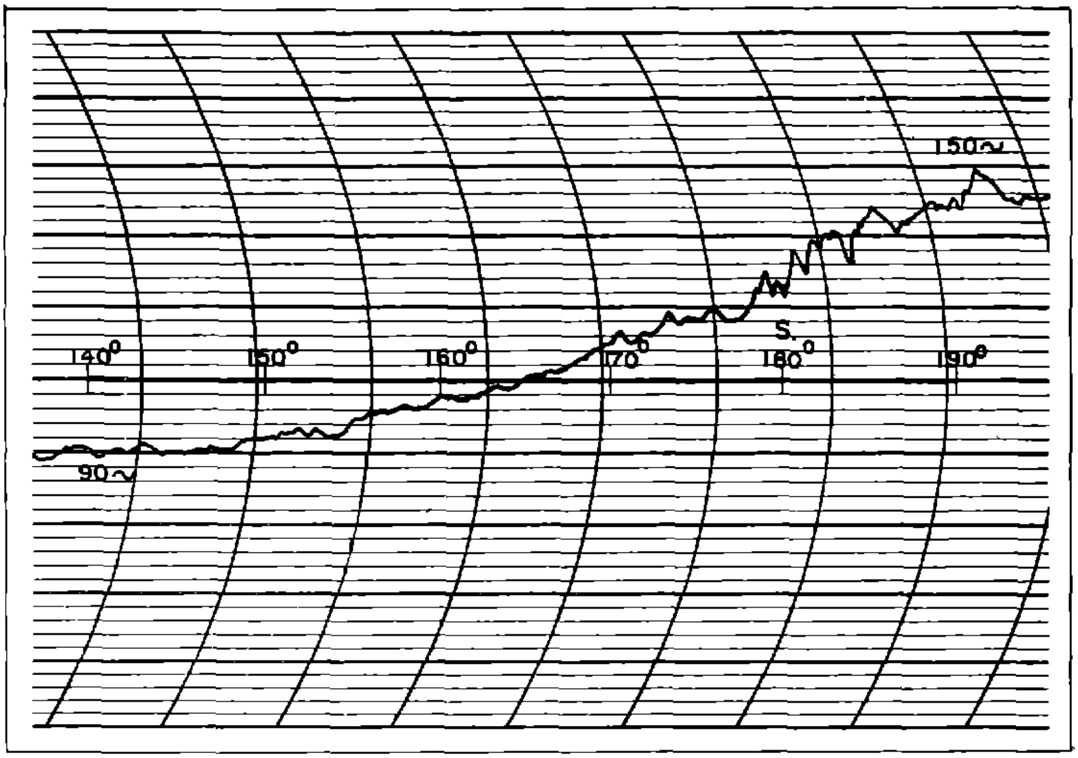


(A) NORTH COURSE, TRANSMISSION FROM OPEN FIELD

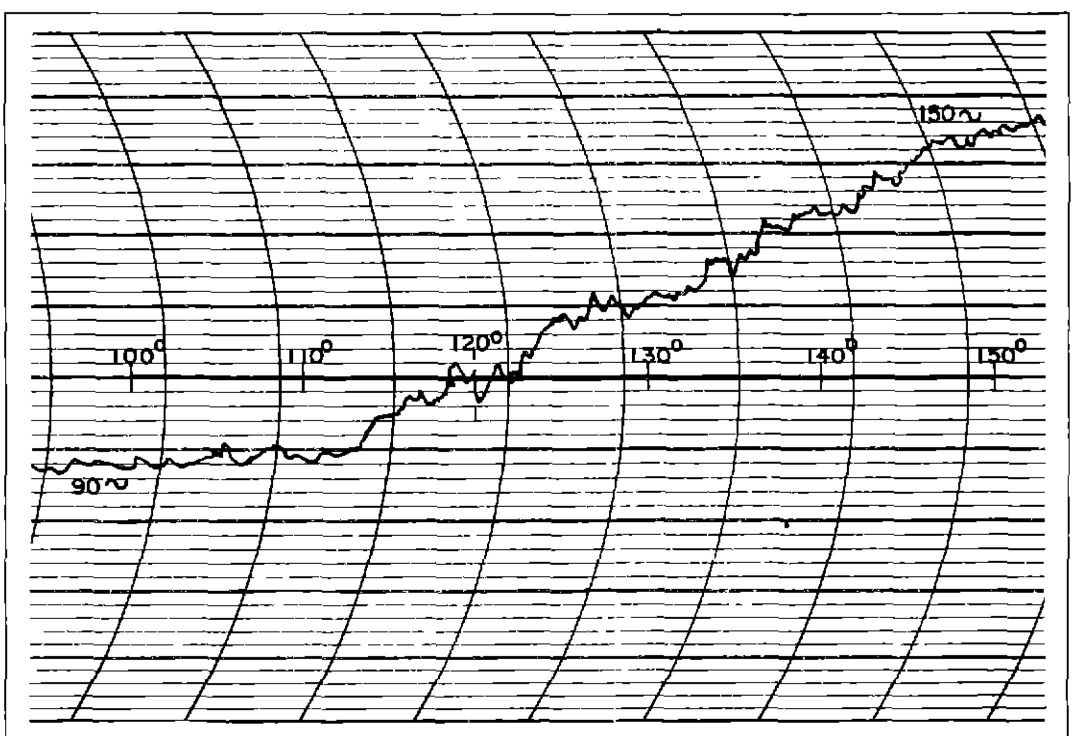


(B) NORTH COURSE, TRANSMISSION NEAR WOODS

Figure 28—125-megacycle, two-course radio range, horizontal polarization (a) North course, transmission from open field (b) North course, transmission near woods

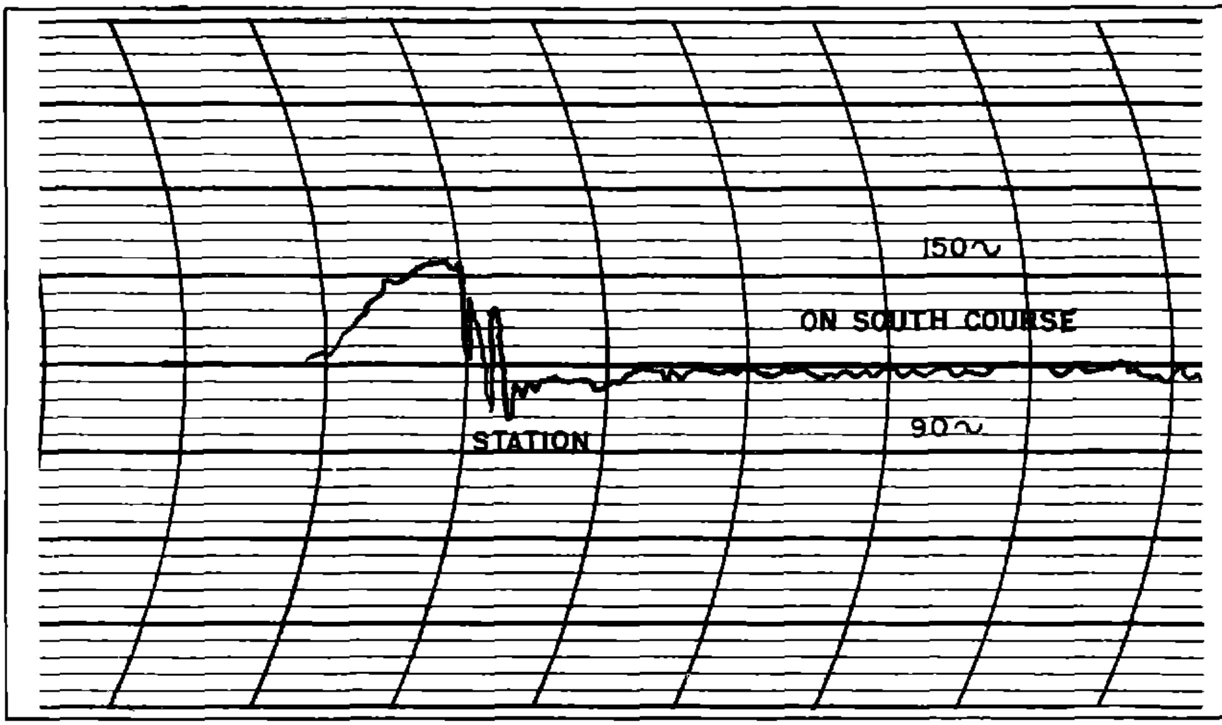


(A) SOUTH COURSE, TRANSMISSION FROM OPEN FIELD

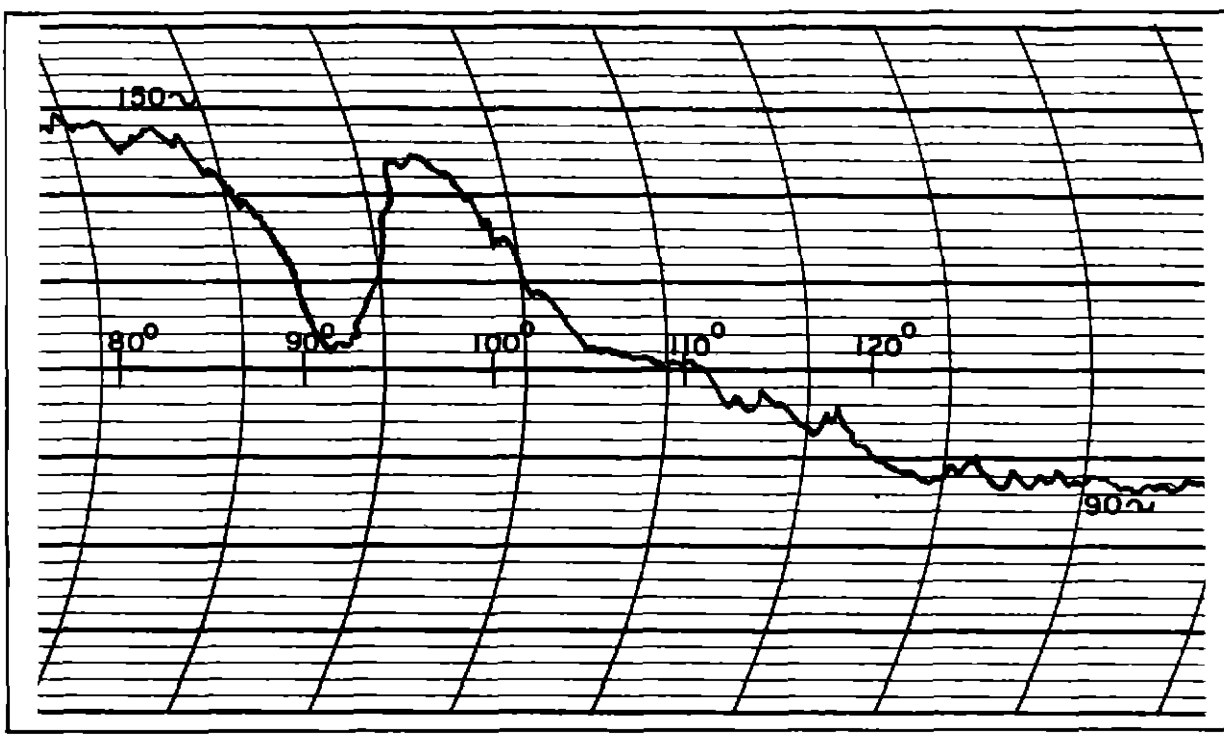


(B) SOUTH COURSE, TRANSMISSION NEAR WOODS

Figure 29—125-megacycle, two-course radio range, horizontal polarization (a) South course, transmission from open field (b) South course, transmission near woods

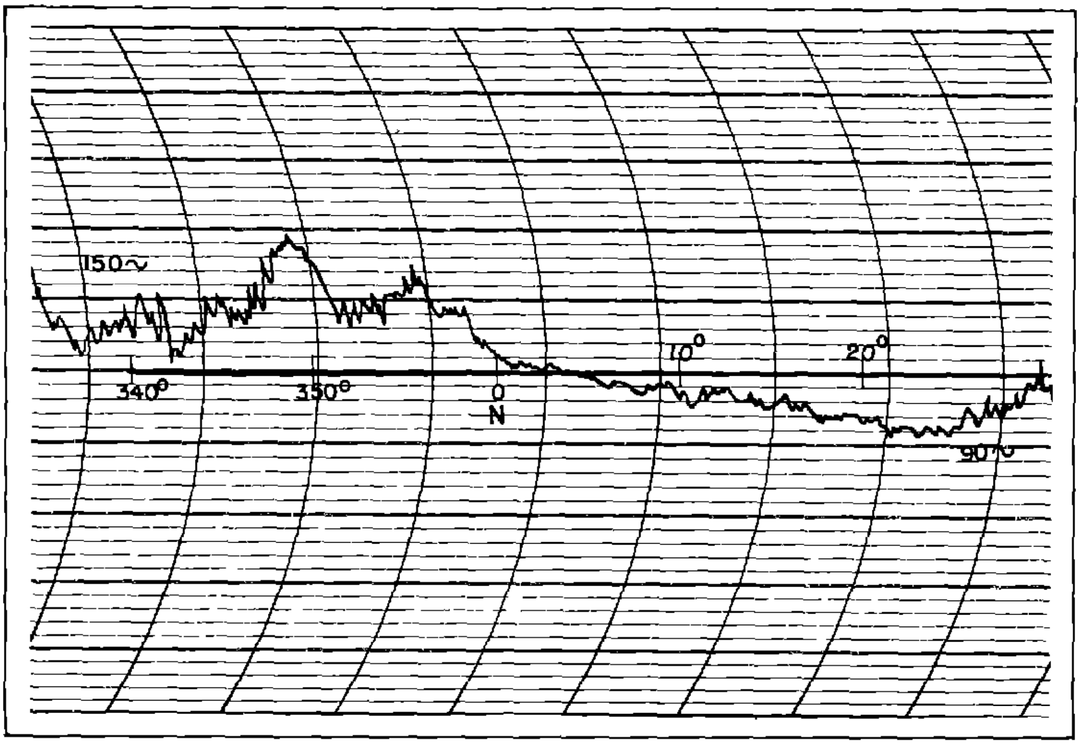


(A) ON-COURSE FLIGHT OVER STATION

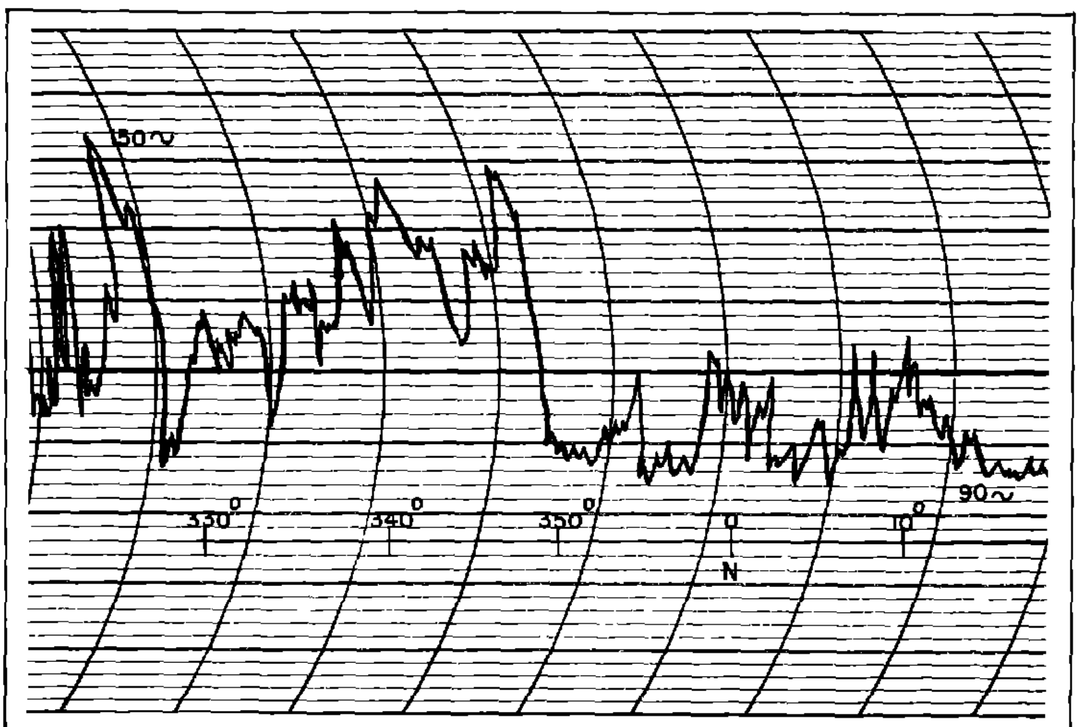


(B) FLIGHT ON END ZONE SHOWING LOBE

Figure 30.—125-megacycle, two-course radio range, horizontal polarization (a) On-course flight over station (b) Flight on end zone showing lobe

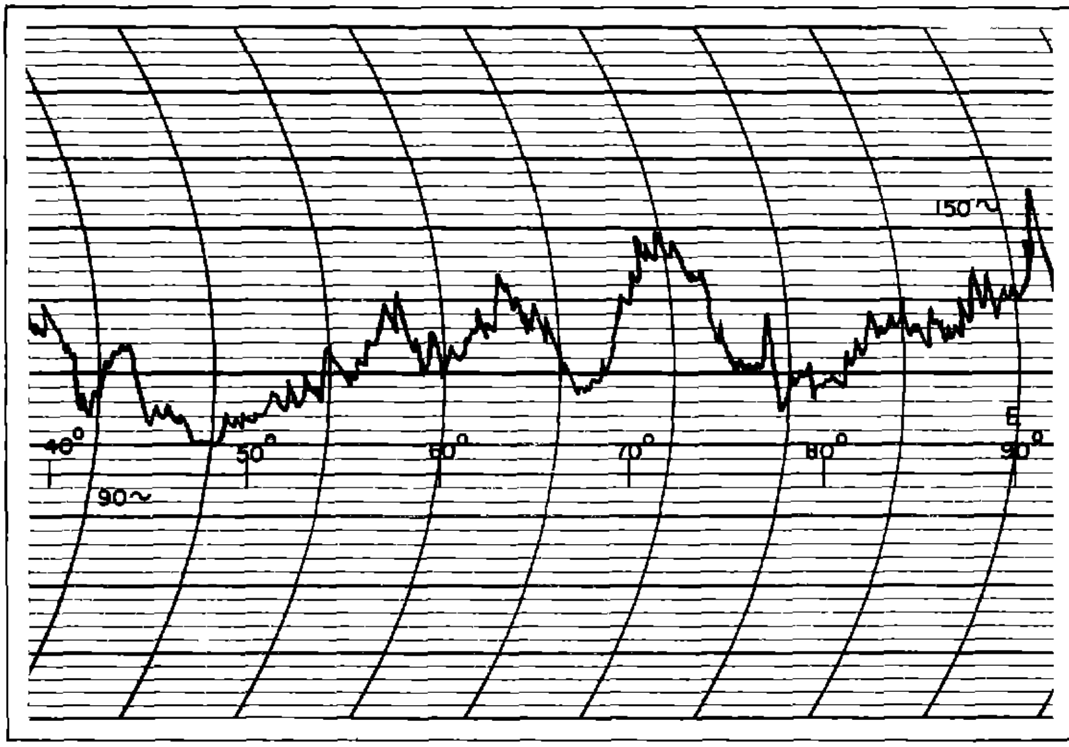


(A) NORTH COURSE, TRANSMISSION FROM OPEN FIELD

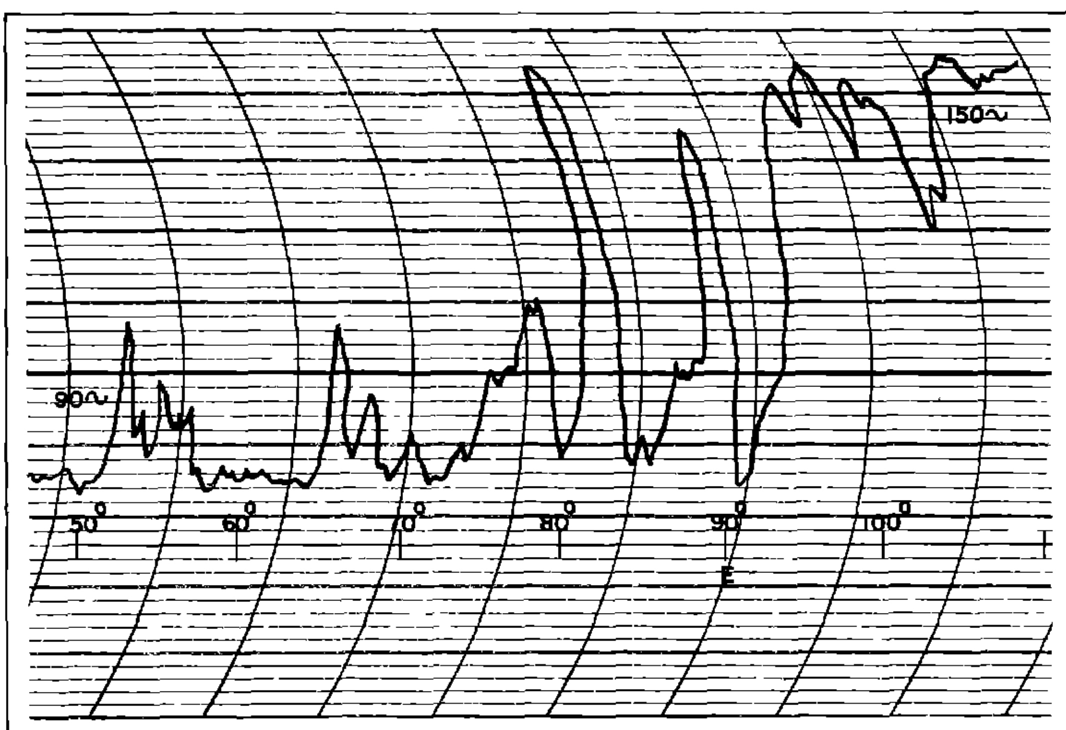


(B) NORTH COURSE, TRANSMISSION NEAR WOODS

Figure 31 —125-megacycle, four-course radio range, vertical polarization (a) North course, transmission from open field (b) North course, transmission near woods

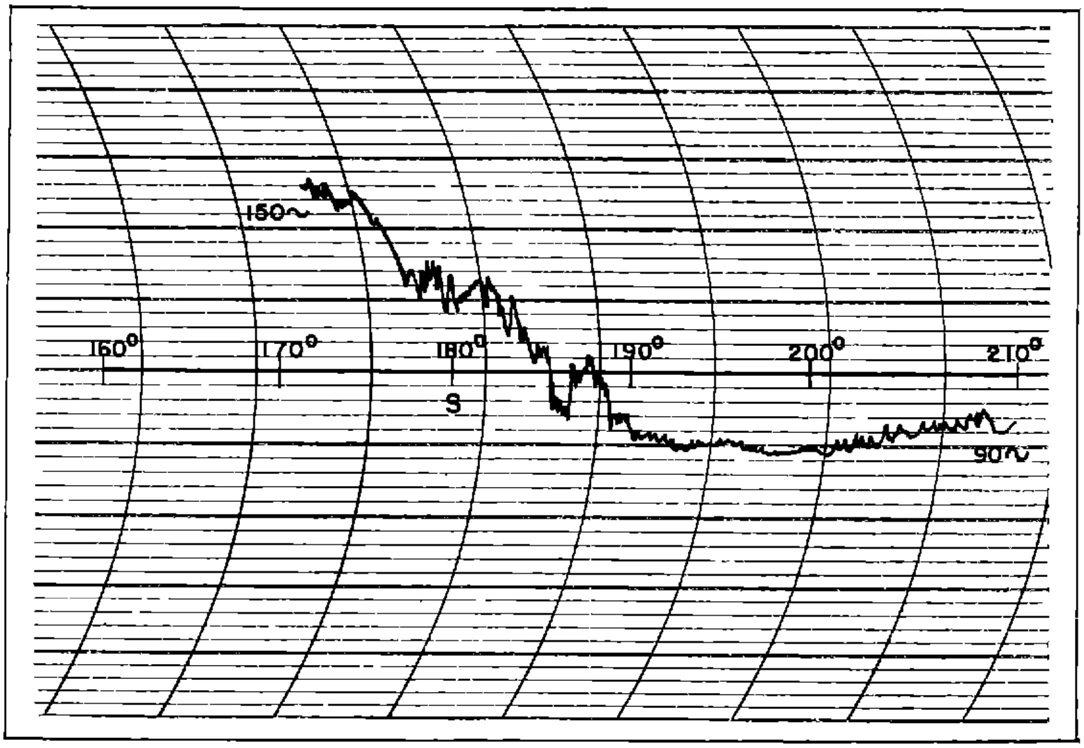


(A) EAST COURSE, TRANSMISSION FROM OPEN FIELD

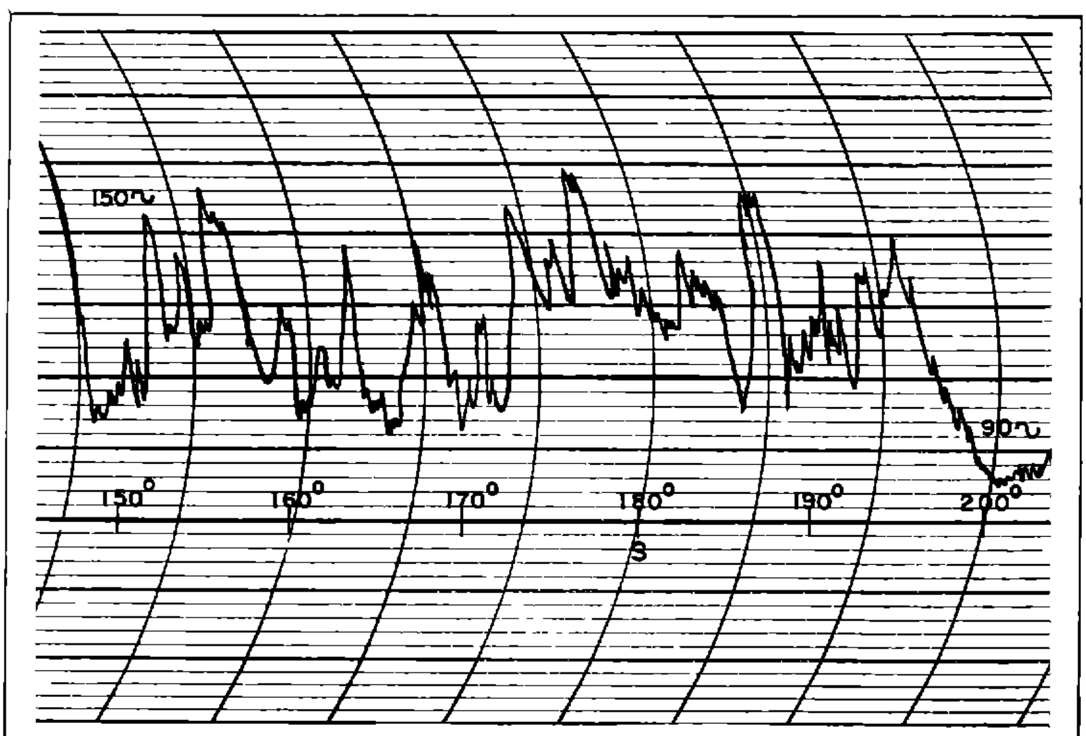


(B) EAST COURSE, TRANSMISSION NEAR WOODS

Figure 32.—125-megacycle, four-course radio range, vertical polarization (a) East course, transmission from open field (b) East course, transmission near woods

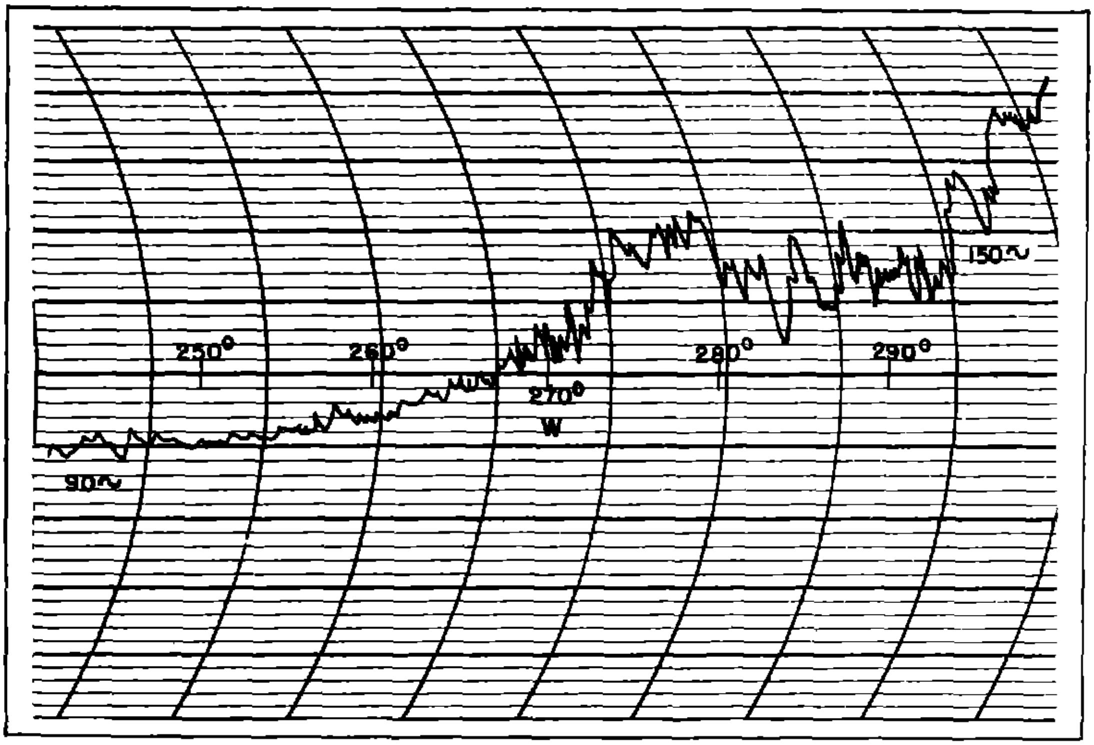


(A) SOUTH COURSE, TRANSMISSION FROM OPEN FIELD

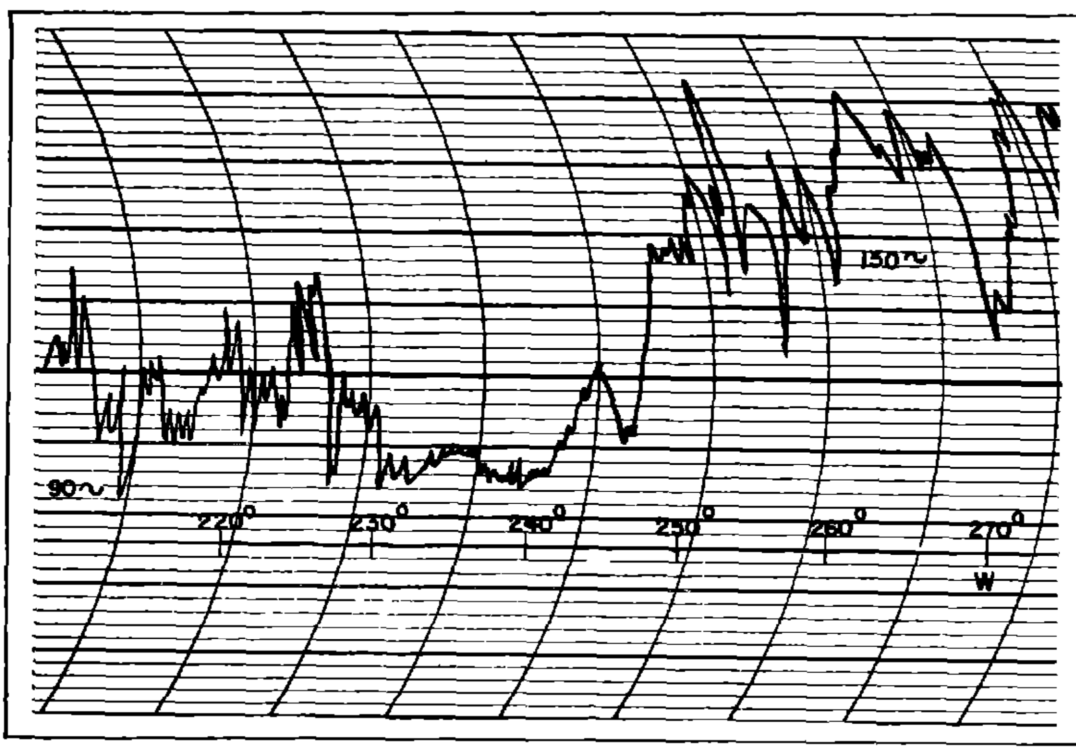


(B) SOUTH COURSE, TRANSMISSION NEAR WOODS

Figure 33 —125-megacycle, four course radio range, vertical polarization (a) South course, transmission from open field (b) South course, transmission near woods

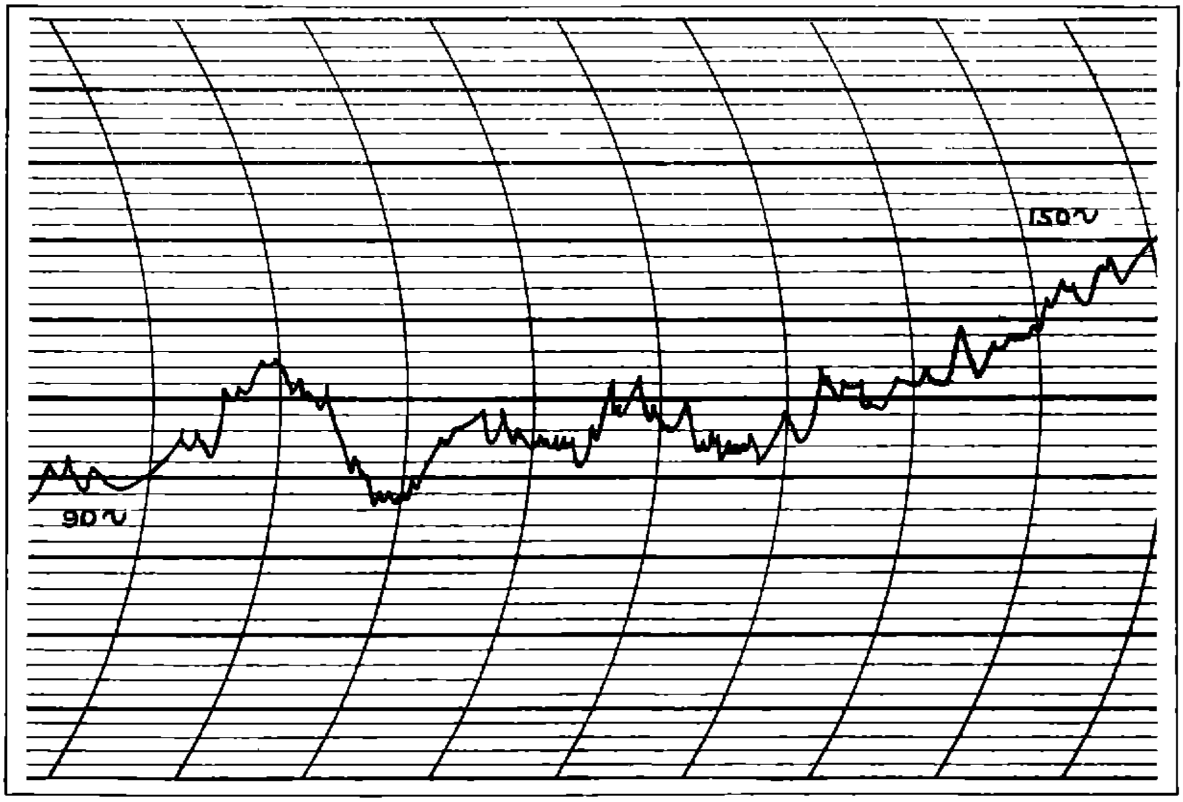


(A) WEST COURSE, TRANSMISSION FROM OPEN FIELD



(B) WEST COURSE, TRANSMISSION NEAR WOODS

Figure 34—125-megacycle, four-course radio range, vertical polarization (a) West course, transmission from open field (b) West course, transmission near woods



FLIGHT ACROSS EAST COURSE, TEN MILES FROM STATION

Figure 35.—125-megacycle, four-course radio range, vertical polarization. Flight across east course, ten miles from station

thick growth to the north was removed approximately 650 feet away.

It is very difficult to analyze the recordings taken on vertical polarization with transmission near the woods. Even in this case, however, the east course was definitely worse than the others.

One cross-course flight was made on the east course at a distance of 10 miles from the station with transmission near the woods. The results of this flight are shown in Fig. 35. Here again there were many indicator reversals, but they were not so severe in amplitude as those encountered closer to the station.

CONCLUSIONS

A survey of the recordings taken indicates that, from the point of view of multiple courses, horizontal polarization is far superior to vertical polarization for ultra-high-frequency radio range applications. This should be particularly true where pure horizontal polarization is obtained.

A second definite use for this equipment is in the investigation of the causes of multiple courses and other phenomena encountered in the use of ultra-high frequencies for radio range work.

The data also indicate that it is possible to locate suitable sites for ultra-high-frequency radio ranges with this equipment. It would be possible to drive the trailer to the site and in a very few hours' flying time it could be determined whether the site was suitable for this application.

It is also concluded that the recordings of a visual type range are much easier to analyze than those taken on a conventional A–N type range.

REFERENCES

1. Instruction book 125 megacycle u h f portable radio range equipment, published by Washington Institute of Technology
2. Proceedings of the Institute of Radio Engineers May, 1929, "Field Intensity Characteristics of Double Modulation Type of Directive Radio Beacon" by Haraden Pratt

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