AN INVESTIGATION TO DETERMINE THE CHARACTERISTICS OF HORIZONTAL AND VERTICAL POLARIZATION FOR VERY-HIGH- FREQUENCY TWO-COURSE VISUAL RADIO RANGES

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AN INVESTIGATION TO DETERMINE THE CHARACTERISTICS OF HORIZONTAL AND VERTICAL POLARIZATION FOR VERY-HIGH-FREQUENCY TWO-COURSE VISUAL RADIO RANGES

SUMMARY

The primary purpose of this investigation was to conduct extensive flight tests using both horizontally and vertically polarized radio range antenna systems, and, from the flight recordings obtained, to determine which type of antenna system was best suited for the very-high-frequency range application The ground transmitting equipment was installed in a trailer to provide easy transport from one position to another The transmitting antenna was so arranged that the change from horizontal to vertical antennas, or vice versa, could be made in seven minutes This feature permitted the polarization tests at given locations to be made without any movement of the trailer with the result that directly comparable data were obtained

Tests were made with the equipment located for the following conditions

1. 400 feet from a hangar on a line perpendicular to the face of the building.

2 400 feet from the same hangar on a line 45 degrees from the face of the building.

3. 300 feet on a line approximately perpendicular to telephone wires

4 In an open location completely surrounded by trees whose distance from the trailer location varied from 360 to 780 feet

5 At various distances from a somewhat isolated group of trees

The results of the tests indicated that, where buildings and telephone wires are the prime reflecting objects, there is very little choice between polarizations. However, at locations where substantial reflections from trees are obtained, horizontal polarization is far superior to vertical polarization

INTRODUCTION

The problem of selecting the proper wave polarization for very-high-frequency air navigation aids has been one of considerable importance in the Civil Aeronautics Administration's development program While it was known that reflecting objects such as buildings, wires and trees often caused serious pattern scalloping with the result that multiple courses were frequently encountered, it was not known exactly to what extent these reflections would react on range systems using either of the two types of polarization

A previous report[1] on this subject indicated that horizontal polarization was superior to vertical polarization in the presence of trees, but the tests made to reach this conclusion were preliminary in nature and not extensive enough to include the action of other reflecting objects

Subsequent to the previous report, several notable advancements were made in the very-high-frequency radio range art resulting in the development of a visual-aural very-high-frequency radio range with simultaneous voice and the very-high-frequency omnidirectional radio range

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[1] J M. Lee and C H Jackson, "Preliminary Investigation of the Effects of Wave Polarization and Site Determination with the Portable Ultra-High-Frequency Visual Radio Range", Technical Development Report No 24, February, 1940

The initial work on the development of these radio range systems was carried on in flat and open country where nearly ideal site conditions prevailed and very little difference was noted between the two types of polarizations

However, later tests made near large buildings, trees and wires indicated that the use of horizontally polarized antenna systems would reduce the site problem for these installations

On the basis of the tests described in the previous report and subsequent information, most of the development of new very-high-frequency navigational facilities was carried on using horizontal polarization. However, it was realized that there would be a number of advantages in using vertical antenna systems provided satisfactory results could be obtained Included in these advantages would be the simplicity of the aircraft receiving antenna, the small physical size of the transmitting antennas compared to the horizontal type of antenna, the ability to place the vertical antennas in close proximity to each other due to their smaller physical size (this is particularly important in some range systems such as the omnidirectional type), the similarity of the electrical characteristics of the vertical antennas considered as compared with the characteristics of the type of transmission line generally used, and the similarity to certain radio range equipment of foreign countries with the resulting adaptation for international use

In view of these facts, it was decided that a complete group of tests should be made to determine the most desirable type of polarization under as many conditions as are normally encountered. The outline for the test program included investigations to determine the amount of reflection from buildings, wires and various conditions of trees and the effect of these reflections on the range courses with each type of polarization These tests were conducted at the Administration's Experimental Station near Indianapolis, Indiana, in June 1944

EQUIPMENT

Trailer

The transmitting equipment required for a complete two-course visual radio range system was housed in the tractor-trailer combination shown in Figure 1. A compartment in the front of the trailer housed a gas-engine driven 220-volt, 60-cycle, power supply having a capacity of 5 KVA The power thus supplied was well-regulated for both frequency and voltage to provide 115 volts, 60 cycles for the type TUD transmitter The center compartment in the trailer contained the transmitter, mechanical modulator, phasing equipment and other necessary apparatus as well as storage space for test equipment and unused antenna units. Figure 2 is a view of the interior of the trailer toward the rear showing the transmitter, while Figure 3 shows the equipment mounted in the forward end.

Transmitter

The type TUD transmitter used in these tests was self-contained and crystal-controlled A schematic block diagram of the transmitter is shown in Figure 4. The transmitter was controlled by a crystal having a fundamental frequency of 5225 kilocycles The BT-cut crystal was mounted in a temperature-controlled holder. The temperature within the crystal holder was maintained above the highest ambient temperature to be expected to prevent moisture condensation within the holder The proper carrier frequency was obtained by multiplying the crystal frequency by a factor of twenty-four Three stages were employed to obtain the required frequency and power output The crystal oscillator employed a type 807 tetrode and was used as a combination crystal oscillator and quadrupler stage with the plate tank circuit tuned to 20900 kilocycles The fourth harmonic frequency appearing in the plate circuit of the oscillator was capacity coupled to the grid of the first doubler tube. The first doubler stage employed another type 807 tetrode with its plate tank circuit tuned to 41800 kilocycles. The eighth harmonic of the crystal frequency was then capacity coupled to the grid of the first intermediate-power amplifier stage The first intermediate-power amplifier stage operated as a neutralized fundamental amplifier using a Gammatron type 54 tube The output of this stage was coupled to the second intermediate-power amplifier by means of an inductive link The second intermediate-power amplifier stage employed two Gammatron type 54 tubes in a push-pull tripler circuit The eighth harmonic of the crystal frequency was impressed upon the grids of these tubes and the plate circuit tuned to the third harmonic of the driving frequency or the twenty-fourth harmonic of the crystal frequency The output of this stage was also coupled to the final power amplifier by means of an inductive link. The power amplifier was a neutralized class "C" fundamental amplifier using two Gammatron type 54 tubes in a push-pull circuit. The transmission line type plate tank was resonated by means of a balanced condenser and was inductively coupled to the twin conductor shielded transmission line by an adjustable pick-up loop.

A power supply using a selenium rectifier gave protective grid-bias to all stages The crystal oscillator and all frequency multiplying stages obtained their direct-current plate and screen potentials from two 866-A tubes in a single-phase full-wave rectifier Plate voltage for the intermediate-power-amplifier and power-amplifier stages was obtained from a high-voltage direct-current supply using two 872-A tubes in a single-phase full-wave rectifier circuit Overload and time-delay relays were used to give ample circuit protection.

The roof of the trailer was approximately twenty feet long and eight feet wide and was covered with No 26 guage galvanized iron. A catwalk, two feet wide and nineteen feet long, was installed along the center line of the roof This rigid catwalk served as a support for the antenna mounting sockets The catwalk was bonded to the galvanized iron roof by means of one-inch wide copper strap. Three cross-straps were also provided for each mounting socket to improve the grounding between the sockets on the catwalk and the galvanized roof.

This procedure played an important part in the design of the two arrays since no time could be used in making adjustments of current or phase when making the changeover In order that a minimum amount of time would be consumed in changing from one antenna array to another so that the airplane making the recordings would not be required to land or do unnecessary flying while waiting for the antennas to be changed, it was planned that the trailer would be set up in a given location and recordings taken of the one type of polarization The antennas would then be changed and another set of recordings would be made of the other form of polarization Therefore, it was decided to install two complete antenna systems with individual antenna terminations, current adjusting loads and phasers which could be operated from a common transmitter and mechanical modulator. A schematic diagram of the transmission line connections are shown in Figure 5 All transmission lines were of the rigid copper pipe construction with the 170-ohm dual transmission line separated and held in position by ceramic beads As will be noted on the drawing, slots were cut in the solid copper shield a quarter wavelength each side of the junction point of the horizontal sideband antennas and the vertical sideband antennas A similar arrangement of slots was also used at the junction point of the center antennas for both systems By placing these slots a quarter wavelength each side of the junction points of each system, a shorting bar could be readily placed across the unused system, thereby electrically disconnecting it from the rest of the system Therefore, in changing from one system of polarization to the other, the only other change necessary, in addition to changing the antennas, was to transfer the two shorting bars from one system to the other Under actual operating conditions, it was found possible to change from one system of polarization to the other in seven minutes

The vertical antennas used in this installation were fed approximately 27 degrees above ground. This design provided a system where the impedance of the transmission line more closely matched the antenna impedance and required a minimum amount of line termination Another advantage of this type of antenna was that it did not require insulation at the base as would be necessary for a quarter wave-length antenna feed at its base Experimental tests showed that when the antenna was 27 degrees above ground and the upper portion of the antenna adjusted so that it would present a pure resistive load to the transmission line, the input resistance was approximately forty-seven ohms and produced a 1 5/1 standing wave ratio on the 70-ohm coaxial transmission line A view of the complete vertical antenna is shown in Figure 6 The extended lower portion of the vertical antenna was provided for the purpose of adapting this antenna to the same mounting socket originally provided with the trailer for supporting the standard horizontal loops Provisions were made so that the outside shield of the coaxial line could be continued through the junction box in order to provide a return path for the currents traveling on the inside of the coaxial shield (see Figure 7) Figure 8 shows the horizontal antennas in place and connected to the two-wire transmission line It will be noted from the above photographs that the coaxial line feeding the vertical antennas enters the box at one end and the dual transmission line enters directly opposite through the mushroom end seal The horizontal antennas used in this installation were the standard loops used by the Administration for range and localizer installations The loops were mounted on a 2 1/2-inch diameter aluminum standard and were supported at a distance of 1/2 wavelength above the counterpoise The bases of these standards were identical to those of the vertical antennas so that they could be used in the same roof sockets

A considerable amount of attention was given to the problem of transferring from a balanced system to an unbalanced system as was necessary to feed the vertical antennas In view of the fact that the mechanical modulator operated under conditions of balanced input and output, it was necessary to devise a means of transferring from a balanced output to a coaxial line to feed the vertical antennas. The most practical method for this particular installation was the addition of a half-wavelength section of line in one side of the dual transmission line This system provided a more rigid installation and maintained a nearly perfect balance when used to operate from a coaxial line to a dual line load or vice-versa. One disadvantage was the introduction of a four-to-one impedance mismatch between the coaxial and dual lines.

Adjustments and Ground Patterns

A very important factor in connection with both antenna systems was the condition for operation of the radiators without parasitic currents Unless precautions were taken, the center loop would induce parasitic currents in the outer loops resulting in a carrier radiation pattern which was no longer circular The line lengths connecting the individual sideband antennas were cut to the proper lengths so as to detune each antenna parasitically. The required 180 degree phase difference between the two vertical sideband antennas was obtained by inserting an additional 180 degrees of line in the tie line between the junction point and one antenna

The antennas were spaced 120 degrees apart and, with this spacing, a current ratio of 1-1 73-1 will provide a theoretical course sharpness of 1 14 decibels at 1 1/2 degrees, a minor lobe clearance of 22 8 decibels and an on-course to maximum signal ratio of 6 7 decibels. A theoretical curve is plotted in Figure 9

The current ratio for each array was adjusted to approximate the above ratio. This ratio was obtained by adjusting the impedance of the current dividing load connected across each line feeding the sideband antennas in order to dissipate one-third of the power going to each pair of sideband antennas This produced within the antennas a power ratio of 1-3-1 or the desired current ratio of 1-1.73-1

Another rather important condition to maintain during the tuning-up process is the impedance balance between the upper outlet of the bridge feeding the center antenna and the lower outlet of the bridge feeding the sideband antennas Although the mechanical modulator was designed to operate into a matched transmission line, a certain amount of mismatch can be tolerated without producing any ill effects It was important, however, that the two above-mentioned impedances be equal, but not necessarily equal to the characteristic impedance of the transmission line by maintaining these impedances equal during current and phase adjustments it can be assumed that any change in antenna currents would be entirely due to changes in the current adjusting impedance and not due to a change of bridge terminating impedances One convenient way of achieving this in practice is to energize the upper bridge through one of the modulation transmission lines feeding one side of the bridge and to disconnect the transmission line feeding the opposite side of the bridge. The disconnected transmission line is then shorted and a sensitive radio frequency detector connected in place of the shorted transmission line When the impedances presented by the antennas are equal, a voltage null will appear at the detector By making slight impedance adjustments by use of stubs in the phaser of the line feeding the sideband antennas, these impedances can be kept very nearly equal.

Upon completion of the installation, a complete set of ground patterns was obtained Figure 10 shows the ground patterns for the horizontal and vertical arrays

From an examination of various field patterns it is apparent that both the horizontal and vertical arrays agree very closely with the calculated theoretical pattern of Figure 9. It is interesting to note that there is a "necking in" of the field pattern of the horizontal antennas that is absent in the field patterns of the vertical antennas This same peculiarity was evident in portable localizer field patterns and was found to be due to the irregular shape of the trailer roof which acted as a counterpoise

Figures 1 and 11 show the horizontal and vertical antenna systems, respectively, mounted on the trailer roof

Aircraft Receiver

The aircraft receiver used in the polarization tests was a Western Electric type 32A. This receiver was specifically designed for airline use and covered the frequency range of 109 to 111 megacycles for localizer service and 119 to 133 megacycles for radio range and traffic control services Figure 12 is a photograph of the receiver

The balanced antenna circuit was inductively coupled through an electrostatic shield to the first tuned circuit Three tuned circuits were provided between the antenna circuit and the control grid of a 6AC7 mixer tube to act as a band-pass filter and insure the required image rejection characteristics The heterodyne oscillator voltage was injected into the control grid of the mixer stage by capacitive coupling The heterodyne oscillator voltage was produced by a variable-frequency oscillator and a harmonic multiplier which used two type 955 tubes. The variable-frequency oscillator operated in the band of 44 to 49 megacycles

Three stages of 13-megacycle intermediate-frequency amplification followed the mixer stage The shape of the intermediate-frequency response curve was such as to provide a band width of approximately 115 kilocycles at 6 decibels attenuation and 395 kilocycles at 60 decibels A type 6AB7 tube was used in the first intermediate-frequency stage and two type 12SG7 tubes in the other two intermediate-frequency stages. A type 12SQ7 multi-purpose tube served as a diode detector, automatic volume control and first audio amplifier Another type 12SQ7 tube acted as a noise limiter and codan or carrier operated noise suppressor A type 12SR7 tube was used as a bias oscillator and its rectified output was used to obtain negative voltage for the operation of the delayed AVC system

The output of the detector system was used to feed both a dual output voice channel arrangement using two type 12A6 tubes and the visual output tube which is a type 6SN7GT tube Resistance-capacity low-pass and high-pass filters were placed in the visual and voice channels, respectively The audio frequency response of the aural channel was attenuated 28 decibels at 100 cycles, 5 decibels at 400 cycles and 8 5 decibels at 4,000 cycles from the response obtained at 1,000 cycles

The visual output was coupled to two band-pass filters in parallel which pass the 90-cycle and 150-cycle modulation frequencies The output of the two filters was applied to copper-oxide rectifier units which were connected in a balanced bridge circuit. Two crossed-pointer instruments connected in parallel were operated by the rectified difference of the two voltages The instruments used in these tests were the new standard type (I-101-C) which differ slightly from those previously used by the Administration A photograph of one of the instruments used is shown in Figure 13

Aircraft Receiving Antennas

A standard U-type aircraft receiving antenna was used for reception of horizontally polarized signals This antenna was designed primarily for the reception of localizer signals and was retuned to operate at 125 4 megacycles for these tests. A photograph of this antenna is shown in Figure 14 The aircraft used for these tests, a Lockheed Model 10, was equipped with a broad-band vertical antenna for operation over a wide range of frequencies in the vicinity of 125 megacycles This antenna which is shown in Figure 15 was used for the reception of vertically polarized signals While there are two vertical antennas shown in Figure 15, only the rear, or right-hand one, was used The front antenna was removed during this investigation

Recording Equipment

The direct current flowing in the crossed-pointer instrument circuits was applied to a standard aircraft direct-current amplifier to obtain sufficient potential for full-scale recordings on an Esterline-Angus 0-5 milliampere graphic recorder The direct-current amplifier operated from the aircraft 24-volt power supply The recorder was adjusted so that zero signal would indicate at the center of the recorder chart while full-scale crossed-pointer deflections to the right or left would cause approximately 75 percent of full-scale recorder deflections in the same directions The direct-current amplifier was balanced to indicate at the center of the chart when the airplane was on course All recordings were calibrated to show the magnitude of amplification The circle at the center of the instrument was considered to be one dot and subsequent dots to be two dots, three dots, four dots and five dots Visual course width was measured in terms of 5 dots to 5 dots on the indicator The filter input voltage was adjusted to provide 20 degree (plus or minus 10 degrees) courses under these conditions.

The percentage of scalloping was computed by measuring vertically along the chart the greatest separation between maxima and minima of deviations that occurred between the full-scale (5-dot) deflection points, and dividing by the distance on the chart representing full-scale (5 dots) right to full-scale (5 dots) left on the crossed-pointer indicator

The following important items were maintained at constant values during all of the flight tests

Filter voltage - 20 volts (Control never changed after initial adjustment)

Altitude - 2,000 feet above the station

Indicated airspeed - 155 miles per hour

In order to expedite the flight test program, ground-to-aircraft communication was accomplished by voice transmission through the trailer equipment, while aircraft-to-ground communication was provided through very-high-frequency communications channels Thus, instructions for moving the trailer or changing antenna systems could be given from the plane, the message acknowledged on the ground, and the desired change made with a minimum of delay

TESTS

Preliminary Tests

A considerable number of preliminary flight tests were made with the trailer located at a fairly suitable location where it could be determined if the equipment functioned properly The site selected was immediately adjacent to the new north-south runway on the west side of the field at a point approximately 1600 feet from the north end. The site was clear of any reflecting objects with the exception of another fixed 125-megacycle radio range installation approximately 600 feet removed

With the trailer positioned to provide east-west courses, excellent cross-course records were obtained for both polarizations The vertically polarized antenna system, however, was found to have a considerable amount of "attitude effect" during flights on course. That is, any change in attitude of the airplane caused an appreciable movement of the indicator although the position of the airplane, with respect to the course, did not change. This same effect resulted in "pushing" of the course when approaching from an off-course position If the course was approached at right angles and a 90-degree turn made at the point where the crossed-pointer meter indicated "on-course", the indicator would show a considerable "off-course" reading upon completion of the turn

When the trailer was positioned for north-south-courses, the same results were obtained except that the cross-course recording on the south course of the horizontally polarized antenna system contained a slight amount of scalloping that was not observed for the vertically polarized system. The scalloping was presumed to be caused by reflections from the nearby horizontally-polarized 125-megacycle range system The same degree of "attitude effect" and "pushing" was noted on the vertically polarized system when the courses were oriented north and south The horizontally polarized system was absolutely free from this effect For this investigation, it was felt that the cross-course recordings would provide the greater part of the desired information, while the on-course records would supply only supplementary data

Although it was determined that the "attitude effect" did not cause any irregularities in the cross-course records, an effort was made to eliminate the condition.

Ground measurements were made to determine the relative amount of the opposite polarization with each array It was found that approximately 12 percent of vertical polarization existed in the horizontal system while approximately 8 percent of horizontal polarization existed in the vertical system At that time it was decided to extend the sides of the counterpoise by fastening some galvanized iron sheeting to the sides of the catwalk and allowing it to extend out over the side of the trailer. This arrangement made the surface of the counterpoise more uniform and provided a counterpoise area of twelve feet by twelve feet. After increasing the counterpoise surface, ground checks were again made and it was found that the horizontal polarization in the vertical system was reduced to about 3 percent.

On-course flight tests with this arrangement showed only a very slight improvement. Since the cross-course recordings were of primary interest in the investigation, it was decided to proceed with the outlined program. Flight recordings of the preliminary tests are shown in figures 16 to 19, inclusive. Figures 16 and 18 are cross-course recordings. Each polarization is directly compared on each Figure.

Building Tests

The building tests were divided into two distinct groups, one with the trailer located at a point at right angles to the front side of the Experimental Station building, and one with the trailer located at an angle of 45 degrees from the side of the building. Three different course orientations were provided for each group of tests, one with the courses perpendicular to the side of the building (north-south), one with the courses parallel to the side of the building (east-west), and one with the courses at a 45-degree angle (northeast-southwest) Northwest-southeast courses were also tested for the trailer location at 45 degrees to the side of the building The Experimental Station building is 120 feet long, 150 feet deep and 30 feet high. The height of the building increases to approximately 38 feet along the side used for the tests along a 45-degree line and contains considerable metallic surface.

The most desirable distance for the placement of the trailer from the building was determined by the amount of scalloping desired If the scalloping were too great, then the recorder chart indications would be so violent that difficulty would be encountered in computing the percent scalloping If, on the other hand, the scalloping were too small, the desired accuracy would not be obtained. An average amount of approximately 20 percent scalloping was determined to be the best condition. Previous tests at this location indicated that the trailer should be located 400 feet from the building for the best results.

Cross-course tests were made at distances varying from ten and one-half to fifteen miles from the trailer depending upon convenient check points. Tests were also made at a distance of one mile from the station The results of the tests made on a line perpendicular to the building are shown in Figure 20 An aerial photograph showing the location of the test point is included on the chart as well as the resulting percentages of scalloping for each course

The corresponding on-course recordings are shown in Figures 21, 22 and 23. A calibration of recorder chart deflections against crossed-pointer dot deflections is shown at the end of each recording

The results of the flight tests made with the trailer located on a line making a 45-degree angle to the sides of the building are shown in Figure 24 A cross-course test on the northwest course was made at three different distances (5, 10 and 15 miles) to determine if any variations in the extremely severe scalloping could be noted. No particular variation was noted except that the scalloping appeared to become more severe at greater distances. The effect of increasing percentage of scalloping with increasing distance had never been observed previously and is believed to be noticeable only when extreme scalloping occurs. This test was made using only the horizontal antenna system The results of this particular test are shown in Figure 25 The on-course recordings corresponding to the cross-course records of Figure 25 are shown in Figures 26 to 29, inclusive An analysis of the scalloping measured during the building tests is shown in Table I.

TABLE I

Location	Course Information	Horizontal Polarization Percent Scalloping	Vertical Polarization Percent Scalloping
Perpendicular to building	N course - through building front	32 percent	9 percent
	S course - opposite building front	12	14
	NE course - 45° to building	10	17
	SW course - 45° to building	23	22
	E course - parallel to building front	15	13
	W course - parallel to building front	5	14
45° from side of building	N course - parallel to building side	11	15
	S course - parallel to building side	20	10
	NE course - through building	11	12
	SW course - opposite building	5	7
	E course - parallel to building front	16	25
	W course - parallel to building front	15	15
	SE course - 45° to building sides	23	27
	NW course - 45° to building sides	83	112
	Maximum Scalloping	83 percent	112 percent
	Minimum Scalloping	5	7
	Average Scalloping	20	22

Wire Tests

Some difficulty was encountered in locating a suitable site for the wire line tests where no other reflecting objects existed The site finally selected was approximately one-half mile northwest of the Experimental Station near the junction of two branches of the Pennsylvania Railroad At this point there are a considerable number of wire lines along the railroad right-of-way The elevation of the lines varied from 8 feet at the top and 3 feet at the bottom to 20 feet at the top and 12 feet at the bottom. The greatest elevation was immediately in front of the trailer

The first flight test at this location was made with the trailer located 400 feet from the highest point on the lines It was found that there was insufficient scalloping at this point for the required accuracy, so the trailer was moved to a point 300 feet from the lines This location provided about the desired amount of scalloping and was used in the remainder of the tests The preliminary wire-line test indicates that a large number of lines do not result in as much scalloping as that caused by a building of the size of the Experimental Station This is probably due to the much lower height of the wires

Cross-course flight tests were made at distances varying from 10 5 to 15 miles as well as one mile from the trailer The resulting flight recordings are arranged in a manner similar to that used for the building tests The results of the cross-course tests are shown in Figure 30 Although the recordings are labeled North, South, East, West, etc , the tests were conducted with the courses oriented about 15 degrees from these directions so that the courses would be actually parallel to, perpendicular to or at 45 degrees with the wire line

The corresponding on-course recordings are shown in Figures 31, 32 and 33 A summary of the scalloping encountered during the wire-line tests is shown in Table II

TABLE II

Course Information	Horizontal Polarization Percent Scalloping	Vertical Polarization Percent Scalloping
North course, through wires	15 percent	13 percent
South course, opposite wires	11	18
Northeast course, 45° to wires	7	23
Southwest course, 45° to wires	32	16
East course, parallel to wires	35	32
West course, parallel to wires	6	24
Maximum Scalloping	35 percent	32 percent
Minimum Scalloping	6	13
Average Scalloping	18	21

Tree Tests

The first tree test was made at a location which was considered to be a typical site that could be found in most parts of the country for installation of very-high-frequency range facilities A clearing was located a few miles southwest of the Indianapolis airport where no trees or brush existed closer than 360 feet The site was completely surrounded by trees whose distance from the selected trailer site varied from 360 feet to 780 feet The height of the trees varied from approximately 6 feet to 70 feet. The average height was about 45 feet. The vertical elevation angles from the trailer site to the trees are shown in Figure 34.

Cross-course flight tests were made at an average distance of 13 miles and at one mile The results of these tests are shown in Figure 35 The corresponding on-course recordings are shown in Figures 36, 37 and 38 Table III contains a summary of the scalloping encountered during this group of tests

TABLE III

Course Information	Horizontal Polarization Percent Scalloping	Vertical Polarization Percent Scalloping
North course	29 percent	65 percent
South course	38	86
Northeast course	44	41
Southwest course	25	55
East course	44	46
West course	27	44
Maximum Scalloping	44 percent	86 percent
Minimum Scalloping	25	41
Average Scalloping	34	56

A second group of tree tests were conducted on a somewhat isolated group of trees on the south side of the Indianapolis airport The purpose of this group of tests was to determine the effect of one group of trees upon course scalloping as compared to a condition where trees existed all around the site The trailer was located 525 feet from the main front of the trees and tests were conducted similar to the preceding group The only trees of any appreciable size were located between 180 and 250 degrees of azimuth from the trailer site. All other obstructions were below a vertical angle of 1 5 degrees The vertical angles from the trailer site to the trees within the azimuth angles of 180 to 250 degrees are shown on curve A of Figure 39 The results of the cross-course tests are shown in Figure 40, with the corresponding on-course recordings shown in Figures 41, 42 and 43 A summary of these tests is included in Table IV

TABLE IV

Course Information	Horizontal Polarization Percent Scalloping	Vertical Polarization Percent Scalloping
North course, opposite trees	30 percent	40 percent
South course, through trees	41	85
Northeast course, 45° to trees	21	48
Southwest course, 45° to trees	32	61
East course, parallel to trees	24	72
West course, parallel to trees	19	58
Maximum Scalloping	41 percent	85 percent
Minimum Scalloping	19	40
Average Scalloping	27	61

A group of panoramic photographs showing the obstructions near the sites for the building, wire and tree tests are shown in Figure 44.

The same group of trees was used to make a further investigation to determine the effect of distance from the trees upon the resulting scalloping The courses were oriented for north-south operation only The trailer was located at positions 525 feet, 825 feet and 1125 feet from the face of the trees. The vertical angles to the trees from each site location are shown in Figure 39. The flight technique for this test was similar to the preceding tests. The results of the cross-course tests are shown in Figure 45, while the on-course recordings are included in Figures 41, 46, and 47.

Table V is a summary of these tests and Figure 48 shows a graphical analysis of the results obtained Figure 49 is a group of panoramic photographs taken from the sites used for the tree-distance tests.

TABLE V

Distance	Course Information	Horizontal Polarization Percent Scalloping	Vertical Polarization Percent Scalloping
525 feet	North course, opposite trees	30 percent	40 percent
	South course, through trees	41	85
825 feet	North course, opposite trees	14	15
	South course, through trees	29	17
1125 feet	North course, opposite trees	6	9
	South course, through trees	15	14

DISCUSSION

A summary of the results of all of the tests is included in Table VI

TABLE VI

Type of Test	Horizontal Polarization Percent Scalloping	Vertical Polarization Percent Scalloping
Building	Average	Average
Wires	20 percent	22 percent
Trees (generally located)	34	56
Trees (one group)	27	61

From this table it can be seen that there is very little choice between the two types of polarization at sites where reflecting objects are buildings of the size used for these tests The two percent differential between the two types is considered of little consequence During the building tests, it was noted that one polarization was better at some locations or angles while the reverse was true for some other location or angle

Although it would seem reasonable to suppose that vertical polarization would be superior to horizontal polarization where reflections from wire lines were concerned, this assumption is not confirmed in Table VI

There is a very definite comparison between the two types of polarization where reflections from trees are considered Table VI shows approximately a 2 to 1 difference in the average percentage of scalloping in favor of horizontal polarization. It is, therefore, concluded that horizontal polarization is greatly superior to vertical under these conditions In fact, since there appears to be so little difference between the two types of polarization under other conditions of reflection, it is concluded that horizontal polarization should be used for all very-high-frequency radio range facilities From the tree-distance tests where only one small group of trees is the primary reflecting medium, it appears that the differential between the two types of polarization decreases with distance until, at great distances, there is only a slight difference The use of horizontal polarization, however, should considerably decrease the amount of tree-clearing necessary in heavily-timbered country for flyable courses

CONCLUSIONS

The following conclusions are reached regarding the most desirable type of polarization for very-high-frequency two-course visual radio range systems

Buildings (of type tested)	- No choice
Wires	- No choice.
Trees	- Definitely horizontal.
General Considerations	- Definitely horizontal

The desirability for horizontal polarization decreases with the distance to reflecting objects until, at great distances, there is little choice For ordinary radio range site conditions, however, where trees are the major consideration, horizontal polarization would be definitely superior to vertical polarization since fewer trees would have to be cleared for equivalent course scalloping.

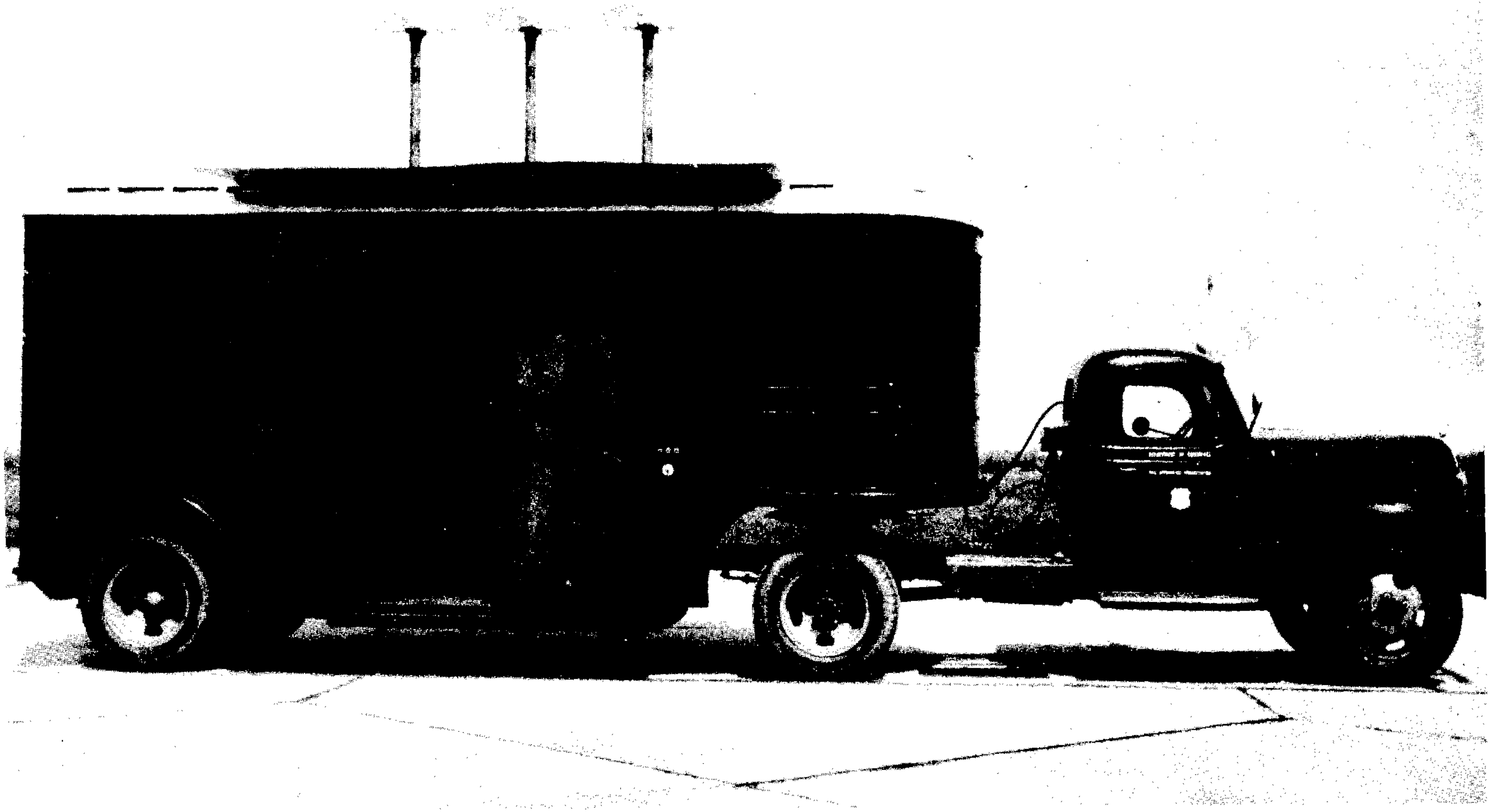


Figure 1. General View of Portable Two-Course Visual Radio Range Equipment.

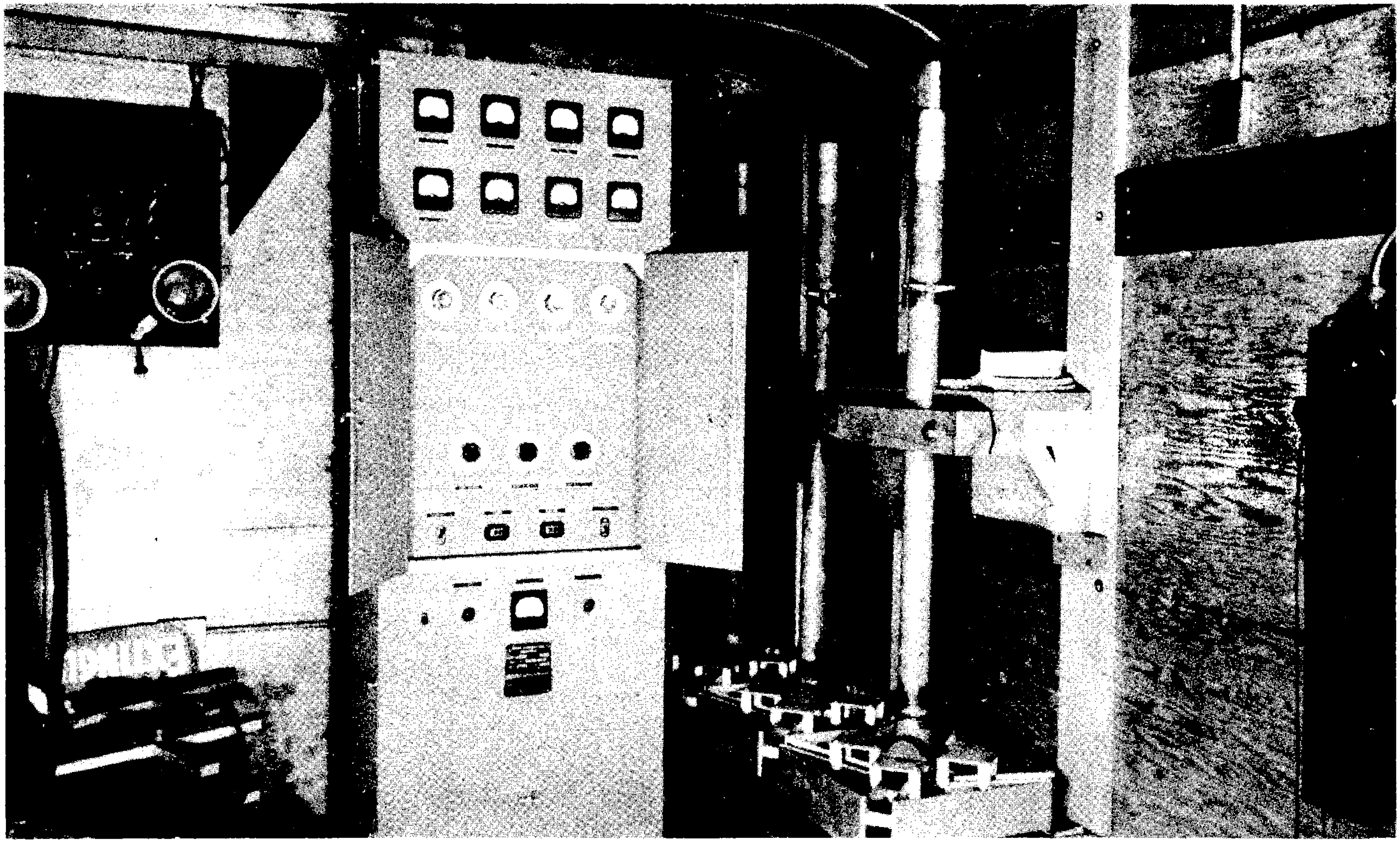


Figure 2. Interior of Trailer Showing Transmitter Installation.

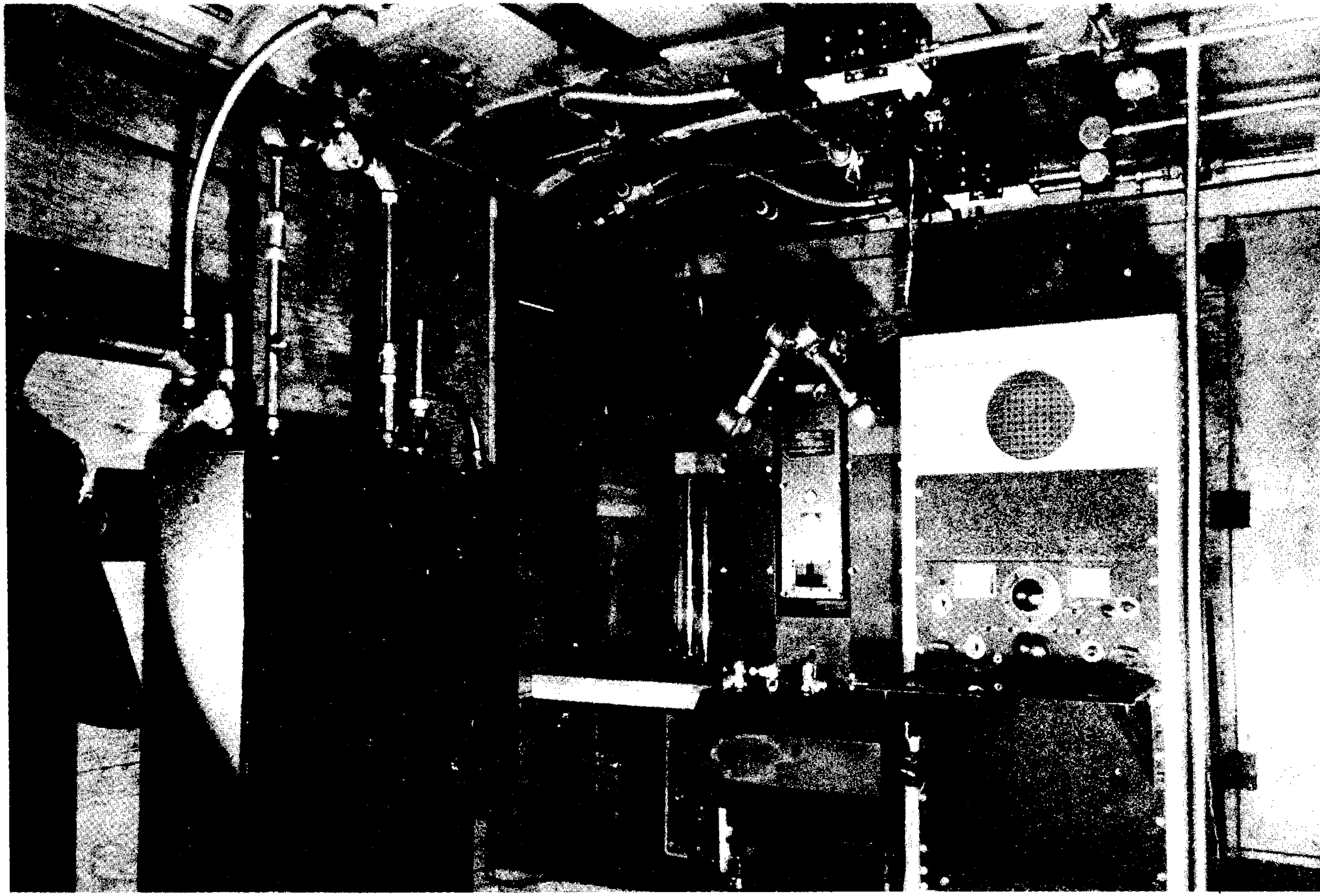


Figure 3. Interior of Trailer Showing Mechanical Modulator, Transmission Lines, and Receiving Equipment.

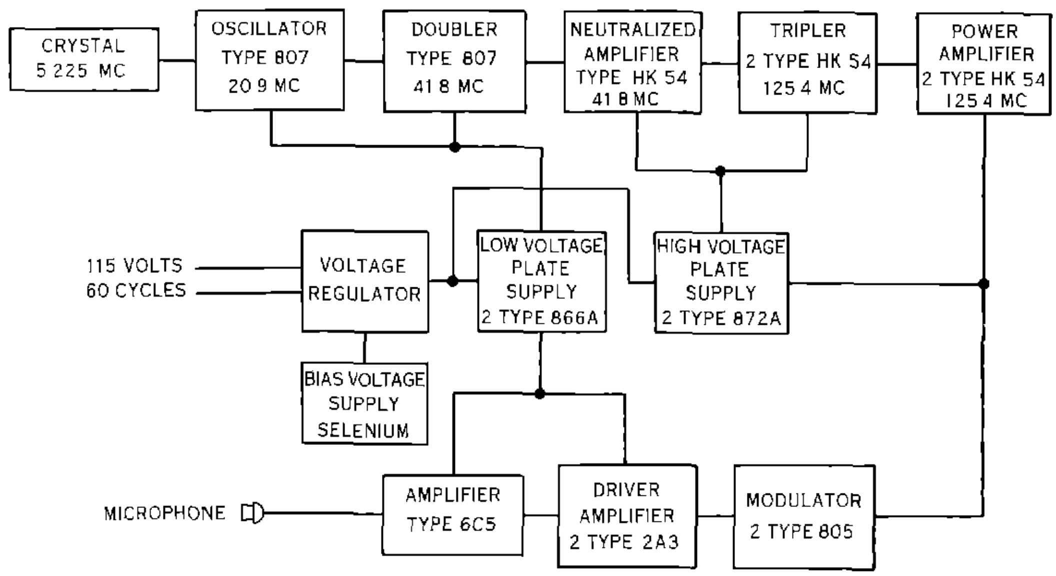


Figure 4 Block Diagram of Transmitter

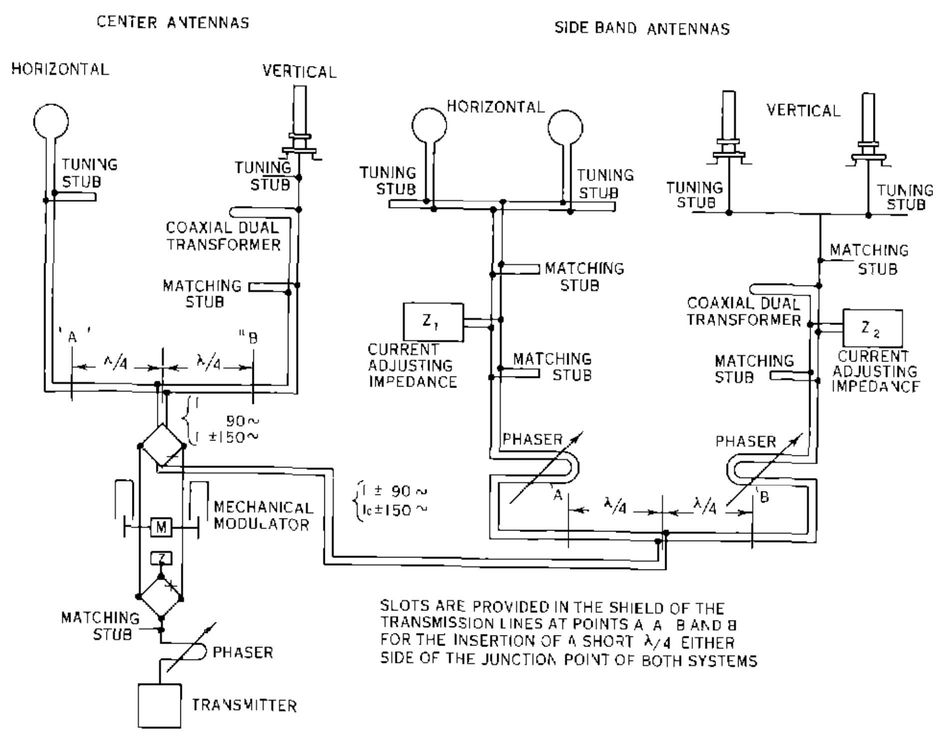


Figure 5 Block Diagram of Complete Range System

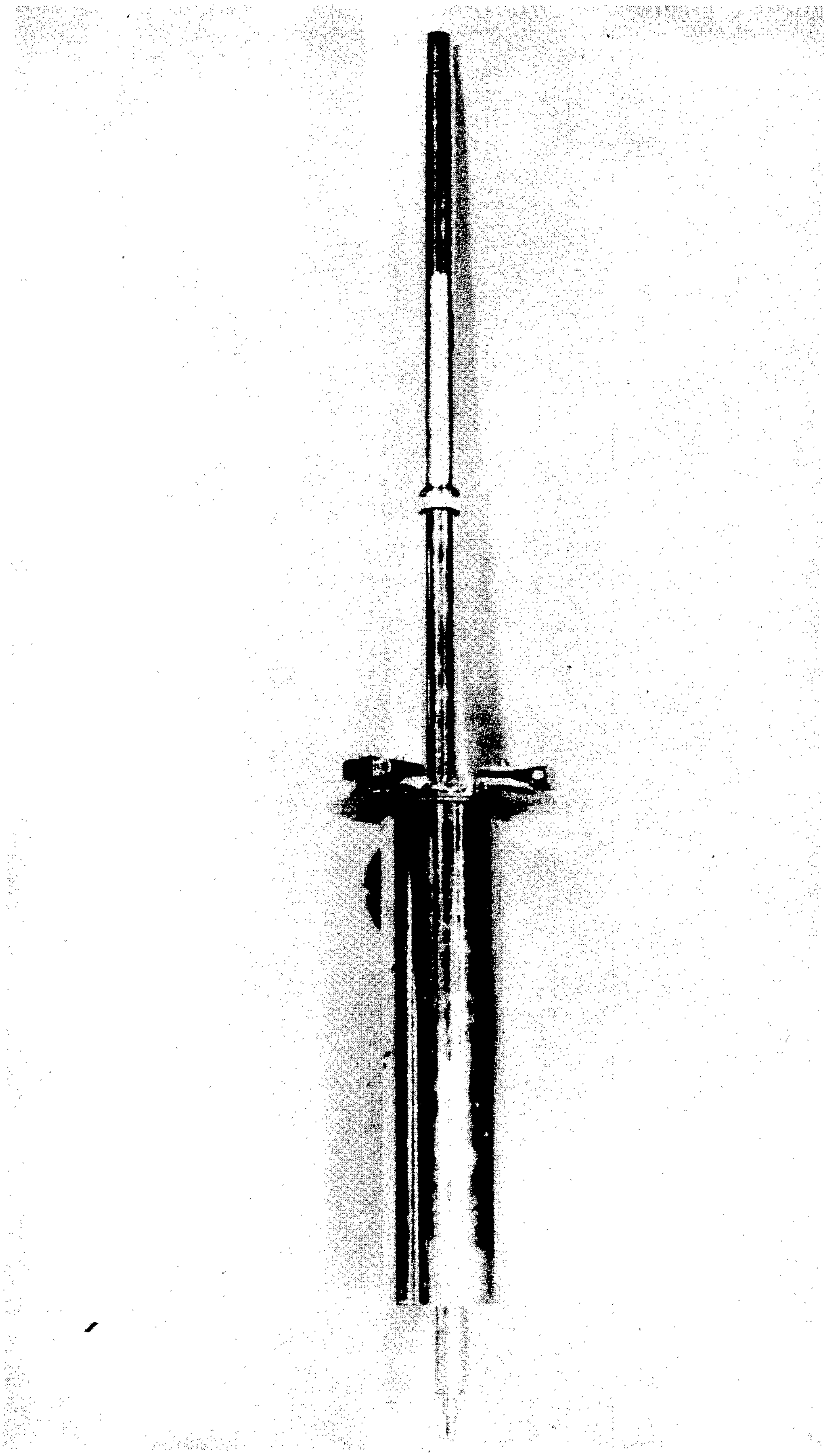


Figure 6. Vertical Antenna.

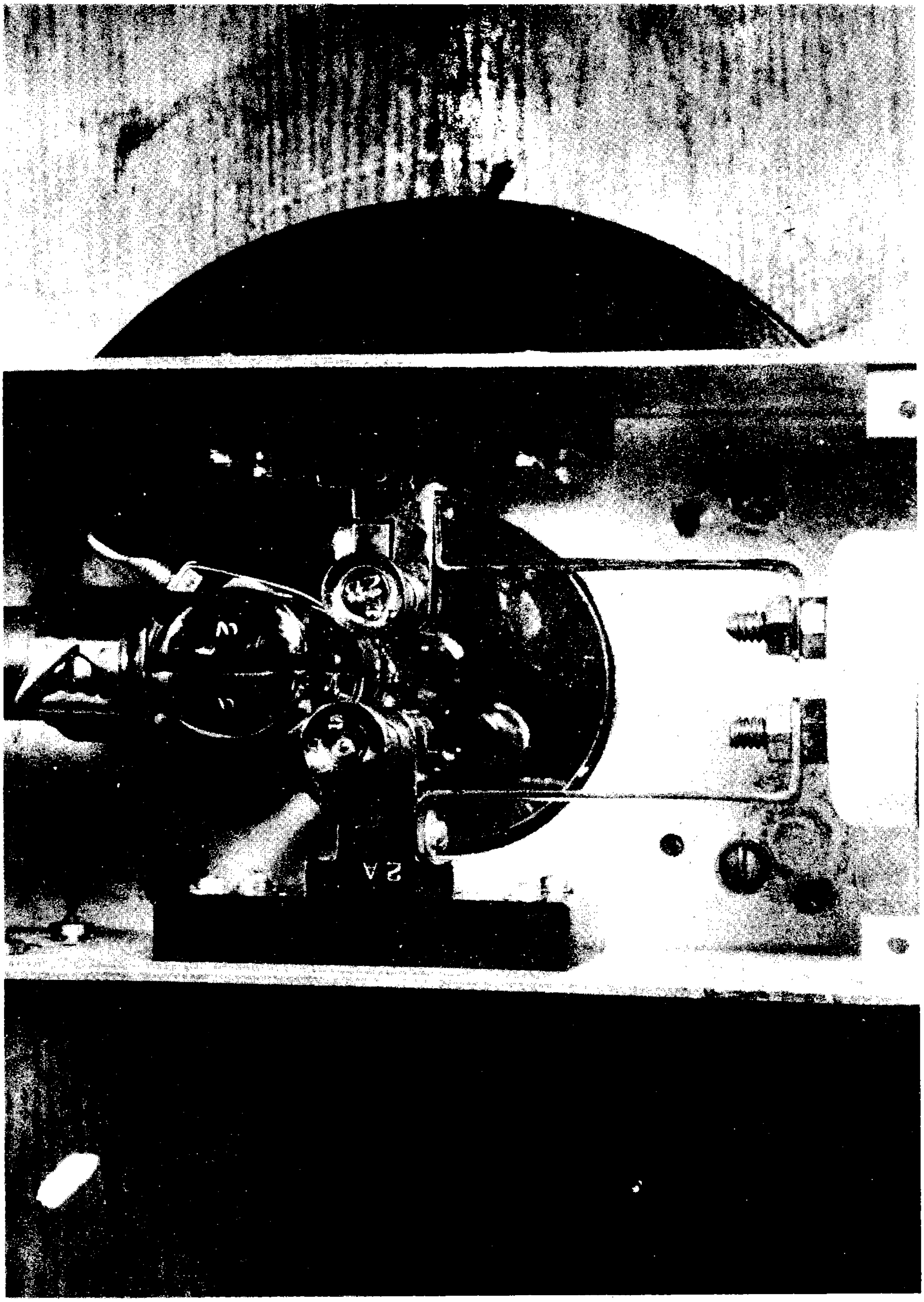


Figure 7. Antenna Connection Arrangement for Vertical System.

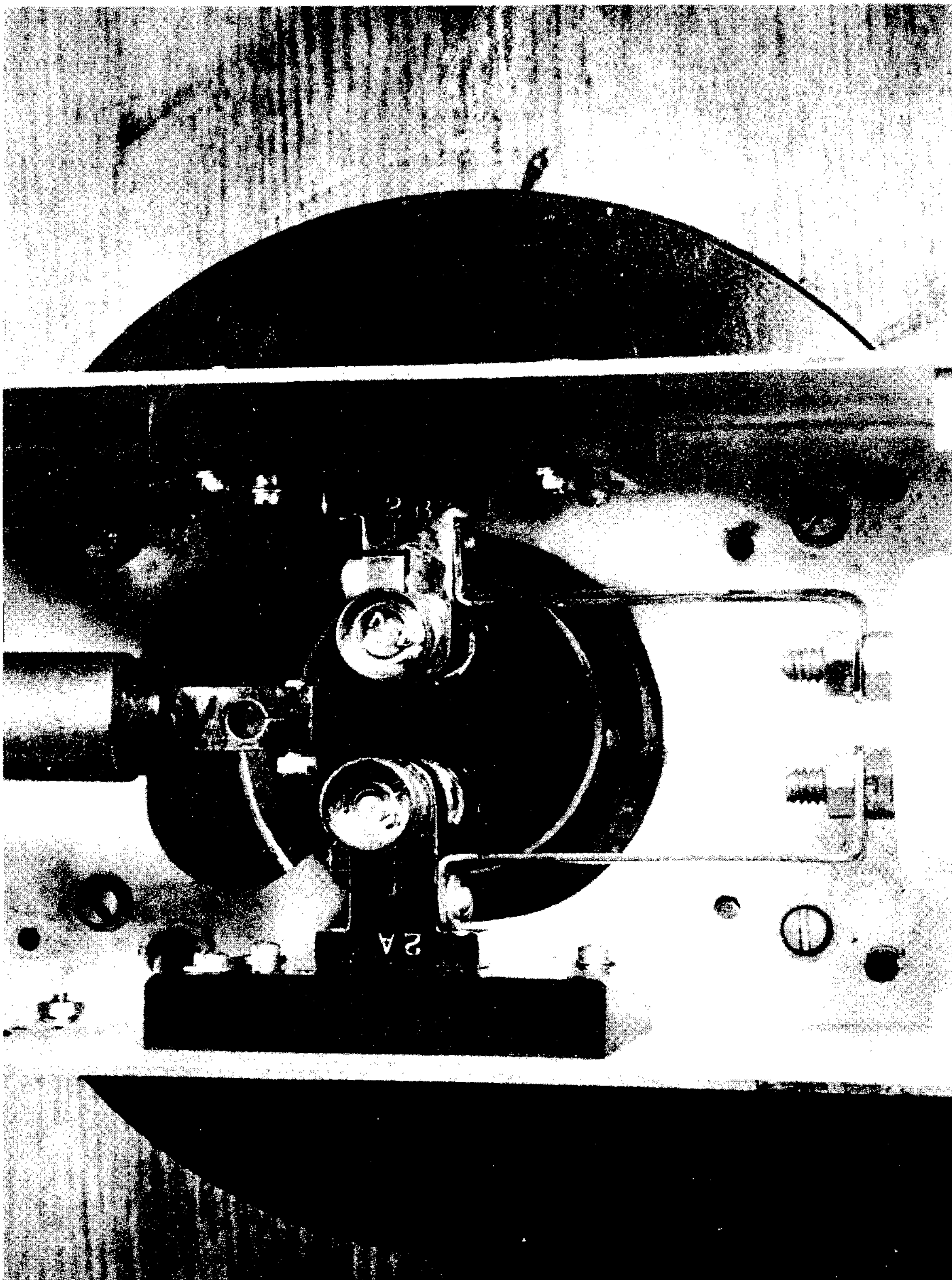
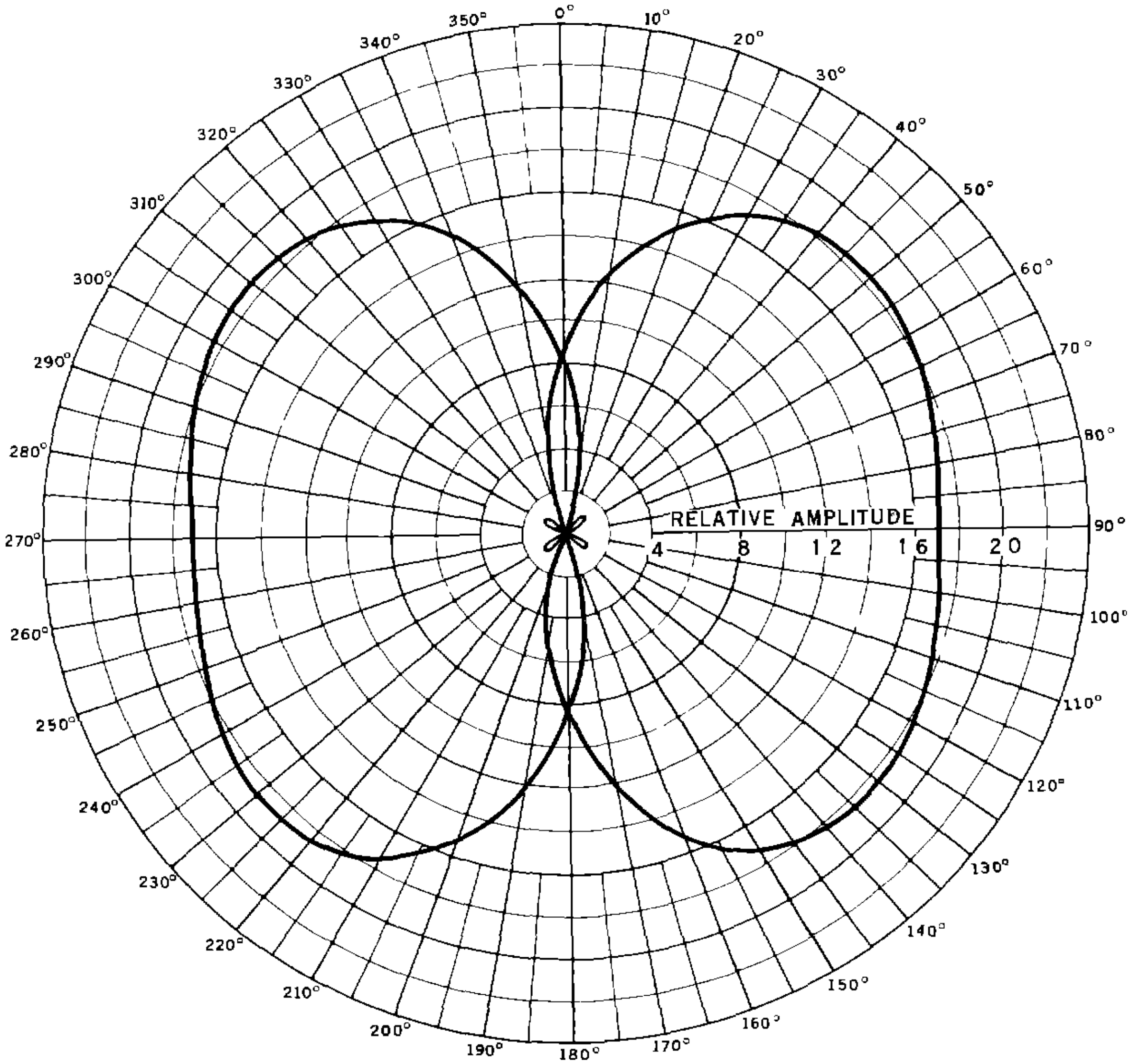
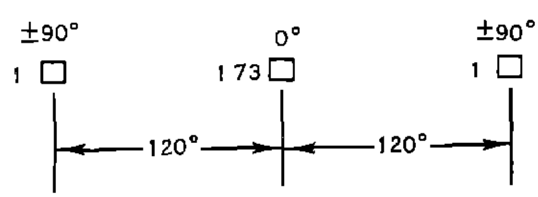


Figure 8. Antenna Connection Arrangement for Horizontal System.



HORIZONTAL FIELD PATTERN



COURSE SHARPNESS AT 1 5° 1 14 DB
MINOR LOBE CLEARANCE 22 8 DB
ON COURSE/ MAXIMUM SIGNAL 6 69 DB

Figure 9 Theoretical Horizontal Field Pattern

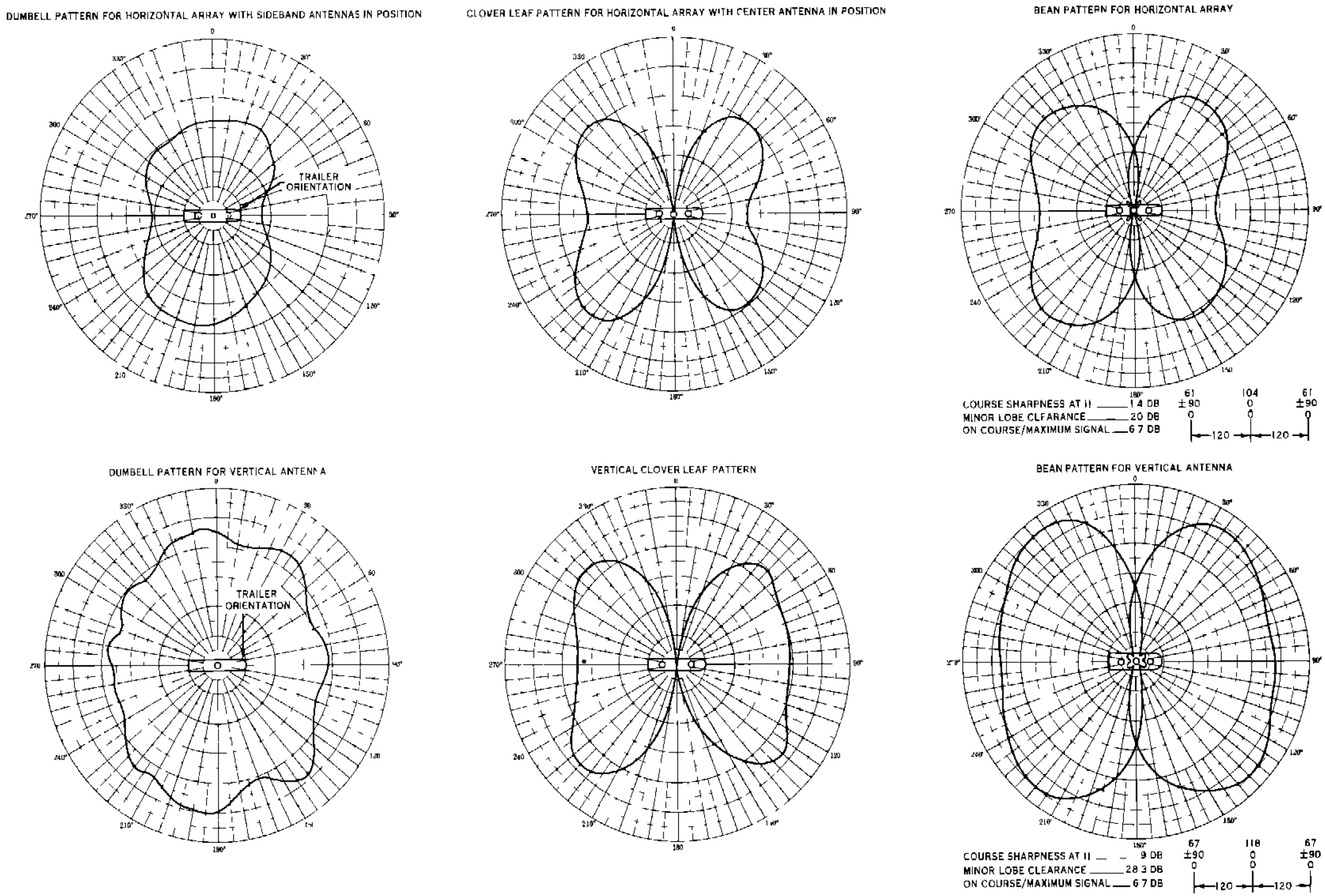


Figure 10 Measured "Dumbell", "Cloverleaf" and "Bean" Patterns for Horizontal and Vertical Arrays

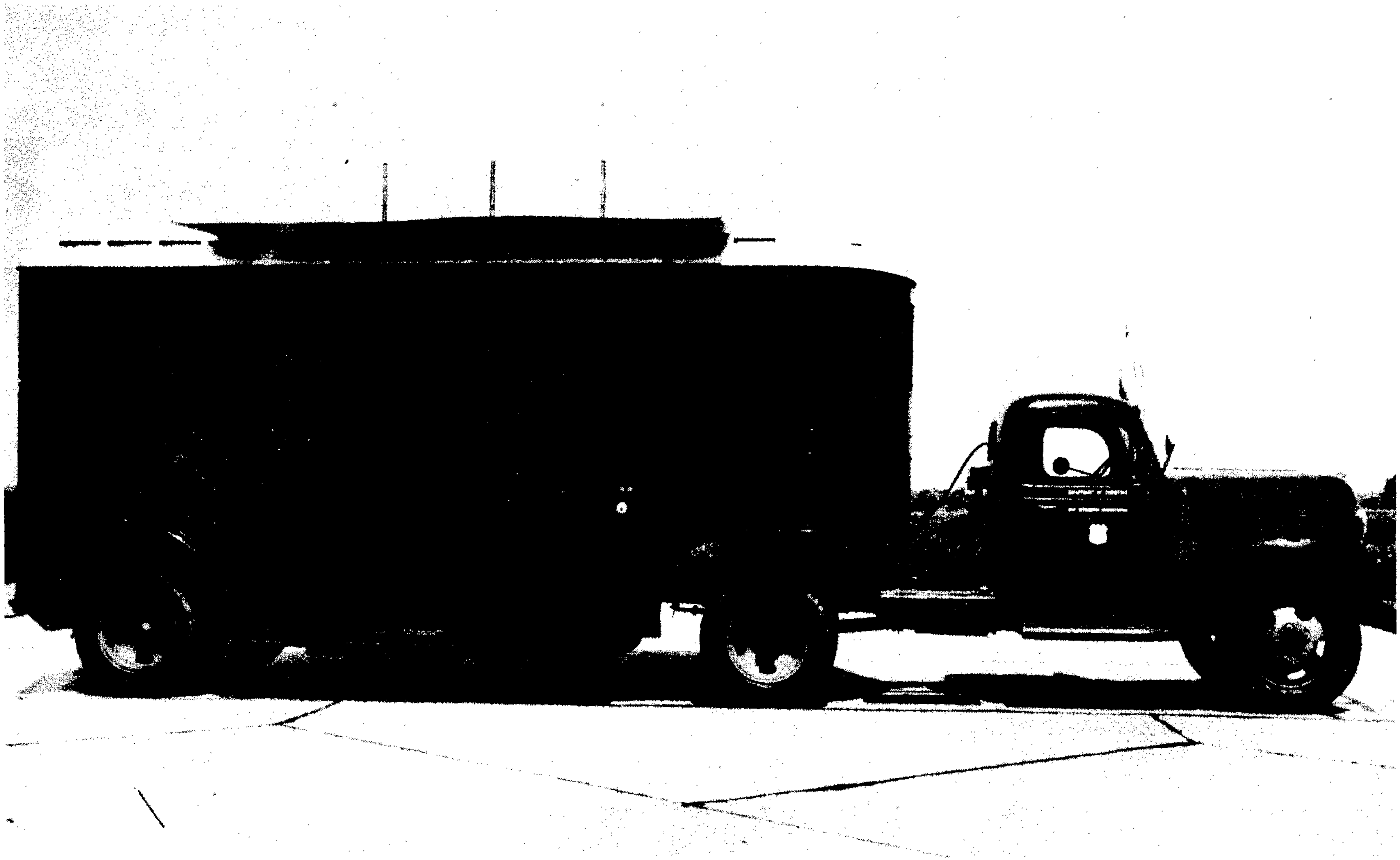


Figure 11. Vertical Antenna System Mounted on Trailer Roof.

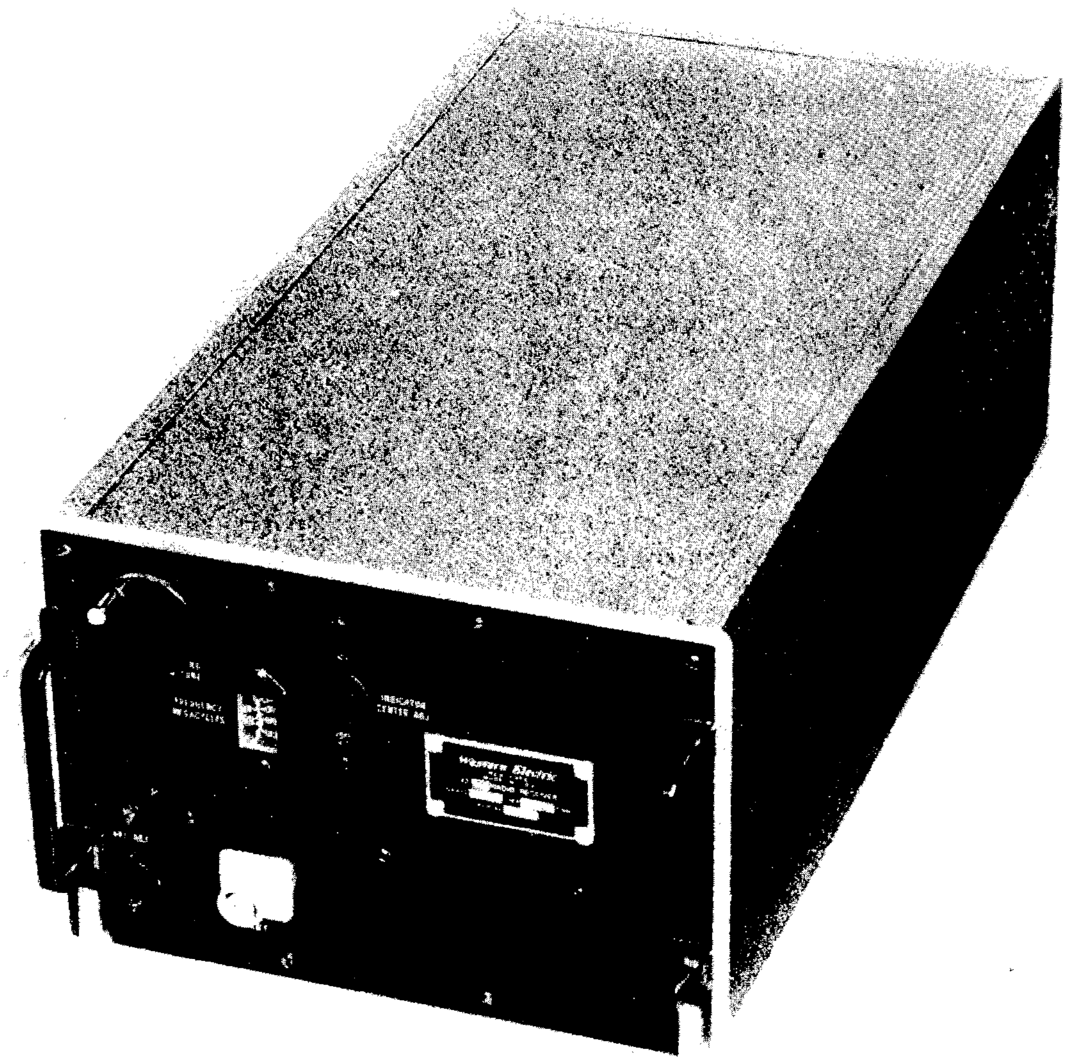


Figure 12. The Aircraft Receiver.

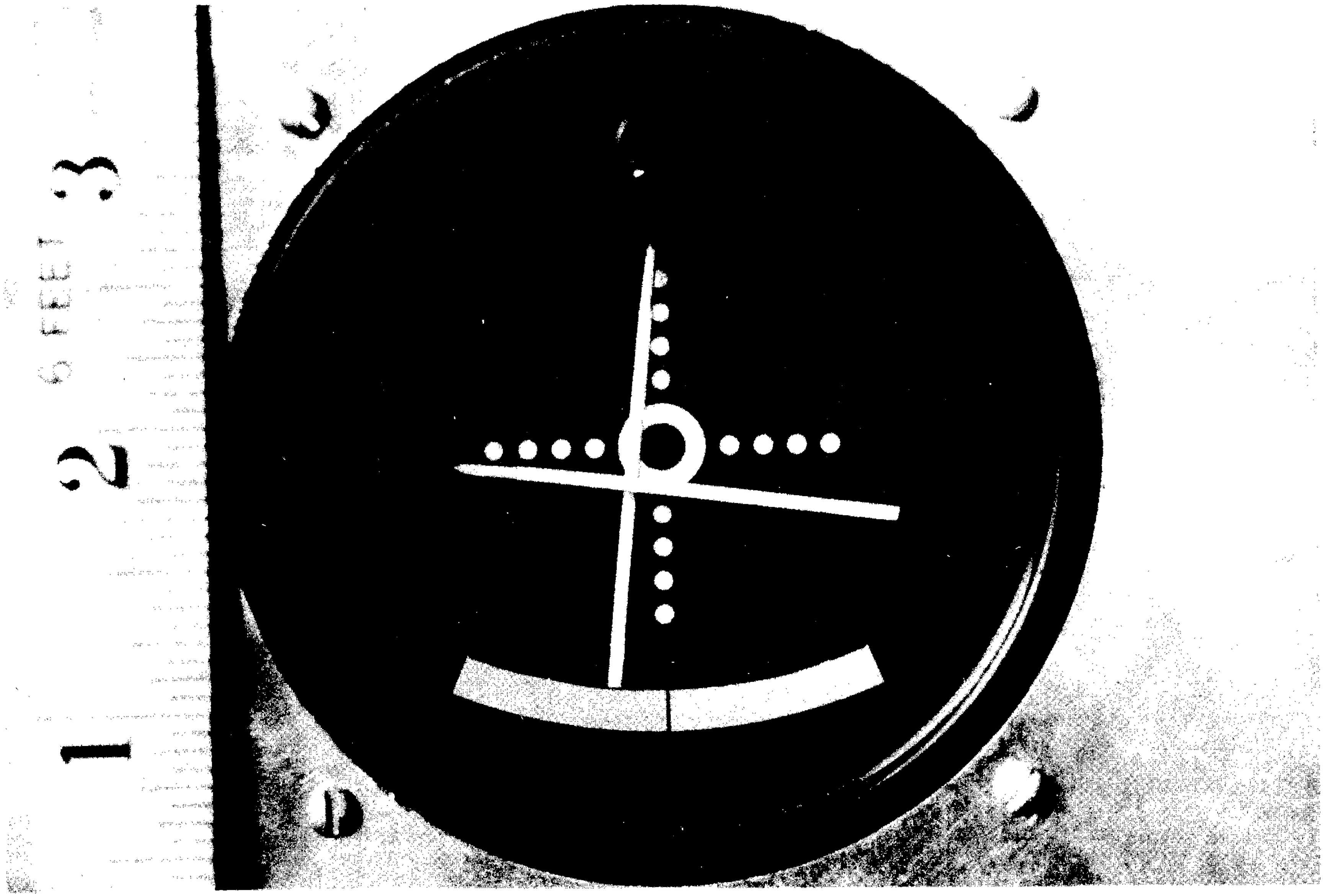


Figure 13. The Crossed- Pointer Instrument.

Figure 14. The Aircraft Horizontal Receiving Antenna.

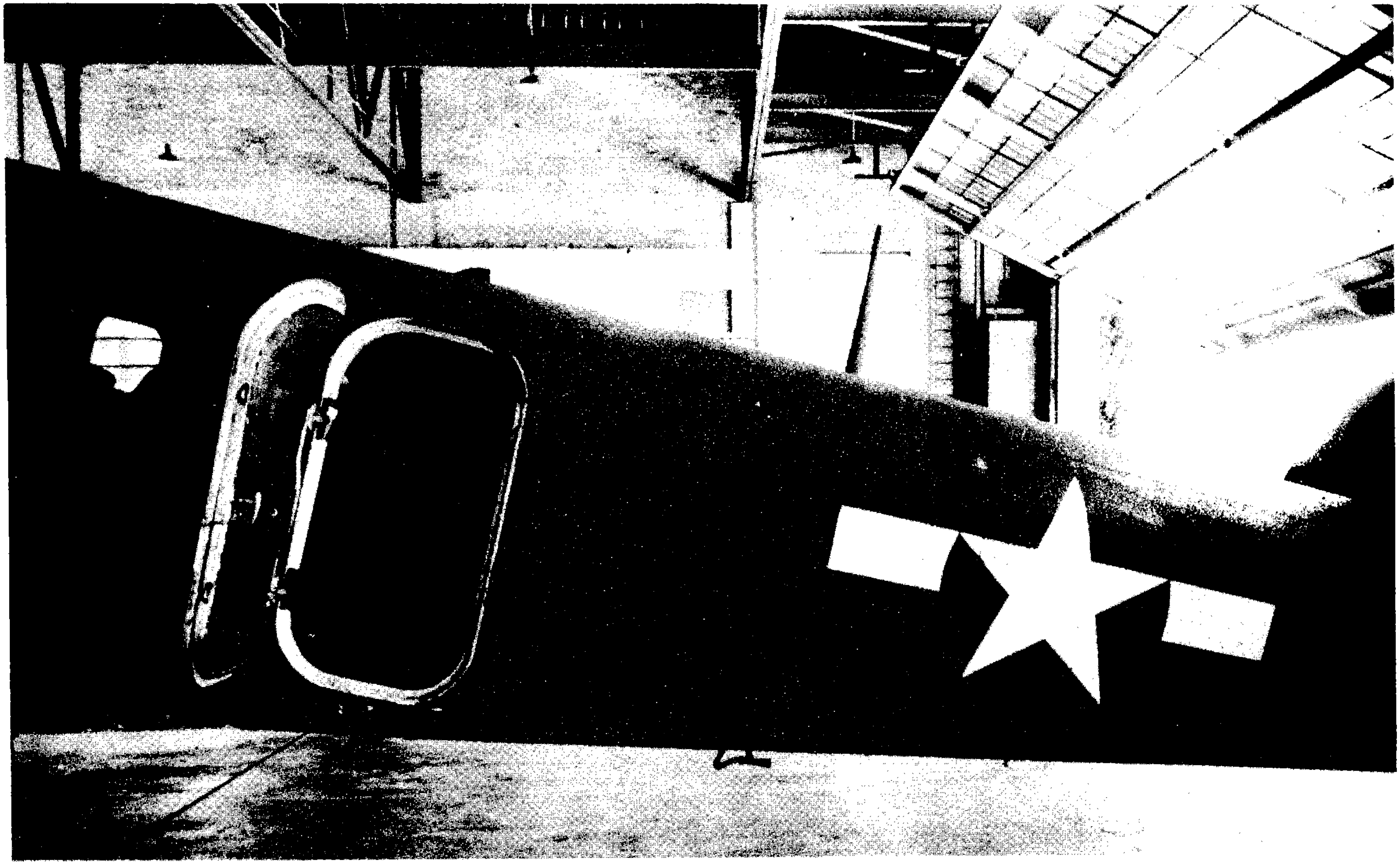
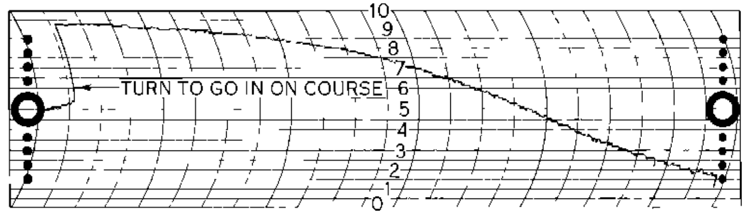
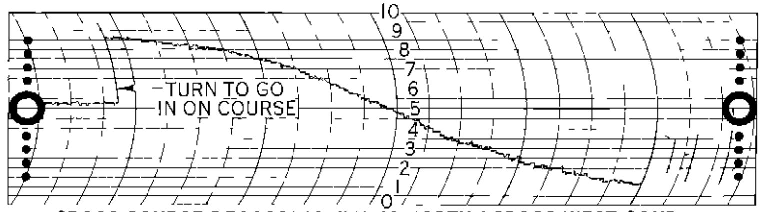


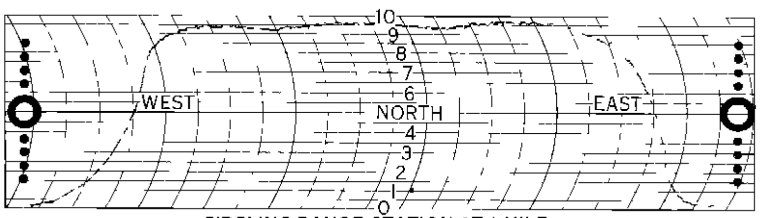
Figure 15. The Aircraft Vertical Receiving Antenna.



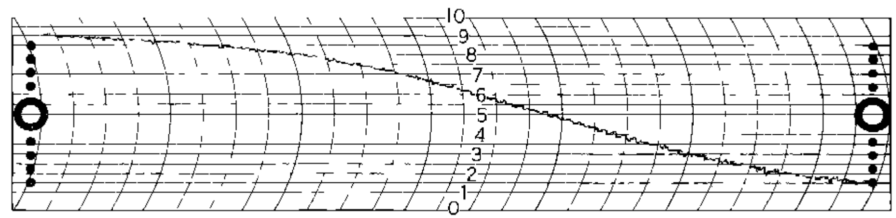
CROSS COURSE RECORDING FLYING NORTH ACROSS WEST COURSE
COURSE EAST WEST HORIZONTAL POLARIZATION 80°F



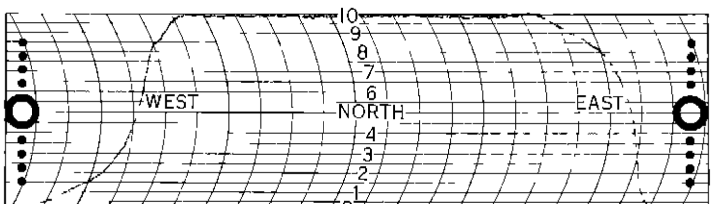
CROSS COURSE RECORDING FLYING NORTH ACROSS WEST COURSE
COURSE EAST WEST VERTICAL POLARIZATION 80°F



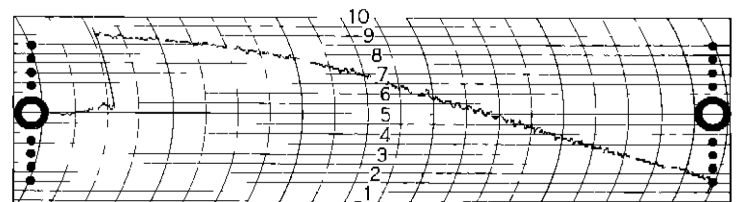
CIRCLING RANGE STATION AT 1 MILE
HORIZONTAL POLARIZATION 80 F



CROSS COURSE RECORDING FLYING NORTH ACROSS EAST COURSE
COURSE EAST WEST HORIZONTAL POLARIZATION 80°F



CIRCLING RANGE STATION AT 1 MILE
VERTICAL POLARIZATION 80°F



CROSS COURSE RECORDING FLYING NORTH ACROSS EAST COURSE
COURSE EAST WEST VERTICAL POLARIZATION 80°F

Figure 16 Preliminary Flight Recordings Showing Cross Course (East West) and Clearance Charts with the Trailer Located at a Nearly Ideal Site

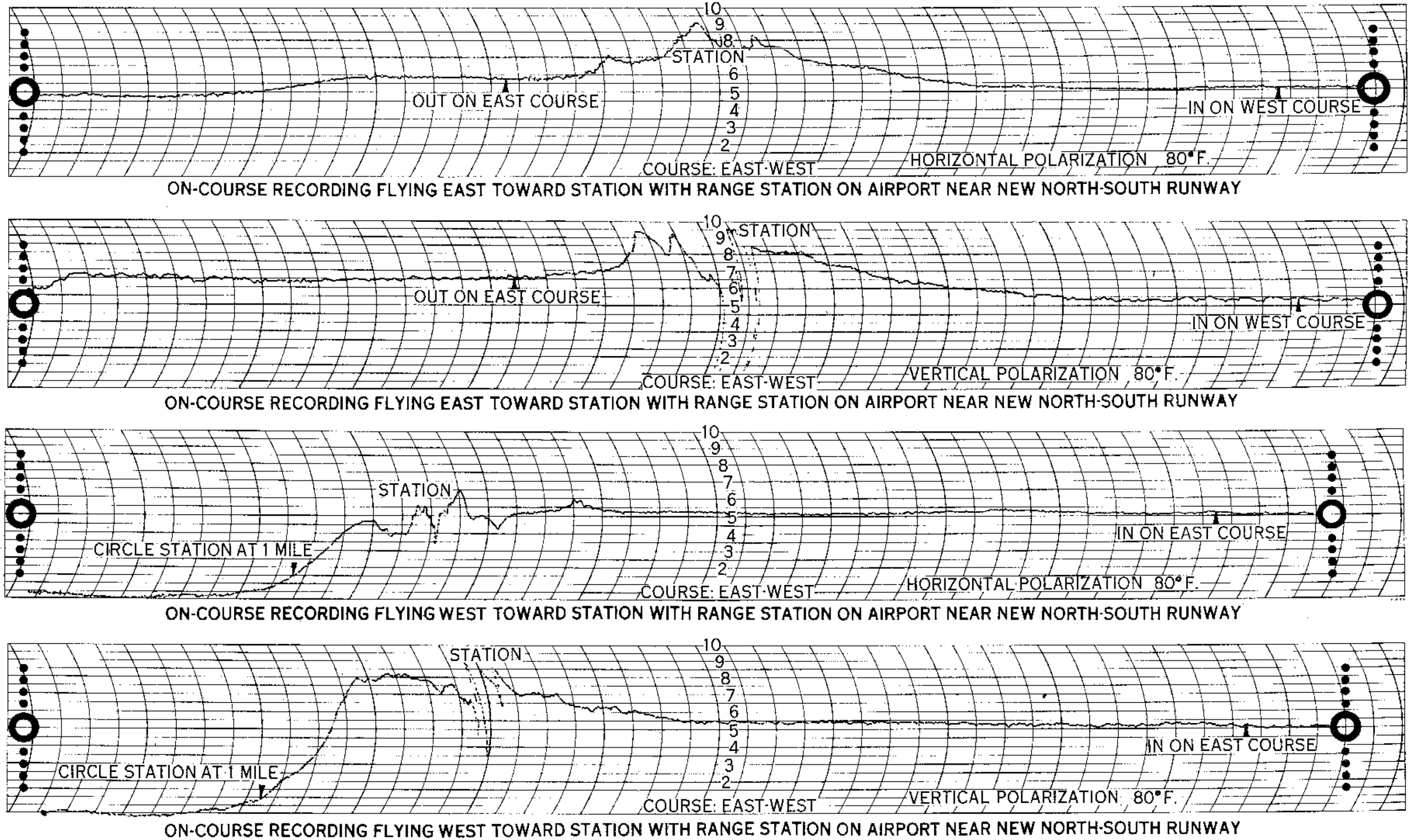


Figure 17. Preliminary Flight Recordings Showing On-Course Charts for the East and West Courses with the Trailer Located at a Nearly Ideal Site.

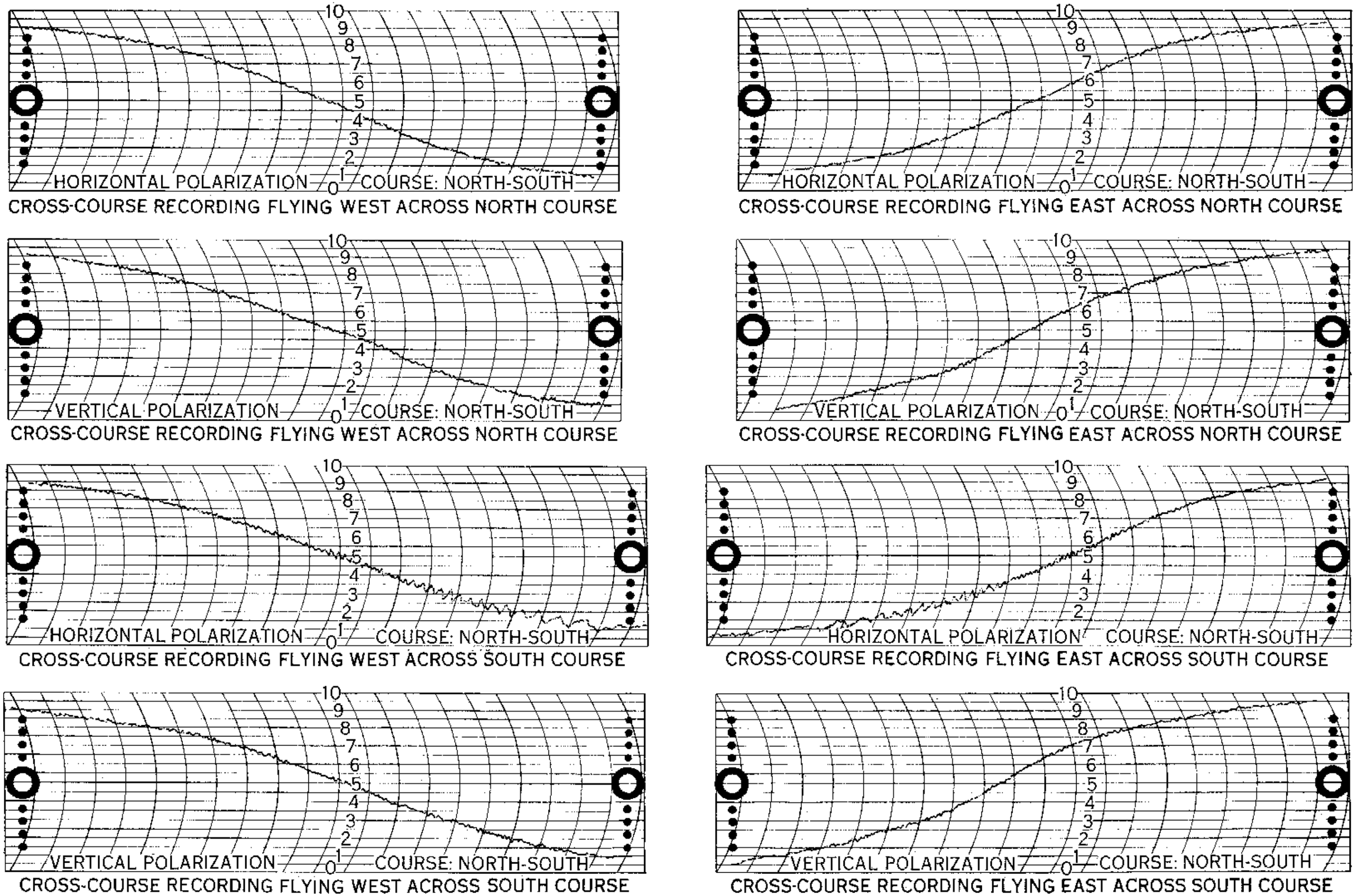


Figure 18. Preliminary Flight Recordings Showing Cross-Course (North-South) and Clearance Charts, with the Trailer Located at a Nearly Ideal Site.

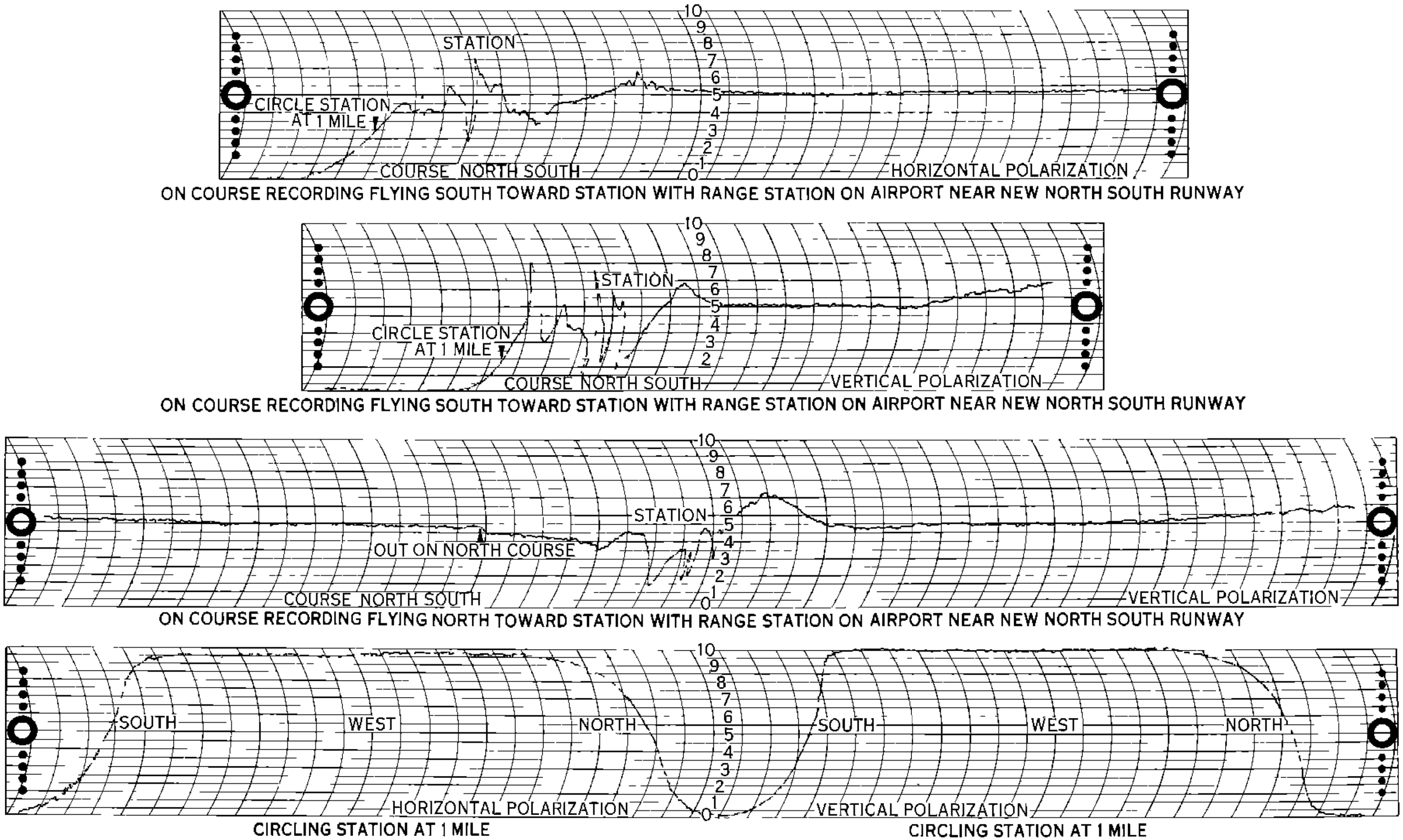
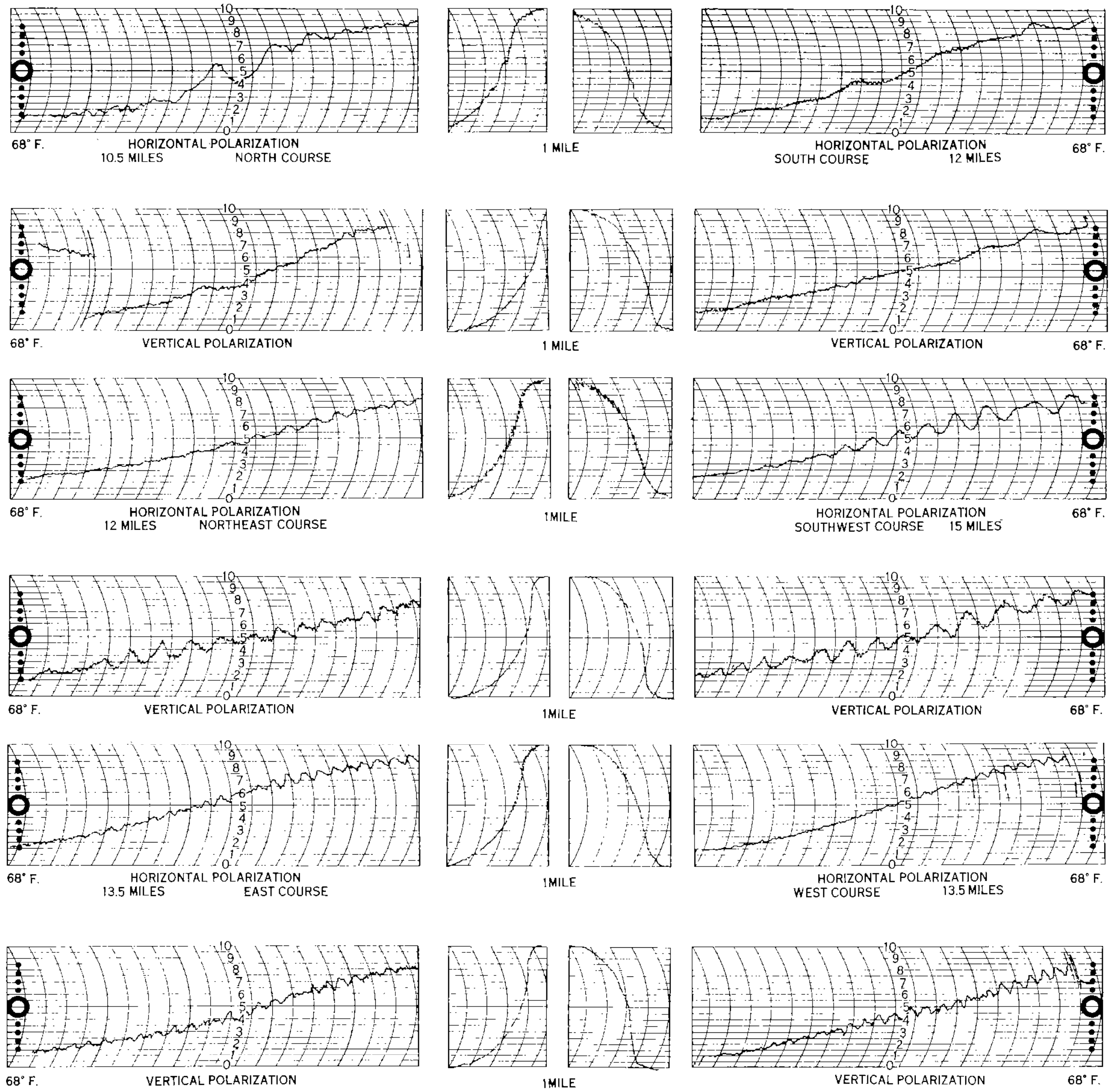


Figure 19 Preliminary Flight Recordings Showing On-Course Charts for the North and South Courses with the Trailer Located at a Nearly Ideal Site



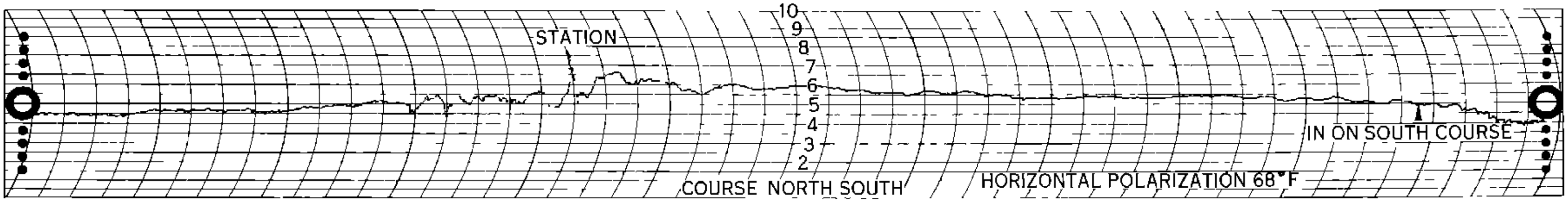
SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

DIRECTION OF COURSES	HORIZONTAL	VERTICAL
NORTH	32 %	9 %
NORTHEAST	10 %	17 %
EAST	15 %	13 %

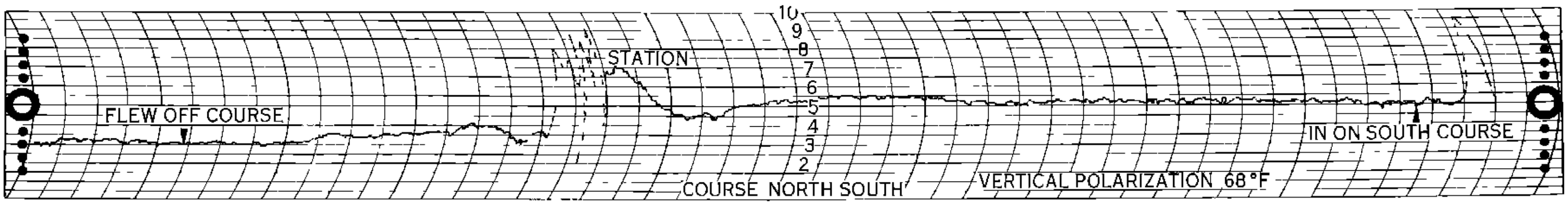
SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

DIRECTION OF COURSES	HORIZONTAL	VERTICAL
SOUTH	12 %	14 %
SOUTHWEST	23 %	22 %
WEST	5 %	14 %

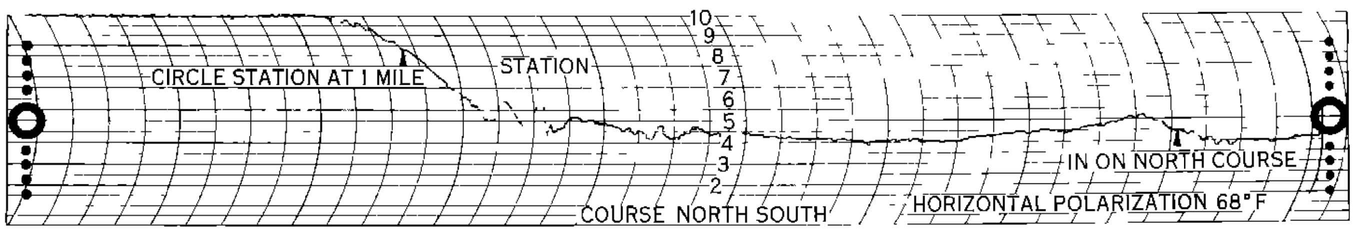
Figure 20. Cross-Course Recordings Showing the Effect of Course Orientation Upon Scalloping with the Portable Range Located 400 Feet South of the Experimental Station.



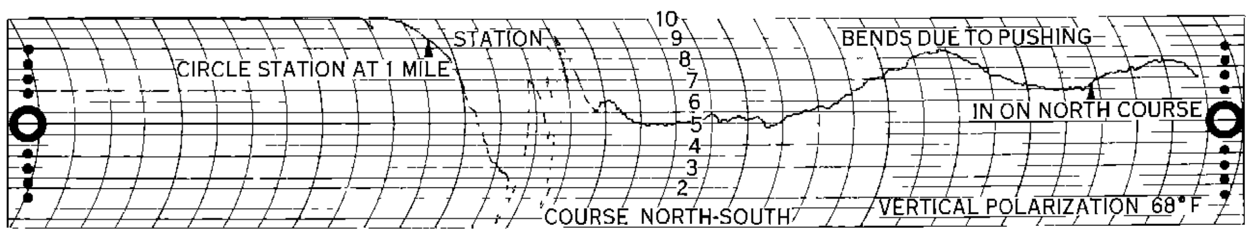
ON COURSE RECORDING FLYING NORTH TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTH OF EXPERIMENTAL STATION



ON COURSE RECORDING FLYING NORTH TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTH OF EXPERIMENTAL STATION



ON COURSE RECORDING FLYING SOUTH TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTH OF EXPERIMENTAL STATION



ON COURSE RECORDING FLYING SOUTH TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTH OF EXPERIMENTAL STATION

Figure 21 On-Course Recordings of the North and South Courses with the Portable Range Located 400 Feet South of the Experimental Station

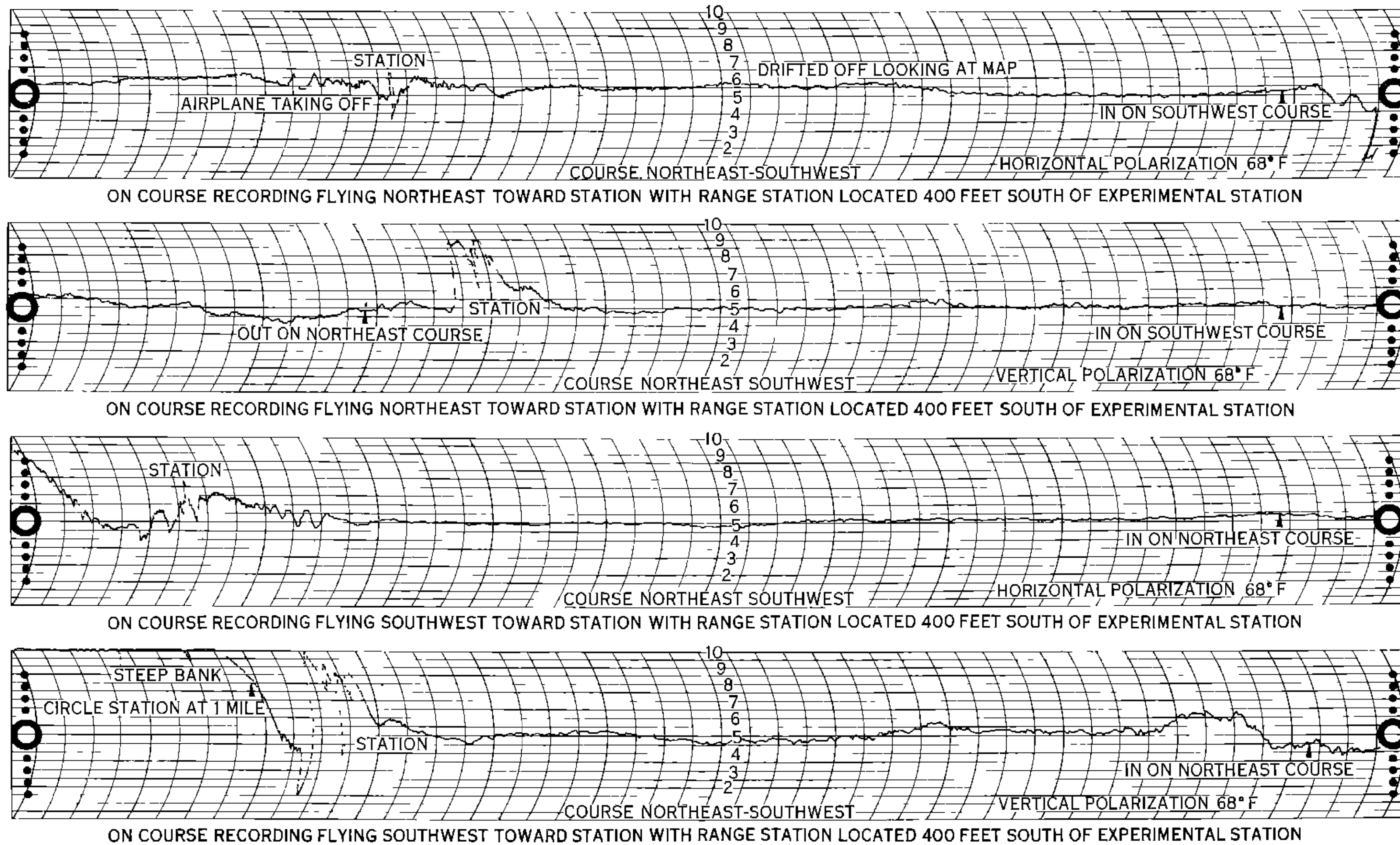
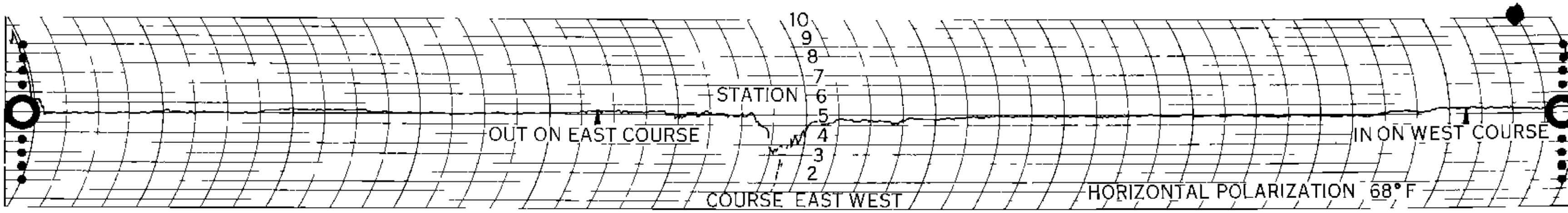
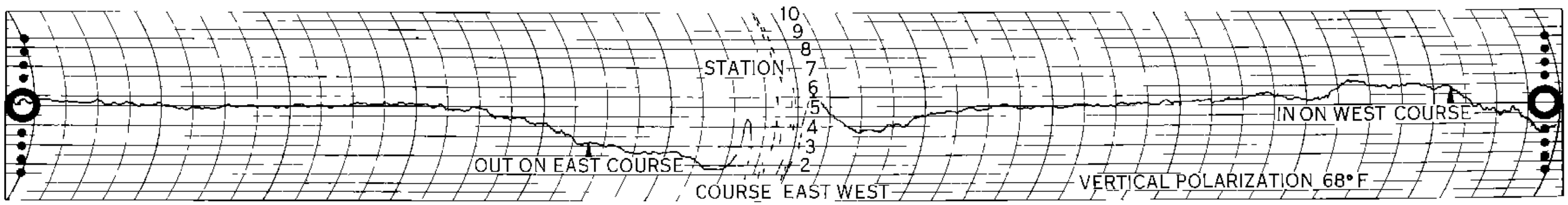


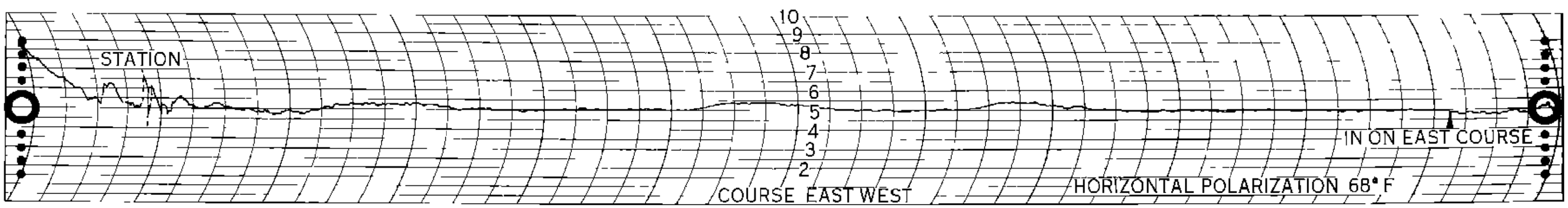
Figure 22 On-Course Recordings of the Northeast and Southwest Courses with the Portable Range Located 400 Feet South of the Experimental Station



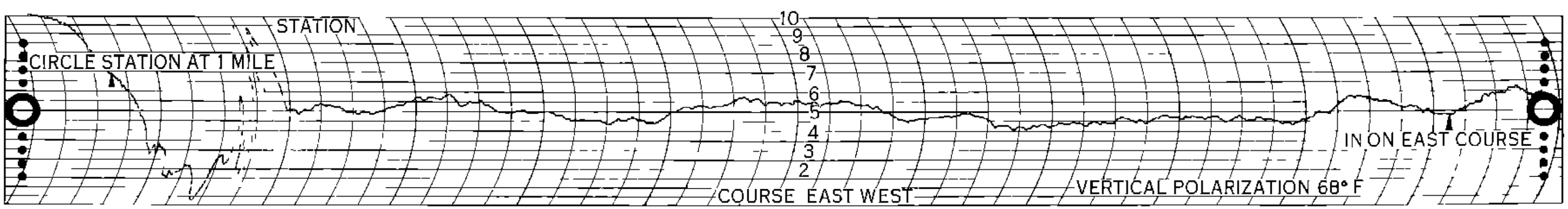
ON-COURSE RECORDING FLYING EAST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTH OF EXPERIMENTAL STATION



ON COURSE RECORDING FLYING EAST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTH OF EXPERIMENTAL STATION



ON COURSE RECORDING FLYING WEST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTH OF EXPERIMENTAL STATION



ON COURSE RECORDING FLYING WEST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTH OF EXPERIMENTAL STATION

Figure 23 On-Course Recordings of the East and West Courses with the Portable Range Located 400 Feet South of the Experimental Station

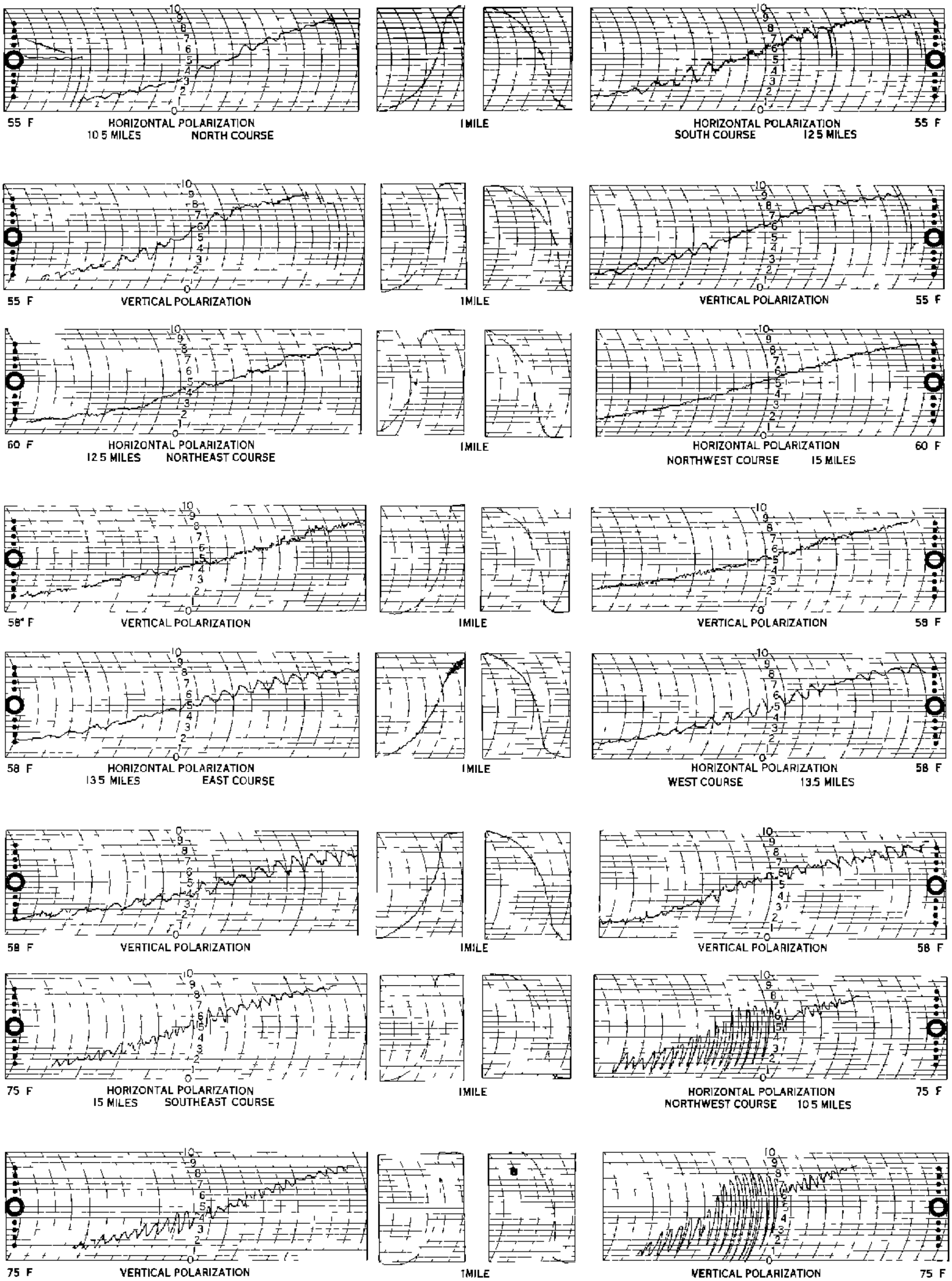
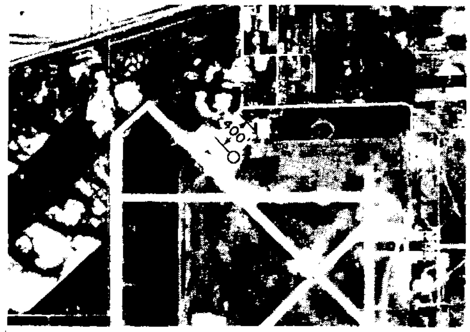


Figure 24 Cross-Course Recordings Showing the Effect of Course Orientation Upon Scalloping with the Portable Range Located 400 Feet Southwest of the Experimental Station

SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

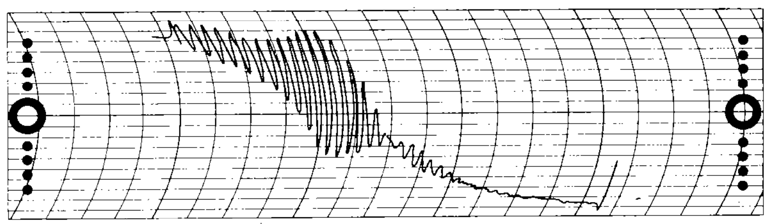
DIRECTION OF COURSES	HOR.	VERT.
NORTH	11%	15%
NORTHEAST	11%	12%
EAST	16%	25%
SOUTHEAST	23%	27%



SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

DIRECTION OF COURSES	HOR.	VERT.
SOUTH	20%	10%
SOUTHWEST	5%	7%
WEST	15%	15%
NORTHWEST	83%	112%

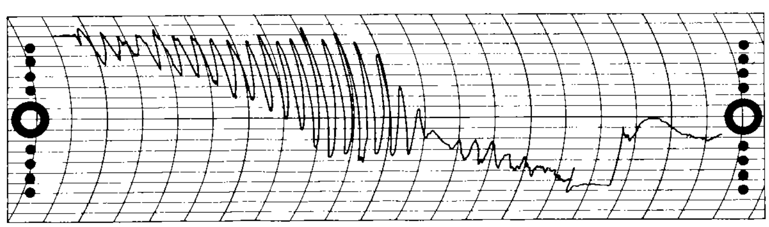
Figure 24A. Portable Range Located 400 Feet Southwest of the Experimental Station.



CROSS-COURSE RECORDING FLYING SOUTHWEST ACROSS NORTHWEST COURSE 5 MILES FROM RANGE STATION

78% SCALLOPING

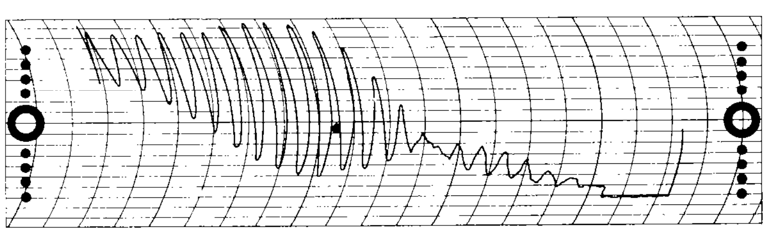
HORIZONTAL POLARIZATION 75° F.



CROSS-COURSE RECORDING FLYING SOUTHWEST ACROSS NORTHWEST COURSE 10 MILES FROM RANGE STATION

85% SCALLOPING

HORIZONTAL POLARIZATION 75° F.

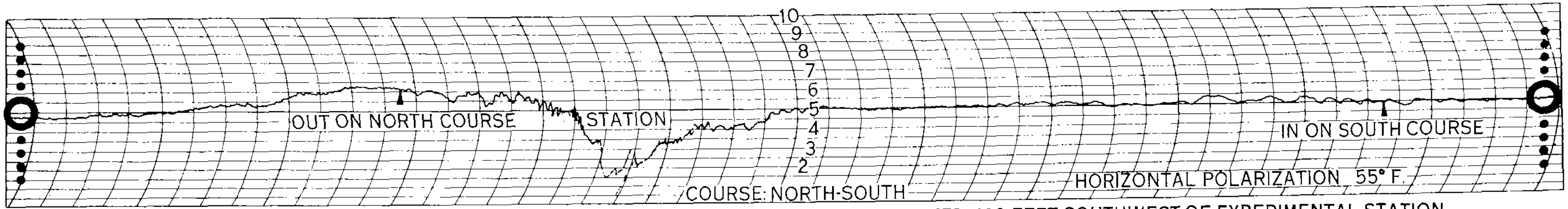


CROSS-COURSE RECORDING FLYING SOUTHWEST ACROSS NORTHWEST COURSE 15 MILES FROM RANGE STATION

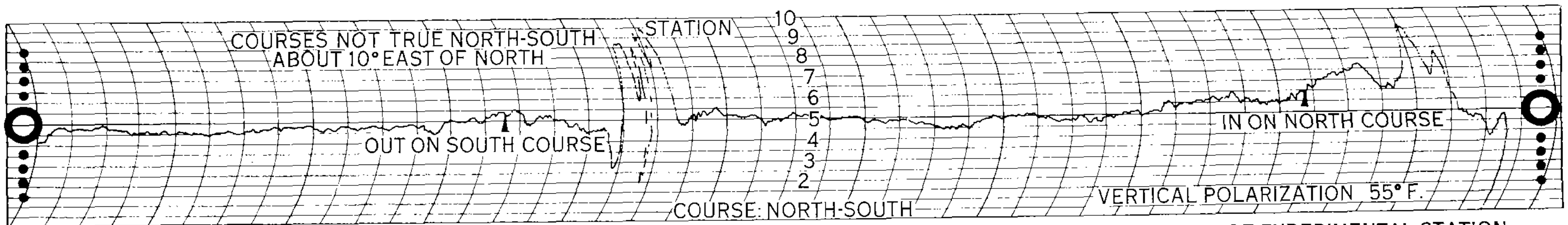
100% SCALLOPING

HORIZONTAL POLARIZATION 75° F.

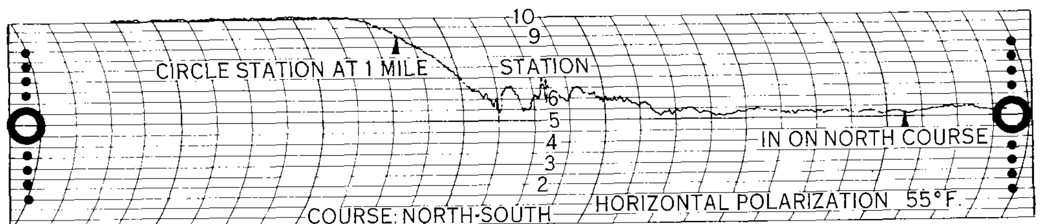
Figure 25. Cross-Course Recordings of the Northwest Course at 5, 10 and 15 Miles from the Portable Range Located 400 Feet Southwest of the Experimental Station.



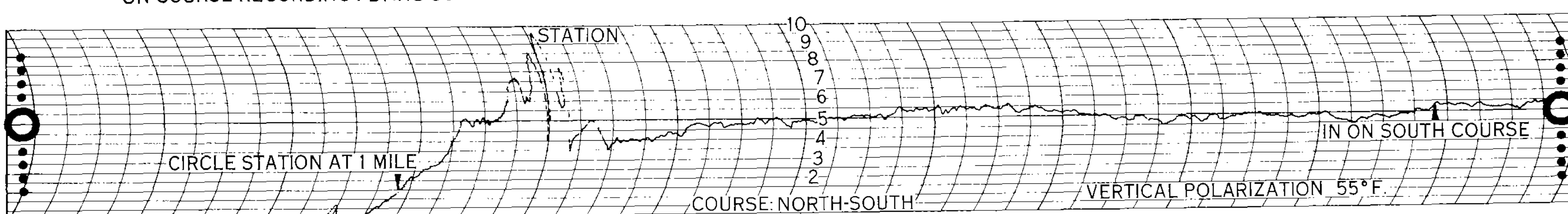
ON-COURSE RECORDING FLYING NORTH TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION



ON-COURSE RECORDING FLYING SOUTH TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

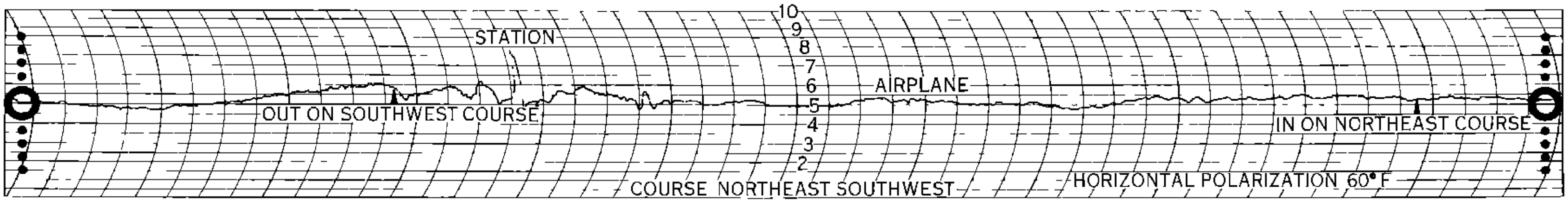


ON-COURSE RECORDING FLYING SOUTH TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

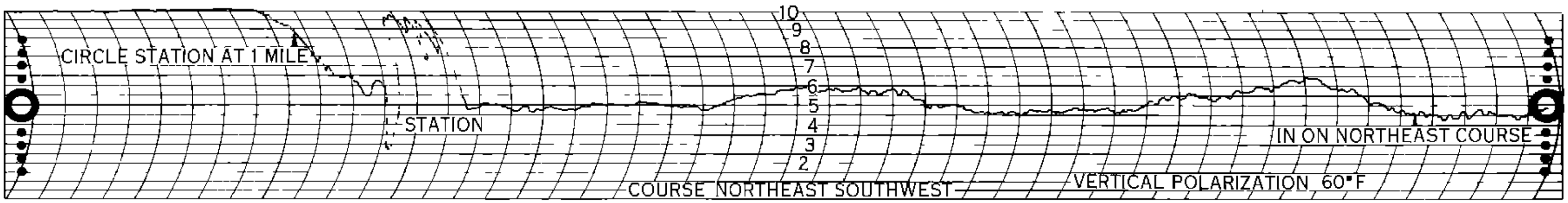


ON-COURSE RECORDING FLYING NORTH TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

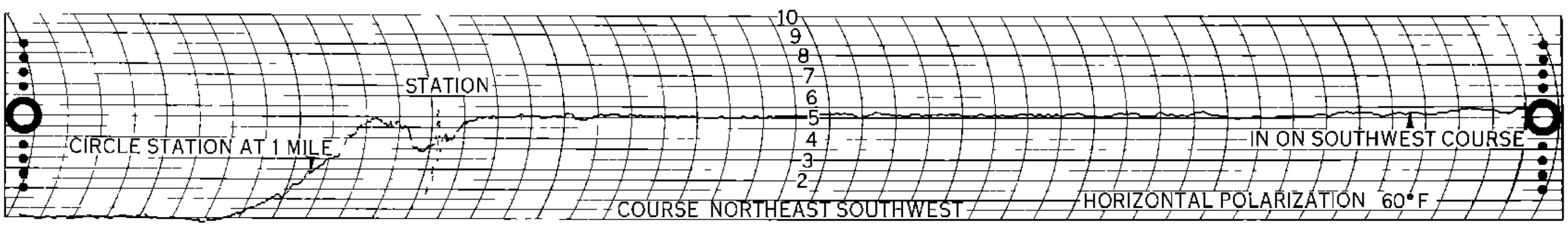
Figure 26. On-Course Recordings of the North and South Courses with the Portable Range Located 400 Feet Southwest of the Experimental Station.



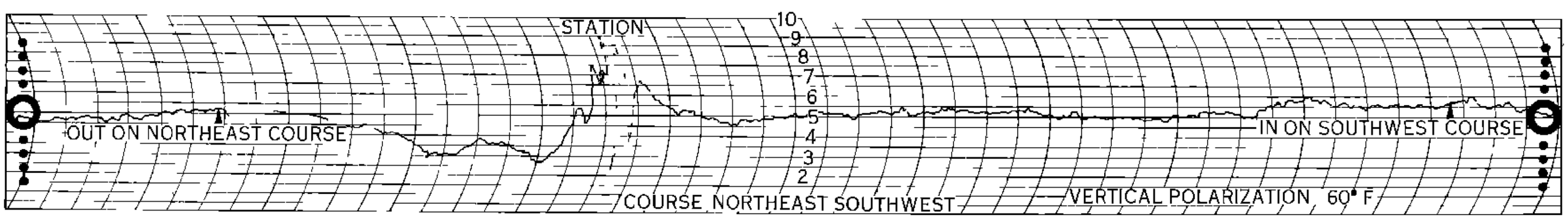
ON COURSE RECORDING FLYING SOUTHWEST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION



ON-COURSE RECORDING FLYING SOUTHWEST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

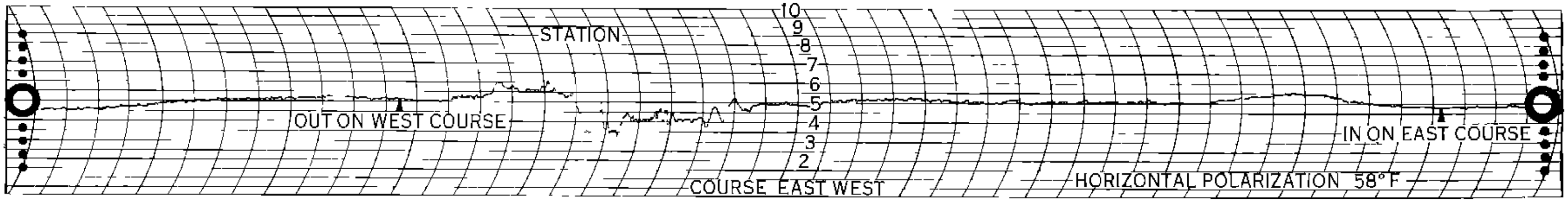


ON-COURSE RECORDING FLYING NORTHEAST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

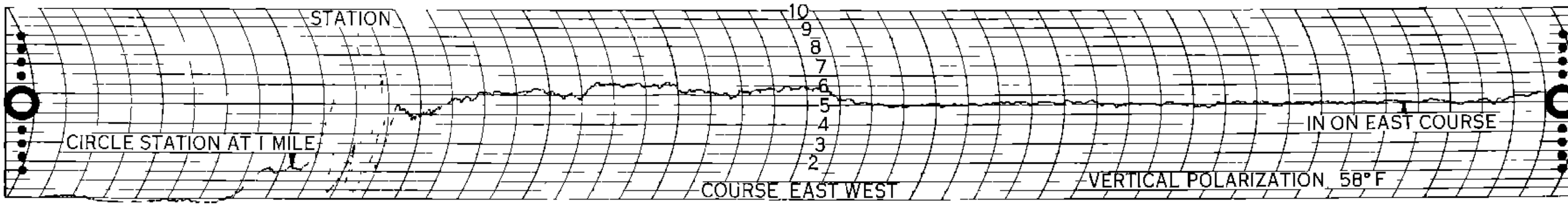


ON COURSE RECORDING FLYING NORTHEAST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

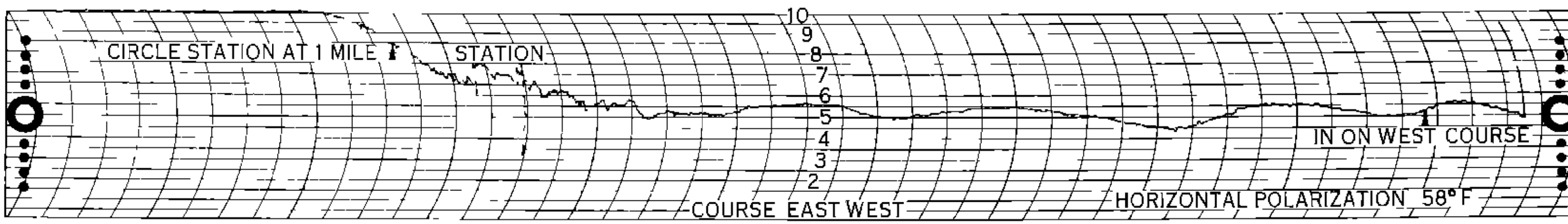
Figure 27 On Course Recordings of the Northeast and Southwest with the Portable Range Located 400 Feet Southwest of the Experimental Station



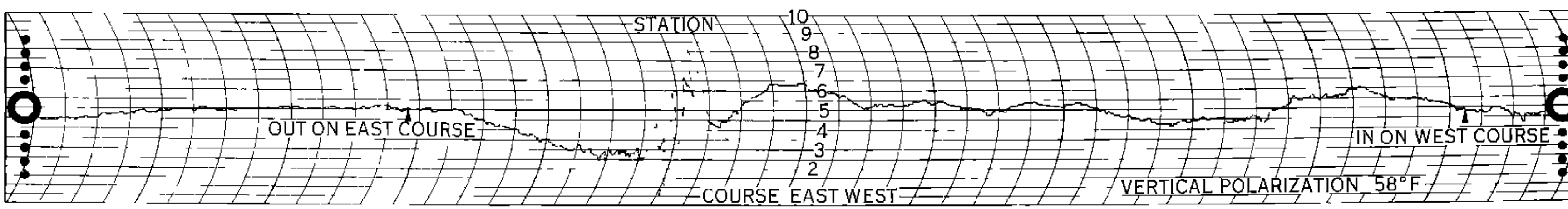
ON COURSE RECORDING FLYING WEST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION



ON-COURSE RECORDING FLYING WEST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

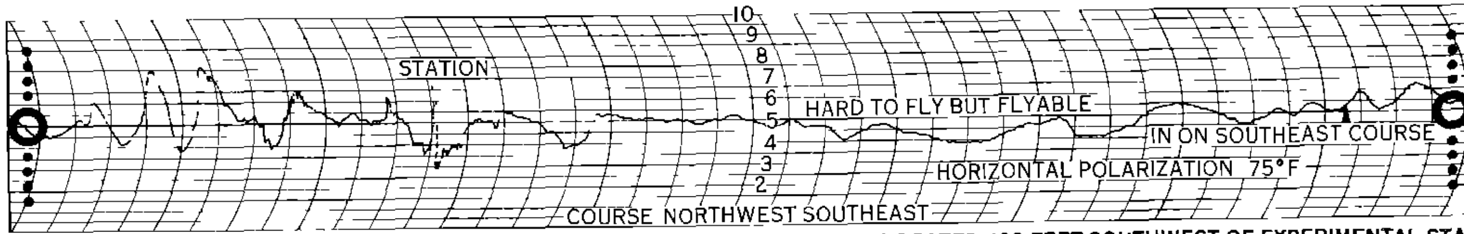


ON-COURSE RECORDING FLYING EAST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

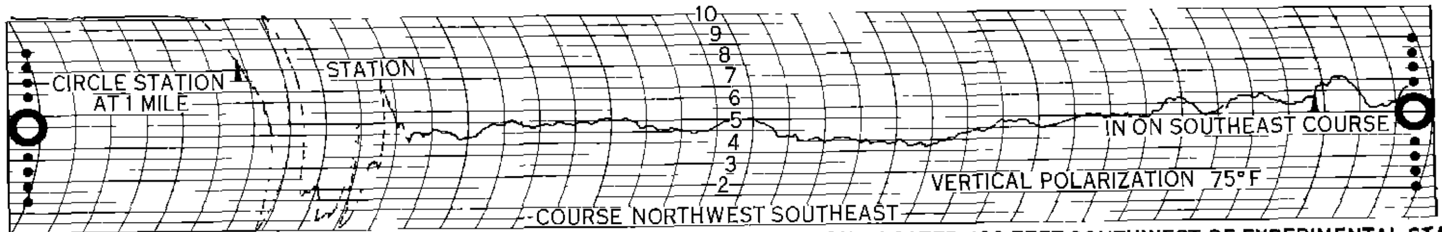


ON-COURSE RECORDING FLYING EAST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

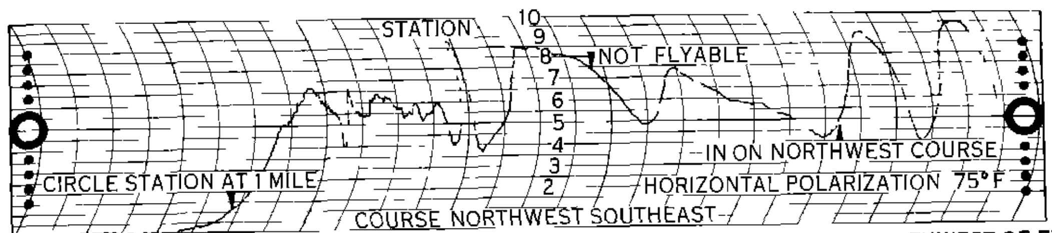
Figure 28 On Course Recordings of the East and West Courses with the Portable Range Located 400 Feet Southwest of the Experimental Station



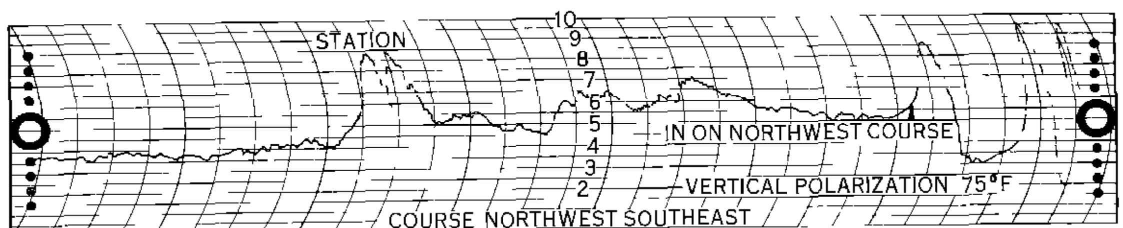
ON-COURSE RECORDING FLYING NORTHWEST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION



ON-COURSE RECORDING FLYING NORTHWEST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

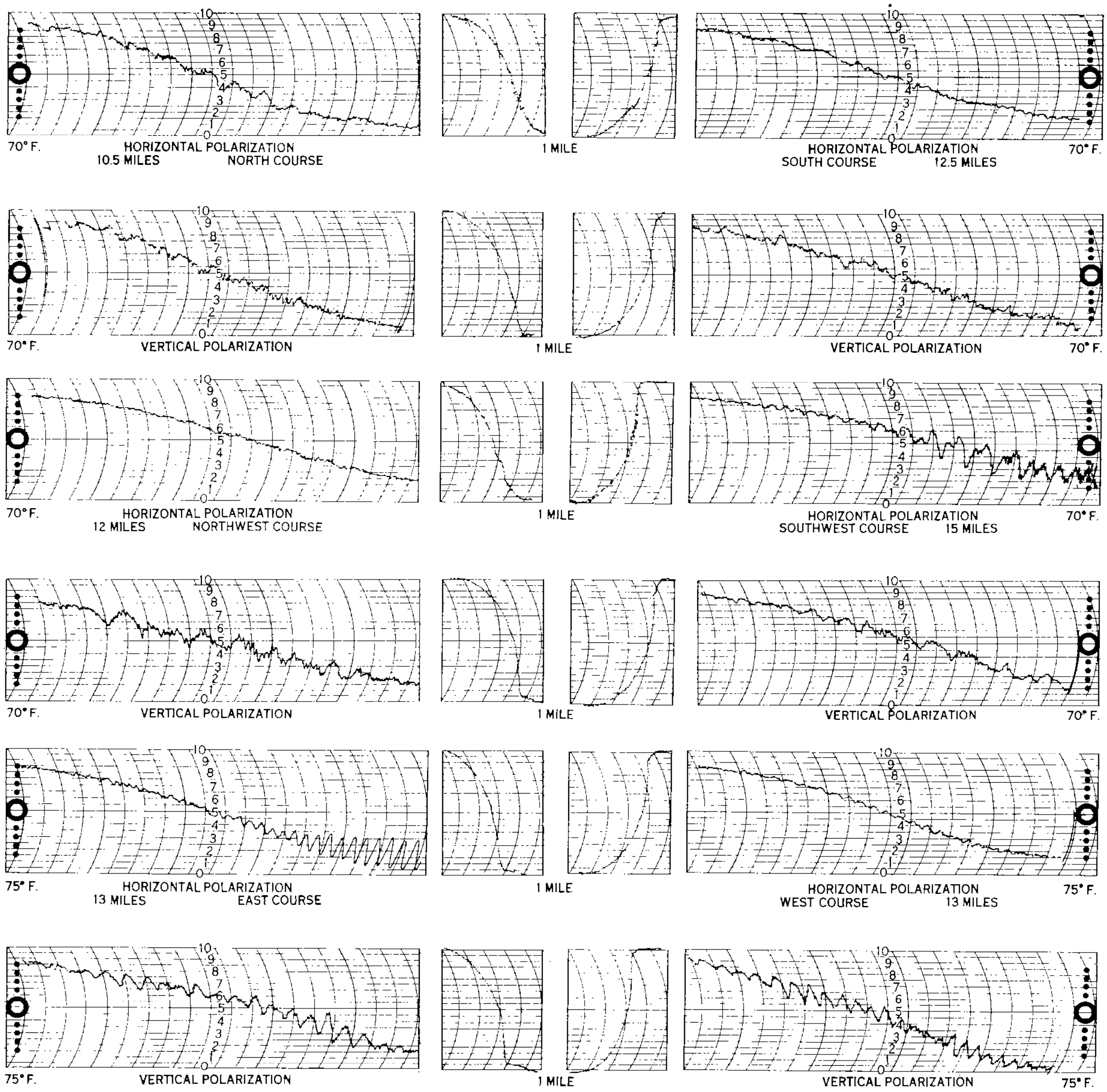


ON-COURSE RECORDING FLYING SOUTHEAST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION



ON COURSE RECORDING FLYING SOUTHEAST TOWARD STATION WITH RANGE STATION LOCATED 400 FEET SOUTHWEST OF EXPERIMENTAL STATION

Figure 29 On-Course Recordings of the Northwest and Southeast Courses with the Portable Range Located 400 Feet Southwest of the Experimental Station



SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

DIRECTION OF COURSES	HORIZONTAL	VERTICAL
NORTH	15 %	13 %
NORTHEAST	7 %	23 %
EAST	35 %	32 %

SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

DIRECTION OF COURSES	HORIZONTAL	VERTICAL
SOUTH	11 %	18 %
SOUTHWEST	32 %	16 %
WEST	6 %	24 %

Figure 30. Cross-Course Recordings Showing the Effect of Course Orientation Upon Scalloping with the Portable Range Located 300 Feet from Wire Lines.

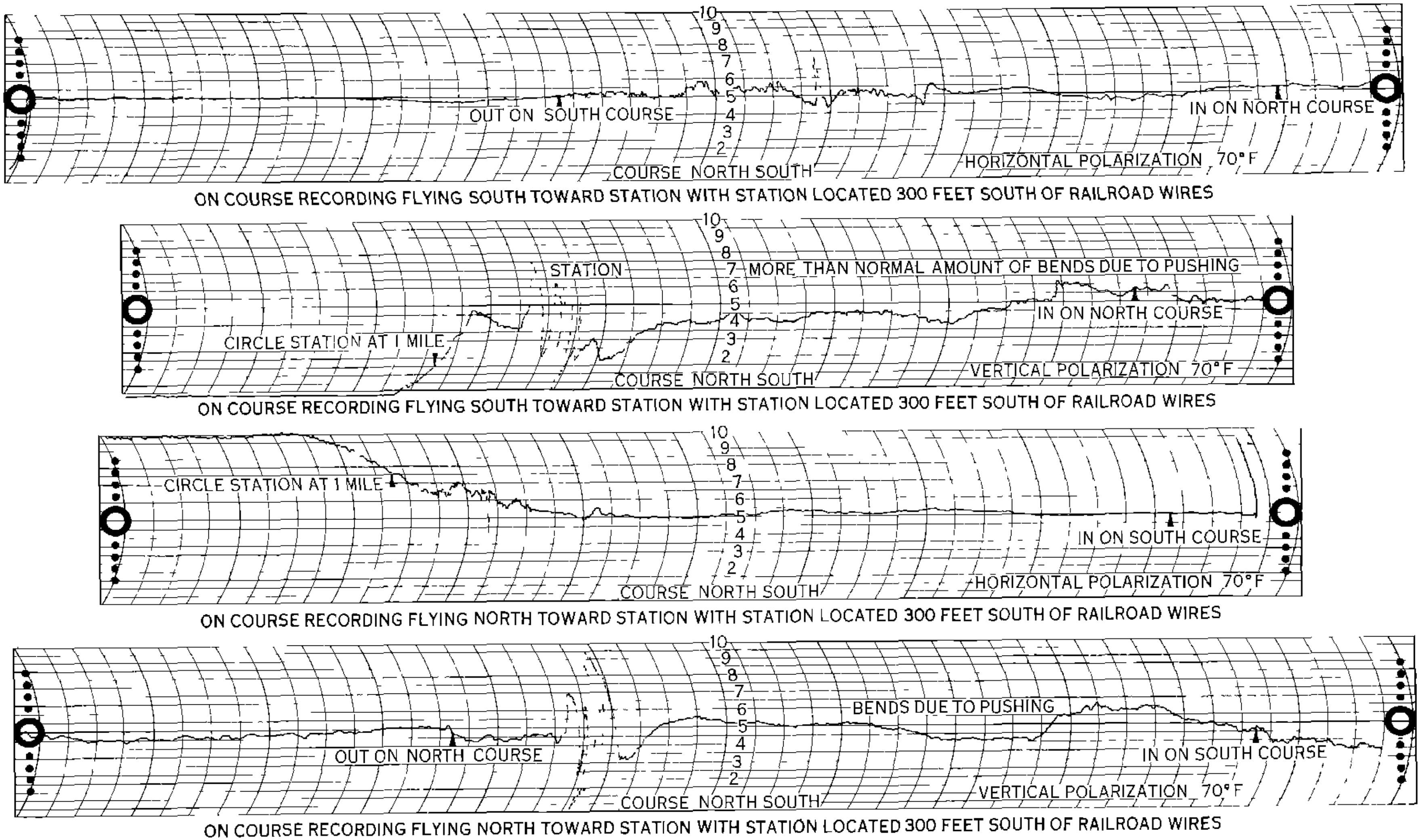
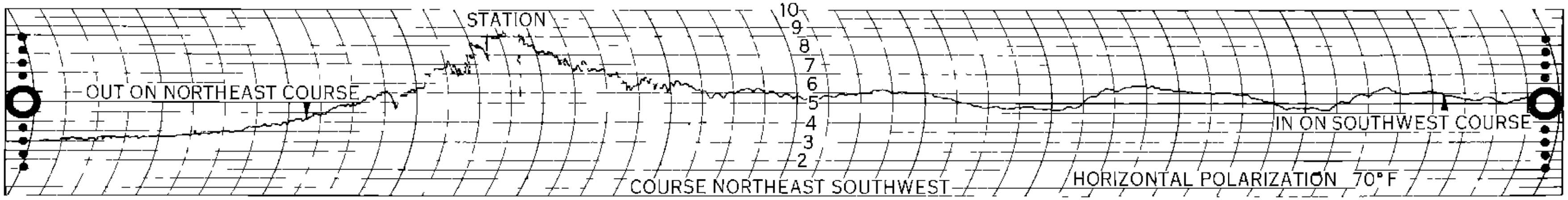
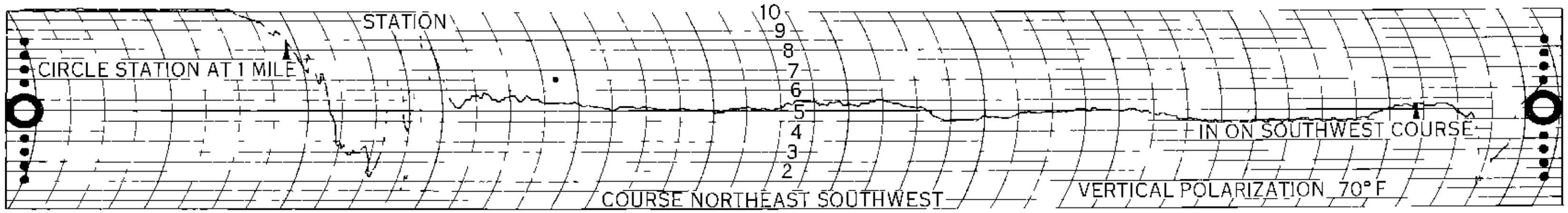


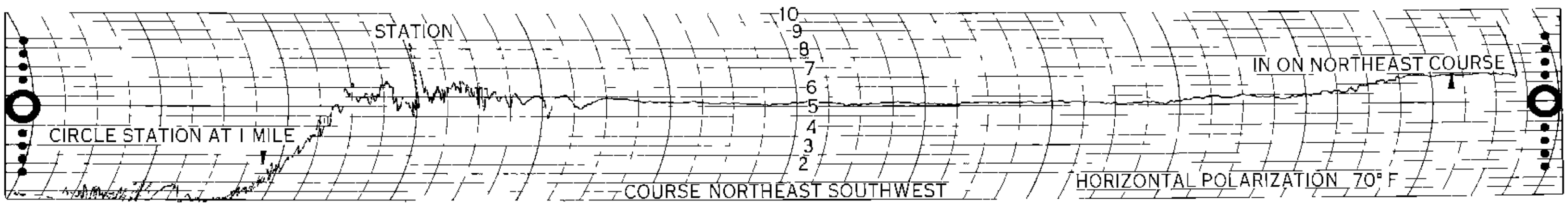
Figure 31 On-Course Recordings of the North and South Courses with the Portable Range Located 300 Feet from Wire Lines



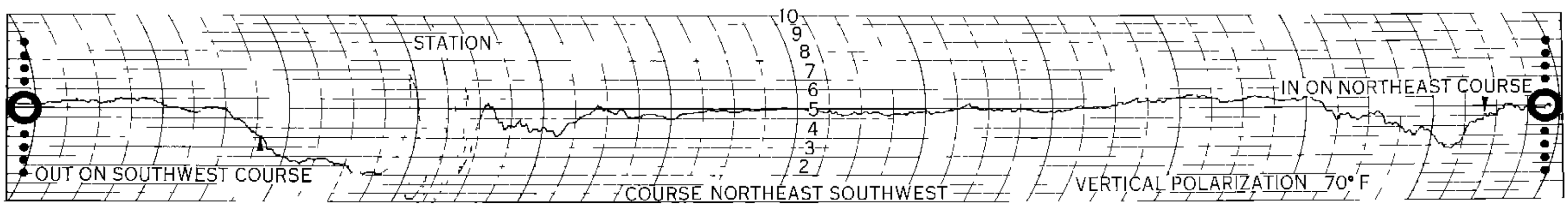
ON COURSE RECORDING FLYING NORTHEAST TOWARD STATION WITH STATION LOCATED 300 FEET SOUTH OF RAILROAD WIRES



ON COURSE RECORDING FLYING NORTHEAST TOWARD STATION WITH STATION LOCATED 300 FEET SOUTH OF RAILROAD WIRES



ON COURSE RECORDING FLYING SOUTHWEST TOWARD STATION WITH STATION LOCATED 300 FEET SOUTH OF RAILROAD WIRES



ON COURSE RECORDING FLYING SOUTHWEST TOWARD STATION WITH STATION LOCATED 300 FEET SOUTH OF RAILROAD WIRES

Figure 32 On Course Recordings of the Northeast and Southwest Courses with the Portable Range Located 300 Feet from Wire Lines

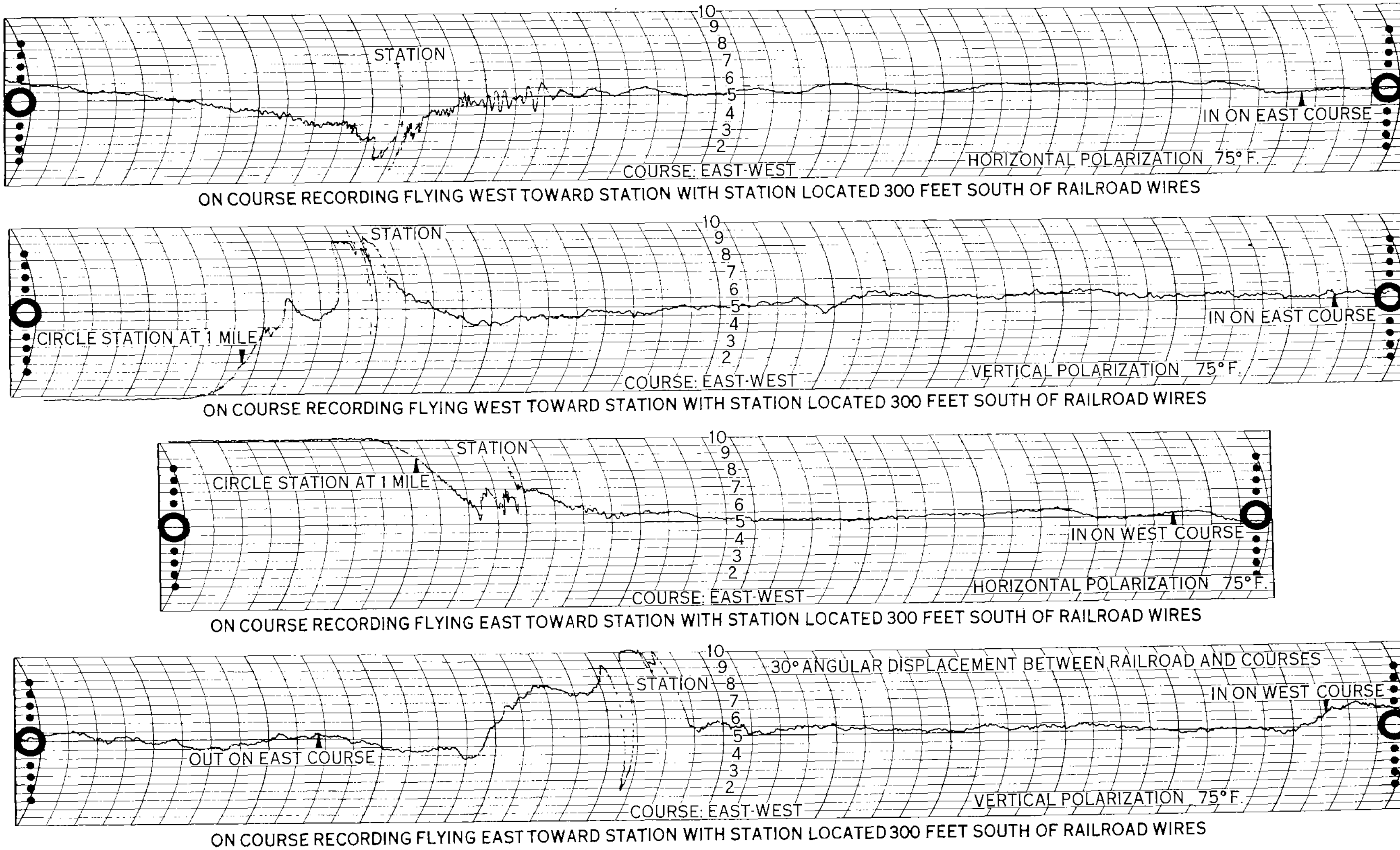


Figure 33. On-Course Recordings of the East and West Courses with the Portable Range Located 300 Feet from Wire Lines.

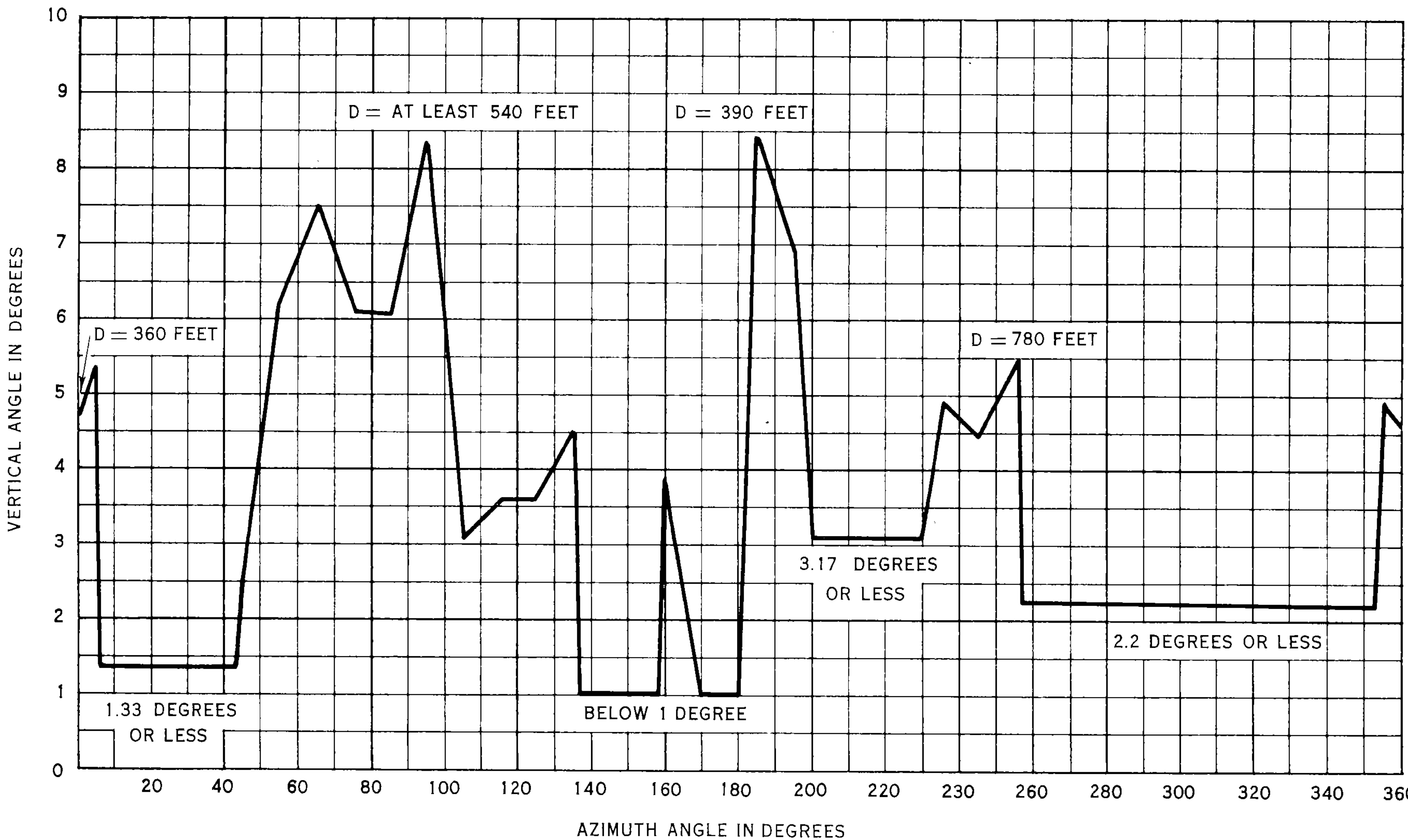
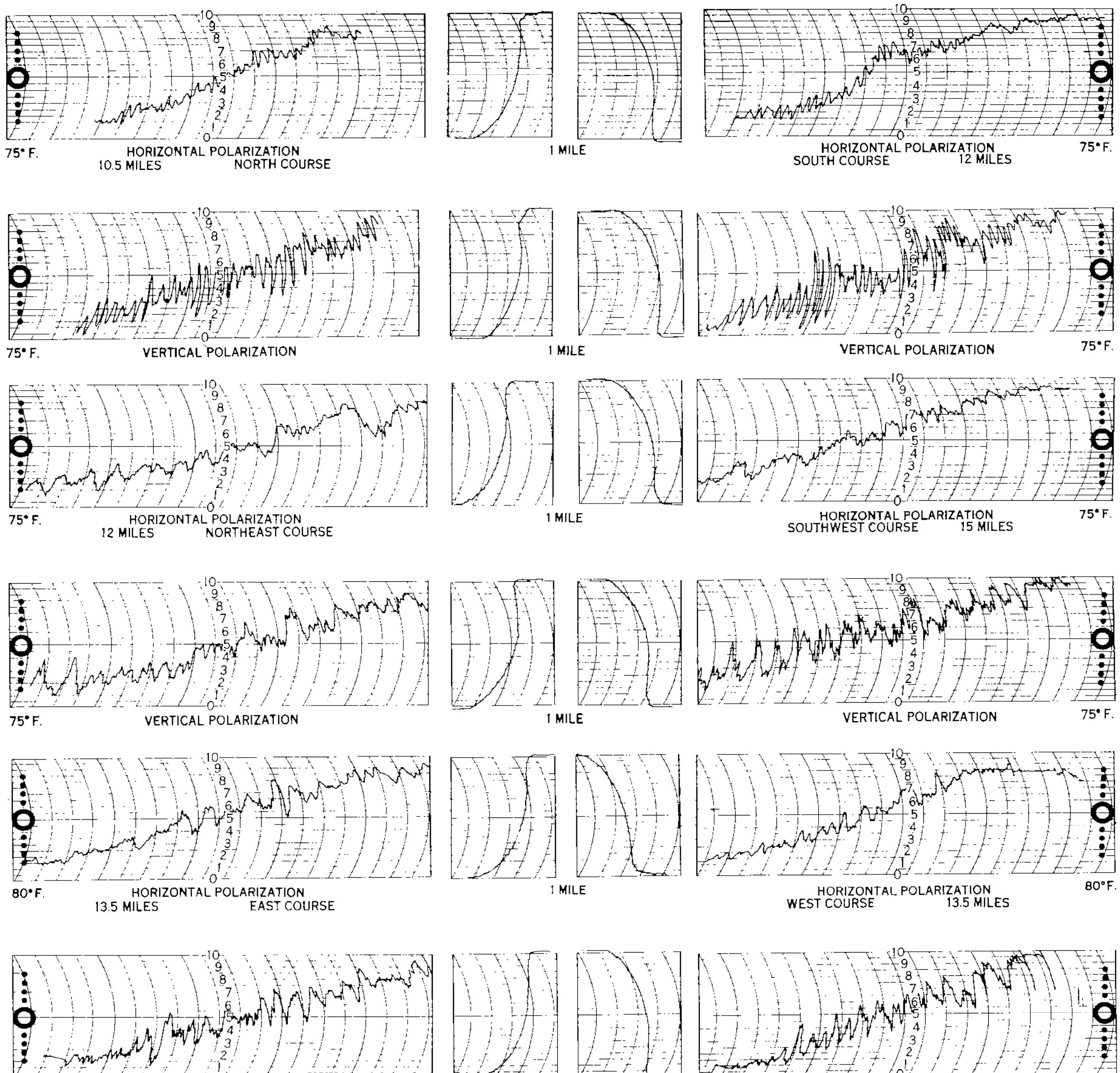
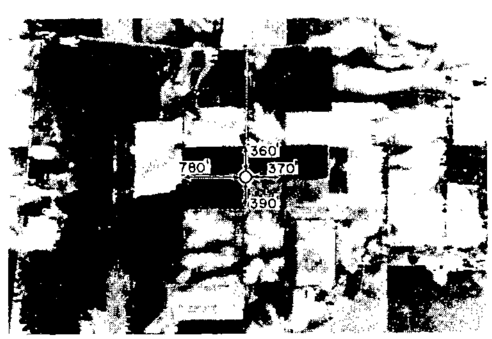


Figure 34. Vertical Angles to Tree Tops from-Site for First Tree Test.



SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

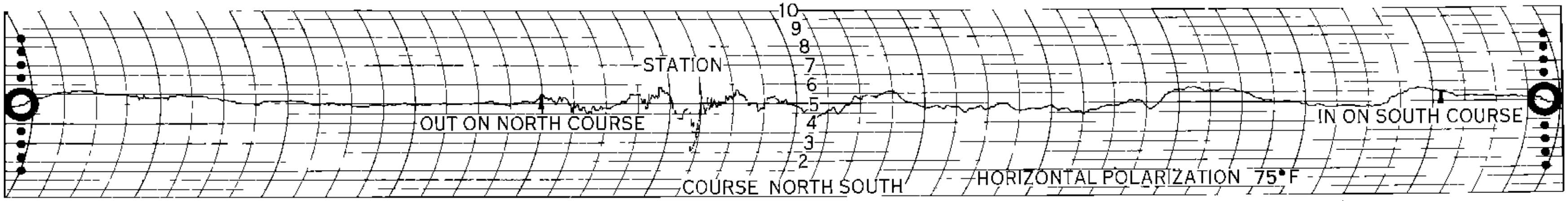
DIRECTION OF COURSES	HORIZONTAL	VERTICAL
NORTH	29 %	65 %
NORTHEAST	44 %	41 %
EAST	44 %	46 %



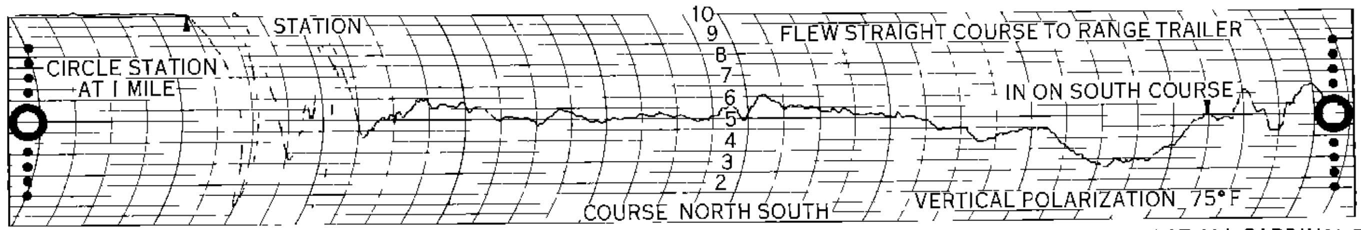
SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

DIRECTION OF COURSES	HORIZONTAL	VERTICAL
SOUTH	38 %	86 %
SOUTHWEST	25 %	55 %
WEST	27 %	44 %

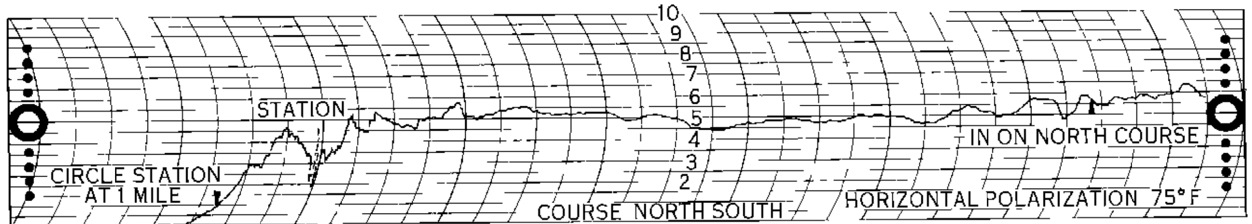
Figure 35. Cross-Course Recordings Showing the Effect of Course Orientation Upon Scalloping with the Portable Range Located for First Tree Tests.



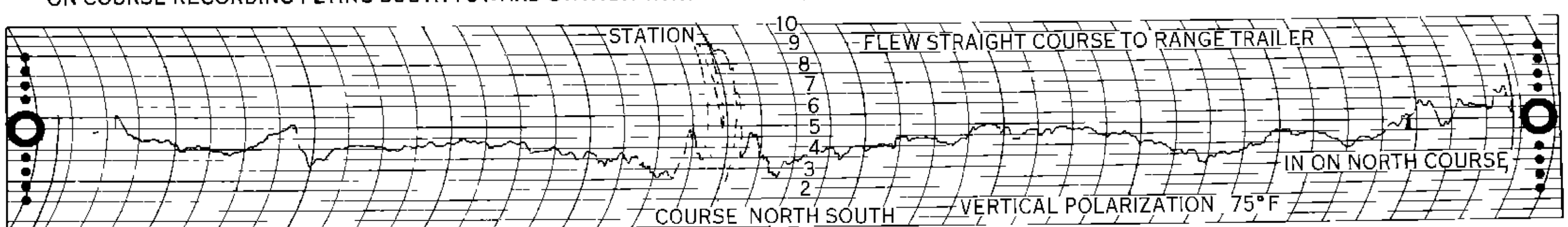
ON COURSE RECORDING FLYING NORTH TOWARD STATION WITH TREES LOCATED AT LEAST 360 FEET FROM STATION AT ALL CARDINAL POINTS



ON COURSE RECORDING FLYING NORTH TOWARD STATION WITH TREES LOCATED AT LEAST 360 FEET FROM STATION AT ALL CARDINAL POINTS



ON COURSE RECORDING FLYING SOUTH TOWARD STATION WITH TREES LOCATED AT LEAST 360 FEET FROM STATION AT ALL CARDINAL POINTS



ON COURSE RECORDING FLYING SOUTH TOWARD STATION WITH TREES LOCATED AT LEAST 360 FEET FROM STATION AT ALL CARDINAL POINTS

Figure 36 On Course Recordings of North and South Courses with the Portable Range Located for First Tree Test

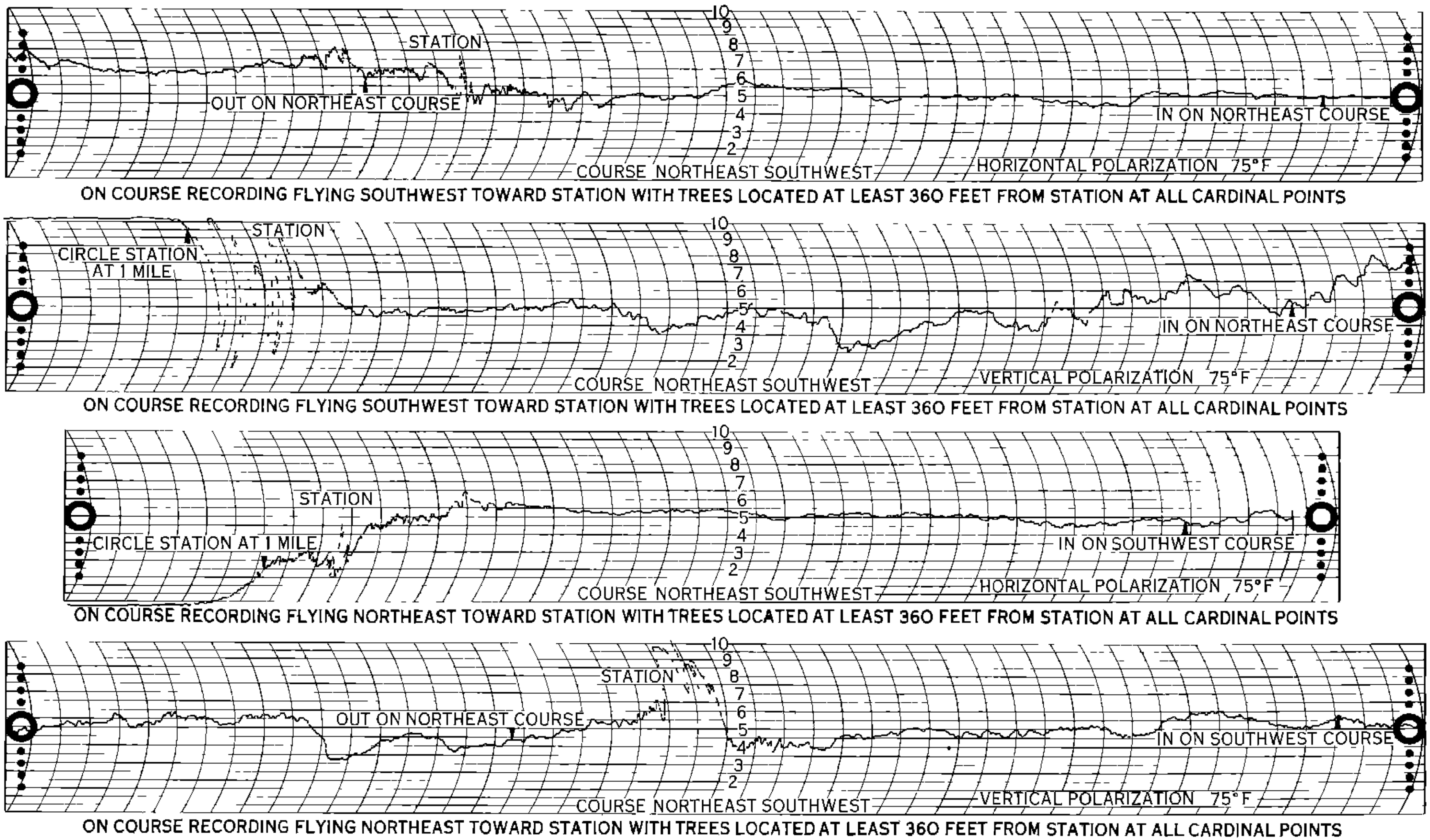
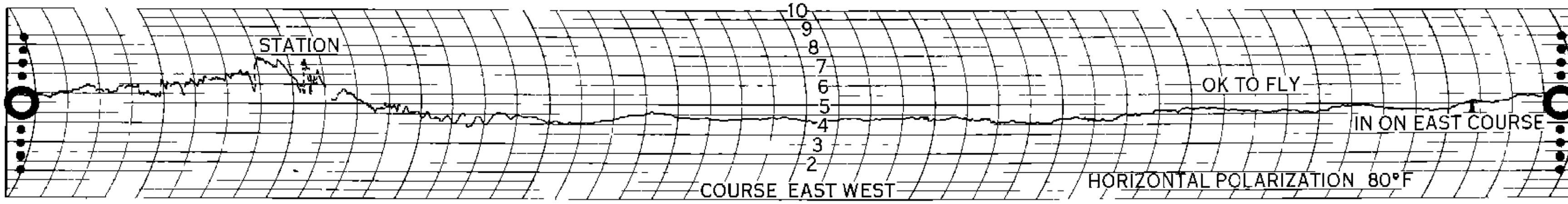
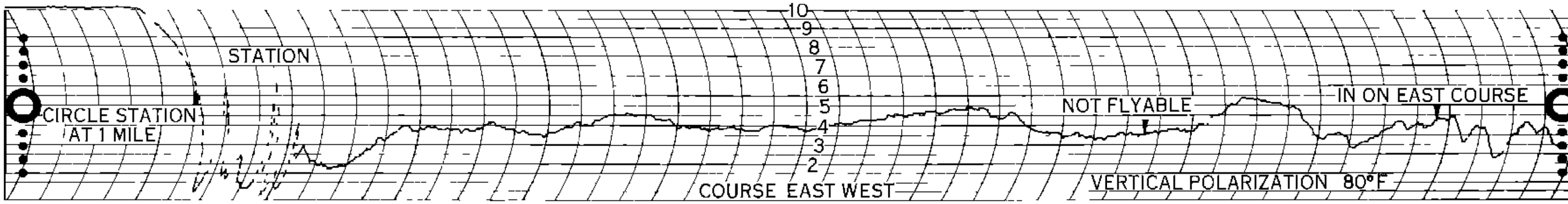


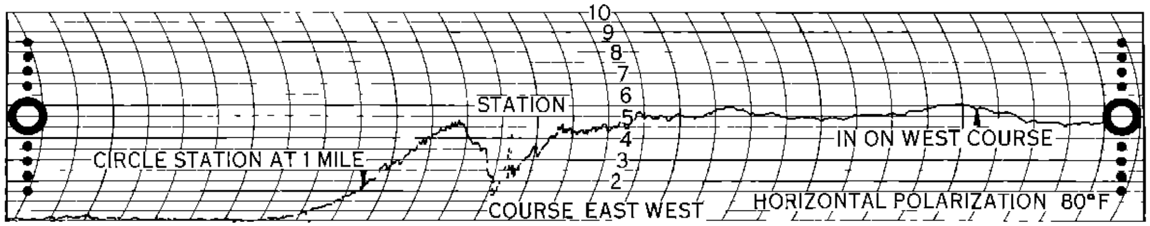
Figure 37 On-Course Recordings of Northeast and Southwest with the Portable Range Located for First Tree Test



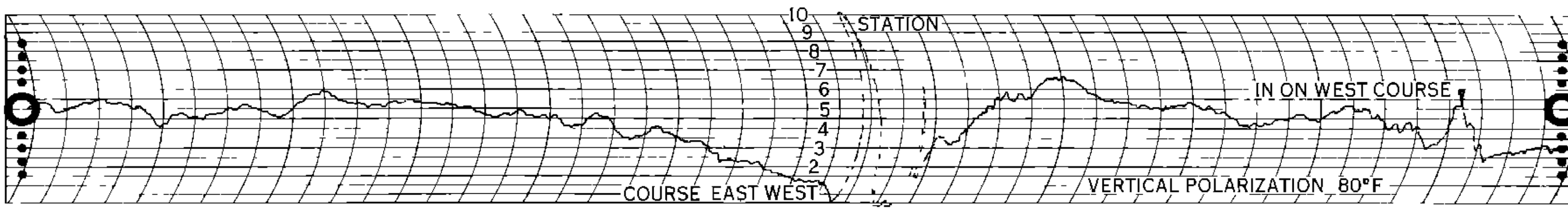
ON COURSE RECORDING FLYING WEST TOWARD STATION WITH TREES LOCATED AT LEAST 360 FEET FROM STATION AT ALL CARDINAL POINTS



ON COURSE RECORDING FLYING WEST TOWARD STATION WITH TREES LOCATED AT LEAST 360 FEET FROM STATION AT ALL CARDINAL POINTS



ON COURSE RECORDING FLYING EAST TOWARD STATION WITH TREES LOCATED AT LEAST 360 FEET FROM STATION AT ALL CARDINAL POINTS



ON COURSE RECORDING FLYING EAST TOWARD STATION WITH TREES LOCATED AT LEAST 360 FEET FROM STATION AT ALL CARDINAL POINTS

Figure 38 On Course Recordings of East and West Courses with the Portable Range Located for First Tree Test

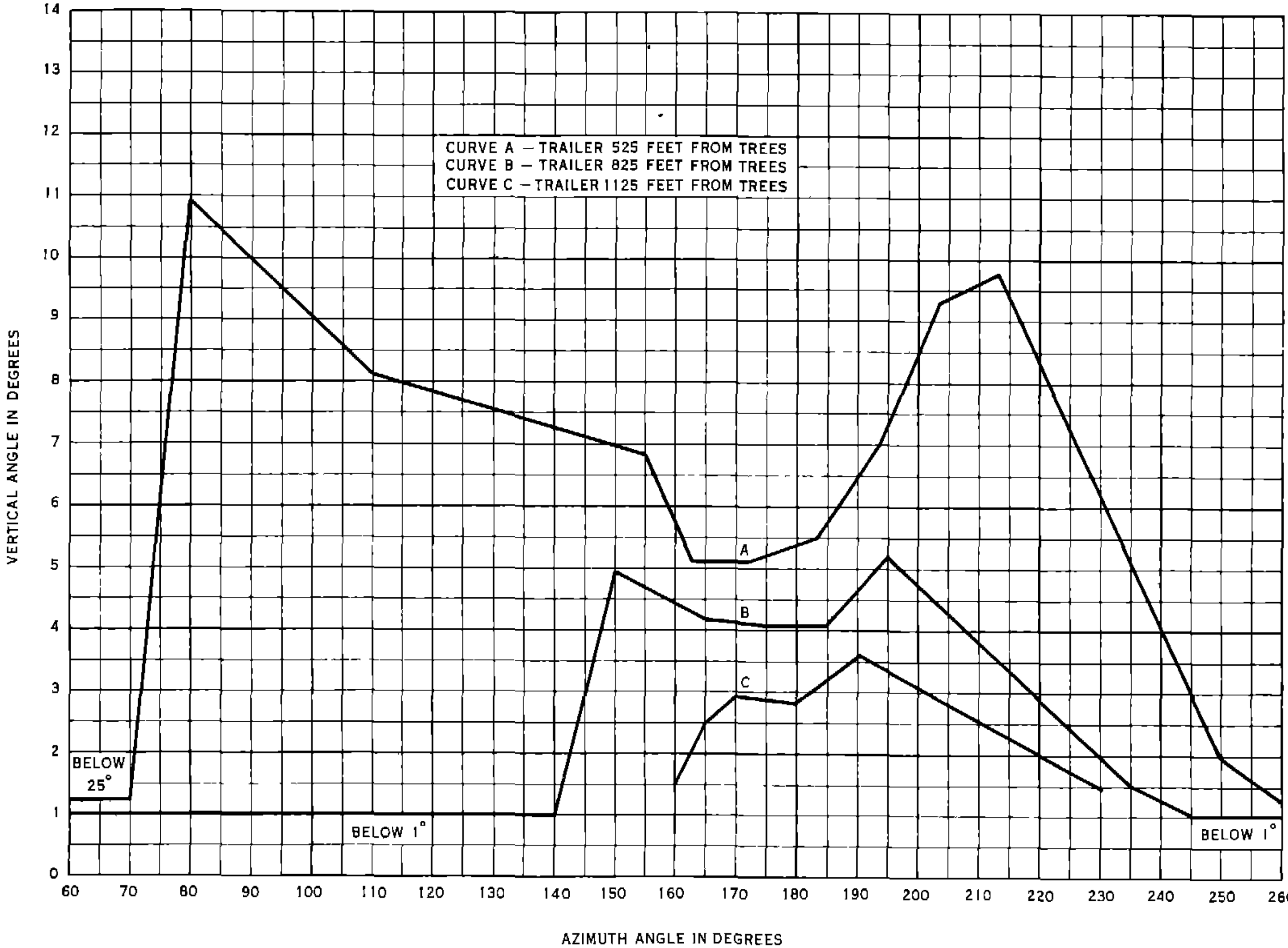
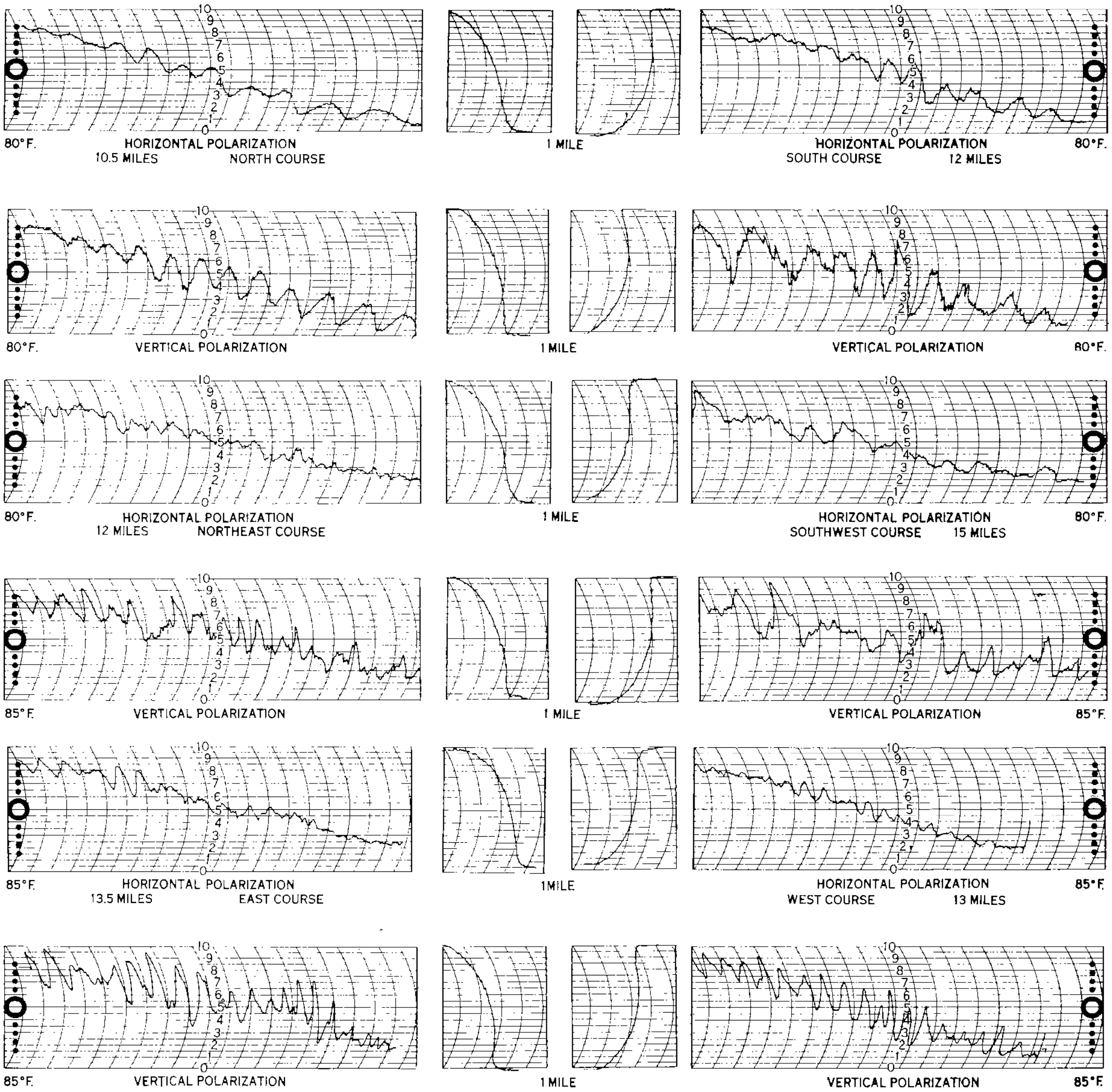


Figure 39 Vertical Angles to Trees from Site for Second Tree Test



SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

DIRECTION OF COURSES	HORIZONTAL	VERTICAL
NORTH	30 %	40 %
NORTHEAST	21 %	48 %
EAST	24 %	72 %

SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

DIRECTION OF COURSES	HORIZONTAL	VERTICAL
SOUTH	41 %	85 %
SOUTHWEST	32 %	61 %
WEST	19 %	58 %

Figure 40. Cross-Course Recordings Showing the Effect of Course Orientation Upon Scalloping with the Portable Range Located 525 Feet from a Group of Trees.

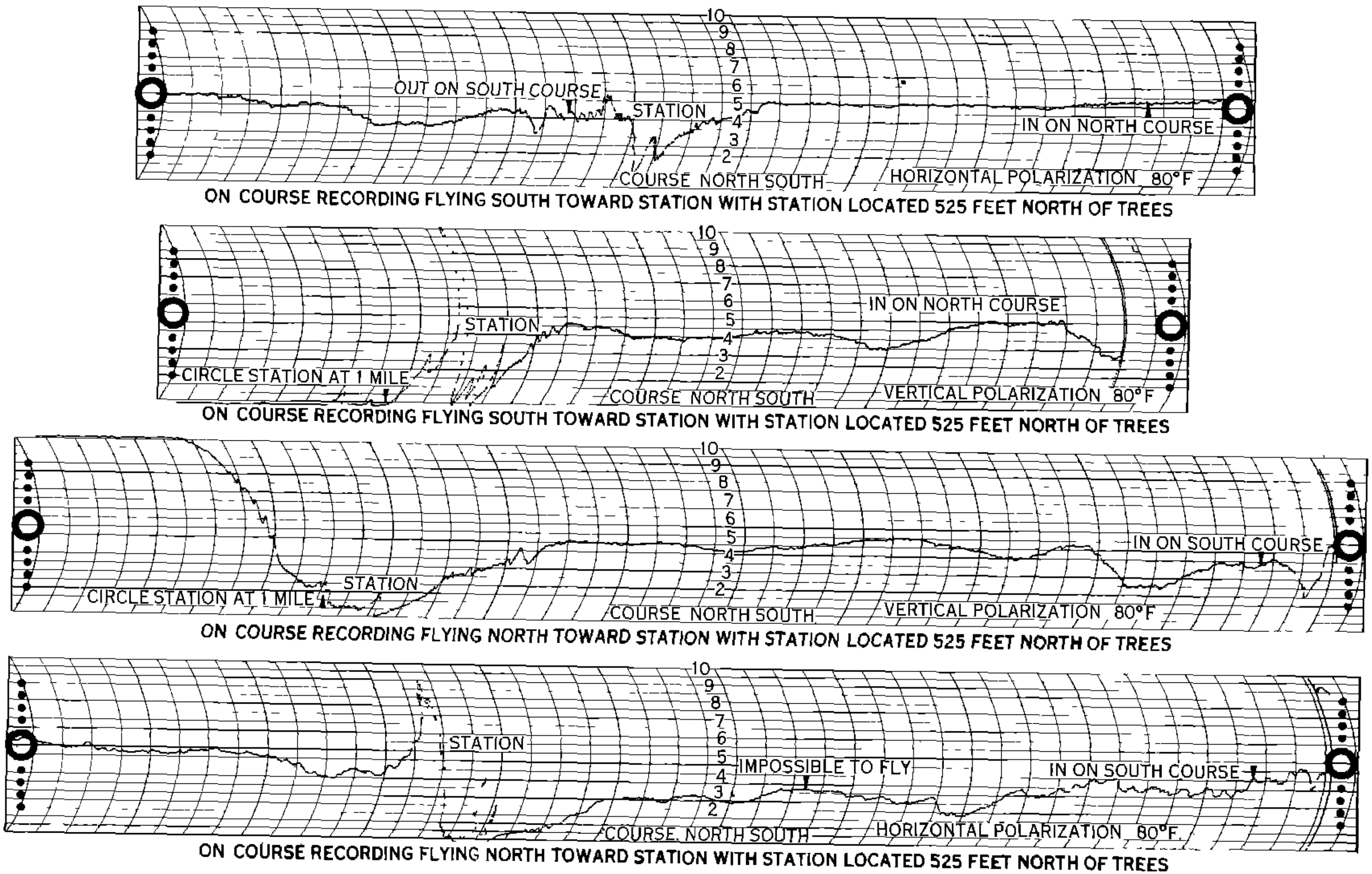
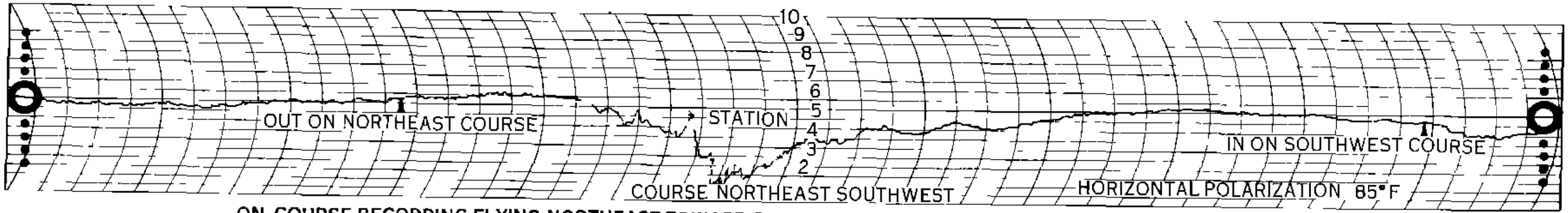
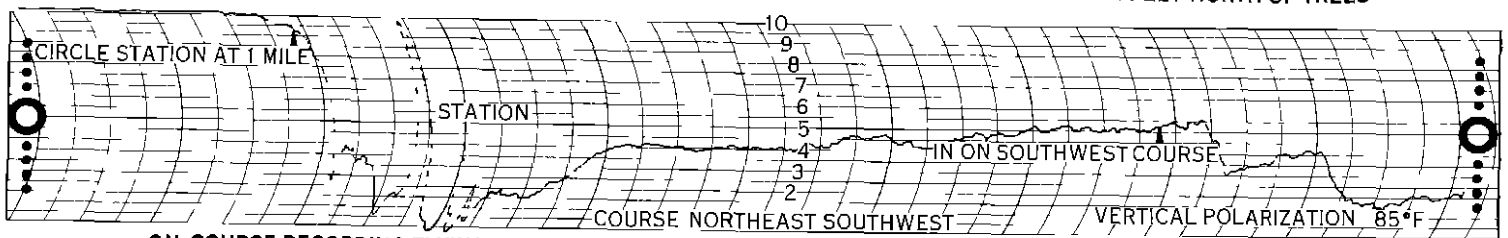


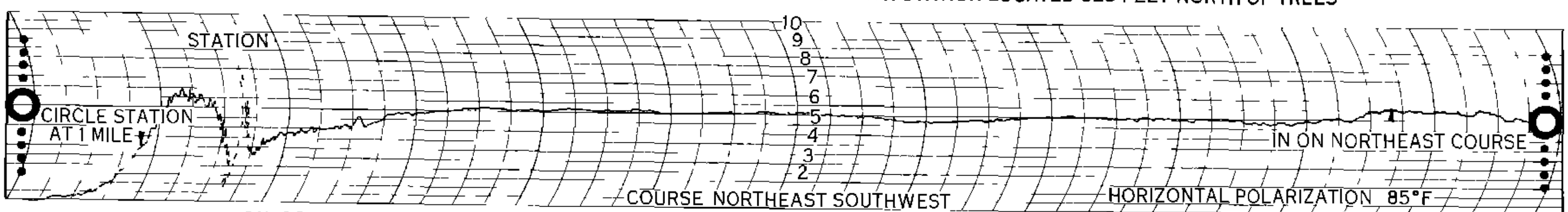
Figure 41 On Course Recordings of the North and South Courses with the Portable Range Located 525 Feet from a Group of Trees



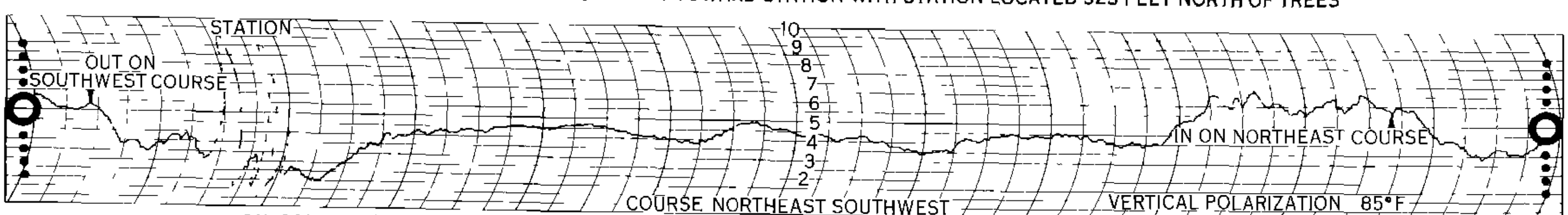
ON COURSE RECORDING FLYING NORTHEAST TOWARD STATION WITH STATION LOCATED 525 FEET NORTH OF TREES



ON COURSE RECORDING FLYING NORTHEAST TOWARD STATION WITH STATION LOCATED 525 FEET NORTH OF TREES

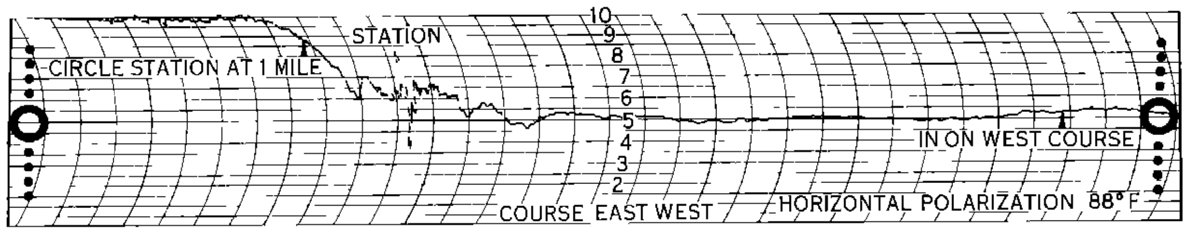


ON COURSE RECORDING FLYING SOUTHWEST TOWARD STATION WITH STATION LOCATED 525 FEET NORTH OF TREES

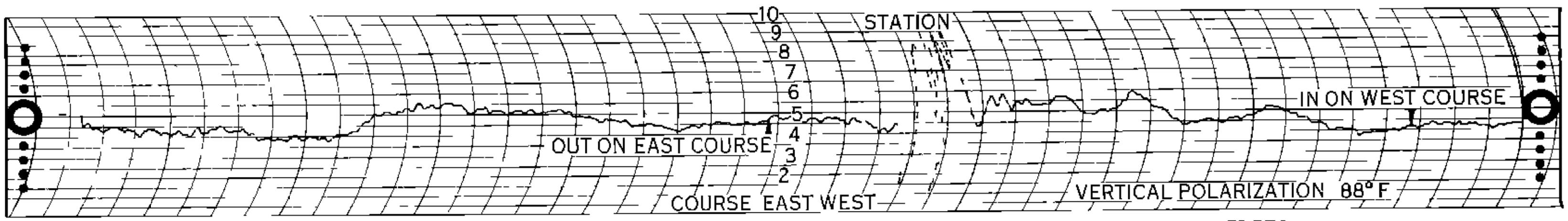


ON COURSE RECORDING FLYING SOUTHWEST TOWARD STATION WITH STATION LOCATED 525 FEET NORTH OF TREES

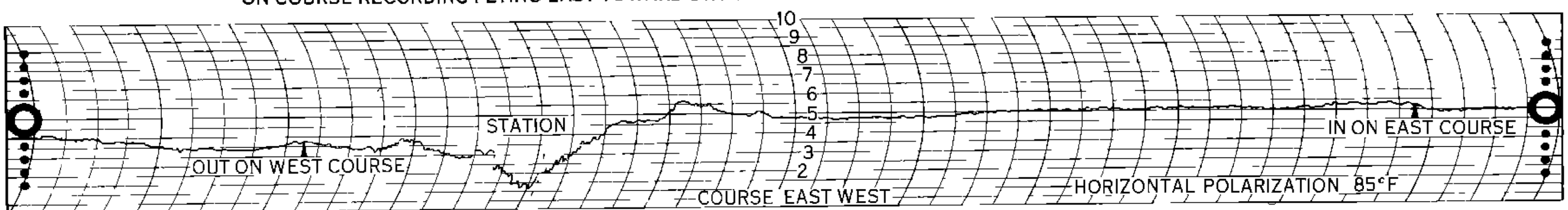
Figure 42 On Course Recordings of the Northeast and Southwest Courses with the Portable Range Located 525 Feet from a Group of Trees



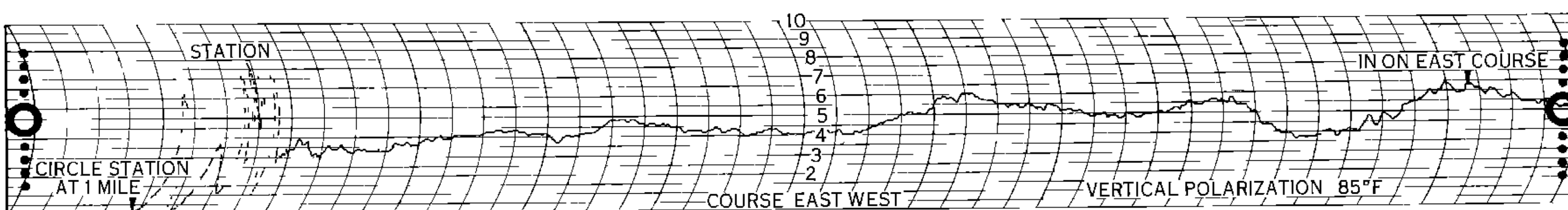
ON COURSE RECORDING FLYING EAST TOWARD STATION WITH STATION LOCATED 525 FEET NORTH OF TREES



ON COURSE RECORDING FLYING EAST TOWARD STATION WITH STATION LOCATED 525 FEET NORTH OF TREES



ON COURSE RECORDING FLYING WEST TOWARD STATION WITH STATION LOCATED 525 FEET NORTH OF TREES



ON COURSE RECORDING FLYING WEST TOWARD STATION WITH STATION LOCATED 525 FEET NORTH OF TREES

Figure 43 On-Course Recordings of the East and West Courses with the Portable Range Located 525 Feet from a Group of Trees

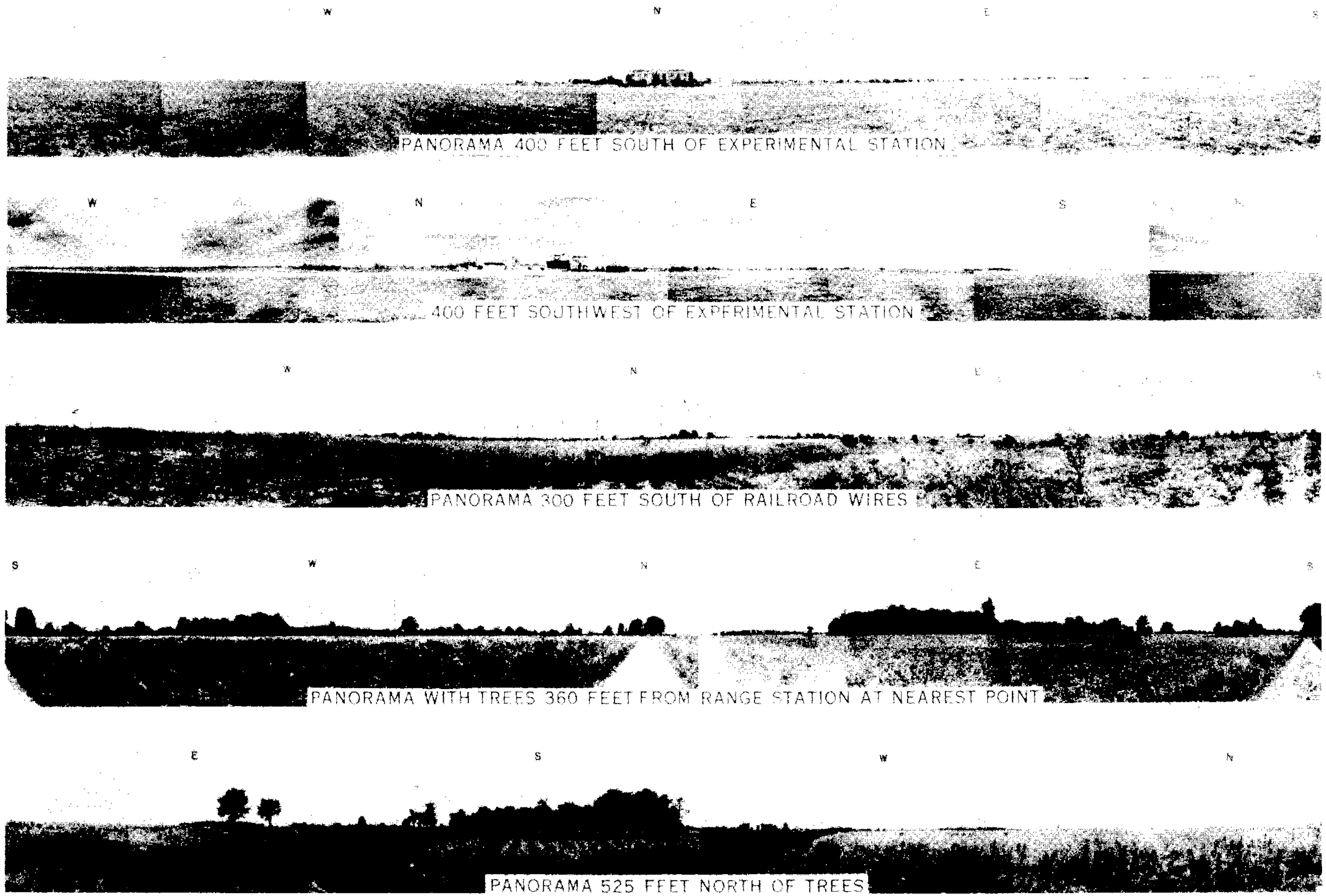
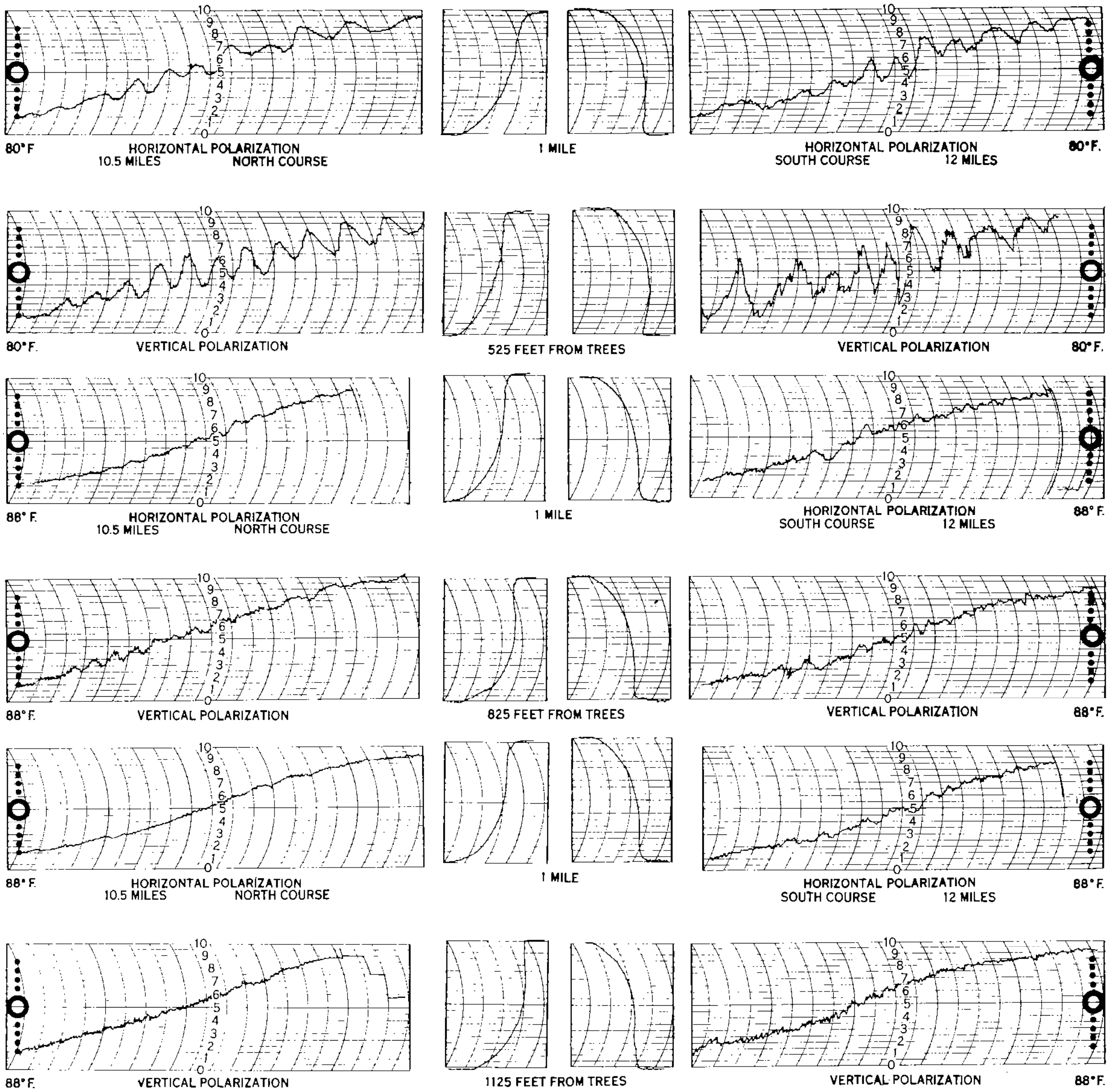


Figure 44. Panoramic Photographs Taken from Sites for Building, Wire and Tree Tests.



SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

DIRECTION OF COURSES	HORIZONTAL	VERTICAL
NORTH	28 %	40 %
NORTH	14 %	15 %
NORTH	6 %	9 %

SCALLOPING IN PERCENT OF 4 DOT TO 4 DOT DEFLECTION

DIRECTION OF COURSES	HORIZONTAL	VERTICAL
SOUTH	41 %	86 %
SOUTH	29 %	17 %
SOUTH	15 %	14 %

Figure 45. Cross-Course Recordings Showing the Amount of Scalloping Encountered with the Trailer Located 525, 825 and 1125 Feet from a Group of Trees.

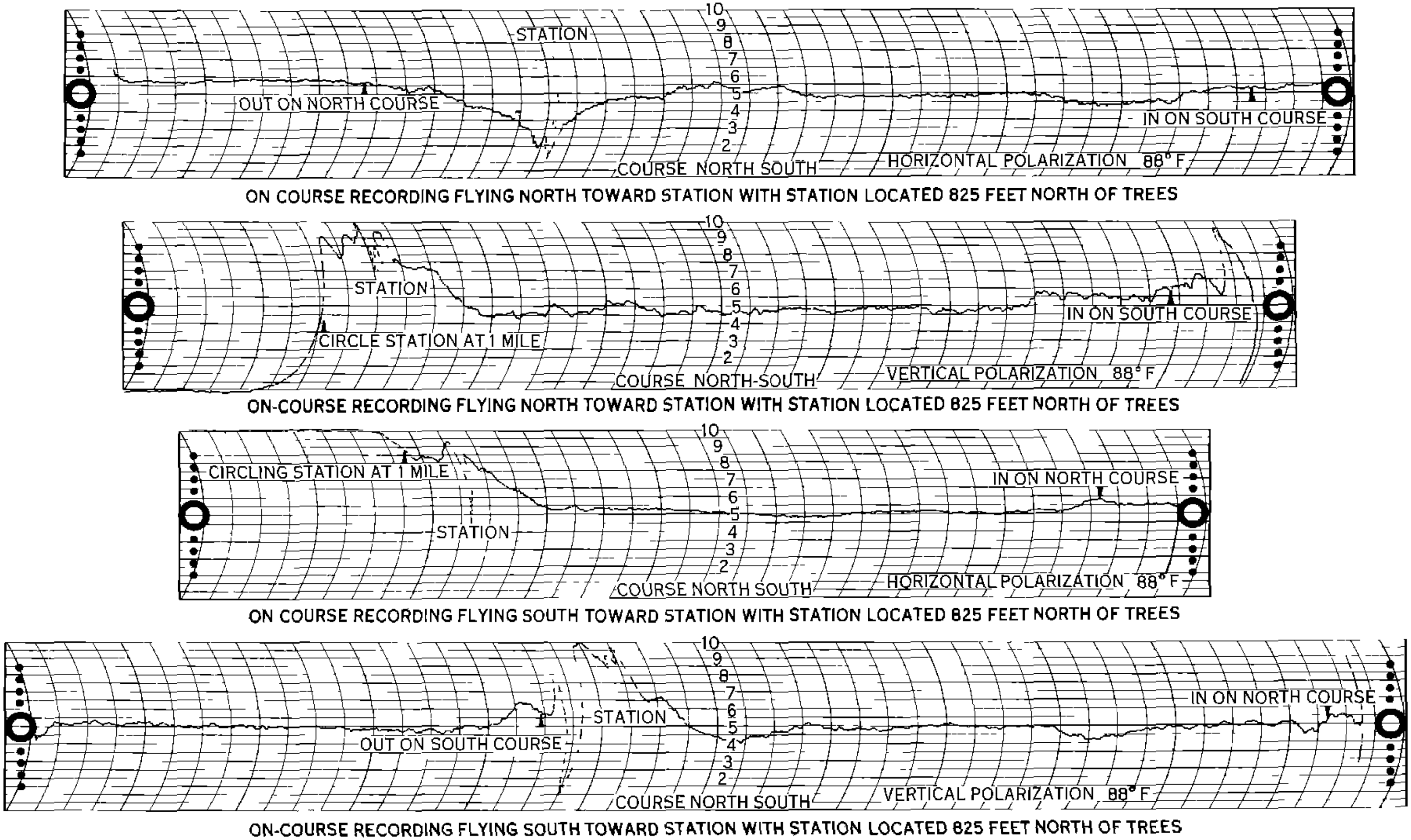
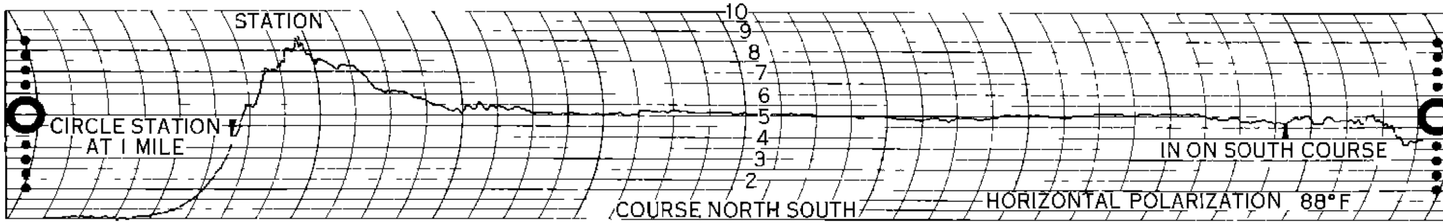
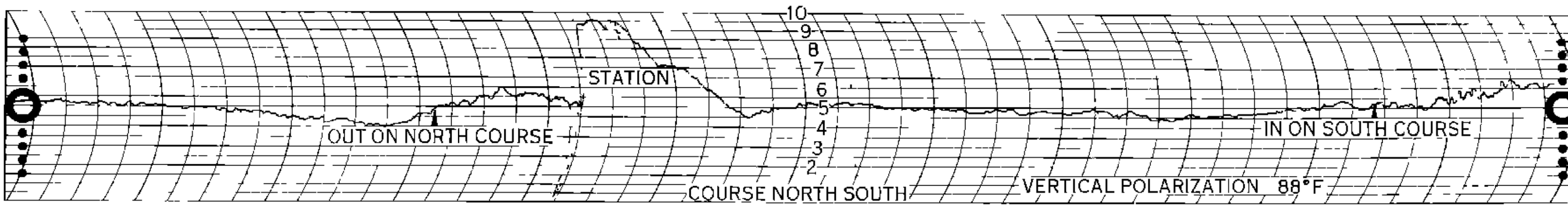


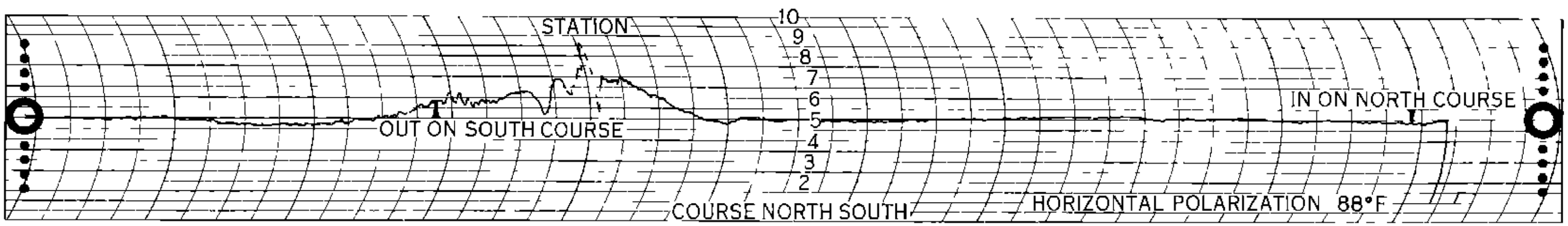
Figure 46 On-Course Recordings of North and South Courses with the Portable Range Located 825 Feet from a Group of Trees



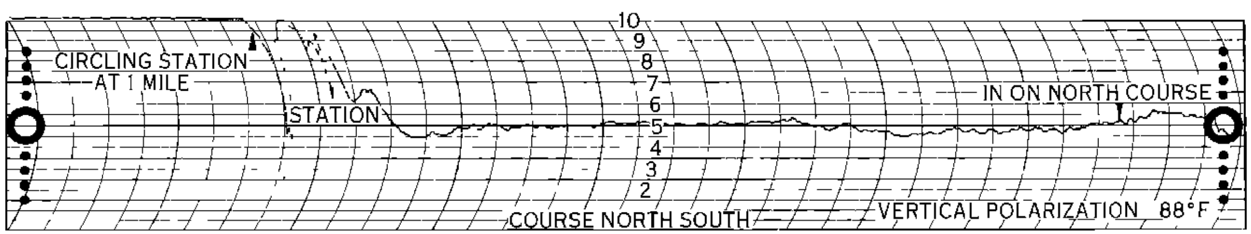
ON COURSE RECORDING FLYING NORTH TOWARD STATION WITH STATION LOCATED 1125 FEET NORTH OF TREES



ON COURSE RECORDING FLYING NORTH TOWARD STATION WITH STATION LOCATED 1125 FEET NORTH OF TREES



ON COURSE RECORDING FLYING SOUTH TOWARD STATION WITH STATION LOCATED 1125 FEET NORTH OF TREES



ON COURSE RECORDING FLYING SOUTH TOWARD STATION WITH STATION LOCATED 1125 FEET NORTH OF TREES

Figure 47 On-Course Recordings of the North and South Courses with the Portable Range Located 1125 Feet from a Group of Trees

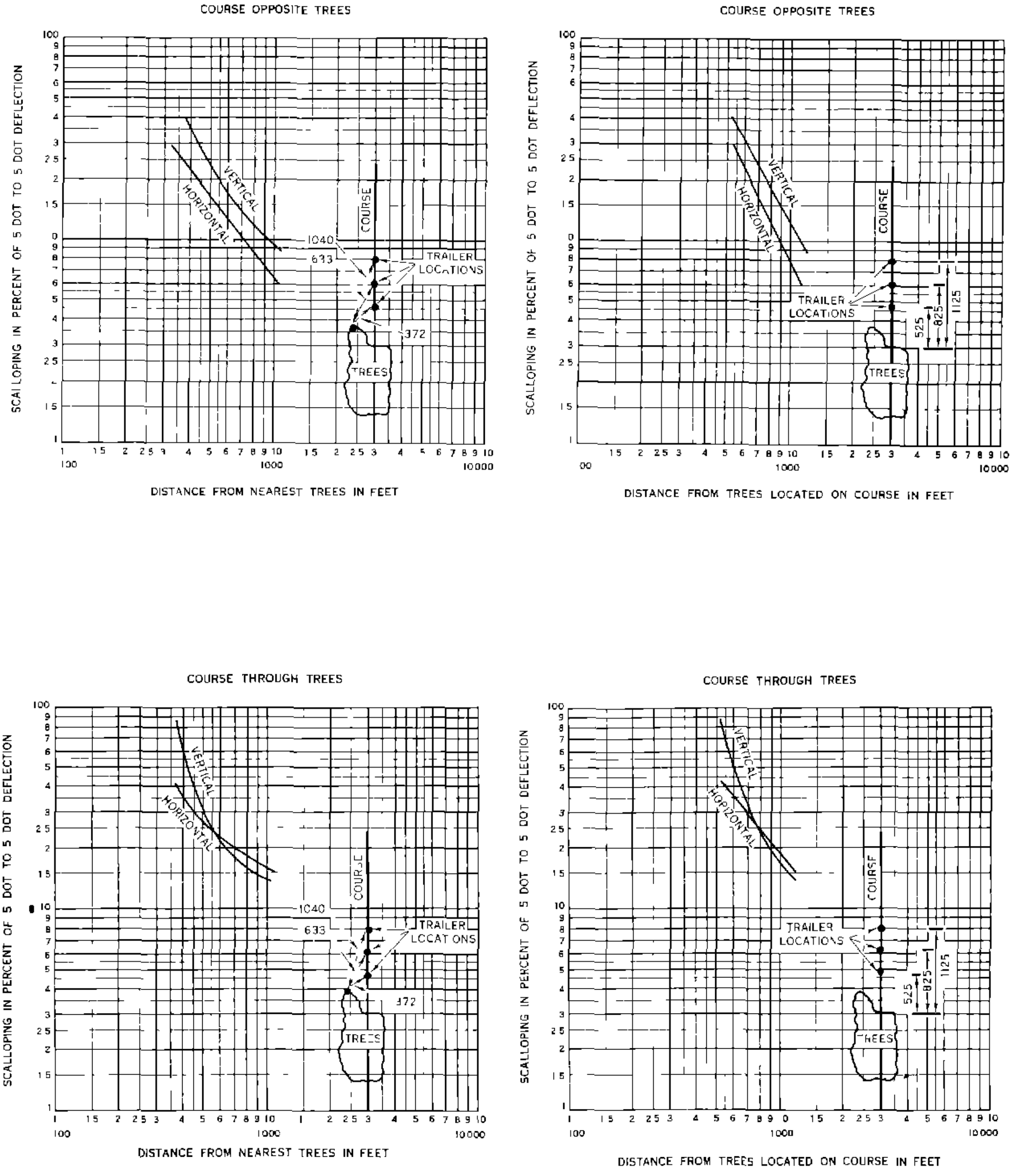


Figure 48 The Effect of Distance upon Course Scalloping with Each Type of Polarization

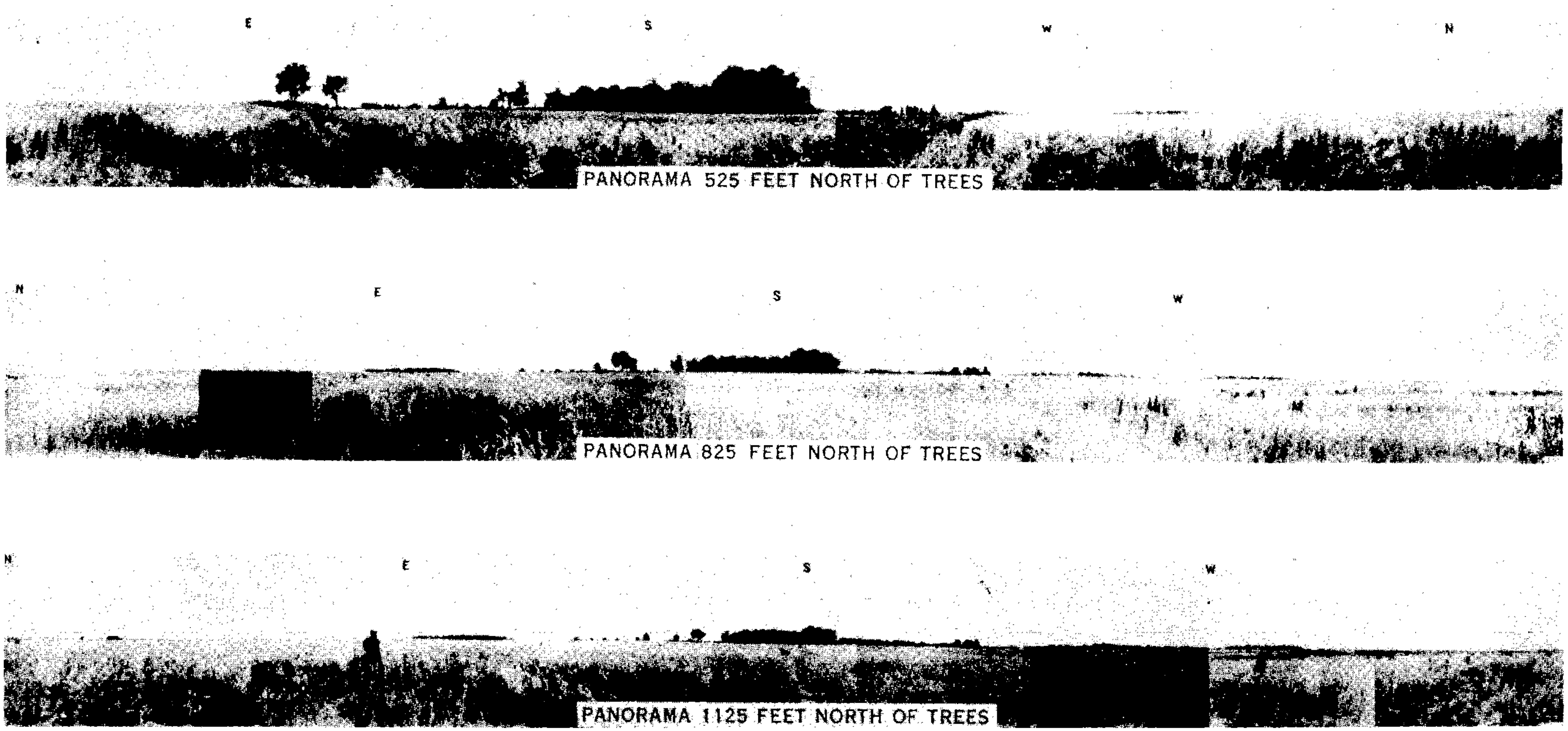


Figure 49. Panoramic Photographs Taken from the Sites for the Tree-Distance Tests.