DEVELOPMENT OF THE ULTRA-HIGH-FREQUENCY RADIO RANGE

PART I

THE ULTRA-HIGH-FREQUENCY AURAL RADIO RANGE

By

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Technical Development Division

Technical Development Report No 42

June 1944

U S DEPARTMENT OF COMMERCE

CIVIL AERONAUTICS ADMINISTRATION

WASHINGTON, D C.

UNITED STATES DEPARTMENT OF COMMERCE

JESSE H JONES, *Secretary*

CIVIL AERONAUTICS ADMINISTRATION

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DEVELOPMENT OF THE ULTRA-HIGH-FREQUENCY RADIO RANGE

PART I-THE ULTRA-HIGH-FREQUENCY AURAL RADIO RANGE

SUMMARY

This report describes a series of aural radio range experiments conducted at Indianapolis, Ind , Pittsburgh, Pa , and Washington, D C , at frequencies of 63 and 125 megacycles The results of numerous ground and flight tests using vertical and horizontal antennas are discussed with particular reference to the radio frequency, multiple courses, cone-of-silence characteristics, polarization effects, reflection effects, noise, atmospherics, distance range, ionosphere reflections, and aircraft antennas The report shows the progression of development from vertical polarization to horizontal polarization using crossed dipoles to the finally adopted horizontally polarized array using horizontal loops which have substantially pure polarization The field pattern of the adopted array possesses two very desirable characteristics, namely, a considerable increase of field strength on-course and a reduction of field strength off-course These characteristics are not available with the conventional crossed figure-of-eight radio range pattern

In the early part of the development, it was shown that the 63- megacycle vertically polarized range was somewhat superior to the 125-megacycle range using either vertical or horizontal crossed-dipole antennas, and particularly is this true as to multiple courses and polarization effects It is shown conclusively, however, that through the use of new developments made available by the rapidly progressing art of applying ultra-high frequencies to the radio range problem, a radio range operating on 125 megacycles and using pure horizontal polarization is superior to any of the other ultra-high-frequency facilities previously developed.

INTRODUCTION

For the past several years the Technical Development Division has been conducting numerous field tests directed toward the application of the ultra-high frequencies to the radio problem The first ultra-high-frequency four-course aural radio range experiments were made on 63 megacycles The results were very encouraging and were disclosed in a previous report[1] in the early part of 1938

These tests indicated that a four-course ultra-high-frequency aural range was practicable, but that further development would be necessary to improve the antenna system and the aircraft receiving equipment It was concluded that further tests should be made in order to obtain more concrete data to show the advantage of an ultra-high-frequency system Additional data were required to determine (1) the advantages of ultra-high-frequency ranges during severe atmospheric disturbances and rain static, (2) the effect of different types of terrain on the operation of the equipment, (3) satisfactory operation of the ultra-high-frequency equipment over long periods of time, (4) the effect of operating ultra-high-frequency ranges on high towers and the effect of counterpoises on cone-of-silence characteristics, (5) site requirements for future installations, and (6) the operation characteristics of a two-course ultra-high-frequency radio range

The 123- to 126-megacycle band was allocated to the Civil Aeronautics Administration for radio range facilities, and investigations were conducted in this band as the art progressed Later this band was extended to include frequencies from 119 to 126 megacycles The development of 125-megacycle equipment was greatly advanced by the development of a substantially pure horizontally polarized ultra-high-

[1] J C. Hromada, "Preliminary Report on a Four-Course Ultra-High-Frequency Radio Range," Civil Aeronautics Authority Technical Development Report No 3, January 1938

frequency loop antenna in connection with a Civil Aeronautics Administration radio instrument landing system contract

The purpose of this report is to describe the equipment used and to discuss the tests and investigations made to date on aural type radio ranges operating at 63 and 125 megacycles

TESTS ON 63 MEGACYCLES

Equipment

The transmitters used in these tests were the type TXI, similar to those used in the previous tests [2] They were crystal-controlled and delivered 100 watts of output power at 63 megacycles A conventional class B modulator was used in conjunction with a 1020-cycle vacuum tube tone oscillator The type TXI transmitter is shown in figure 1 A block diagram of this transmitter is shown in figure 3 A modified type AC-74 interlock relay, shown in figure 2, was used to key the radio-frequency transmission lines in the A-N sequency The interlock relay was mounted on top of the transmitters in these tests instead of outdoors as was done in the previous tests

For the reception of 63-megacycle signals, a type RUB crystal-controlled ground station receiver was modified for use in an airplane This receiver used a loaded coaxial line input circuit, a two-stage intermediate-frequency amplifier at 3850 kilocycles with a 40-kilocycle band width, and a two-stage audio-frequency amplifier A vibrator type power supply unit furnished the necessary high voltage. Figure 4 is a block diagram of the complete receiver and power supply. The receiver is shown in figure 5 Some of the audio output of the receiver is rectified to operate a high-speed graphic recorder For this purpose, an Esterline-Angus type AW (0-5) direct-current recording milliammeter was fitted with a vacuum tube amplifier-rectifier This unit was attached to the back of the recorder as shown in figure 6 The receiver power supply also furnished the power for operating this unit

Tests

After the completion of the preliminary tests with the vertically polarized 63-megacycle range at Indianapolis in October 1937, the equipment was moved to Pittsburgh where flight tests were conducted to determine the effects of irregular and mountainous terrain Through the courtesy of the Westinghouse Electric & Manufacturing Company, arrangements were made to utilize the site of the abandoned Westinghouse receiving station near Wilkinsburg, Pa The antenna was on very rough and hilly ground about 50 feet from the station building and 200 feet from a large barn which was fitted with a number of lightning rods Flight tests showed the presence of several widely separated multiple courses, such as would be due to nearby reflecting objects

A search for a better radio range site resulted in the leasing of a plot of ground located approximately 2 miles south of the Allegheny County Airport near Clairton, Pa This plot of ground was a rounded knoll sloping downward on all sides about 10 feet at a 100-foot radius The antenna was erected on a 12-foot pole above a small shack which housed the transmitter The closest obstructions, which were trees on the east side and a power line on the west side, were well below the level of the antenna, about 400 feet down the hill

Flight tests on all four courses of this range did not reveal any multiple courses The record shown in figure 7A is derived from an actual flight recording and is an example of a typical cross-course flight In this figure, the actual keyed (A-N) signals have been removed from an actual recording, and the distance between the two intersecting lines represents the difference between the levels of the two signals This has been found to provide an easy method of analyzing re-

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[2]See reference 1, page 1

cordings of this type, inasmuch as an intersection of the two lines indicates a course When the two lines approach each other but do not intersect, there is an indication of a tendency toward multiple course This record was taken at 20 miles, on the northwest leg of the range, at 3,200 feet above ground There is a moderately slow rate of scalloping of the field patterns Figure 7B is a similar record taken at 45 miles on the northwest leg in a flight across the course at 2,800 feet above ground

The range exhibited multiple cones-of-silence as the antenna was three-quarters wavelength above ground

In June, 1938, a metallic screen or counterpoise was erected at the Pittsburgh site, one-quarter wavelength below the center of the radiators, in an effort to eliminate the multiple cones-of-silence A wooden frame-work 30 feet square was built around the transmitter building, and the entire top of the framework was covered with 3/4-inch galvanized chicken wire mesh This installation is shown in figures 8 and 10 Recordings of the cone-of-silence again were made, one of which is shown in figure 9 The rise in signal between the fore and aft surges is probably due to irregularity of the receiving antenna field pattern in the vertical plane and to effects of the airplane structure This recording was taken in a flight over the station at 2,500 feet above ground. Cross-course flights also were made on all four courses No multiple courses were found within 50 or 60 miles of the station The southeast leg was flown to Berlin, Pa , a distance of about 76 miles, where cross-course flights showed very slight indications of multiple courses These multiples were of doubtful character, often appearing as an on-course signal just off the course and lasting only during the time of a single A or N interlock, and could not be detected on the recordings

During the cross-course flights, accurate checks were made against ground landmarks, and it was noted that a slight "pushing" of the course resulted On flights perpendicular to a course from an A quadrant into an N quadrant, the on-course signal appeared displaced forward from its true position some distance into the N quadrant Similarly, on flights back from the N quadrant to the A quadrant, the observed on-course appeared displaced forward to a position in the A quadrant At 76 miles, this "pushing" effect was about one mile. Under certain conditions an opposite or "pulling" effect was noted Pushing and pulling effects of the courses have been observed on numerous occasions at low frequencies when horizontal V or L antennas are used instead of a vertical mast, and they are due to pick-up of the horizontal component of the transmitted signal Considerable horizontal component was observed on the ground at Pittsburgh with a portable field detector and was due to radiation from the coaxial lines which were not properly terminated

In the majority of the flight tests at both Indianapolis and Pittsburgh the aircraft receiving antenna was a quarter-wave vertical whip antenna mounted on top of the fuselage of the Civil Aeronautics Administration Stinson airplane NC-80, just back of the pilot's seat (see fig 34) The antenna was tuned by means of a coil and condenser in series with the whip A flexible coaxial cable coupled the antenna to the receiver During a portion of the flight tests a half-wave whip antenna mounted through the fuselage just forward of the rudder post was used This antenna was found to be inferior to the first one During flight tests it was observed that when either wing was pointed to the station on flights perpendicular to the course, the signal was very clear and free from what appeared to be extremely rapid and irregular amplitude modulation effects. In flights directly away from the station, the signals were not so clear and could be considered only fair in tone character During flights with headings toward the station the signals were very badly cut up, and it was only with difficulty that the course could be flown The course appeared to be somewhat broadened because of this modulation effect In subsequent tests it was determined that this signal flutter was due to reflector or director action of the rotating propeller and hence was termed propeller modulation In this particular case the antenna, by chance, was very nearly one wave-length back of the propeller.

In June 1938, another 63-megacycle vertically polarized radio range was erected at Indianapolis with a view to improving the known faults of the first antenna system Figure 11 is a schematic diagram of the new antenna The dipoles were of the coaxial end-fed variety, and each pair of diagonally opposite dipoles could be adjusted to reduce the standing waves on the inside conductor as well as on the outside of the coaxial lines to a negligible value. The center of the dipoles was 20 feet above ground. One-quarter wave below the center of the dipoles was a circular counterpoise 30 feet in diameter, made of 2-inch-square galvanized iron mesh as shown in figure 12. In this figure there is a fifth element shown at the center of the antenna system This element was added to the array for the purpose of tests on simultaneous range and voice transmission When the lower telescoping sleeves on the dipoles have been adjusted, the standing wave on the outer conductor of the transmission line is reduced to a negligible value independent of the standing wave on the inner conductor. The line-shunting condenser, C, and the upper dipole telescoping sleeves are then adjusted to obtain a minimum standing wave ratio on the inner conductor This antenna system gave very good results, and the horizontal component of the electric field could be reduced to less than 1 percent of the vertical component The array has the disadvantage of not being as easily rotated to align the courses as the array installed at Pittsburgh In the design of this array, a diagonal spacing of 0 2 wave-length was used to provide sharper courses and a small physical size (See fig 59)

The Indianapolis range, equipped with this antenna, was flight checked to 125 miles and no multiple courses, or pushing or pulling effects, were found on any of the four legs Figure 13 represents an average set of curves plotted from data taken on this range with a rather high airplane ignition-noise level Curves 1 and 2 show the effective loss of distance range when a counterpoise is used Curve 3 may be directly compared with curve 1 to show the improvement in distance range which may be obtained with a reduction of ignition, charging regulator, and generator noises. The data for curve 3 were obtained in the same flight as the data for curve 1, except that the engine was throttled down considerably in the case of curve 3.

Toward the latter part of the year, the Civil Aeronautics Administration loaned two 63-megacycle crystal-controlled receivers to American Airlines and Transcontinental & Western Air, Inc These companies made numerous flight tests of the Indianapolis and Pittsburgh radio ranges The tests made it possible for a large number of pilots to compare the ultra-high-frequency range with the standard low-frequency ranges Several typical airline pilots' comments are quoted below:

> "'Maximum range of 90 miles at a time when the low-frequency beacon was practically useless because of heavy static '
> 'Unusually fine beam ' 'Good tone ' 'No bends ' 'Good cone at 1,500 feet ' 'No static with lightning around ' 'Highly satisfactory '
> 'No shifting or waving.'"

An interesting comparison between the 254-kilocycle range and the 63-megacycle range at Pittsburgh is shown in figure 14 The figure shows the data obtained from cross-course flights recorded over Somerset, Pa , a distance of 52 miles from Pittsburgh, at an altitude of 4,300 feet above ground They clearly show the superiority of the 63-megacycle over the 254-kilocycle range

TESTS ON 125 MEGACYCLES, VERTICAL POLARIZATION

Equipment

The type TXI transmitter as used on 63 megacycles also was used on 125 megacycles except that the neutralized driver stage was converted into a frequency doubler, the output of which was sufficient to fully excite the power amplifier at 125 megacycles (See fig 3)

In all flight tests at 125 megacycles the aircraft receiver shown in figure 15 was used. This receiver[3] is a superheterodyne, using tuned coaxial line input

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[3] P D McKeel, "An Ultra-High-Frequency Aircraft Receiver," Civil Aeronautics Authority Technical Development Report No 17, September 1938

circuits and a tunable coaxial line radio-frequency oscillator of high stability The receiver has a tuning range of 60 to 130 megacycles Its stability is excellent after a warm-up period of approximately 1 minute. A block diagram of this receiver is shown in figure 16

Tests

In December 1937, the first 125-megacycle vertically polarized range was set up at Indianapolis within 200 feet of the old 63-megacycle station The transmitting antenna and interlock relays were similar in design to those used on 63 megacycles Considerable difficulty was experienced in obtaining a good field pattern on the ground Figure 18 is a representative pattern drawn from the data taken at 125 megacycles For comparison, the field pattern of the 63-megacycle range, figure 17, is reproduced from Technical Development Report No 3[4] A large percentage of horizontal component was observed on the ground with the aid of a portable field meter, and it was further noted that the position of the course changed with the angle of the receiving antenna Flight tests on all four courses revealed that all were practically unflyable Multiple courses were numerous even at distances as close as 2 miles, and the attitude of the airplane affected the received signal to a marked degree Often a 15° bank would change the signal from an A to an N, or vice versa. The antenna, being three wavelengths above ground, produced multiple cones-of-silence which were later removed by means of a counterpoise consisting of a large area of 3/4-inch galvanized chicken wire mesh placed one-quarter wavelength below the center of the antenna The multiple courses were reduced somewhat by the addition of the counterpoise but were still very pronounced

The equipment was then moved to a new location about 1,000 feet away from the old range building (the closest obstruction) and re-erected With the portable field detector a large proportion of horizontal component was found Placing a metal screen over the transmitter greatly reduced this component, although the transmitter itself was in a perforated aluminum cabinet The entire house (approximately 5 feet square by 7 feet high) was then screened and tightly closed The horizontal component was reduced to less than 1 percent The ground pattern was somewhat improved over that taken in the old location. (See fig 19) No multiple courses were observed in flights up to 20 miles At 30 miles, cross-course flights showed no less than six closely spaced multiple courses on the east leg Assuming that these multiple courses were caused by some distant reflecting object, calculations indicated that such an object should be approximately 1,560 feet away Figure 20 is a sketch made from aerial photographs in which are shown the various obstructions in the vicinity of the antenna It should be noted that none of the obstructions were over 75 feet in height and all of them were below an angle of 1 7° with the antenna

In April 1938, tests were conducted on a 125-megacycle two-course antenna system supplied through the courtesy of the International Telephone Development Company, Inc., based on the same principles of operation as the Lorenz beacon[5] developed in Germany for use on 33 megacycles A schematic diagram of the International Telephone Development Company system is shown in figure 21, and figure 22 shows the complete installation The central dipole was continuously fed from the transmitter while the left and right reflector elements were keyed "open" and "closed" by means of relays in the usual interlocked A-N sequence The two-course range provided a greater degree of flexibility than the four-course in that the shape of the A-N patterns could be controlled and varied with ease, and course sharpness could therefore be controlled Figures 23, 24, and 25 are representative ground patterns which were tested In each case the dipole elements were carefully tuned and the lines terminated A large horizontal component was observed on the ground until a number of radio-frequency chokes were inserted in the horizontal leads to the relays The pattern shown in figure 23 produced very broad courses, and many multiples were found

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[4]See reference 1, page 1

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[5]E Kramer and W Hahneman, "The Ultra-Short-Wave Guide-Ray Beacon and Its Application," Proc I R.E , Vol. 26, January 1938.

at distances greater than 14 miles A slight improvement was observed when the system was tuned to give the pattern shown in figure 24 The ground pattern in figure 25 provided one broad course and one sharp course. Slightly fewer multiples were observed in flight tests on the sharper course

A cross-course record taken at 20 miles, and obtained with the transmitting pattern of figure 24, is shown in figure 26 The scalloping of the pattern is bad The actual signals heard in the headphones are marked on the recording

In the fall of 1938 the four-course and the two-course vertically polarized antennas were moved to Pittsburgh and successively tested at the new site 2 miles south of the Allegheny County Airport. The antennas were erected one-quarter wave above the 30-foot square counterpoise As at Indianapolis, multiple courses were present with both types of ranges Scalloping of the A and the N patterns was quite severe A typical cross-course flight record is reproduced in figure 28 On this record, taken at 20 miles and 2,600 feet above the ground on the southwest leg of the range, wide multiple courses and severe scalloping are seen A similar record, which was taken at 30 miles, 2,600 feet above ground, on the northeast leg of the range, is shown in figure 28B

On-course flights either toward or away from the station revealed a signal flutter which was different in character and more severe than the propeller modulation found on 63 megacycles This fluctuation of signals appeared to be a very low-frequency variation of low amplitude with a higher frequency superimposed The effect was noted when the aircraft was being flown over mountains Similar flutter was observed in the vicinity of the Pittsburgh Airport An example of this flutter is shown on the recording, figure 29A, taken during an on-course flight from near Bentleyville, Pa., toward the station at 3,000 feet above ground. The flutter is more noticeable on passing over mountains and varies with altitude, becoming less violent and higher in frequency at the higher altitudes The effect is probably due to the random combination of the direct wave and a reflected wave from the ground

Another interesting example of signal flutter due to reflections is shown in figure 29B This record was obtained at Indianapolis on 125 megacycles using vertical polarization At the time the recorder was operated, the plane was on the ground about 1-1/2 miles from the transmitter in the N quadrant The interlock relay was being keyed by hand during the process of some adjustments An Army pursuit plane appeared, flying about 700 feet above ground at a 1-mile radius around the airport The oscillations recorded appeared at intervals during the circling of the plane This type of flutter would exist, of course, regardless of the type of polarization

The distance range of the Pittsburgh station was in the neighborhood of 90 miles at 2,000 feet above ground, and 115 miles at 3,000 feet above ground, considerably greater than that obtained over level terrain with the Indianapolis station The fact that the transmitting antenna was mounted on a pole one-quarter wave above. a screen counterpoise reduced the multiple cones-of-silence materially (see fig. 27), in spite of the fact that the antenna was 12 feet or one and one-half wavelengths above ground

TESTS ON 125 MEGACYCLES, HORIZONTAL POLARIZATION, USING CROSSED-DIPOLE ANTENNAS

Following the 125-megacycle tests with vertically polarized antennas, an array consisting of two horizontal crossed dipoles was constructed for the purpose of testing horizontal polarization. A schematic diagram of the crossed-dipole antenna system is shown in figure 30 Figures 32 and 33 show the installation The U-shaped sections of transmission line and the feeding transmission line are of standard 7/8-inch 70-ohm coaxial cable. With this array the feeding line is automatically terminated if the dipole resistance is approximately 72 ohms

Figure 31 is a sample ground pattern taken with a portable field meter at Indianapolis Comparison between figure 31 and figure 19 shows a considerable improvement in the field pattern of the horizontal crossed dipoles over the vertical antenna at the same site. Flight tests also indicated less scalloping of the field in the case of the horizontal antenna. A very large percentage of vertically polarized component of the field was observed on the ground, and a small tilt of the receiving antenna from the horizontal completely displaced the course or changed the received signal from one quadrant to the other. This is to be expected, since the electric field from a horizontal dipole contains a considerable proportion of vertical component.

With a vertical receiving antenna, an N signal was heard at all points on a 100-foot radius except when the receiving antenna was in line with either of the crossed dipoles. At these points an on-course signal was heard. At the same radius, 10° off the true course, tilting the receiving antenna clockwise from the horizontal gave a strong A signal and tilting the antenna 10° counter-clockwise from the horizontal gave a strong N signal. The mutual coupling between the crossed dipoles and the standing wave ratio on the transmission line outer conductors were negligible. The receiving antenna used during the flight tests was a 15-inch horizontal loop mounted 9 inches below the fuselage of NC-80. It is illustrated in figure 34. Tuning of the loop was accomplished by adjusting the position of the horizontal bar across the loop. A double coaxial feeder line provided coupling to a balancing unit, shown in the diagram, from which a single coaxial line was connected to the receiver. The balancing unit is adjusted by shunting the loop end of the double coaxial line (with the loop disconnected) and feeding the two coaxial lines in parallel from a signal generator. Condenser C, is then tuned to a null, after which the loop is reconnected to the lines.

Extended flight tests were made on the horizontal antenna up to about 65 miles and altitudes up to 5,500 feet above ground. A large number of cross-course flights were made on all four legs of the range. On some of the legs multiple courses were observed, although the over-all scalloping of the N and A signals and the multiple course phenomena were considerably less than those observed with vertical polarization on the same frequency. The courses observed, both aurally and by means of the recorder, were, on the average, narrower than the 3° courses of the vertically polarized range. A tabulation of a number of flights on the Indianapolis crossed-dipole range is given in figure 35.

Figures 36A and 36B are records derived from cross-course flights taken on the north leg at 30 miles and 3,500 feet above ground, and 36 miles and 3,400 feet above ground, respectively. It is seen from these records that the multiples were slight, often appearing as a single false signal which could be detected only by aural methods. During the course of the flight tests it was further observed that when the airplane was making a turn a few degrees off-course, the received signal would change from an A to on-course to an N. Thereafter it was the practice to fly about 10° off-course, execute a flat 360° turn, and observe this "circling effect." This is a more critical method of observing "pushing" or "pulling," which are actually the same phenomenon. Circling effect was almost universally observed with the crossed-dipole antenna.

Within a radius of 5 or 6 miles of the station it was impossible to fly an accurate course. If a gyro course was held accurately from a distance of 10 miles, as the high-angle lobes of the vertical radiation patterns were crossed, the course appeared to shift from its normal position to one side or the other.

Figure 37 is a cone-of-silence record taken when the interlock relay was locked on one side. The antenna in this case was one and one-half wavelengths above ground and one-half wave above the 30-foot-square galvanized iron screen counterpoise. The altitude of the plane was 2,700 feet above ground and the air speed 110 miles per hour.

Further experiments with the crossed-dipole array were conducted at Pittsburgh. As in the case of the vertical antennas, the crossed dipoles were erected above a counterpoise (one-half wave in this case). The flight tests again showed considerably fewer multiple course phenomena and less scalloping of the A and N patterns.

The distance range, as in the case of vertical polarization, was much greater at Pittsburgh than at Indianapolis and in about the same ratio as in the case of the vertical polarization, violent fluctuations of signal were observed during flights over mountains, as illustrated in recording A of figure 39 This recording was taken in the vicinity of Chestnut Ridge during an on-course flight at 120 miles per hour, 2,800 feet above ground, from Pittsburgh to Somerset, Pa Another example of flutter is given in figure 39B. This record was taken in a flight toward Somerset and over the steel mills of Pittsburgh at 120 miles per hour, 2,800 feet above ground Circling effect was also observed in practically all tests This is illustrated in the recording of figure 38 taken near Ruffsdale, Pa , approximately 20° off-course in the N quadrant, while the airplane was flying in a short-radius flat circle The record shows reversal of signal

A and B of figure 40 are cone-of-silence records taken with the interlock relay locked on one side The recording of figure 40A was taken at 3,500 feet above ground, 120 miles per hour, transmitting antenna one and one-half wavelengths above ground, and the counterpoise one-half wavelength below the antenna This figure also shows flutter of signal as the plane passed over the Allegheny County Airport The recording of figure 40B was taken with the counterpoise removed These records show the improvement in the cone-of-silence when a counterpoise is used

During September 1938, the 125-megacycle crossed-dipole antenna system was mounted on the top of a 125-foot steel tower at the Silver Hill Experimental Station near Washington, D.C Flights were made on the south and west legs with cross-course checks at Indian Head and Herndon, Va , respectively Both courses were found to be very poor In general, they were characterized by flutter and roughness, probably due to wave interference, and were subject to rapid and violent changes in intensity The west course in the vicinity of Herndon was particularly poor, being comprised of several multiples extending over a sector approximately 9° wide Another steel tower located 400 feet from the antenna probably was the cause of the severe splitting of the course Figure 41 is a record derived from an actual flight recording taken of one of the test flights over Herndon at 2,300 feet above ground The scalloping of the A and N patterns is seen to have been very severe During flights within one-half mile of the Arlington towers which were in line with the Herndon course, wide fluctuations of signal were observed, indicating strong wave interference due to reflections Pushing effect and circling effect were very severe The south course was comparatively free from multiples but had a serious bend about 5 miles south of the Experimental Station In other respects this course was no better than the west course

On-course signals were observed to change to A, to on-course, to N, etc , when a steady gyro course was held which coincided with the radio range bearing All attempts to fly a course over the station were unsuccessful This may be ascribed partially to the fact that numerous cones-of-silence were present, since the antenna was 16 wavelengths above ground These multiple cones-of-silence were recorded and are shown in figure 42A

In October 1938, a 30-foot-square counterpoise of 3/4-inch galvanized wire mesh was installed on the tower one-half wavelength below the crossed-dipole antenna There was a considerable reduction in the multiple courses on the west leg Course discontinuity was still noticeable close to the station Pushing and circling effects were also unchanged The cone-of-silence, however, was improved considerably, as shown in figure 42B A view of the 125-foot tower and counterpoise is shown in figure 43

DISCUSSION

Multiple Courses

(a) Effect of Course Sharpness

Most of the experiments on 63 and 125 megacycles utilized the four-course radio range, the theoretical horizontal space pattern of which fundamentally comprises two crossed figure-of-eight patterns as shown in figure 44 The course sharpness may arbitrarily be defined as the ratio of N/A (signal strength) or its reciprocal at a point 1° from the intersection of the two patterns In the practical case, however, the figure-of-eight patterns are somewhat scalloped instead of being smooth, because of reflections from obstructions Figure 45A is a small sector of a radio range pattern showing the on-course region Occasionally the scalloping is severe enough to produce two or more cross-overs in the on-course region as shown, resulting in spurious or multiple courses At low frequencies, the scalloping is due to reflections from large objects (comparable with the wavelength) such as mountains At ultra-high frequencies, reflections from small nearby objects will cause scalloping of the patterns It is an interference phenomenon between the direct wave and the reflected waves If the A and N patterns are then changed to intersect on-course at a more acute angle, the ratio of N/A at 1° from the intersection will be greater and the course sharpness will be increased, as shown in figure 45B

It is evident that the greater the course sharpness, the fewer are the cross-overs, and there is a consequent net reduction in multiple courses It is readily seen that since the field strength at any point is the vector sum of all the signal components received at that point, any increase in the ratio of on-course/off-course field strength will reduce the amount of scalloping, and hence the number and intensity of multiple courses The tests on the two-course range with several degrees of sharpness did indicate some improvement with the sharper courses The two-course range permits greater flexibility in shaping the field patterns, and in special instances these patterns may be purposely shaped to reduce the field strength toward reflecting objects If the range is to provide a useful aid to air navigation, there is, however, a limit to the amount of reduction of the off-course radiation which can be tolerated The subject of practical radio range patterns will be discussed in more detail later in the report

(b) Effect of Frequency

In figure 46A is illustrated the same general scalloping of the A and N patterns as in figure 45A If the frequency is halved, for example, the interference phenomenon is decreased and less scalloping results Consequently, as shown in figure 46B, there will be fewer cross-overs and fewer multiple courses This fact indicates that the number of multiple courses is apt to decrease almost proportionately with a decrease in frequency and partially explains why, at a given location under identical conditions, the 63-megacycle range had almost imperceptible multiples or none at all, whereas the 125-megacycle range had considerably more Figure 46 demonstrates the effect of a change of frequency, and there has been no attempt to show the results of any changes in the amplitude of the scalloping

It has already been shown that it is possible to reduce multiples by controlling radiation in the direction of reflecting objects, and later in this report it is shown conclusively that it is possible to produce a 125-megacycle range that is equal or superior to the 63-megacycle range already described This range was made possible by the rapidly advancing art of controlling radiation at these frequencies

(c) Bends in Courses

In some ultra-high-frequency range installations not covered by this report, course bends have been observed These bends are believed to be borderline cases of multiples where the scalloping of the pattern changes at increasing distances from the station. The scalloping is usually caused by reflections from buildings, wires, trees, and rugged terrain Bends have not been encountered at Pittsburgh or Indianapolis at angles of elevation below approximately 20° on either 63 or 125 megacycles However, bends are very severe on the Pittsburgh low-frequency range Experience indicates that bends in low-frequency ranges are caused by conditions over which the engineer has no control On the other hand, the engineer can control the factors which cause bends on ultra-high frequencies

Polarization

Perhaps the most significant fact brought about in the previously described tests on both 63 and 125 megacycles is the necessity for a radio range antenna system providing a constant polarization of the electric field at all points in space, that is, one in which the polarization for the A pattern is the same as that for the N pattern For purposes of illustration, let us assume that the vectors A and N shown in figure 47A represent the field strength and polarization for the A and N patterns of a radio range Then a vertical dipole in the position midway between these vectors will receive equal A and N signals or an on-course If the dipole is tilted to one side, as shown in figure 47B, the A signal will predominate over the N with an off-course indication as a result Similarly, if the dipole is situated a few degrees off-course and is polarized at an angle from the vertical, as shown in figure 47C, the vector combination of the A and N fields will produce an on-course signal Such a condition often exists with ultra-high-frequency aircraft antennas where a vertical quarter-wave antenna may receive considerable horizontal component of the transmitted signal because of pick-up on the aircraft structure itself This condition produces the so-called pushing or pulling or circling effects already described The metal frame, control wires, instrument tubing, etc , on small aircraft can hardly be expected to act as a "ground" for the ultra-high-frequency antenna On large all-metal transports, the extended metal wing and fuselage surfaces are more apt to provide a reasonably good "ground " Although no opportunity was had to make definite measurements on large aircraft, tests on 63 megacycles in several Douglas DC-2 and DC-3 transport planes showed that no pushing or circling effect was present, and the receiving antenna patterns were apparently more uniform than those obtained on the Civil Aeronautics Administration Stinson NC-80. Moreover, none of the airline pilots who tested the Pittsburgh and Indianapolis 63-megacycle ranges have reported any pushing or circling effect

It is obvious that the requirement for constant polarization affects both the transmitting and the receiving antennas, but if either one can be made to produce or respond to only one polarization, no difficulties will be encountered The transmitting antenna system is under full control of the designing engineer and hence is the proper place to control the polarization On the other hand, the aircraft receiving antenna is not under full control, and each aircraft, even among airplanes of the same general type, is apt to have widely different characteristics

As the experiments on 63 and 125 megacycles with vertical polarization proceeded, every effort was made to reduce the amount of horizontal component as measured on the ground in the vicinity of the station With reasonable care, spurious radiations from the transmission lines or from the transmitter itself can be suppressed In the case of the experiments using the horizontal crossed dipoles, pushing and circling effects were always encountered, and a large percentage of vertical component was always present in ground tests The reason for this condition is that the crossed-dipole antenna does not radiate pure horizontally polarized waves in all directions

No pure horizontally polarized antenna had been developed by the end of 1938 Tests with the horizontal crossed-dipole antenna on 125 megacycles revealed fewer multiple courses than those with vertical polarization, and slightly more multiple courses than those with vertical polarization on 63 megacycles. The pushing and circling effect and reversal of quadrant signals in turning and banking maneuvers made the horizontal crossed-dipole antenna inferior for navigational purposes A number of test flights on 63-megacycle horizontal crossed-dipole antennas at Indianapolis confirmed these conclusions

One other point regarding the relative merits of horizontal versus vertical polarization is noteworthy horizontally polarized waves are reflected more efficiently from the ground than are vertically polarized waves,[6] except at very low angles

[6]Bertram Trevor and P S Carter, "Notes on the Propagation of Waves Below Ten Meters in Length," Proc I R E , Vol. 21, March 1933

when both are reflected nearly perfectly Vertically polarized waves may be considered as being horizontally polarized with respect to vertical objects such as trees and vertical walls of buildings Hence, the so-called vertically polarized waves are subject to severe reflections from the objects often encountered near radio range installations. This fact was sufficiently demonstrated in the 125-megacycle tests where the ground patterns were freer from scalloping in the case of horizontal polarization On the other hand, it is to be expected that trouble may arise in the case of horizontally polarized systems because of the presence of horizontal telephone and telegraph wires in the close vicinity of the antenna

From the data obtained in the experiments described to date and other tests on a visual type radio range,[7] it is quite definitely indicated that horizontal polarization would be superior to vertical polarization provided purely polarized waves could be obtained Nearly all of the objectionable features of a horizontally polarized range derived from the large vertical component present in the radiation from the crossed horizontal dipole array would be automatically eliminated provided this component could be eliminated It was this knowledge that led to the development of the purely polarized horizontal loop antenna referred to later in this report

Signal Flutter and Spurious Modulations

In all tests on 125 megacycles at Pittsburgh with both horizontally and vertically polarized arrays, a disturbing signal flutter or superimposed low-frequency modulation was observed. This is due to rapid variations in the amplitude of the received signal caused by continually changing reflections from rugged terrain The flutter was most severe at low altitudes and diminished with increasing altitudes, although it was encountered higher than 4,000 feet above ground This phenomenon was barely noticeable at a distance or 63 megacycles, however, it was severe in the immediate vicinity of the range Although it is very disturbing in the headphones on aural reception, it is believed that its effects can be greatly diminished in a double-modulation visual radio range system where automatic gain control can be used to advantage.

Propeller modulation was encountered only on 63 megacycles where the size of the airplane propeller is comparable to one-half wavelength. However, this effect may be minimized by proper location of the receiving antenna In one of the airline tests on a Douglas DC-3 the propeller modulation was barely noticeable, and none of the airline pilots mentioned it

Course Discontinuity

During the Indianapolis tests with horizontal polarization on 125 megacycles, it was observed that it was almost impossible to fly a range course within a radius of about 6 miles from the station The difficulty was at first attributed to bends in the courses Later, the same trouble was noted at Pittsburgh, and again at Washington, D C Further flight tests, with constant gyro headings, established the fact that as successive high-angle radiation lobes were crossed, the range course suddenly became discontinuous The course was observed to shift to the left and then to the right, etc , indicating that the on-course cross-overs of successive high-angle lobes were not in alignment The effect was noted also in the case of vertical polarization, but to a much smaller degree At Washington, D C , where the antenna was 16 wavelengths above ground, the discontinuities were so irregular that the courses could not be flown within a radius of several miles of the station. Discontinuities of course were still present at Pittsburgh and Washington when counterpoises were used, even though the minimums between the high-angle lobes were pushed out to 60 or 80 percent of the intensity of the lobes From these results, it is apparent that this effect is serious enough to preclude the possibility of using very high antenna structures.

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[7] 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," Civil Aeronautics Authority Technical Development Report No 24, February 1940

Distance Range

Under average noise conditions, in an airplane equipped with the usual shielded plugs and harness, the distance range of the 63-megacycle 100-watt transmitter was 40 to 50 miles at 1,000 feet, when the transmitting array was 16 feet high and one-quarter wavelength above a counterpoise, in flat country such as the vicinity of Indianapolis In mountainous terrain, such as at Pittsburgh, with the antenna 12 feet high, one-quarter wavelength above a counterpoise, the distance range was 60 to 65 miles at 1,000 feet above ground This increase in distance range was no doubt due to an increase in line-of-sight conditions caused by the downward sloping of the terrain away from the station. Distance range results on 125 megacycles at the two sites were identical to those obtained on 63 megacycles Similarly, no appreciable difference in distance range was observed between horizontally and vertically polarized antennas at either site

Curves 1 and 2 of figure 13 show that the counterpoise decreases the useful distance range to about 83 percent of the distance obtained without a counterpoise

Curve 3 of figure 13 indicates that a 90 percent improvement in distance range may be obtained simply by reducing the noise pick-up In the case of curve 3, the engine was throttled down to about 1,700 revolutions per minute The regulator on the battery-charging generator was responsible for the major noise received in this test In general, it is believed that for ultra-high-frequency work, both primaries and secondaries of ignition systems will require more thorough shielding than is ordinarily necessary at low frequencies.

Atmospherics

The vast improvement which the ultra-high frequencies offer over the low frequencies in the reduction of atmospheric static has already been reported,[8] and this fact has been substantiated from time to time during the progress of these tests

A limited amount of information has been gained to date relative to the effects of precipitation static, and most of the experience obtained in this direction was from airline pilots' observations during the test periods on the 63-megacycle range installed at Pittsburgh and Indianapolis Among pilots' reports are the following comments:

> "'Little static on UHF, considerable on low frequency ' 'Little rain static Very heavy static on low frequency ' 'Very little atmospheric static—none close to station 25 miles out ' 'No static with lightning around.'"

Ionosphere Reflections

The tremendous advantages offered by the ultra-high frequencies in minimizing reflections from the ionosphere make these frequencies particularly adaptable for radio range services Considerable information has been obtained and data have been published in various magazines and journals with regard to sporadic long distance communication on some of the ultra-high frequencies, particularly by radio amateurs in the frequency bands 56 to 60 megacycles In this respect it appears that some interference due to Heaviside layer reflections might be experienced in a radio range system in the 60- to 66-megacycle band but would be highly improbable in the 119- to 126-megacycle band

AIRCRAFT RECEIVING ANTENNAS

To illustrate some of the effects of airplane structure on the characteristics of ultra-high-frequency receiving antennas already mentioned in the Discussion, a

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[8]See reference 1 on page 1 and reference 5 on page 5

number of antenna patterns are shown in figures 48, 49, and 51 to 55, inclusive. All of these patterns were obtained by recording the signal strength while the airplane was making a 360° turn in the middle of a quadrant, several miles from the transmitting station, with the transmitter operating key-locked Signal level is plotted in decibels up and down about an arbitrary zero level so that all patterns are comparable and show the resulting aural variation of signal at all azimuth angles The airplane diagram in the center of the patterns gives its true bearing toward the station, that is, directly up on the page is "tail-to" station, directly down the page is "nose-to" station, etc In each case two flight records were made, one in the clockwise direction (solid thin curve), and one in the counter-clockwise direction (dotted curve), each taken with a 10° bank The solid heavy curve represents the average of the clockwise and counter-clockwise curves, as would be observed in a flat turn in either direction

Figure 48 represents the characteristic obtained on a one-quarter wavelength whip antenna at 63 megacycles. The antenna was mounted above the fuselage of Stinson NC-80 just back of the pilot's seat, as shown in figure 34 The low potential end of the tuning system was connected to the metal tubing of the airplane structure A horizontal V antenna, normally used for plane-to-ground communication on 3,105 kilocycles, was installed from wing tips to rudder post, but the lead-in was not connected to the transmitter The pattern is seen to vary an average of about 8 decibels but has a deep dip forward of the left wing in clockwise rotation which disappears on circling counter-clockwise In a clockwise turn, the left wing is high and between the antenna and station This wing contained the long air speed pitot tube. In the counter-clockwise rotation the left wing is down, and there is no obstruction between the antenna and the station.

In figure 49 all of the above conditions are the same except that the high-frequency V antenna was entirely removed The clockwise pattern is considerably worse than before, although the counter-clockwise and average curves are little changed Apparently the V antenna, although "floating," provided greater uniformity of "ground" beneath the whip antenna

Figure 50 amply illustrates the effect of the airplane structure on the tuning of the antenna This recording was taken during an on-course flight at Pittsburgh in airplane NC-80. The 63-megacycle vertically polarized range was in operation and the receiving antenna was the one-quarter wavelength vertical whip shown in figure 34 The plane was equipped with a medium high frequency reel antenna which was fully reeled out when the recorder was started The recording shows successive resonances in the tuning as the high-frequency antenna was being reeled in

Figure 51 shows the characteristic of the same antenna taken at another time The high-frequency transmitting antenna was of the trailing wire type and the wire was reeled out to a point between the resonance peaks shown in figure 50 A 30-inch copper foil counterpoise was installed underneath the fabric in the roof of the plane below the whip antenna The same general trend in the clockwise and counter-clockwise curves is noted as in figures 48 and 49, but for some reasons the null in the clockwise pattern was deeper in these measurements The measurements were repeated with the trailing wire reeled out to conform with a resonance peak (fig 50), and the resulting curves of this test are shown in figure 52 The trailing wire had very little effect on the contours, although slight improvement is seen with the trailing wire tuned.

Figure 53 shows the characteristic of the one-half wavelength antenna which is shown just forward of the rudder post in figure 34 Although the characteristic of this antenna is reasonably good and without deep nulls in any direction, this antenna gave bad propeller modulation, having been located about one wavelength behind the propeller.

In figure 54 is given the characteristic of a 125-megacycle whip antenna located in the position shown in figure 34 This characteristic was very uniform over the tail and about 60° to either side of the tail and, in general, was not affected greatly by the banking of the plane

The characteristic of the 125-megacycle horizontal loop is given in figure 55. The loop and methods of mounting below the belly of the plane are shown in greater detail in figure 34. The average curve shows maximum variations of about 9 decibels. A slight difference was observed in clockwise and counter-clockwise rotation. In the clockwise turn the landing gear shielded the loop with the right wing toward the station, and in the counter-clockwise turn the landing gear shielded the loop when the left wing was toward the station.

The above representative cases show that it is difficult to predict the antenna characteristic pattern which may be expected of any given type airplane. On all occasions, however, the shielding effect of wing and landing gear structures was apparent when these structures became interposed between the transmitting stations and the receiving antenna, and was very marked in the case of the Douglas airliners. Although this effect might be considered detrimental during orientation maneuvers, it is conceivable that the reverse may be true. It may provide an indication of the direction of the station from the aircraft.

TESTS ON 125 MEGACYCLES USING PURE HORIZONTALLY POLARIZED LOOP ANTENNAS

Following the previously described tests, and as a result of the development of a pure horizontally polarized ultra-high-frequency loop antenna[9], in connection with the Civil Aeronautics Administration radio instrument landing system,[10] greater impetus was received in furthering the radio range development on 125 megacycles with horizontal polarization. It was apparent that if radio ranges could be developed in the 125-megacycle band, a single-band ultra-high-frequency receiver might be used for ranges, instrument landing localizers, and airport traffic control, thereby simplifying and reducing the cost and weight of the aircraft installation. In view of these facts, several experimental installations were set up at Indianapolis using various combinations of pure horizontally polarized loop radiators mounted on a counterpoise structure 30 feet high.

Theoretical Discussion

An important part of the development of a radio range is the design of the antenna system. When the size of the radiating elements is small, compared to a wavelength, relatively close spacings may be used and satisfactory field patterns produced. The perfect crossed figure-of-eight pattern consisting of four circles (see fig. 44) is the optimum shape that can be obtained when only two pairs of elements are used to produce a four-course range. The circles are approached only when the spacing of the elements is small compared to a wavelength. The loop type antennas which have been developed to radiate pure horizontally polarized waves have dimensions which are an appreciable portion of a wavelength. The physical size of the loop radiators precludes a system in which the elements are spaced less than 70 electrical degrees. Electrically it is difficult to use spacings smaller than 130° because of complications brought about by coupling between the elements. In order to use this type of radiator to produce a four-course range, it was found desirable to depart from the conventional four-element antenna system and the essentially circular patterns which it produces.

An antenna system of five loops can be set up to radiate a wide variety of field patterns. The shape of the field patterns is controlled by adjustment of the independent variables of the array, namely, spacing of elements, currents in the elements, and phase relationships of the various currents. It is obvious that there are many possible combinations of adjustment and that some combinations are not

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[9]Andrew Alford and A. G. Kandoian, "Ultra-High-Frequency Loop Antennas," Trans. A. I. E. E., January 1940.

[10]W. E. Jackson, A. Alford, P. F. Byrne and H. B. Fischer, "The Development of the Civil Aeronautics Authority Instrument Landing System at Indianapolis," Trans. A. I. E. E., December 1939.

applicable to the four-course range As with the four-element antenna, the course results from alternately radiated overlapping field patterns A range with reciprocal courses at right angles permits a symmetrical placement of radiators and an economical and practical method of feeding them

In the present state of the art, course alignment other than the above requires considerably more complex feeding networks Such systems are beyond the scope of this discussion Let us consider a configuration of five radiators in which four are located in the corners of a square with the fifth in the center. The centrally located radiator is to be fed continuously with constant current and will be considered the reference point with respect to phase relationship of the other elements Diagonally opposite elements may be interlock keyed Figure 56 is a diagram of such an arrangement The advantages gained by the use of five radiators are (1) possibility of wide spacings suitable for relatively large loop type elements, (2) increased course sharpness, and (3) increased percentage of signal in the on-course region

The field patterns of elements spaced more than 180 electrical degrees are apt to have secondary lobes, and careful consideration must be given to the vertical as well as to the horizontal patterns in designing a radio range antenna array It is possible to tune an array to produce excellent range characteristics at low angles and yet have quadrant reversals at high angles well outside the cone-of-silence. Such a condition cannot be tolerated when the reversal takes place well outside the cone-of-silence zone.

An analysis of the descriptive geometry of various radiation characteristics reveals that two distinct types or families of field patterns may be obtained First let us consider point source radiators and free space patterns Two radiator elements fed in phase opposition yield the first family When the spacing between the radiators is small, the space pattern radiated resembles two tangent spheres with their collinear axes coincident with a line joining the radiators. As the spacing between the radiators is increased, these spheres become oblate along the line joining the radiators until, at about 180°, the radiation along this line begins to decrease, reaching zero at 360° spacing. At all times the field in the plane midway between the radiators and perpendicular to their axes is zero Let us call this type of pattern Type I (see fig 57) The second type of pattern is radiated by two elements fed in-phase When the elements are very close together the pattern is spherical, but as they are moved apart, this pattern becomes condensed along a line joining the two radiators, forming a toroid when the spacing is one-half wavelength At spacings greater than one-half wavelength a secondary lobe appears along the line joining the radiators and increases to predominate in cross sections at 360° The field in the plane midway between the elements and normal to a line joining the elements is always maximum Let us call this family of patterns Type II (see fig 57)

Comparison of the drawings of space field patterns of the two types shown in figure 57 will clarify this classification In these three dimensional plots a quarter-section has been cut away to show more clearly the form of surfaces obtained At any angle the field strength is proportional to the length of the radius drawn to the surface of the solid

Introduction of a third radiating element in-line and midway between the two previously considered elements, and fed either at 0 or 180° phase with one (or both) of them, may yield radiation patterns of either type or a combination of both. By proper manipulation of the three variables (spacing, current phase, and current amplitudes) of the array, a wide variety of shapes may be obtained

In a radio range, it is desirable to radiate a high percentage of signal on-course in order to provide maximum service along the course At the same time it is desirable to reduce the percentage of signal radiated toward the center of the quadrant in order to minimize the possibility of reflections from local objects At a distance where the angle of elevation is low, only the horizontal field pattern need be considered and either the Type I or the Type II field pattern is suitable

Considering higher angle radiation, field patterns of this first type will not retain these characteristics, the maximum signal at high angles will be in the center of the quadrant Patterns of the second type, on the other hand, will retain the high percentage of on-course signal at all angles of elevation, but, at high angles near the cone-of-silence, quadrant reversals may be encountered

In practice we cannot have point source radiation and we cannot assume free space patterns The antenna "form factor" and "ground factor" must be considered in the calculation of the vertical plane radiation patterns These factors may be used to advantage to improve the cone-of-silence region It must be emphasized, however, that if quadrant reversal occurs at a given angle, that angle cannot be changed by manipulation of these factors The loop type radiators used during this development have a form factor which produces a cone-of-silence regardless of the vertical pattern of the point source array Various ground factors are obtained by adjustment of the height of the array above ground. For instance, placing the array one-half wavelength above the ground (or counterpoise) will reduce the signal at high angles, but placing it one-quarter wavelength above ground will reinforce high-angle signals If an array can be designed which possesses all the desirable characteristics mentioned but has quadrant reversal at very high angles, this effect may be made unobjectionable from a navigational viewpoint by widening the cone-of-silence The reversal will then occur when the signal is very weak, or probably inaudible The manner in which such a field pattern may be obtained will be discussed later

Let us start with the derivation of the simple expressions for radiation patterns of the first type in which there is zero field in the plane normal to a line joining the elements Consider first three radiators in-line, spaced S electrical degrees apart This is the same situation as in a five-element antenna in which one pair of loops is tuned to be inactive when not fed directly through the interlock relay If the currents in the active outside elements are equal and in-phase, the current in the center element is equal to the sum of the currents in the outside elements and 180° out of phase with them The expression for the relative field produced at a distance, D, may be written

$$F_p = N\frac{MG}{D}\left[\cos\,(S\,\cos\theta)\,\cos\phi\,-1\right]$$

For point source radiators in free space, the factors M and G are unity When loop antennas are used and mounted on a counterpoise above ground

- F_p = relative field strength at distance, D, when D is sufficiently great that S/D is very small.
- N = a constant
- M = the antenna form factor in the vertical plane which for loop radiators may be considered equal to cos ϕ
- G = the ground factor which, as explained below, may have two values

$$G_1 = \sin\,(h_1 + h_2)\sin\,\phi \quad \text{when } \phi < \tan^{-1}\frac{h_2}{R}$$

$$G_2 = \sin\,(h_2 \sin\phi) \quad \text{when } \phi > \tan^{-1}\frac{h_2}{P}$$

- S = the spacing from outside elements to the center element in electrical degrees
- h_1 = the height of the counterpoise above ground in electrical degrees
- h_2 = the height of the antenna above the counterpoise in electrical degrees
- R = the radius of the counterpoise in electrical degrees
- θ = the azimuth angle measured from a vertical plane passing through the array

ϕ = the elevation angle from the horizontal plane

The two values of the ground factor are based on the assumption that at elevation angles less than $\left(\tan^{-1}\frac{h_2}{R}\right)$ at which reflection takes place from the ground, only G_1 applies At elevation angles greater than $\left(\tan^{-1}\frac{h_2}{R^2}\right)$ at which reflection takes place from the counterpoise, only G_2 applies Strictly there is not an abrupt change in this factor at the critical angle Imperfect reflection at the edge and diffraction over the edge of the counterpoise cause a gradual change in the interference pattern produced Computation of the pattern in this region is of purely academic interest At any given installation slight irregularities in terrain make any mathematical analysis of the situation only approximate The ground factors are based on the approximation that the reflection coefficients of both the earth and the counterpoise are unity, and the phase change at reflection is 180°

Figure 58 shows several curves representing the field patterns in the horizontal plane, plotted in rectangular coordinates, for the three-element array arranged with various spacings of elements. Figure 59 is included to show comparative theoretical patterns of a two-element antenna (four-element range) The pattern for 60° spacing approaches a figure eight consisting of two circles However, this spacing is physically unattainable because of the size of the loop type antennas All the patterns of the three-element array are superior to those of the two-element array in course sharpness and ratio of on-course to maximum quadrant signal

From figure 58 it is seen that the course sharpness decreases while the ratio of on-course signal to maximum signal increases with increased spacing At spacings beyond 180° the pattern provides decreasing radiation in the off-course region Curve 1 of figure 58 is considered the best compromise between these factors and shows a very desirable field pattern for radio range operation

Now let us consider the five-element array which comprises the complete range antenna fed as shown in figure 56 A slight improvement of the on-course signal may be obtained by feeding a small amount of current into the idle loops in phase with the main outside loops (for instance, parasitically). When this is done, a small secondary lobe appears in the vertical pattern This is of minor importance if the ratio of this current to that in the main loops is kept small so that any quadrant reversal occurs within the cone-of-silence region At the same time the phase of the center loop may be changed slightly from 180° The resulting expression for the field pattern is:

$$F_p = \frac{NMG}{D}\left\{4\left[K_1 \cos(S\cos\theta)\cos\phi + K_2\cos(S\sin\theta)\cos\phi\right]^2 + 4\cos\psi\left[K_1\cos(S\cos\theta)\cos\phi + K_2\cos(S\sin\theta)\cos\phi\right] + 1\right\}^{\frac{1}{2}}$$

where K_1 = the ratio of the current in the main outside loops to current in the center loop

K_2 = the ratio of the current in the secondary outside loops to that in the center loop

ψ = the phase angle of the center loop with respect to the corner loops The corner loops are all in phase

Figure 60 represents the field patterns of the original three-element array with different phase angle adjustments. It is evident that the optimum phase angle is 180° Figure 61 represents field patterns of a five-element array spaced 180° from center-to-corner elements, the corner elements fed in-phase and 180° out of phase with the center element These curves are for various current ratios Curve 4 is included for comparison with the most desirable combination using a three-element array With the five-element array, there is a slight gain in both the course sharpness and the ratio of on-course to maximum signal There is also a desirable decrease in the ratio of the signal 45° off-course to the maximum signal However, the secondary lobes in the horizontal plane must be considered In the worst case, the secondary lobe is only 10 percent of the complementary signal This effect occurs in the centers of the quadrants and within an angle of 15° In the patterns represented by curves 1 and 2 the effect is within 6° and 10°, respectively, and of such magnitude as to be undetectable in an aural range system

The effect of these lobes in the vertical plane is of major importance Figure 62 represents the free space range signals in the vertical plane for point source radiations. The two sets of curves are for azimuth angles of 0° and 40°, corresponding to center-quadrant and 5° off-course flight, respectively The curves correspond to the horizontal pattern of figure 61, curve 2 This particular set of adjustments gives quadrant reversal at elevation angles of 57° and 59° for center-quadrant and 5° off-course flight, respectively. As previously explained, this effect is not a function of the antenna form factor or the ground factor

Figure 63 is calculated for the same array as figure 62 but includes the antenna form factor and ground factor It is seen that the quadrant reversals occur at nearly the same angles Although the maximum signal is in the center of the quadrant at very high angles, the percentage of the signal on-course is always quite high

The criterion of the allowable magnitude of this quadrant reversal effect is the actual signal received in the airplane while the plane is passing through the cone-of-silence region Figure 64 shows calculated values of signal strength as would be received in an airplane flying through the cone-of-silence along the middle of the N quadrant at an assumed altitude of 2,000 feet Computations for this figure were based on an antenna array tuned to produce the horizontal pattern of curve 2, figure 61 The computations for these curves were made assuming loop type transmitting antennas one-half wavelength above ground and a receiving antenna having characteristics of a horizontal loop in free space with linear detection. In this case quadrant reversal takes place at a horizontal distance of 1,400 feet from the station At this point the signal strength is 16 decibels down from maximum and rapidly decreases as the station is approached

If we assume an air speed of 150 miles per hour (220 feet per second), the total duration of the effect will be 12 7 seconds, about 6 seconds of which the signal will be below audibility because of the cone-of-silence Under these conditions, between one and two A-N interlocks will be received on each side of the cone Under normal conditions the effect would not be detectable because of the precise flying required to distinguish the effect from that heard when a normal cone is missed by a short distance It can therefore be said that there is a definite limit to the allowable parasitic current in the idle loops The high-angle quadrant reversals caused by such currents may be undetectable while the increase of signal on-course is a slight advantage The course sharpness obtained with this tuning is slightly greater than that obtained from an antenna with greater spacing giving the same ratio of on-course to maximum signal but without parasitic current in the idle loops Curve 3 of figure 61 may be said to be the limiting case If the parasitic currents are greater than in this case, the quadrant reversal effect may be considered undesirable

Figure 65 is similar to figure 64 but is calculated for the antenna adjustment producing the Type II pattern, the horizontal field of which is shown in figure 66 Here it is seen that the quadrant signal reverses approximately 1,400 feet before the maximum signal is reached, which is more than one-half mile from the station during flights 2,000 feet above the ground When the same assumptions are made as before, between six and eight reverse signals will be heard each side of the cone The incorrectly identified area in this case is of sufficient size to cause difficulty in orientation over the station Because of this, the otherwise highly desirable antenna adjustment cannot be used Quadrant reversal along the center of the quadrant occurs at 32 5° elevation

The characteristics of the four- and five-loop arrays are shown in table 1 Elevation angles at which quadrant reversal takes place are given for flights along the middle of a quadrant In all cases the data are calculated in accordance with

Table I

Tabulation of Various Characteristics of Four-Loop and Five-Loop Radio Range Antenna Arrays						
Figure	Antenna Type Curve	Course Sharpness (db/degrees)	On-course max signal (percent)	Center-Quadrant max signal (percent)	Max Signal degrees off-course	Quadrant Reversal (degrees elevation)
60	1	0 18	88	100	45	None
	2	0 20	80	100	45	None
	3	0 24	77	100	45	None
	4	0 30	71	100	45	None
59	1	0 25	92	92	12.5	None
	2	0 30	81	100	45	None
	3	0 35	76	100	45	None
	4	0 40	70	100	45	None
61	2	0 30	80	100	45	None
	3	0 31	82 5	100	45	None
	4	0 32	84	100	45	None
62	1	0 26	93.5	82	10	55
	2	0 27	93	81	10	59
	3	0 29	92	80	10	63
67	1	0 50	76 5	49	15	32 5

previously outlined theory, and the figures should not be confused with the experimental results described later

A review of the discussion indicates that it is possible to obtain very satisfactory ultra-high-frequency radio range operation when a three-element system adjusted as described for curve 1 of figure 58 is used Actually, the system providing operation as shown in figure 66 was tested prior to the other tests described herein However, it was found that the severe quadrant reversal effect could not be tolerated and tests proceeded or other combinations, as will be described later The discussion also indicates that a five-element array (five loops using parasitic current in the two idle loops) may be adjusted to give performance characteristics slightly superior to the three-element array (five loops with zero current in the two idle loops) These characteristics are shown in curve 2 of figure 61 The tests described later in this report will show the superior performance of the three- and five-element arrays over the original two-element (four-loop) system Figure 67 is included to compare the best possible combination using loop type antennas for each of the three systems (two-, three-, and five-elements)

It is not difficult to adjust either a three-element or a five-element array to produce any of the radiation patterns described The loops, figure 56, are mounted at the desired spacing and the center antenna is connected to the transmitter through its transmission line Before any lines are connected to the corner loops, each unit is individually tuned to resonance. This tuning is done by exciting the center loop and adjusting the stub, Q, or the desired corner loop until maximum current is obtained at the center of one of the loop sides. The remaining three corner loops are short-circuited during the tuning process One corner loop is then connected to the transmitter and the center loop is disconnected from its line and resonated

The five-loop system then may be connected as shown and the lines terminated by means of the terminating stubs, P At this point the length of the feeding lines A-B and C-D must be adjusted to exactly the same electrical length The current ratio of corner-to-center elements may then be set with the relay energizing loops A and B, while loops C and D are shorted, and the current in E is adjusted by means of the stub and tap at the sending end The same adjustment will be correct for loops C and D if the preceding adjustments have been made correctly The phasing of the corner and center elements may be determined by measurement of the field pattern. During these measurements it is very important that the idle loops be short-circuited. Correction of the phase relationships is made by means of the phasing line. When the connections are as shown, the line feeding the idle loops is open at the interlock relay. Adjustment of the length of this line permits independent adjustment of the impedance of the idle loops and hence the magnitude and phase of the parasitic current in them The phase relationship of the parasitic current to the current in the excited loops will depend on the distance of the parasitic loops from the excited loops and their tuning Manipulation of the length of the feeding line permits a reasonably wide range of conditions

When the spacing, S, is 180°, the phase and current relations shown in figure 61 are obtained when the loops are resonated It should be remembered that the system must be symmetrical When a three-element array is used, the same adjustment procedure is followed except that the currents in the idle loops are eliminated. The line lengths to the corner loops must be adjusted simultaneously It should also be emphasized that if the lines are not terminated properly, and if a standing wave exists along them, adjustment of the phasing line will change the magnitude of current in the load as well as its phase It has been found that actual field patterns taken at a distance of several wavelengths serve as an accurate check on the antenna adjustments Measurements so made eliminate the necessity of a person's working close to the antenna elements with the consequent probability of his disturbing the field pattern

Equipment

(a) Counterpoise and Tower

The tests described were all made with the antenna system mounted on a circular counterpoise of 1/2-inch-square galvanized iron mesh, 30 feet in diameter, and supported 30 feet above ground The structure was fabricated entirely of wood. A frame building located under the counterpoise housed the transmitter and associated equipment. Figure 68 is a view of the station

(b) Transmitter

The 125-megacycle transmitter used in this project was excited by an 807 oscillator-tripler controlled by a 5208.33-kilocycle crystal The oscillator was followed by an 807 doubler These two tubes and their power supply comprised the exciter unit, which was mounted in a relay rack with the keyer and the interlock relay rectifier The exciter was link-coupled to the transmitter proper by means of a flexible coaxial line The transmitter was built in a type TXI frame and consisted of two HK-54 (triode) doublers followed by a final amplifier consisting of two HK-254 triodes operated in push-pull Link coupling was used between each stage. The final amplifier tank was of the loaded transmission line type All other tuned circuits used coils and condensers The high-voltage power supply for the HK-54 and the HK-254 tubes was supplied by a bridge type selenium dry disc rectifier This rectifier was made up of 28 stacks of 32 plates each and supplied 1,650 volts to the transmitter It has proved excellent from the maintenance point of view The power input to the stage was 330 watts (unmodulated) The plates of the power amplifier were 90 percent modulated at 1020 cycles A block diagram of the transmitter is shown in figure 69 The high-voltage power supply was mounted in a second relay rack which was placed adjacent to and to the right of the exciter rack A third rack placed between the transmitters and the exciter rack was used as a frame to support the various radio-frequency networks used to feed the antenna system

Because of the remote location of the station, poor voltage regulation of the power source, and intermittent loads on the line, it was necessary to use a voltage regulator to secure satisfactory service This regulator was an automatic unit of three KVA rating which has no moving parts It had the very desirable characteristic of drawing but 300 watts when the output terminals were short-circuited, thus eliminating the need for heavy line fuses or circuit breakers. The normal operating characteristics were as follows. output voltage 110 volts plus or minus 1 1 volts with input voltage of 110 plus or minus 16 volts, full load power factor 90 percent and an efficiency of 85 percent

(c) Antenna and Transmission Lines

During the tests two methods of feeding the antenna were used The first consisted of a single concentric line run from the transmitter output circuit to the interlock relay The relay output was fed to balancing networks, and shielded two-wire transmission line was used for the remainder of the system Figure 70 is a schematic diagram of the arrangement This method was used only for the tests conducted with the four-loop antenna array. The second method consisted of dual line throughout. This balanced system was used with the five-loop antenna In order to make this possible, it was necessary to develop a suitable double-pole interlock relay. The double-pole relay was built from a standard interlock relay. It was, of course, necessary to redesign the contact system, and in the new design it was found possible to completely shield and isolate all radio-frequency conductors The parts were so proportioned that there would be a minimum of impedance discontinuity Figure 71 shows the contact mechanism of the relay.

As previously explained, the five-loop antenna required very exact adjustment of phase and amplitude of the various radiator currents A trombone type of adjustable phasing line was built to phase the corner loops with respect to the center loop. This line was built from telescoping tubing and was of such length that the phase could be varied over a range of about 120° The sizes of tubing used were selected so that the characteristic impedance of the section would be the same as that of the two-wire line Figure 72 is a view of the phasing unit and shielded interlock relay The dual interlock relay was mounted on the top of the relay rack with the phasing section directly beneath it.

The antenna array schematic shown in figure 56 was used This method of feeding was found quite satisfactory mechanically as well as electrically Because of the short duration of the tests no effort was made to maintain gas within the lines However, they were thoroughly dried out and sealed against the entrance of moisture Figure 73 is a view of the five-loop array mounted on the counterpoise

(d) Receiving Equipment

Field patterns in the horizontal plane were taken using a portable vacuum tube field detector Readings were taken at 10° intervals on the ground around an accurately staked circle of 240-foot radius Although there was some variation in ground level, it was possible to obtain accurate field patterns by compensating the height of the field meter

The airplane equipment consisted of a tunable ultra-high-frequency receiver and the Esterline-Angus recording milliammeter already described. A horizontal ultra-high-frequency loop antenna was mounted on top of the fuselage of airplane NC-80. This antenna was similar in design to that used in the instrument landing tests[11] and is shown in figure 74

[11]See reference 9 on page 14.

Tests

The tests conducted consist of two distinct parts The first part covered operation of the four-loop antenna system and the second part covered operation of the five-loop array Various combinations of phasing and current ratios were tested, and from the results an optimum set of adjustments was determined It should be mentioned at this time that the tuning operations were greatly simplified after the dual transmission line was used throughout the feeding system Although no serious difficulty was experienced in adjusting the single to dual line networks, they were found somewhat critical in adjustment At a frequency as high as 125 megacycles, short lengths of exposed conductors introduced appreciable reactances, and in an installation such as this, great care was necessary to preserve reasonable impedance relationships Shielding of the entire relay system was found necessary in order to keep radio-frequency currents from appearing on the outer surfaces of the lines The use of the dual transmission lines completely eliminated all these difficulties

Extensive flight and ground tests of both systems were made to determine the characteristics and service ranges for various adjustments A theoretical analysis of the cone-of-silence led to a thorough flight investigation of this region Recordings were made during these flights and reproduction of representative curves are included in this report A series of measurements was made to determine the effect of stringing wire along the members of the counterpoise supporting structure This was done in order to make the wooden tower simulate a steel structure Number 12 copper wire was used and strung on all four sides of the framework in vertical, horizontal, and diagonal directions. Both before and after application of the wire, it was not possible to detect any vertical component in the radiated signal around the station

In general, the experimental results agreed with the previously outlined theory The flight tests showed that the five-loop antenna was capable of producing more desirable characteristics and greater service range than the four-loop antenna Most of the data presented for the five-loop system are for conditions using five elements (parasitic currents in the idle loops) This is because the results obtained with this arrangement were slightly superior to those obtained with the three-element five-loop system All ground and flight measurements indicated that the most desirable adjustment of the five-loop antenna was that which corresponds to curve 2 of figure 61 Figure 75 is a plot of the measured horizontal field pattern of this adjustment of the antenna The calculated pattern is included for comparison Curve 2 of figure 59 approximates the horizontal pattern of the four-loop system, and figure 76 is a plot of the calculated and measured field The field pattern of the three-element five-loop system is very similar to the five-element five-loop system shown in figure 75

The range characteristics due only to propagation phenomena were the same for both types of antennas Because of the pure polarization of the signals radiated from the loop type antennas, the pushing and circling effects were reduced to a minimum In all cases both effects were much less than had previously been observed on ultra-high-frequency ranges The greatest pushing amounted to less than 1/2° (0.46 miles at a distance of 40 miles) and in most cases was too small to be measured It is possible that a large percentage of the pushing is due to the airplane installation There was no tendency at any time toward bent, multiple, or discontinuous courses The quality of the course signals was at all times excellent and contrasted strikingly with early attempts to produce a 125-megacycle range with crossed-dipole radiators Key clicks were almost undetectable both with single-pole and double-pole relays. Slight fades near the station were encountered but were of such a nature as not to confuse a pilot. The characteristics of the four- and five-loop systems are summed up in table 2

It is not possible to show directly comparable recordings of the various course characteristics because of the different weather and wind conditions under which they were made Figures 77 and 78 are cross-course records taken at distances of 15 and 31 miles, respectively, from the four-loop station A similar record for the five-element, five-loop antenna taken at a distance of 30 miles is shown in

Table 2

Tabulation of the Various Characteristics of the Ranges Using Four-Loop and Five-Loop Antennas

Four-Loop System		Five-Loop System	
Course sharpness Average width	3 5 degrees or slightly broader than the present low-frequency ranges (SBRA)	Average width	2 8 degrees or slightly narrower than the present low-frequency ranges
Cone-of-silence Average width	15 degrees each side of station, which is quite noticeably wider than the low-frequency ranges	Average width	20 degrees each side of station
Quadrant reversal	None	None in the 3-element system Detectable in the 5-element system only when receiver gain is very high and station is approached along exact center of quadrant For navigational purposes the effect may be called negligible	
Distance range	50 to 60 miles at an altitude of 1,000 feet over flat country	60 to 70 miles at an altitude of 1,000 feet over flat country	
Multiple courses·	None	None	

figure 79 Figure 80 is a recording made during a flight on-course over the station and shows the cone-of-silence characteristic of the four-loop antenna Figure 81 represents the on-course cone-of-silence characteristic of the five-element, five-loop antenna The surges and fades shown as the station is approached and passed are functions of both the height of the transmitting antenna (ground factor) and the characteristics of the airplane receiving antenna In this connection the ground factor is responsible for the two surges farthest from the station The surges near the station are caused by the receiving antenna The problems of antenna installation on tall towers will be covered in a subsequent report Figure 82 is a recording made during a flight through the cone-of-silence along a quadrant center The gain of the receiver was turned very high in order to show the quadrant reversal effect This recording shows the previously outlined theory remarkably well It was quite difficult to fly the range with sufficient precision to record the reversal It may be said conservatively that the effect is so minor that it may be disregarded This, however, cannot be said of the adjustments shown in figures 65 and 66 Although no actual recordings were made, flight observations indicated a very wide angle in which quadrant signals were reversed The diameter of the region was approximately 1 mile at an altitude of 4,000 feet

Figures 83 and 84 are included to give a comparison of the ultra-high-frequency range with the simultaneous low-frequency ranges now in use These figures are recordings made of the Indianapolis simultaneous range (266 kilocycles) through the cone-of-silence and across a course at a distance of 15 miles As a navigational aid, the five-loop system giving a high percentage of signal on and near the courses proved to be very desirable With the same input power to the transmitter, the on-course distance range was appreciably increased During orientation under the hood, it is very difficult to tell that the field pattern is not the same as that of the

Table 3

Radio Range Operation Considering
Undesirable Features

Undesirable Features		Radio Range Operation				
		63 Megacycles		125 Megacycles		
		V	H	V	H	HP
Multiple courses		Good	Good	Poor	Good	Good
Pushing and circling		Good	Poor	Fair	Poor	Good
Propeller modulation		Poor	Fair	Good	Good	Good
Flutter modulation		Fair	Fair	Poor	Poor	Good
Atmospheric static		Good	Good	Good	Good	Good
Rain static		Good	Good	Good	Good	Good
Ignition noise		Fair	Fair	Good	Good	Good
Ionosphere reflection		Fair	Fair	Good	Good	Good

V - Vertical Polarization

H - Horizontal Polarization (Crossed Dipoles)

HP - Horizontal Polarization (Pure UHF loop antenna)

present ranges because the ratio of A to N quadrant signals gradually approaches unity as the course is approached

The undesirable features of a radio range, together with the relative freedom from these undesirable characteristics obtained for the various types of antennas and frequencies tried, as reported in this paper, are shown in table 3

Conclusions

The following conclusions have been reached as a result of the ultra-high-frequency range tests described in this report

1 The 125-megacycle pure horizontally polarized aural radio range described in this report is the most satisfactory aural type ultra-high-frequency radio range that has been tested or developed by the Civil Aeronautics Administration

2. Both the three-element and the five-element pure horizontally polarized arrays are economical to install and easy to maintain. The three-element array provides very satisfactory results and is somewhat simpler in adjustment than the five-element system, which gives slightly sharper courses. Slight quadrant reversals appear in the cone-of-silence area with the five-element system which are not present with the three-element array

3 The five-loop system (either three- or five-elements) is more desirable than the four-loop system because it will provide increased course sharpness together with a 15 percent increase in field strength on-course

4 The optimum adjustments for the three-element and the five-element antenna systems as described herein are as follows

	Three-element	Five-element
Relative current in corner loops	1	1
Relative current in idle corner loops	0	0 36
Relative current in center loop	2	1 18
Phase angle between current in center loop and current in the corner loops	180°	180°
Spacing between corner loops	420°	360°

5 The results of this development show that the three-element system is the most desirable ultra-high-frequency aural range because of the absence of quadrant reversals in the cone-of-silence

6 Horizontal polarization is definitely superior to vertical polarization

7 The use of pure polarization, either horizontal or vertical, is essential in an ultra-high-frequency radio range system in order to reduce undesirable pushing and circling effects.

8 Pure horizontally polarized waves minimize the discontinuity of courses near the station

9 Tests indicate that the use of metal structures (instead of wood) for supporting the counterpoise and antennas will not introduce appreciable vertical component in the transmitted signals

10 The 63-megacycle vertically polarized antenna system is far superior to the 125-megacycle vertically polarized antenna system and is somewhat superior to the 125-megacycle horizontal crossed-dipole antenna Propeller modulation is the major disturbing effect at 63 megacycles

11. For equivalent antenna heights at 125 megacycles, the horizontally polarized crossed dipoles are definitely superior to the vertically polarized antennas with regard to the number of multiple courses Horizontal crossed dipoles exhibit more pronounced course pushing and slightly worse course discontinuity in the vicinity of the station but are subject to less flutter modulation of the received signal due to reflections from rough terrain

12 Very high antenna structures are undesirable because of the inability of a counterpoise, which is necessarily limited in size, to eliminate a multiplicity of low angle lobes There is, however, a very noticeable increase in distance range when high towers are used.

13 With the application of the ultra-high frequencies to the Civil Airways of the United States, it is expected that a wide variety of reflecting objects will be encountered In a few extreme cases it may be necessary to resort to specially shaped space patterns in order to reduce reflections and eliminate multiple courses In this respect the two-course radio range permits greater flexibility than the four-course range

14 The site requirements for the five-loop four-course range are not so rigid as those for the conventional four-loop range with figure-of-eight patterns With equivalent site conditions, satisfactory operation of ultra-high-frequency ranges may be obtained in either flat or mountainous terrain

15 Ultra-high-frequency radio ranges are far superior to the present low-frequency type with respect to atmospheric disturbances Very little interference to ultra-high-frequency range operation may be expected during extreme static conditions

16 In mountainous terrain the absence of multiple and bent courses makes the ultra-high-frequency radio range superior to the low-frequency range

17 The absence of ionosphere reflections on 125 megacycles makes this frequency superior to 63 megacycles from the interference point of view.

18 Aircraft receiving antennas having satisfactory characteristics are obtainable

FIGURE INDEX

TABLES

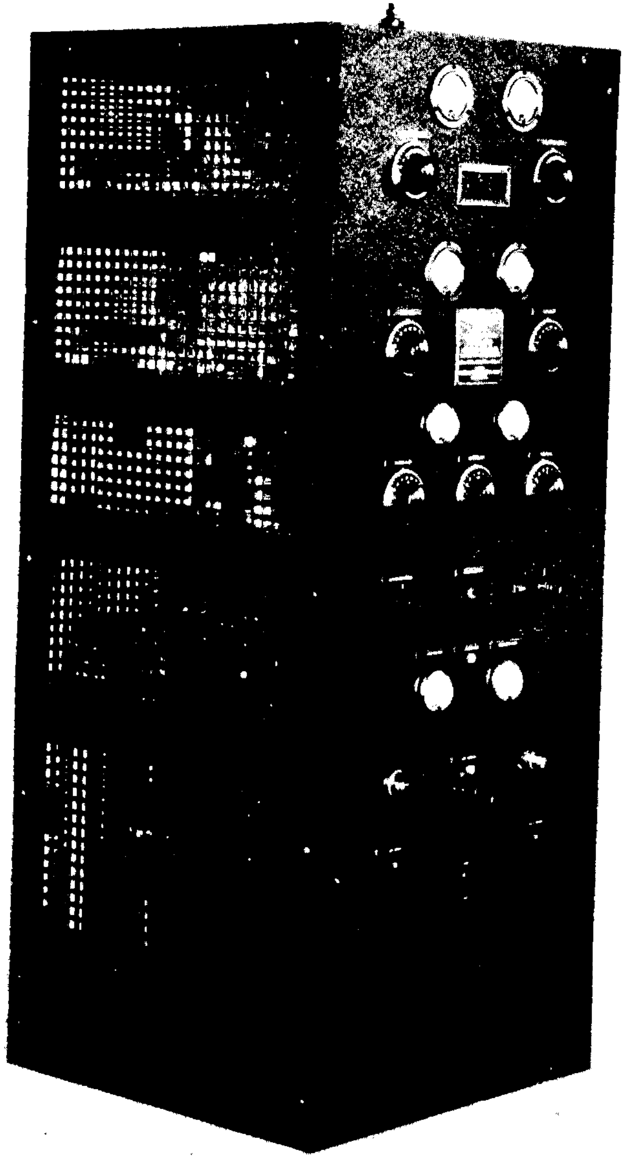

Figure 1. Type TXI Transmitter.

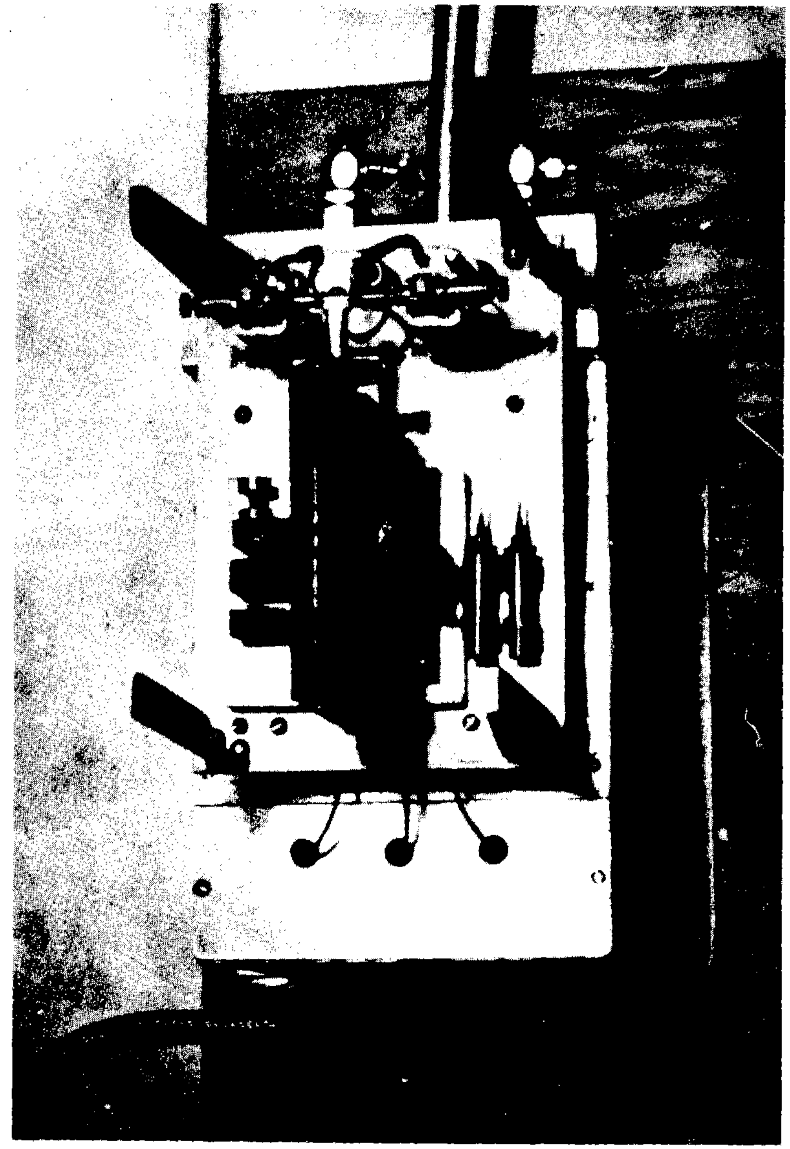

Figure 2. Interlock Relay.

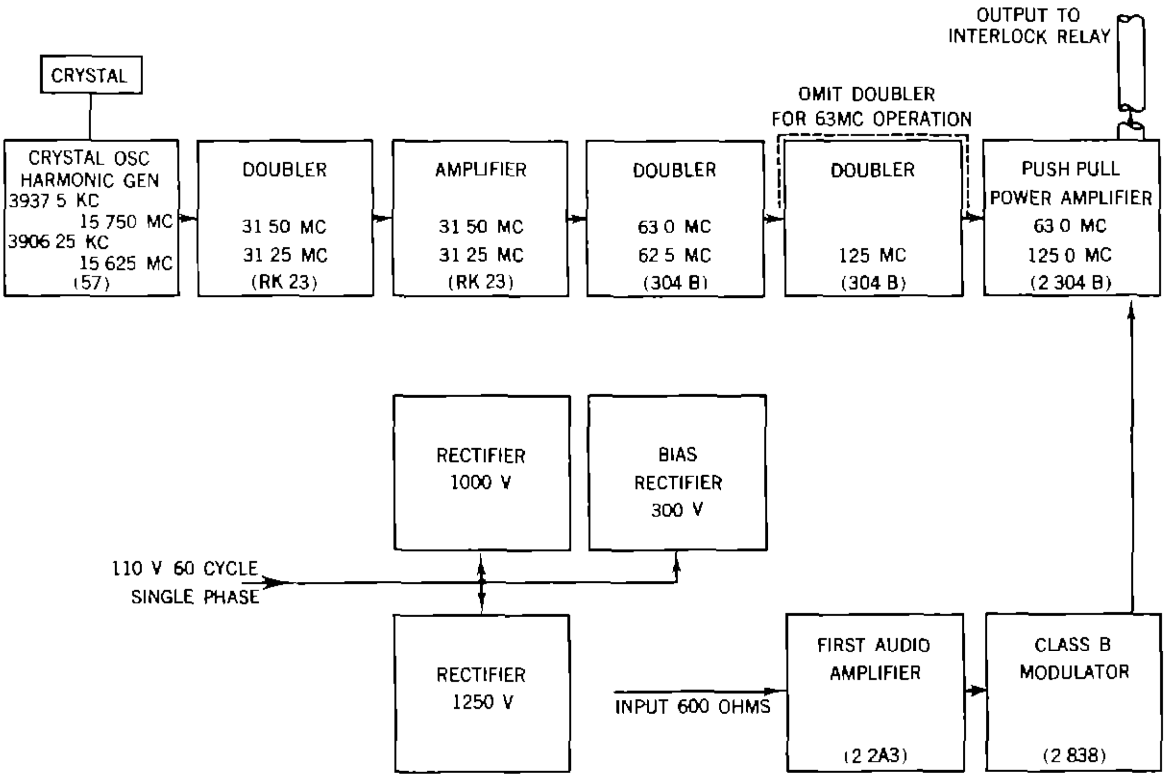

Figure 3 Block Diagram of the Type TXI Transmitter

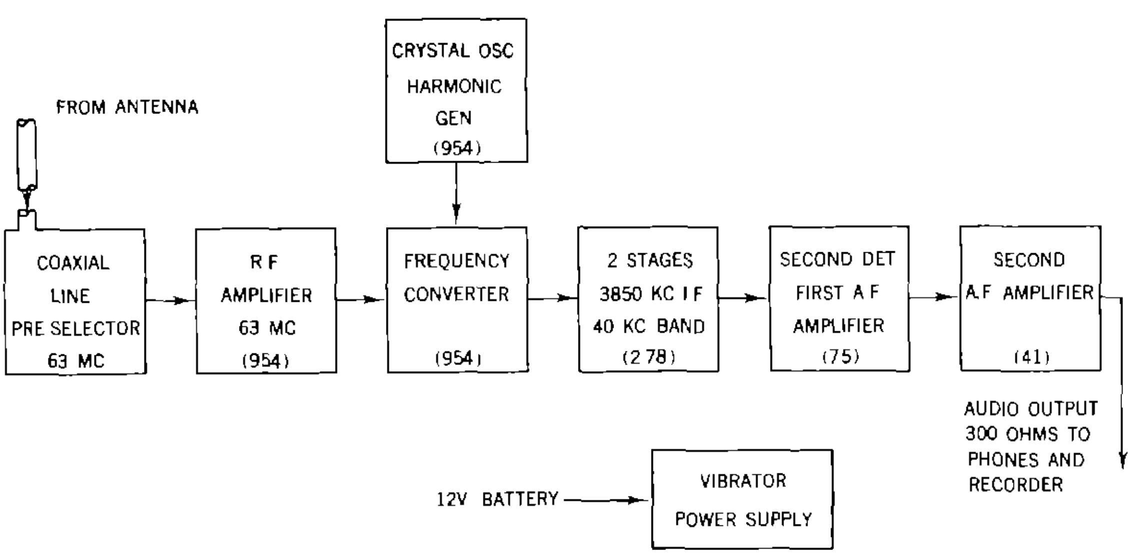

Figure 4 Block Diagram of the 63-Megacycle Receiver

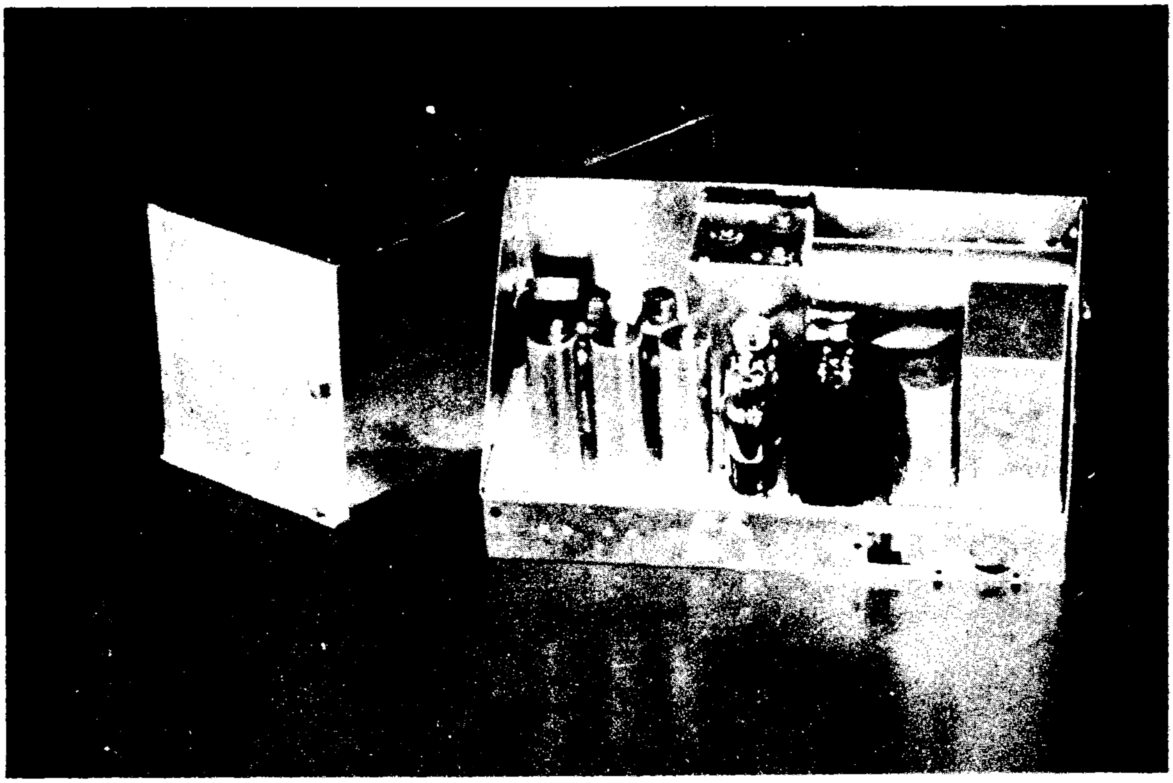

Figure 5. 63-Megacycle Aircraft Receiver.

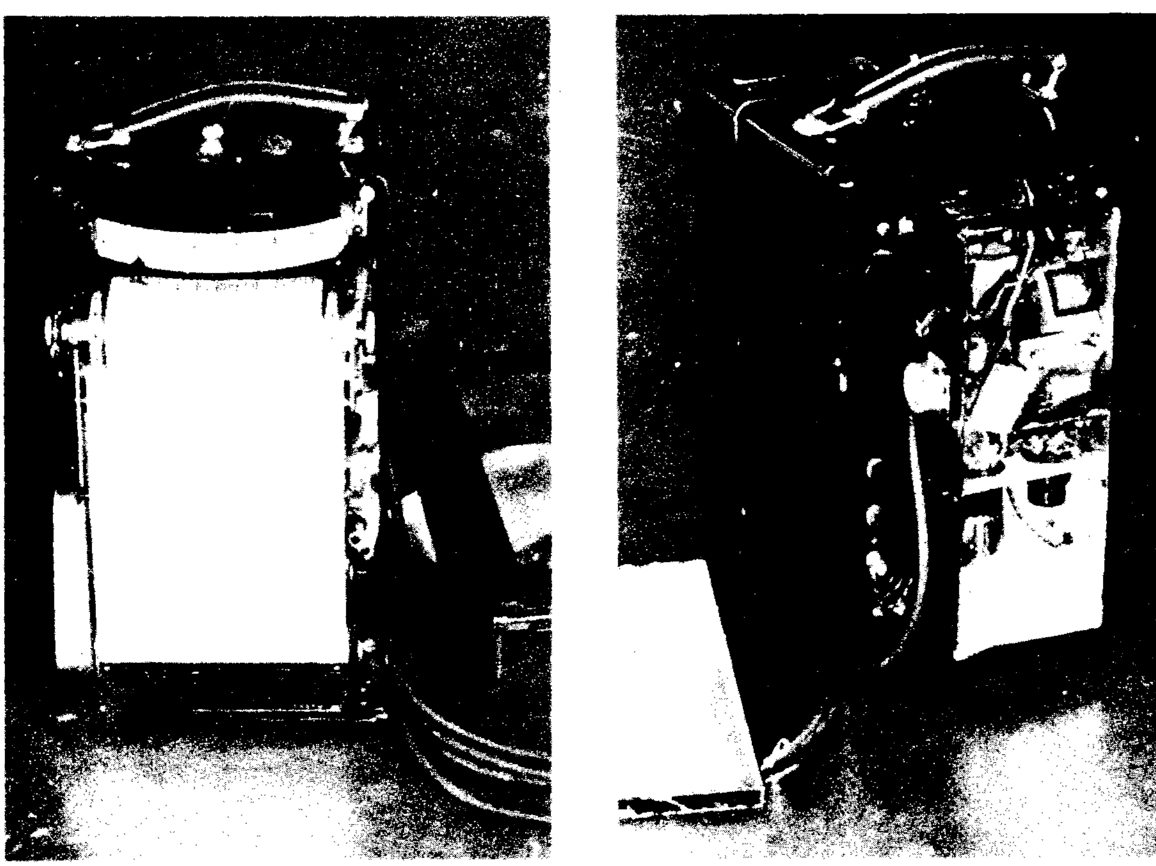

Figure 6. High Speed Graphic Recorder.

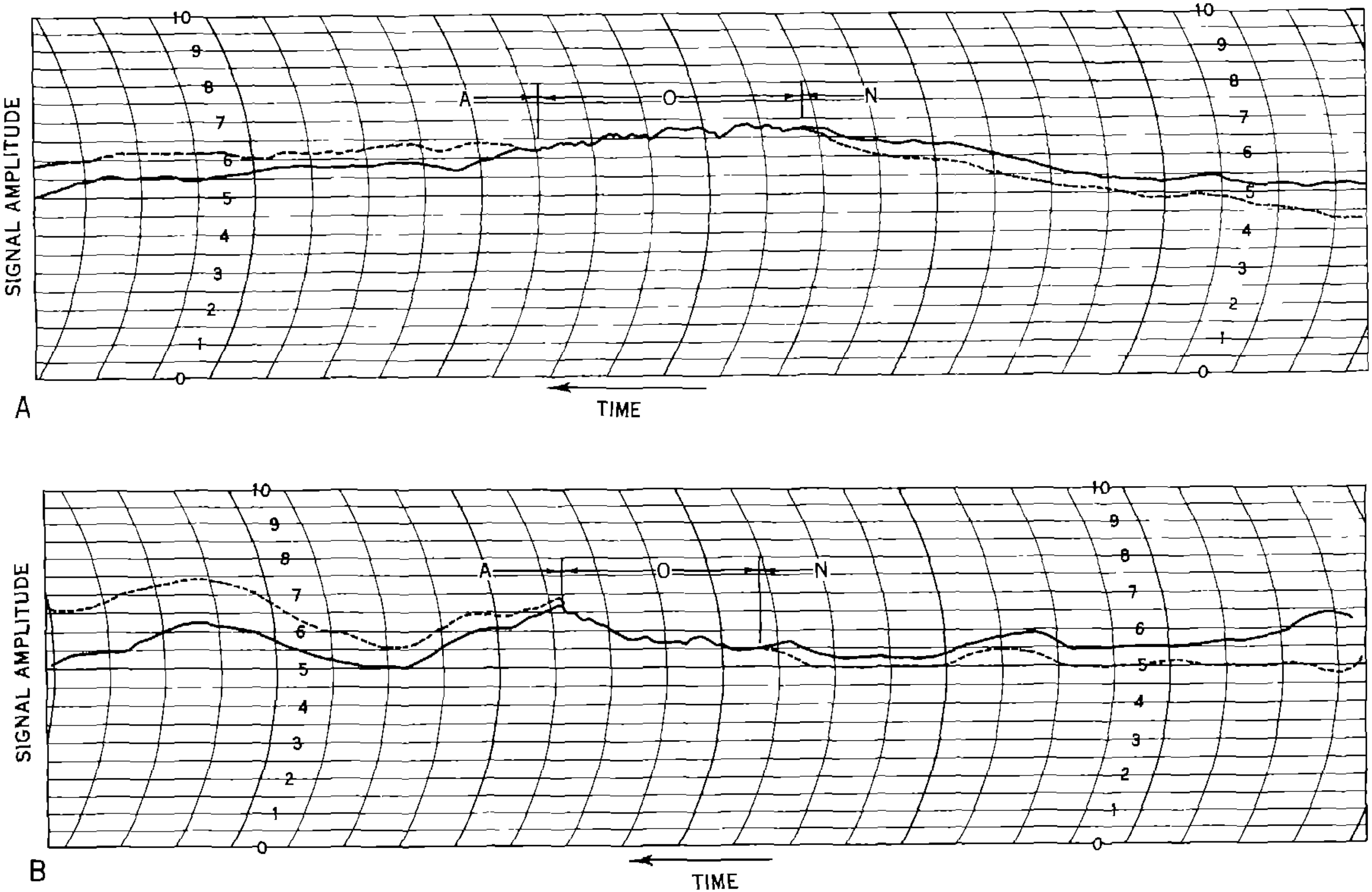

Figure 7 Recording, A, Taken on a Cross-Course Flight of the 63-Megacycle Range at 20 Miles, and Recording B, Taken on a Cross-Course Flight of the 63-Megacycle Range at 45 Miles

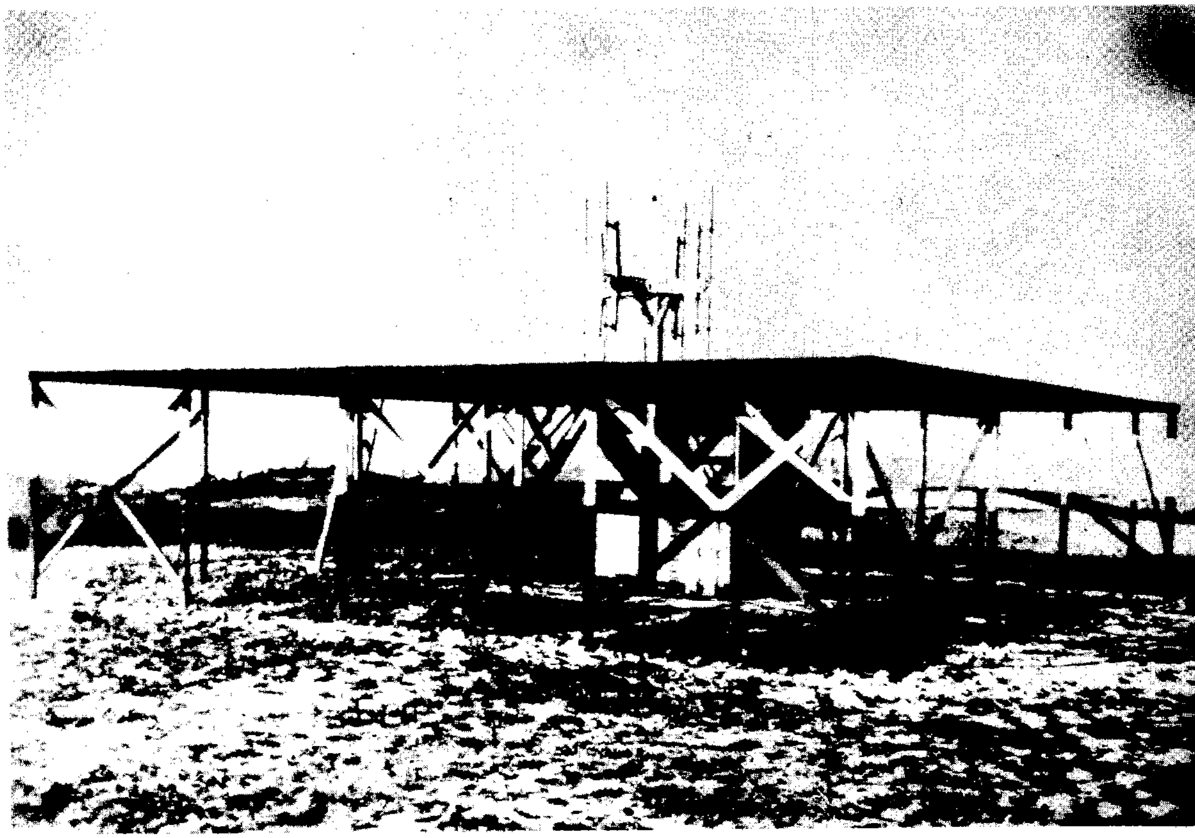

Figure 8. The 63-Megacycle Radio Range Installation at Pittsburgh, Pa.

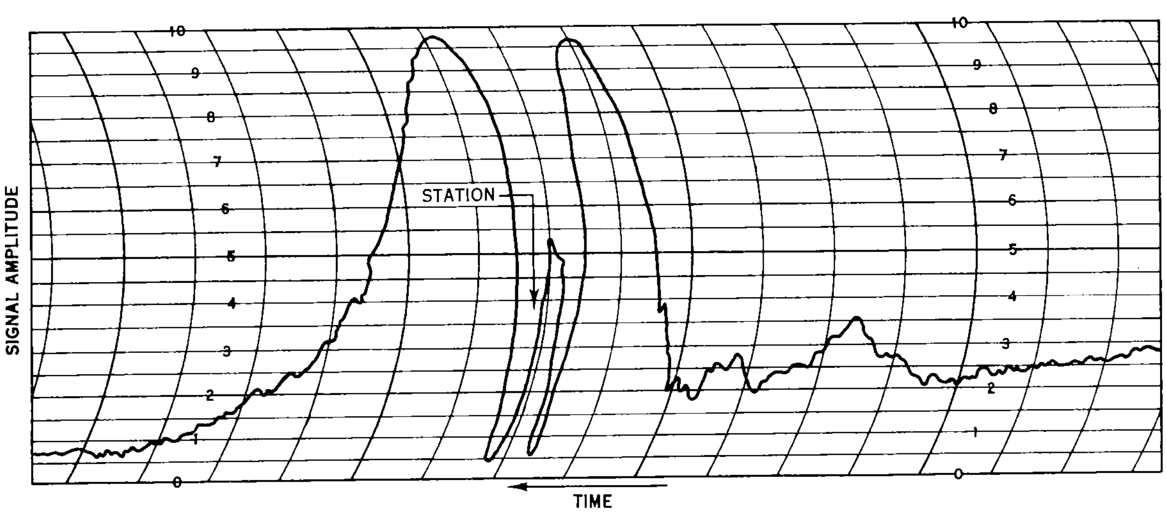

Figure 9. Recording of the Cone-of-Silence over the Pittsburgh 63-Megacycle Range, Antenna Above Counterpoise.

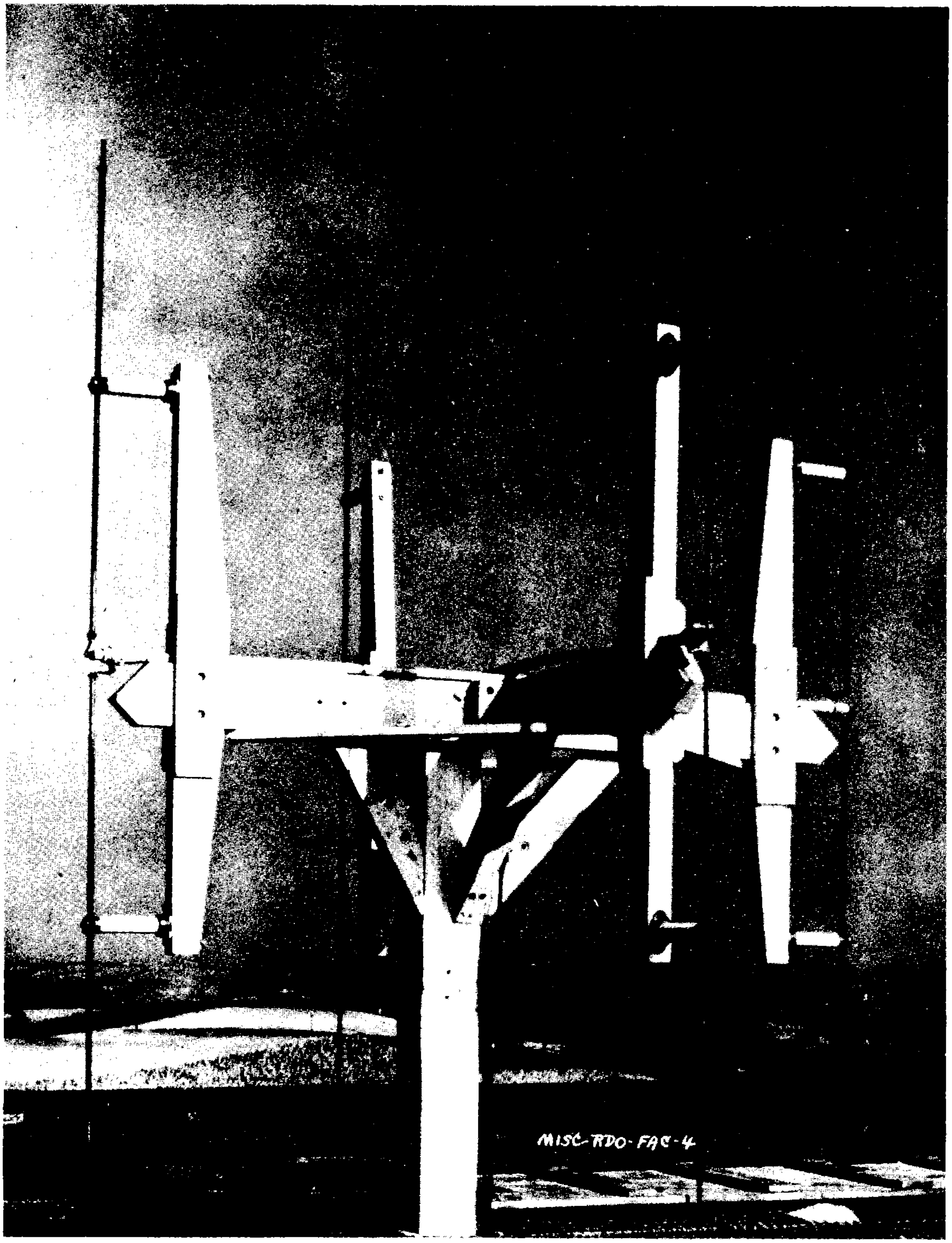

Figure 10. The Pittsburgh 63-Megacycle Vertical Radio Range Antenna System.

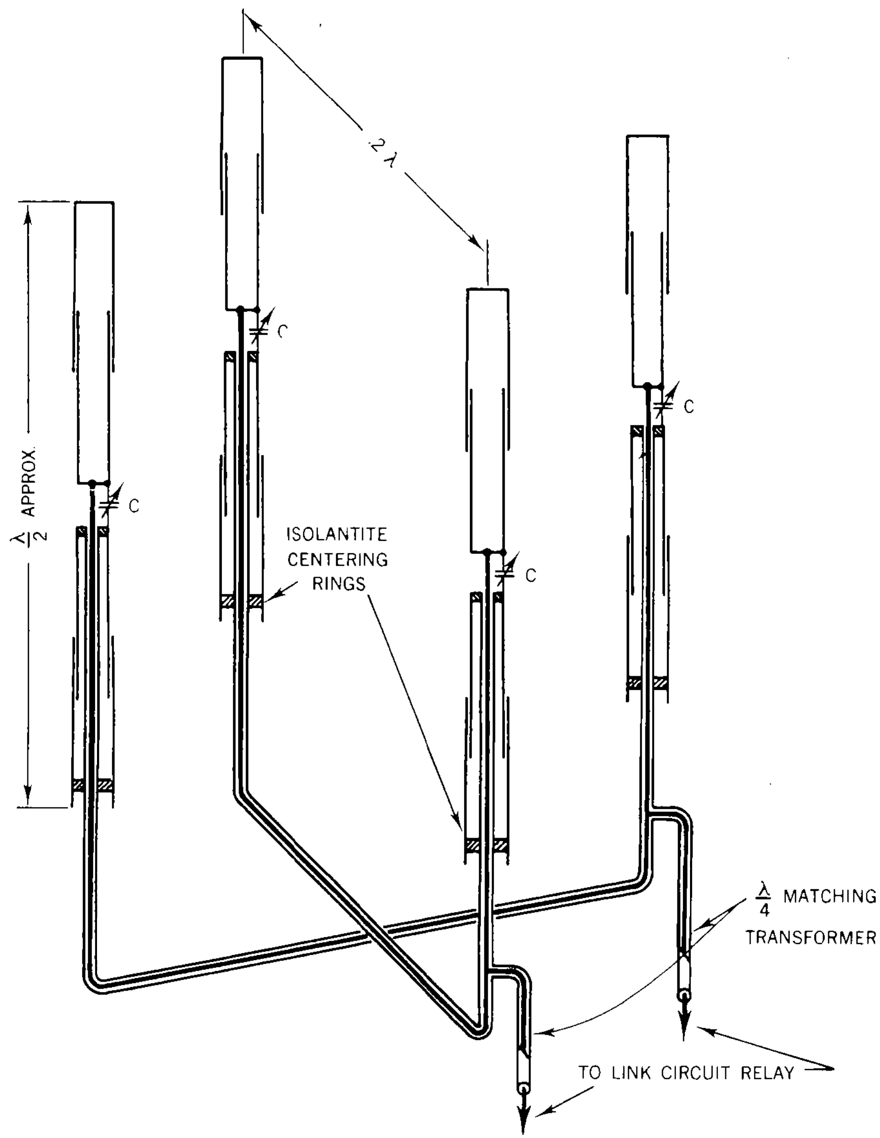

Figure 11. **Schematic Diagram of the Indianapolis 63-Megacycle Four-Course Antenna Array, Using End-Fed Coaxial Dipoles.**

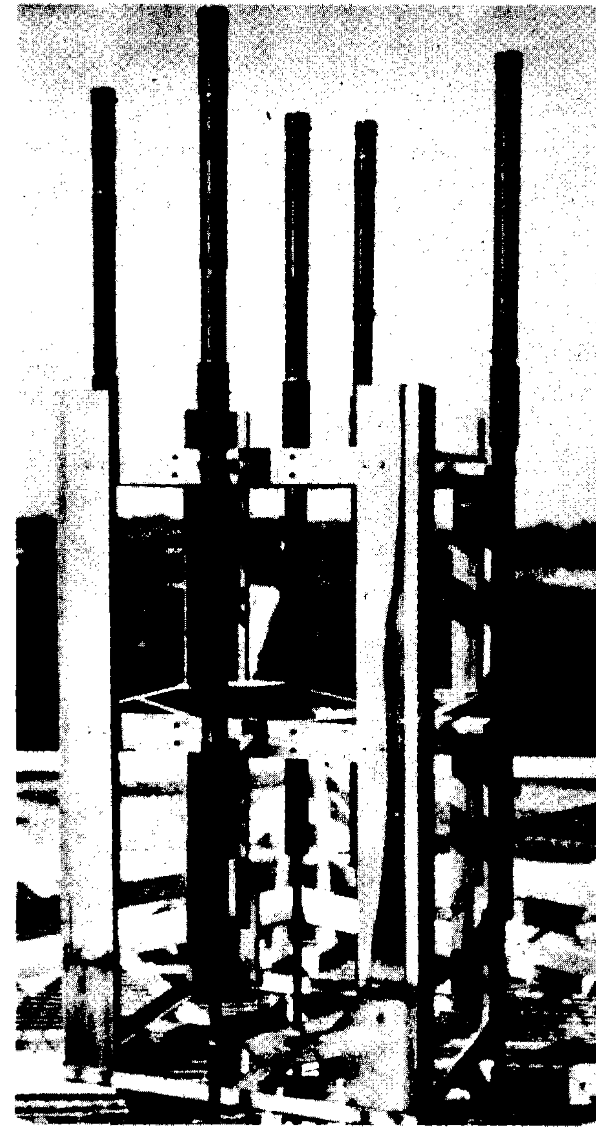

Figure 12. **63-Megacycle Vertical Radio Range Antenna System, Using Coaxial End-Fed Dipoles.**

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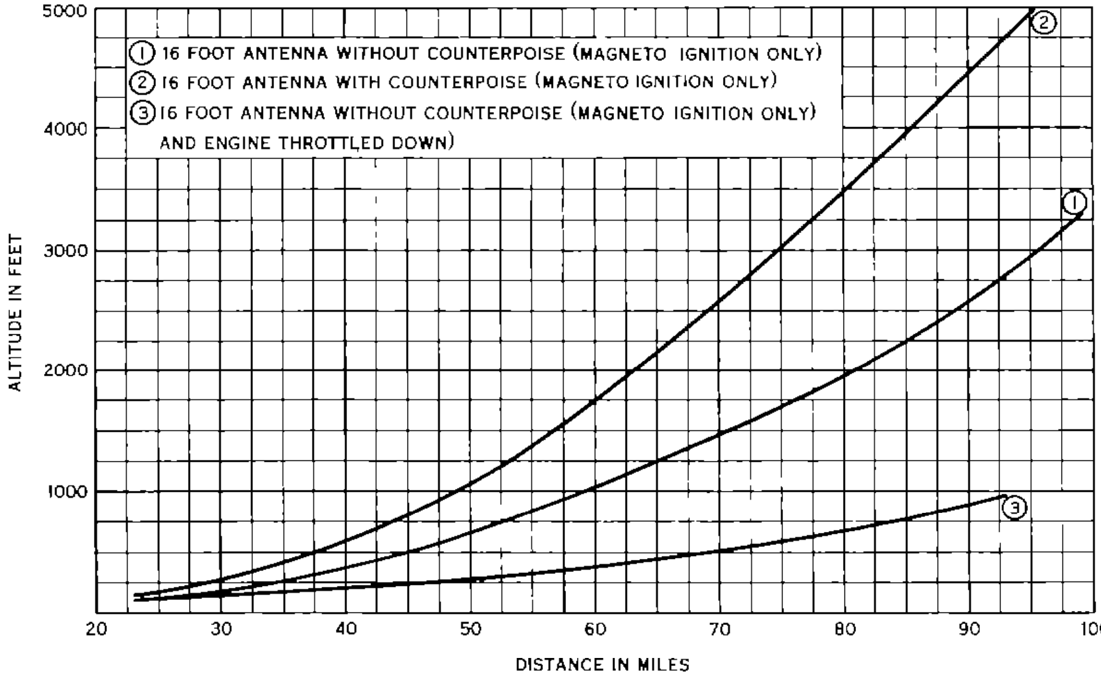


Figure 13 Curves of Distance Range vs Altitude, Indianapolis, 63 Megacycles

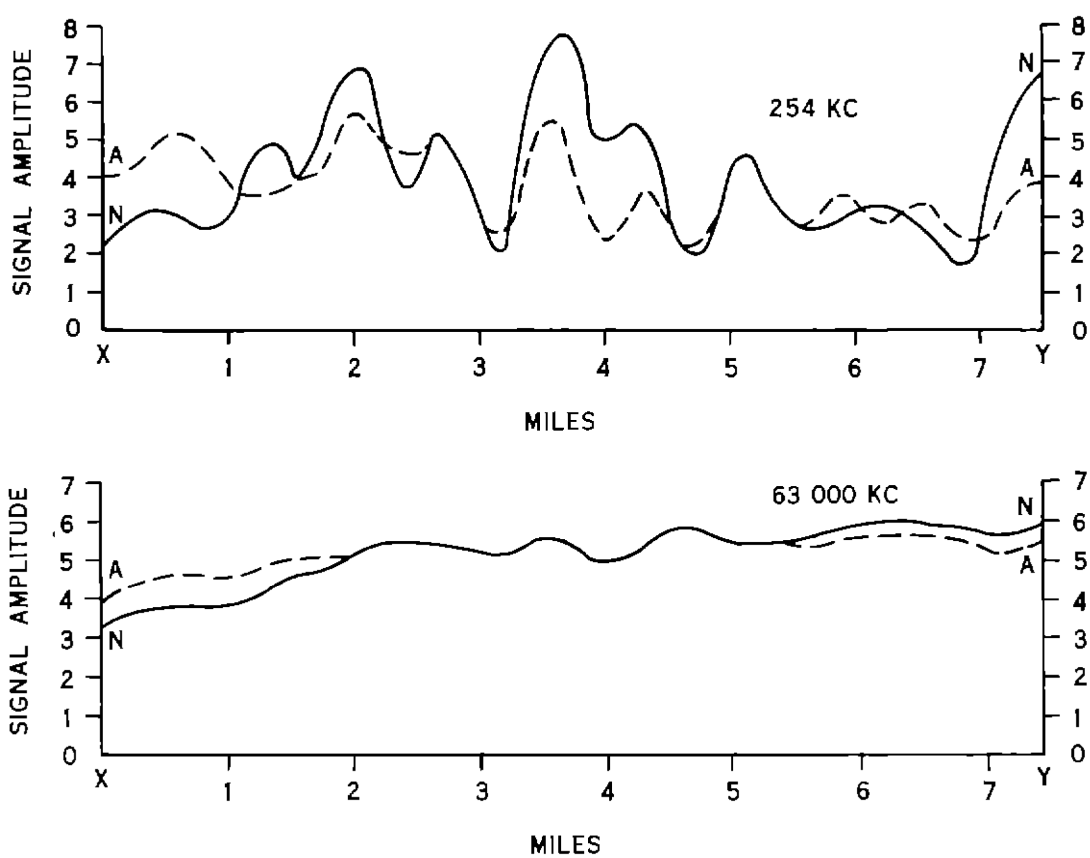


Figure 14 Recordings of Cross-Course Flights Taken 5 Miles from Pittsburgh Showing the Comparison Between the 63-Megacycle and 254-Kilocycle Radio Ranges

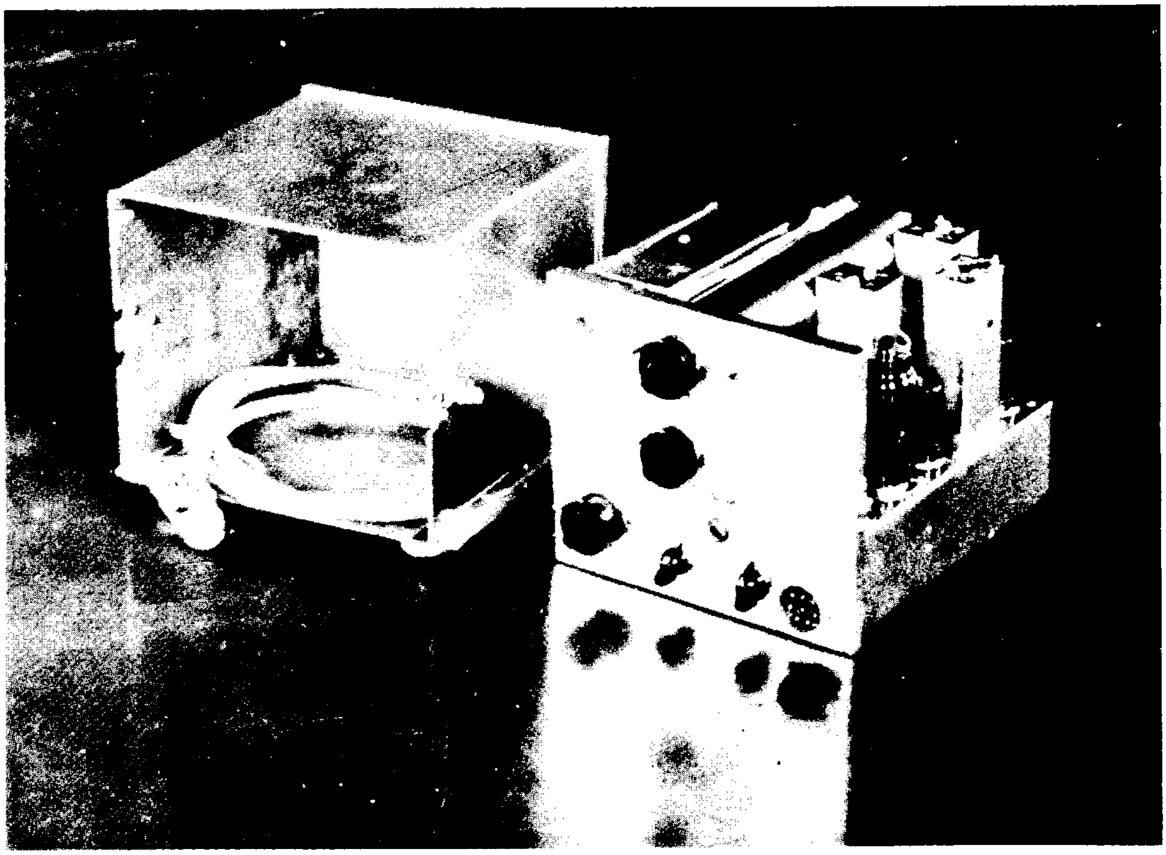


Figure 15. 125-Megacycle Tunable Aircraft Receiver.

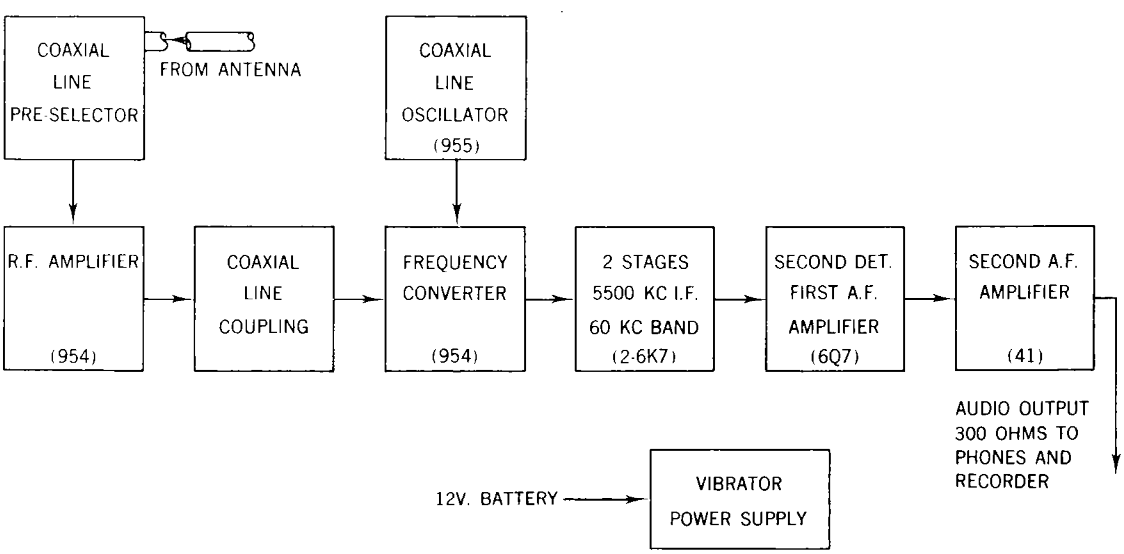


Figure 16. Block Diagram of the 125-Megacycle Tunable Receiver.

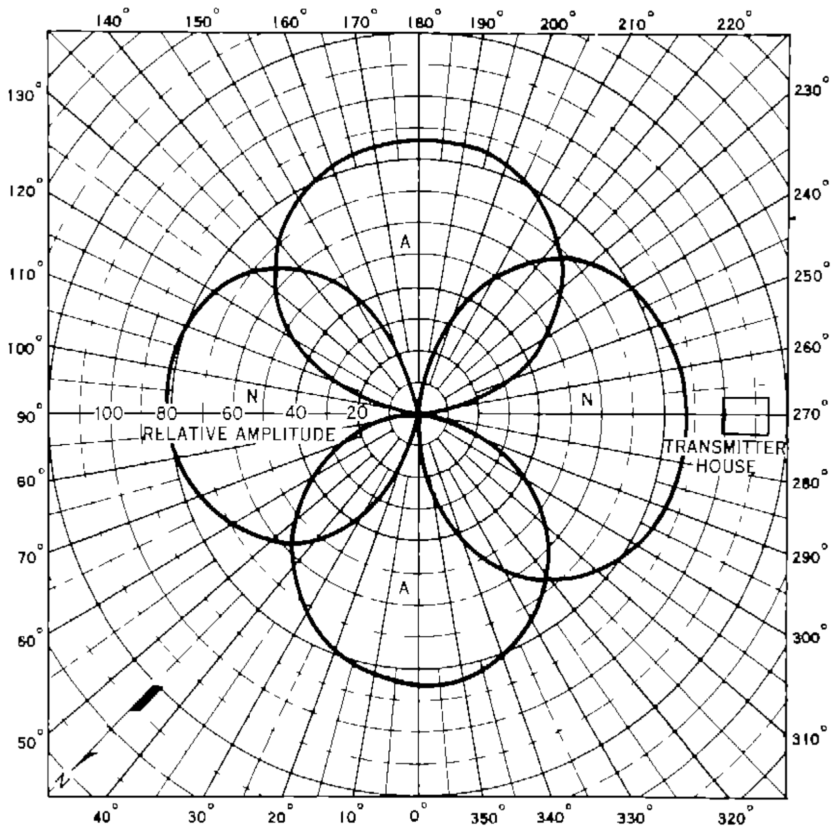


Figure 17 Horizontal Field Pattern of the Indianapolis 63-Megacycle Vertically Polarized Radio Range, Site No 1

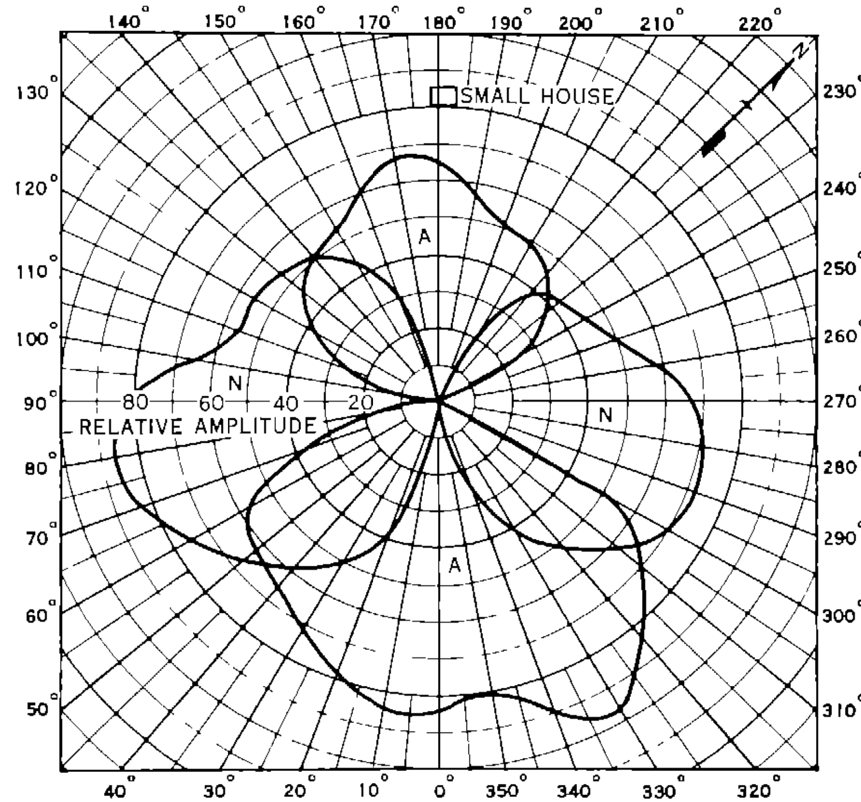


Figure 18 Horizontal Field Pattern of the Indianapolis 125 Megacycle Vertically Polarized Radio Range, Site No 2

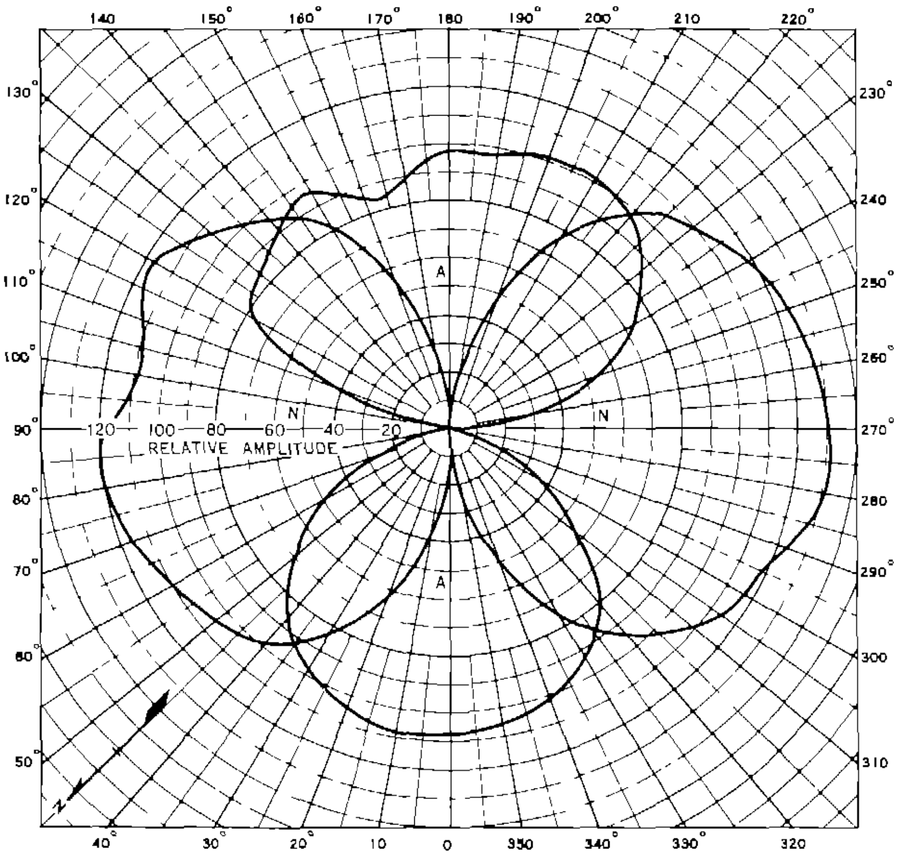


Figure 19 Horizontal Field Pattern of the Indianapolis 125 Megacycle Vertically Polarized Radio Range, Site No 3

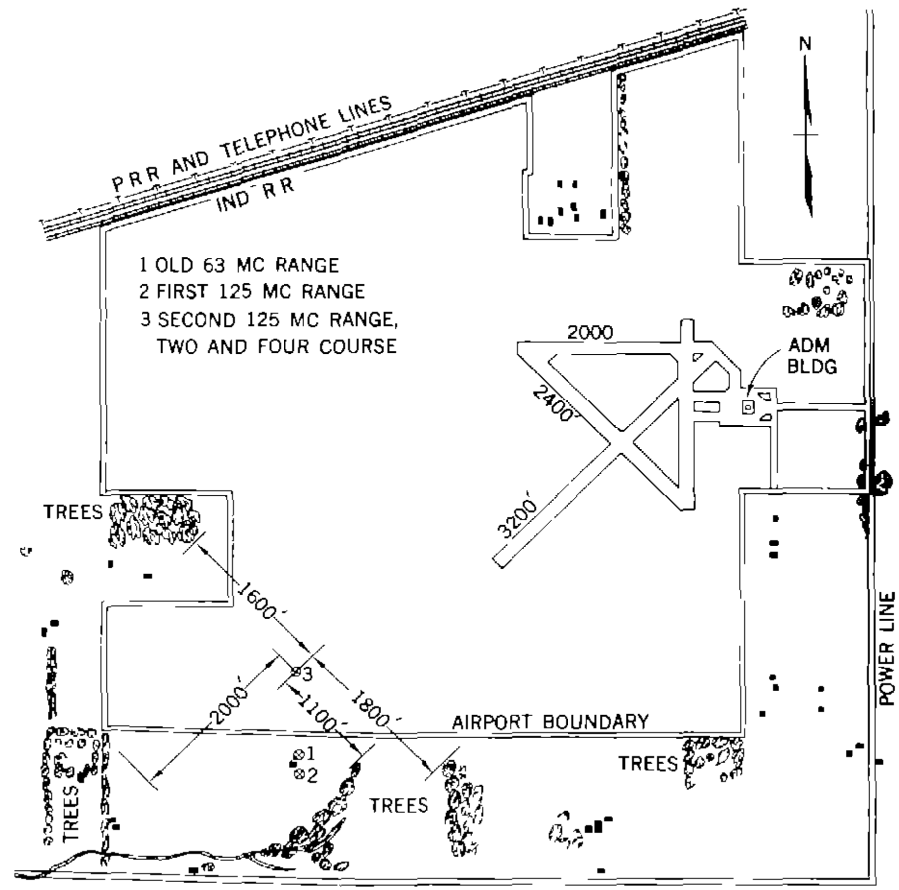


Figure 20 Diagrammatic Sketch of the Indianapolis Airport and Vicinity Showing Radio Range Sites

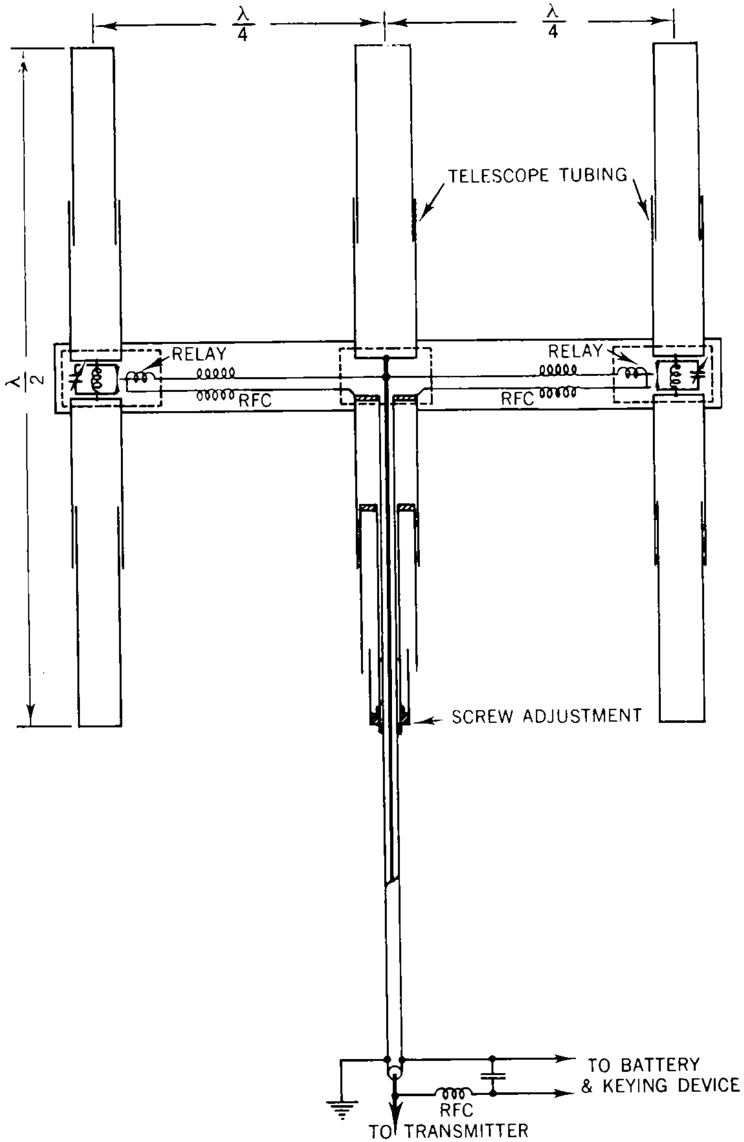


Figure 21. Schematic Diagram of the I. T. D. Co. 125-Megacycle Two-Course Radio Range Antenna.

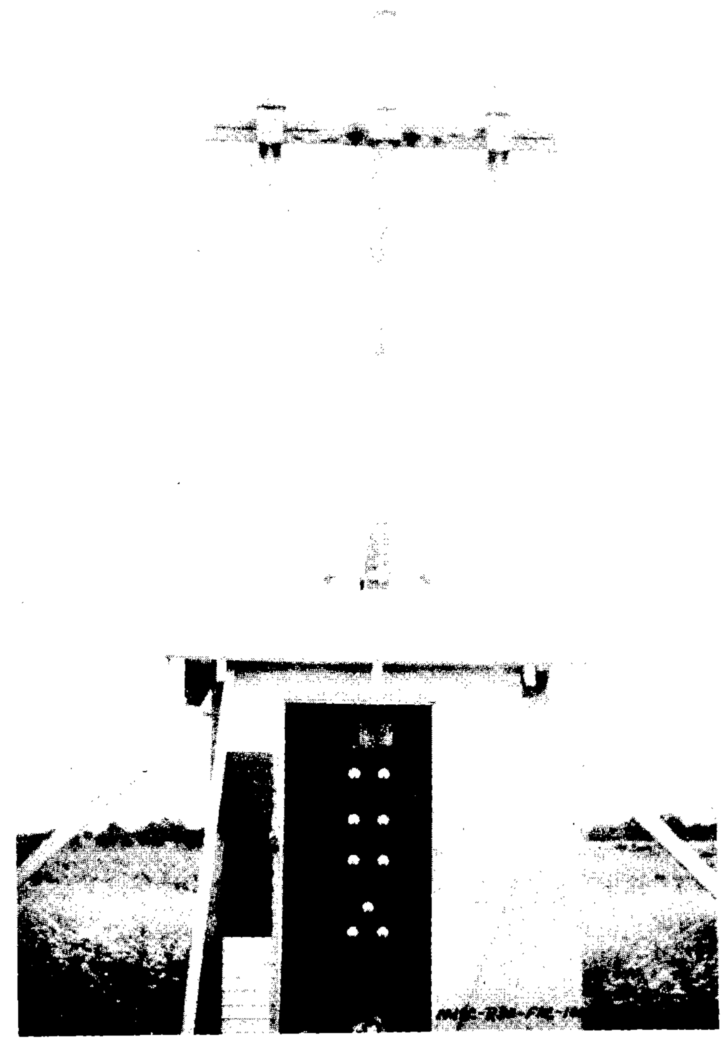


Figure 22. Indianapolis Two-Course 125-Megacycle Radio Range Installation.

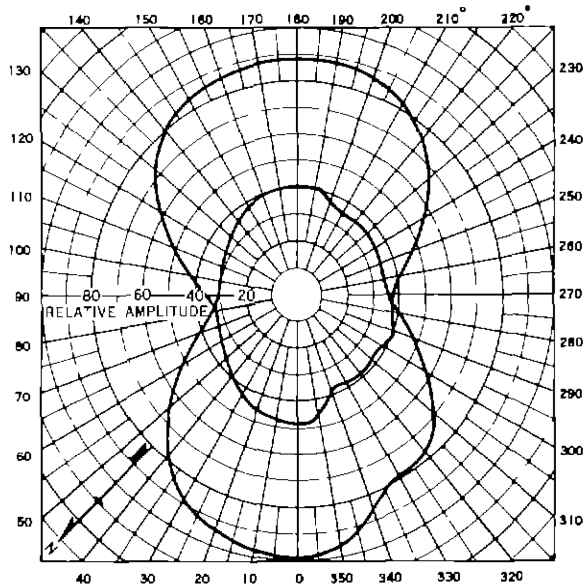


Figure 23 Horizontal Patterns of the 125 Megacycle Two Course Vertically Polarized Radio Range System Which was Tested at Site No 3

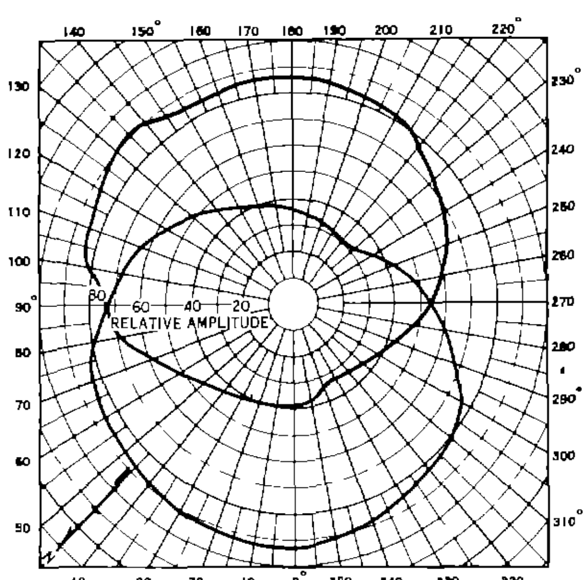


Figure 24 Horizontal Patterns of the 125 Megacycle Two Course Vertically Polarized Radio Range System Which was Tested at Site No 3

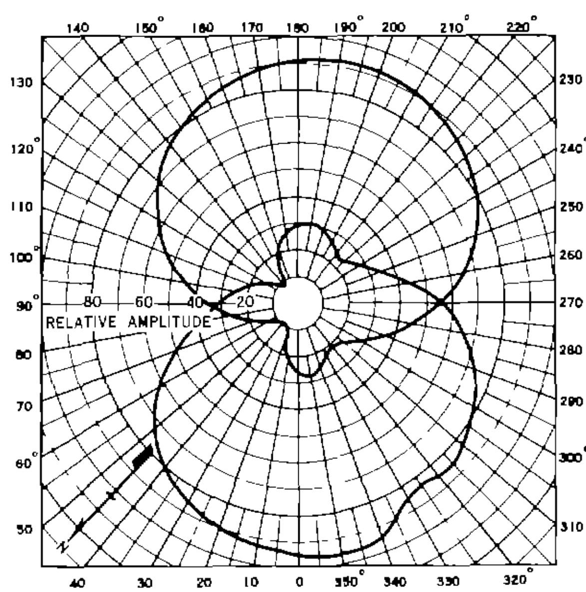


Figure 25 Horizontal Patterns of the 125 Megacycle Two Course Vertically Polarized Radio Range System Which was Tested at Site No 3

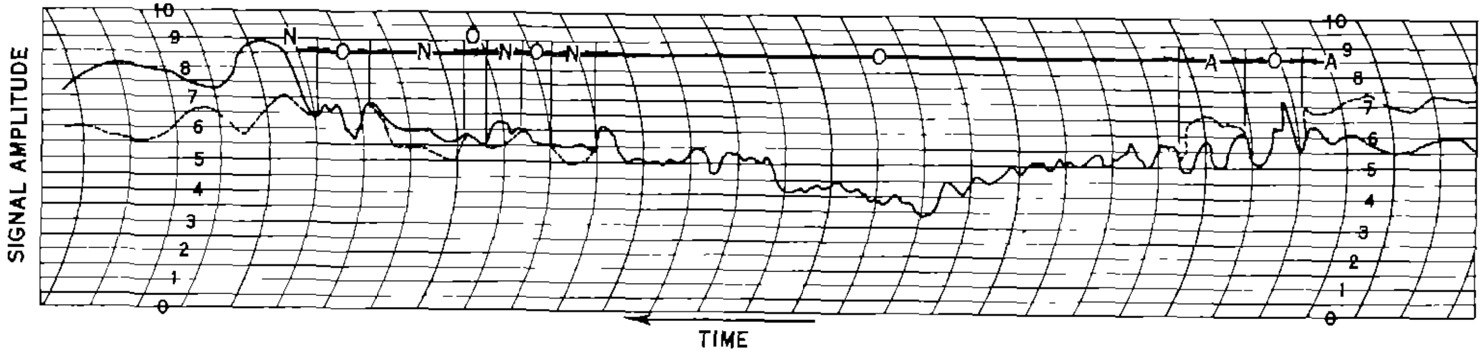


Figure 26 Recording of a Cross Course Flight of the 125-Megacycle Two Course Range, With Field Pattern Shown in Fig 25

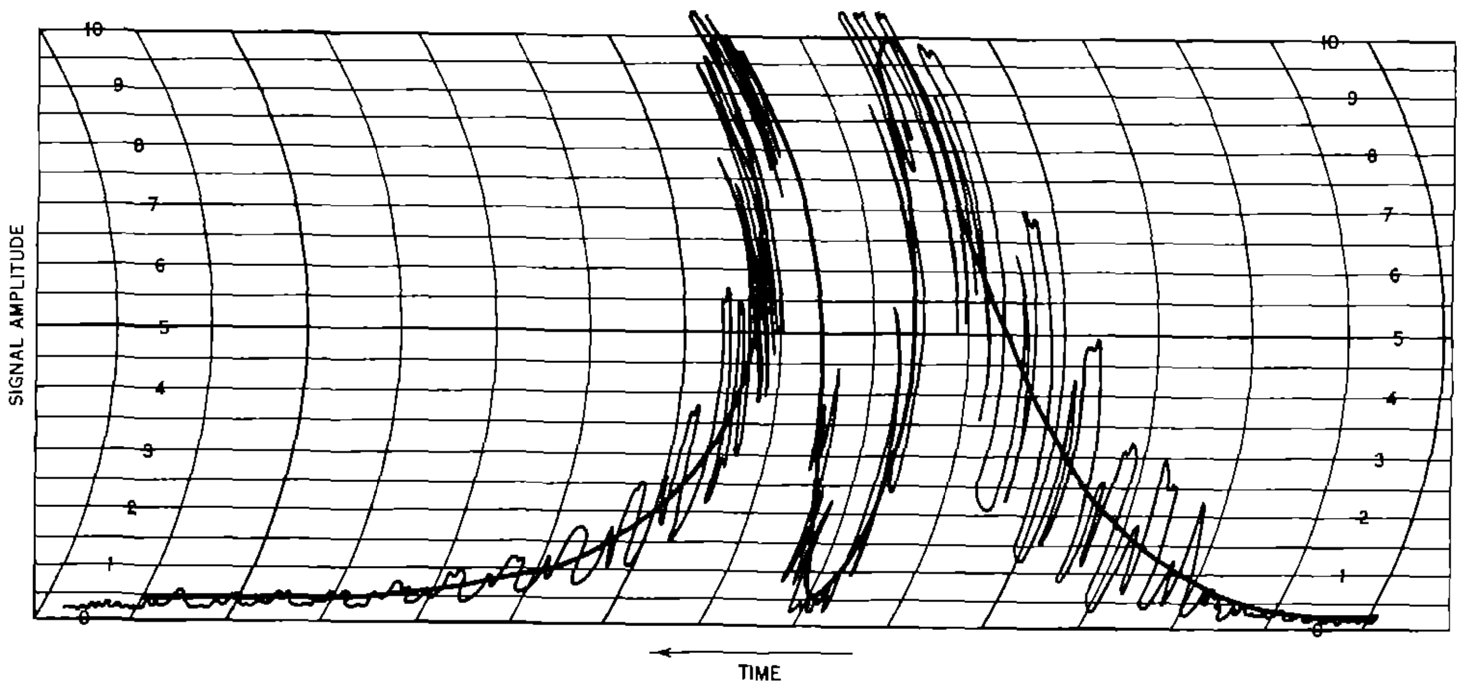


Figure 27 Cone of Silence Record Taken at Pittsburgh on the 125-Megacycle Vertically Polarized Range, Antenna Above Counterpoise Plane Passed Station Considerably Off Course

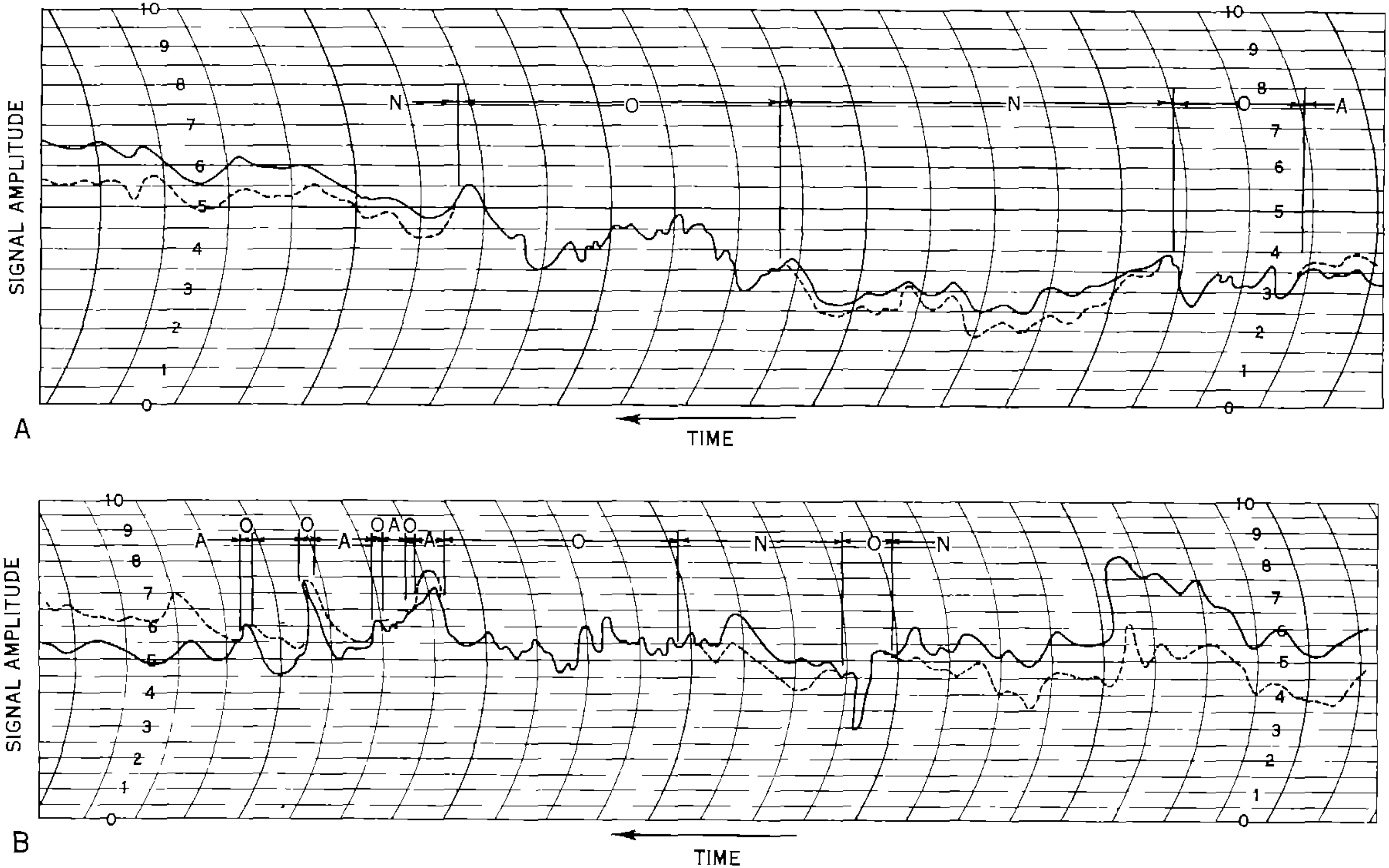


Figure 28 Typical Cross Course Recordings of the Pittsburgh Four Course and 125 Megacycle Vertically Polarized Range at, A, 20 Miles, and B, 30 Miles

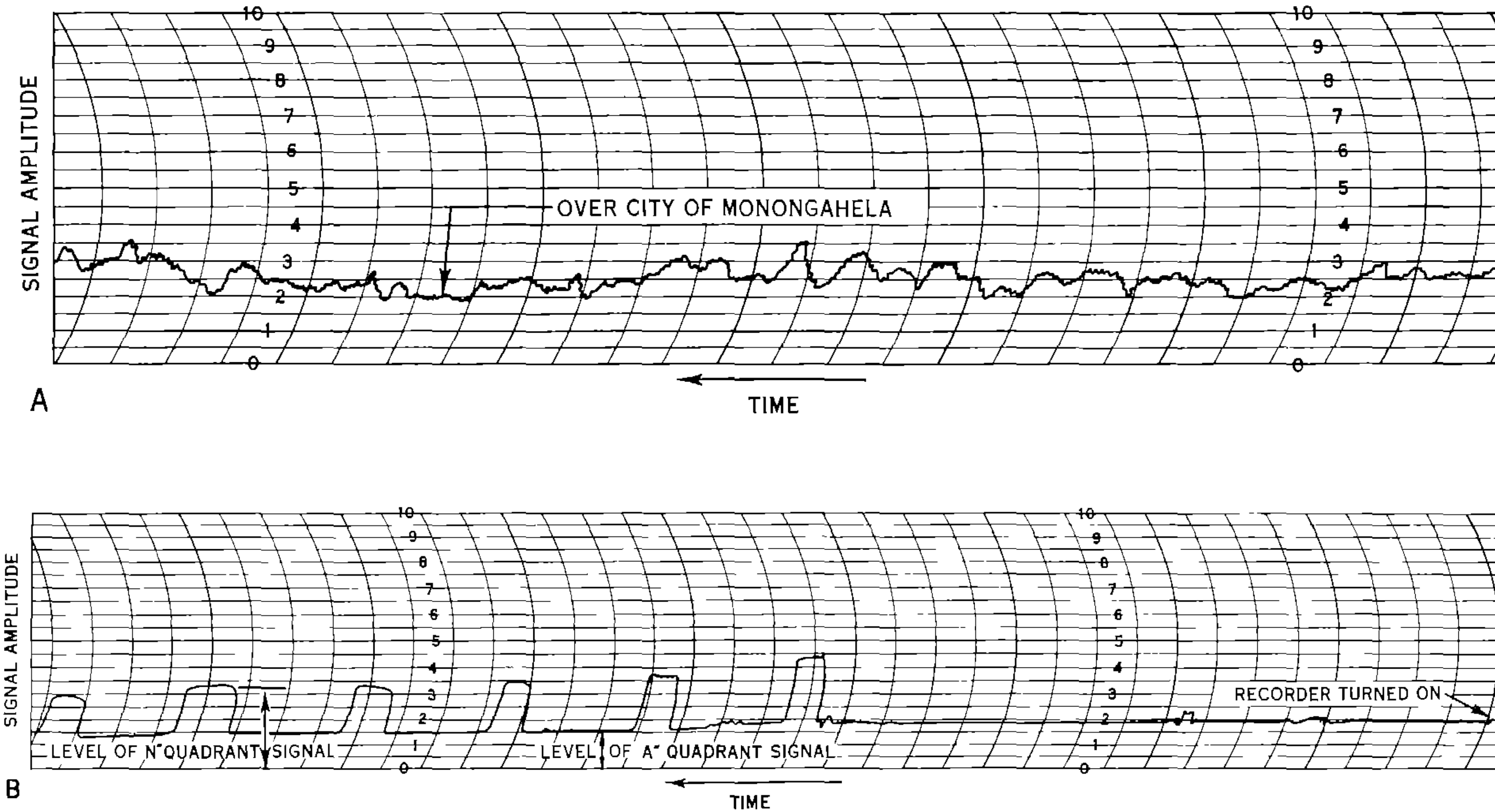


Figure 29 Recordings Showing Superimposed Flutter Modulation of, A, the On-Course Signal at Pittsburgh, on the 125-Megacycle Vertically Polarized Radio Range, and B, Flutter of Signal Received at Indianapolis on the Ground due to Nearby Aircraft in Flight

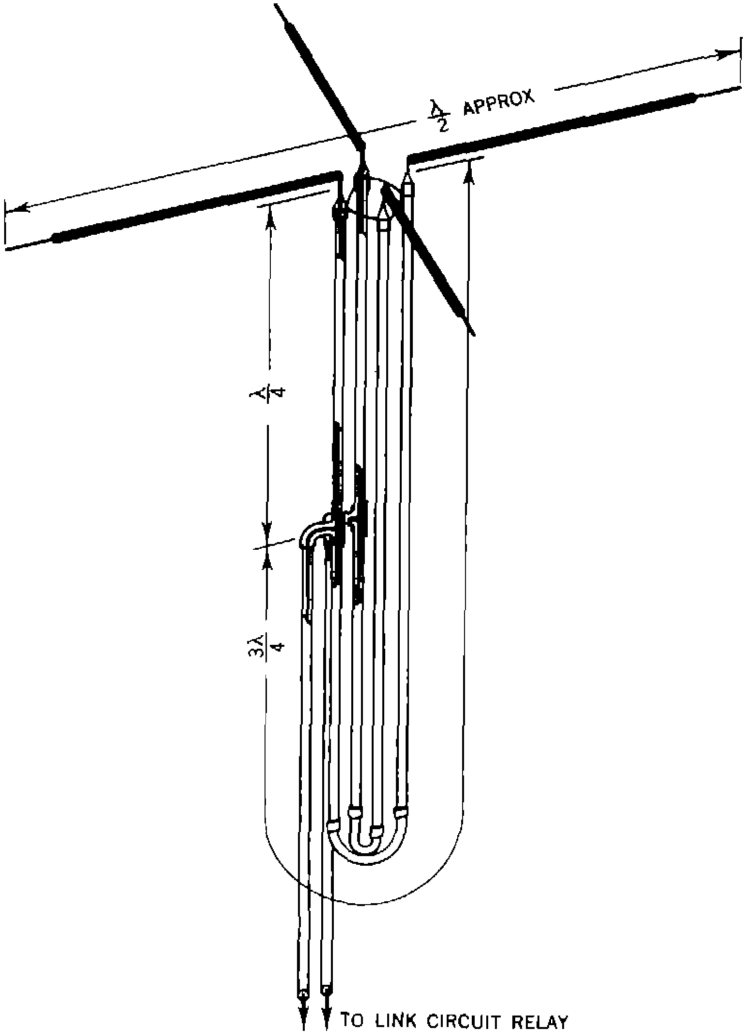


Figure 30 Schematic Diagram of the 125-Megacycle Horizontal Crossed- Dipole Antenna Array

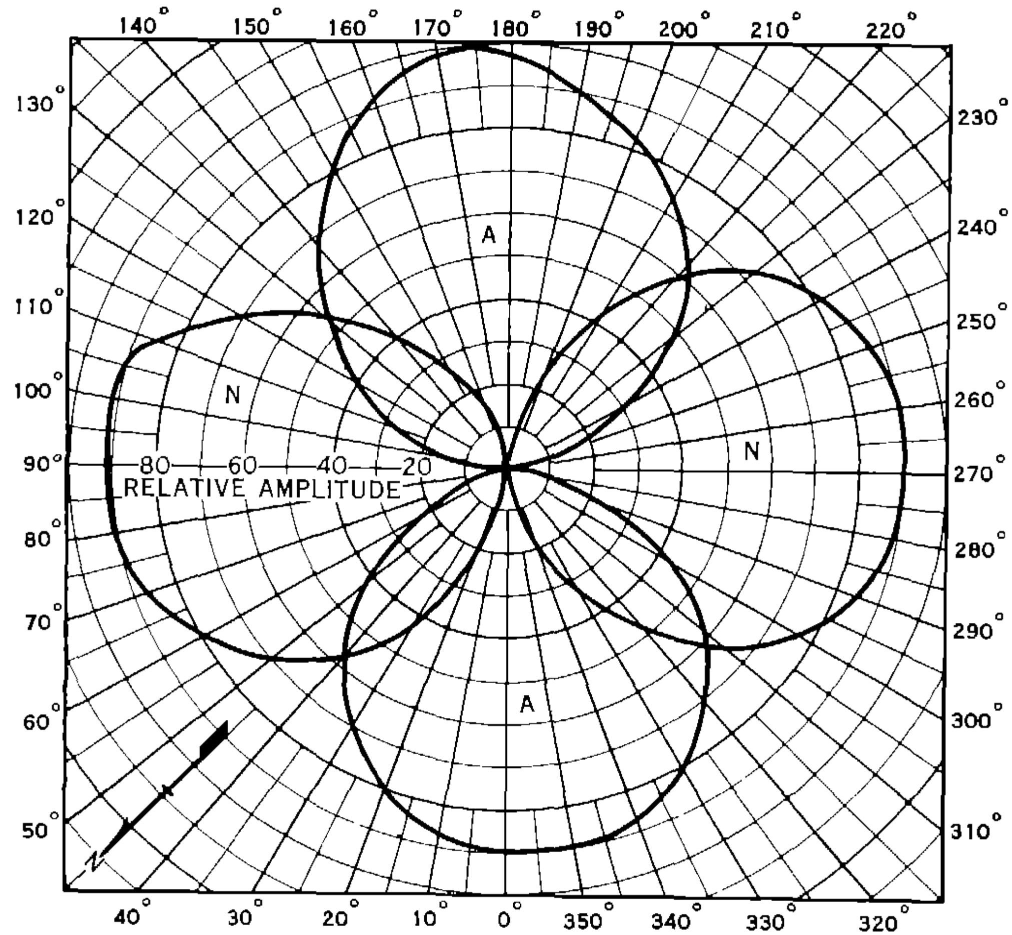


Figure 31 Horizontal Field Pattern of the 125-Megacycle Crossed Dipole Antenna at Indianapolis, Site No 3

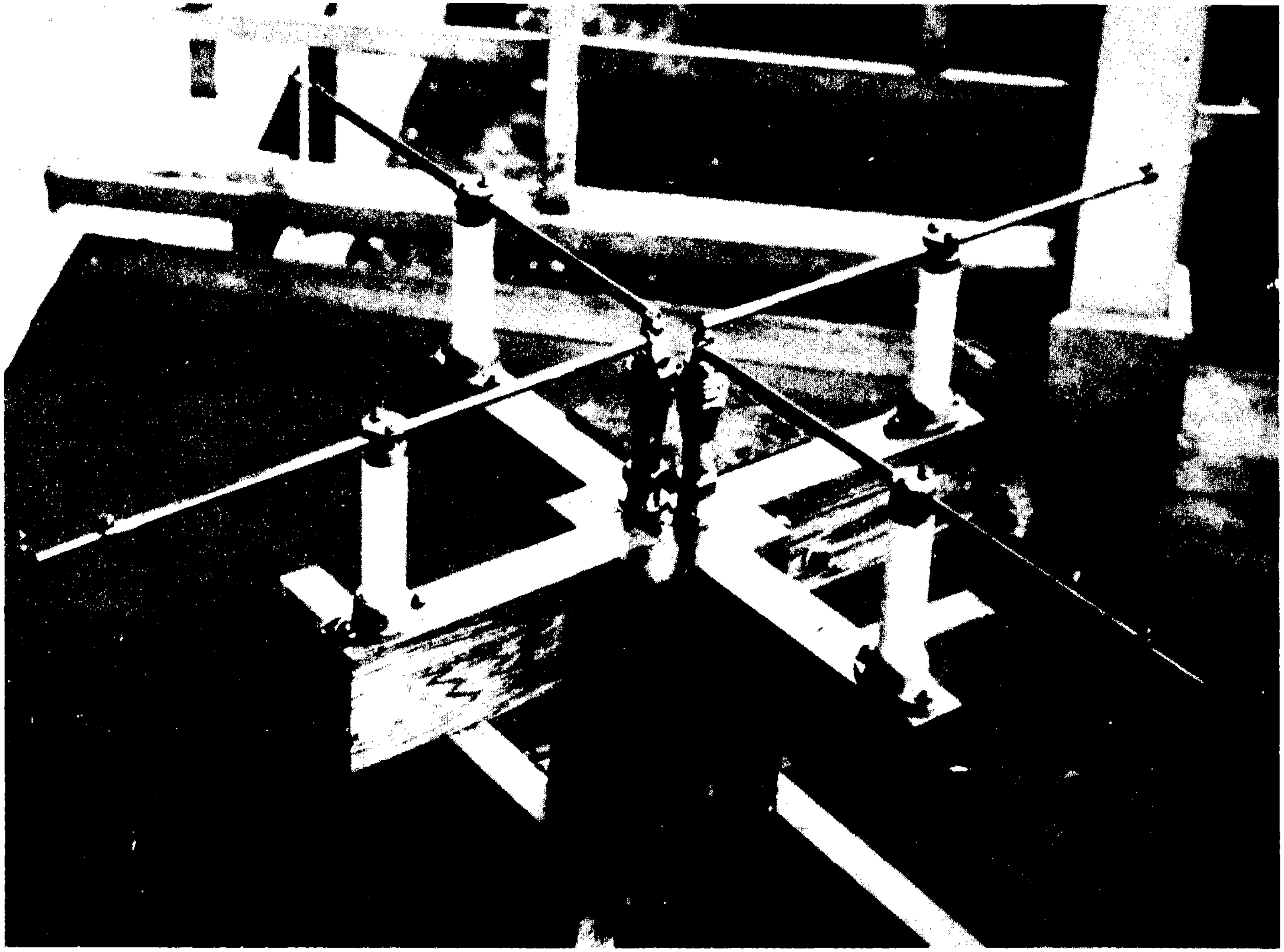


Figure 32. 125-Megacycle Horizontal Crossed-Dipole Antenna.

Figure 33. 125-Megacycle Crossed-Dipole Antenna on Top of the Counterpoise at Indianapolis.

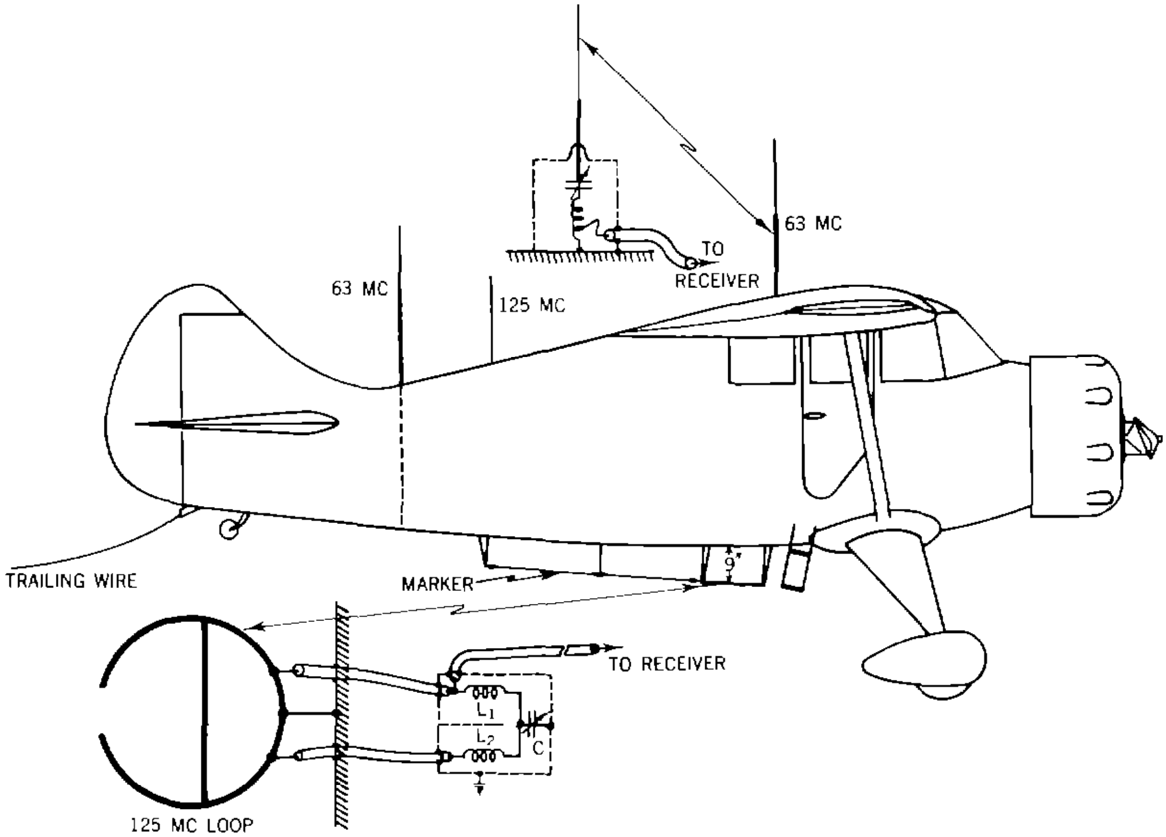


Figure 34 Diagram Showing the Various Types of Receiving Antennas Used and Their Locations on Stinson NC-80

NO	DATE	COURSE	DISTANCE (MILES)	ALTITUDE ABOVE GROUND (FEET)	COURSE WIDTH (DEGREES)	AURAL OR RECORDER OBSERVATION	OBSERVED SIGNAL CROSS-COURSE O-ON COURSE N AND A QUADRANTS
1	6/28/38	NORTH	35	3700	0 4	A	NONOOOOA
2	8/17/38	NORTH	16	3500	1 6	R	NO MULTIPLES
3	8/17/38	NORTH	28	4300	3 5	R	NO MULTIPLES
4	6/28/38	EAST	35	4100	0 7	R	AOOAAOOOOOOON
5	6/28/38	EAST	35	4100	1 1	R	NONNNOONONOOOOA
6	6/28/38	EAST	35	4300	0 8	R	AOOOAOOOON
7	7/20/38	EAST	40	8000	2 7	R	NO MULTIPLES
8	7/20/38	EAST	70	8500	1 2	A	NO MULTIPLES
9	6/30/38	SOUTH	20	3400	1 7	A	AOAOAOOON
10	6/30/38	SOUTH	35	4000	2 1	R	AOAAOAANNON
11	6/30/38	SOUTH	38	4700	1 7	A	NOAAOOAAOA
12	6/30/38	SOUTH	38	5200	0 7	R	AOOONNNNNON
13	7/27/38	SOUTH	25	4100	0 8	R	NO MULTIPLES
14	7/27/38	SOUTH	35	4000	1 4	R	NO MULTIPLES
15	7/5/38	WEST	35	5400	0 5	R	VERY SLIGHT MULTIPLES- POOR RECORD
16	8/16/38	WEST	10	2900	1 6	R	NO MULTIPLES
17	8/16/38	WEST	33	2800	3 5	R	NO MULTIPLES
18	8/16/38	WEST	33	3000	3 0	R	NO MULTIPLES

Figure 35 Tabulation of Eighteen Separate Flights on the 125-Megacycle Horizontal Crossed-Dipole Radio Range

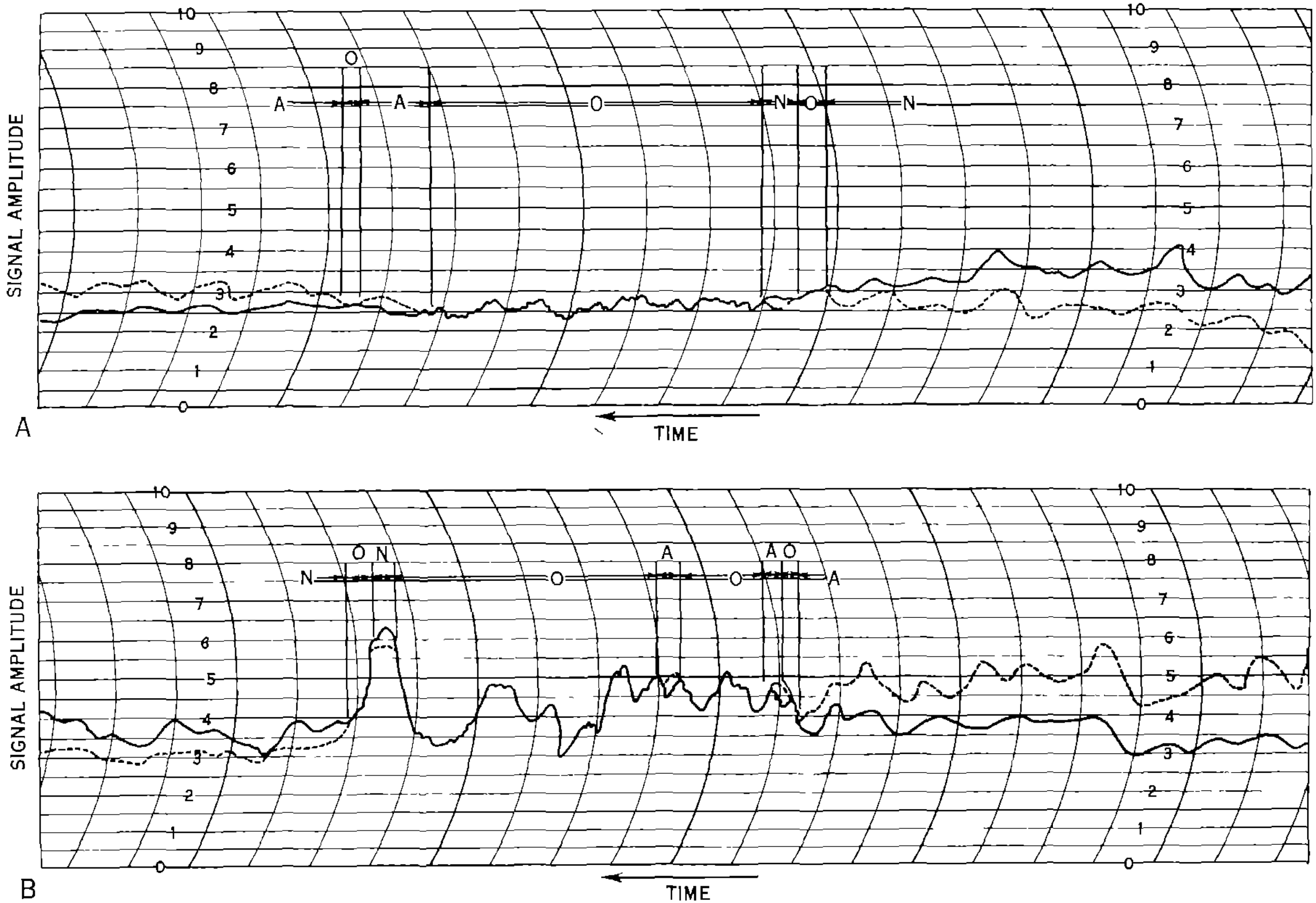


Figure 36 Sample Recordings of the 125-Megacycle Horizontal Crossed- Dipole Radio Range at, A, 30 Miles, and B, 36 Miles

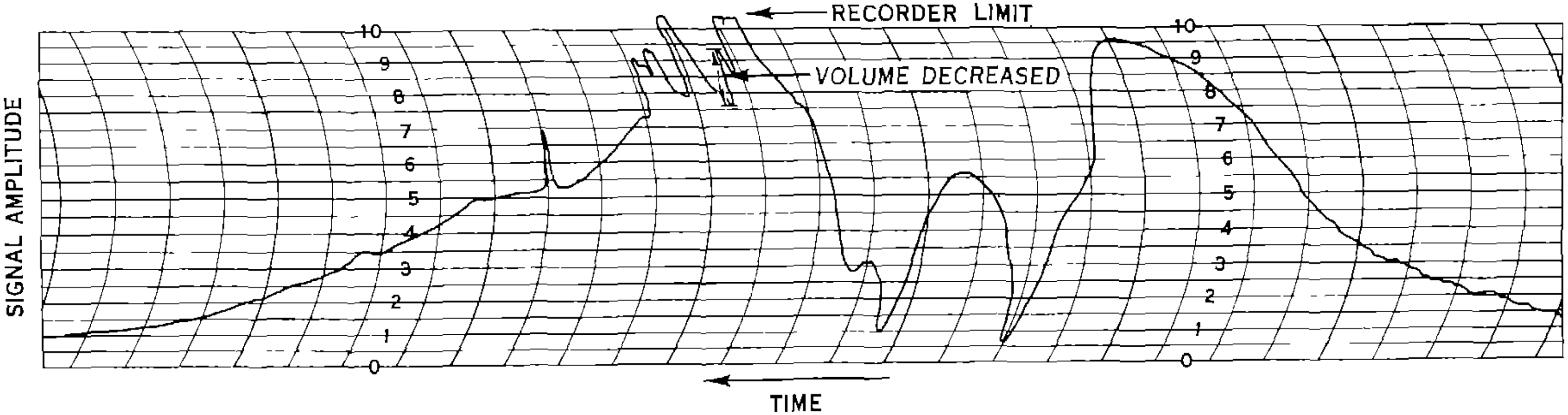


Figure 37 Cone of Silence Record of the 125 Megacycle Horizontal Crossed-Dipole Radio Range at Indianapolis Antenna One-Half Wavelength Above Counterpoise

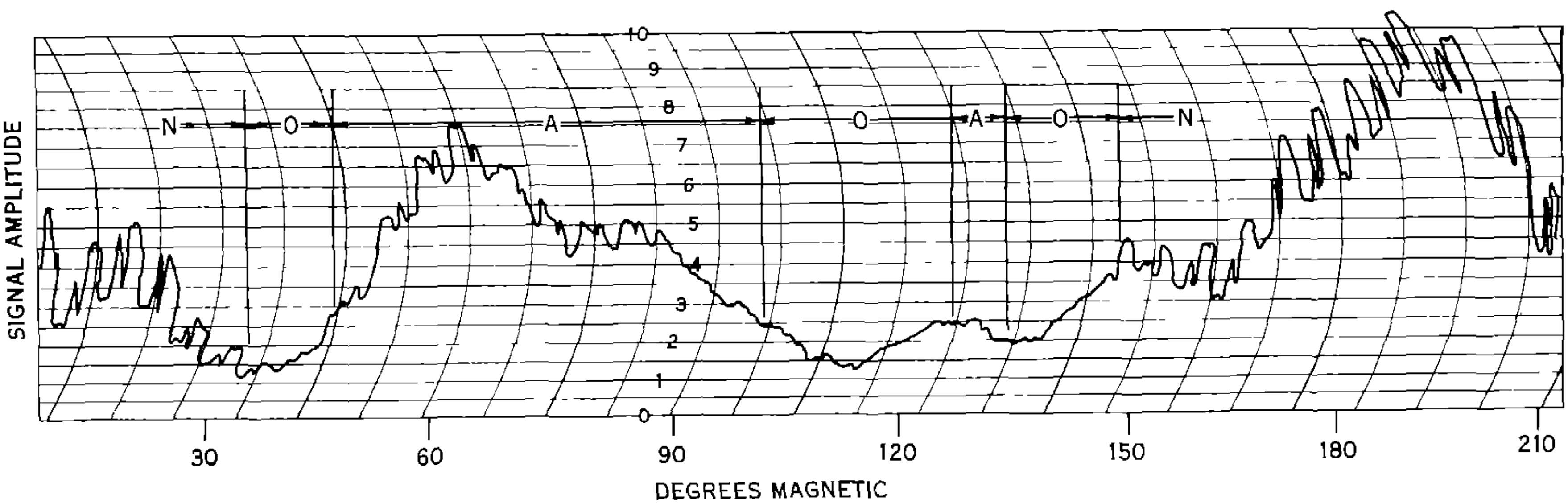


Figure 38 Recording of "Circling Effect" Taken on the Pittsburgh 125-Megacycle Horizontal Crossed-Dipole Radio Range

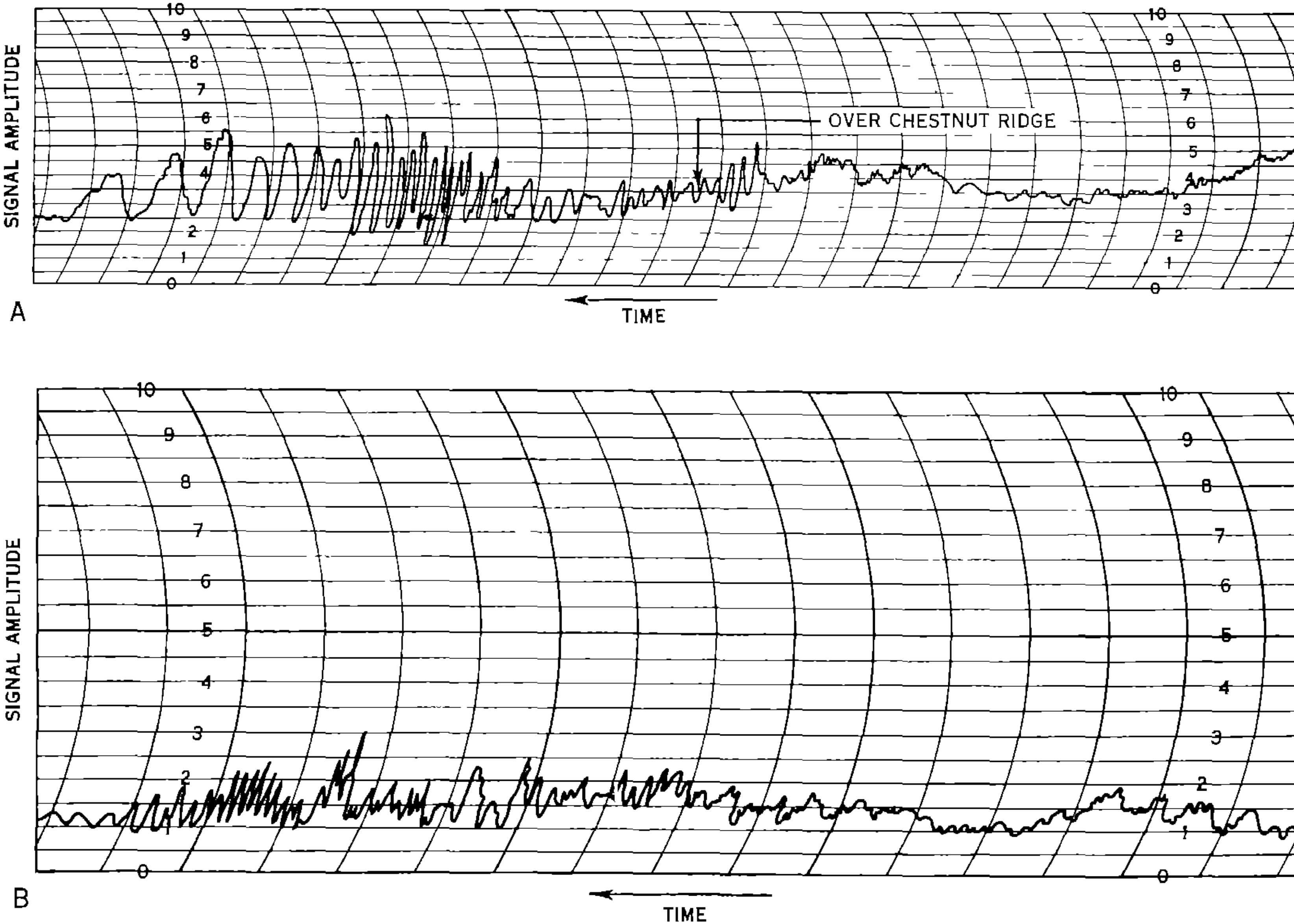


Figure 39 Example of Fluctuations in Received Signal Strength in the Vicinity of Chestnut Ridge, A, and Over Steel Mills in the Vicinity of Pittsburg Airport, B Horizontal Crossed-Dipole Antenna 125 Megacycles

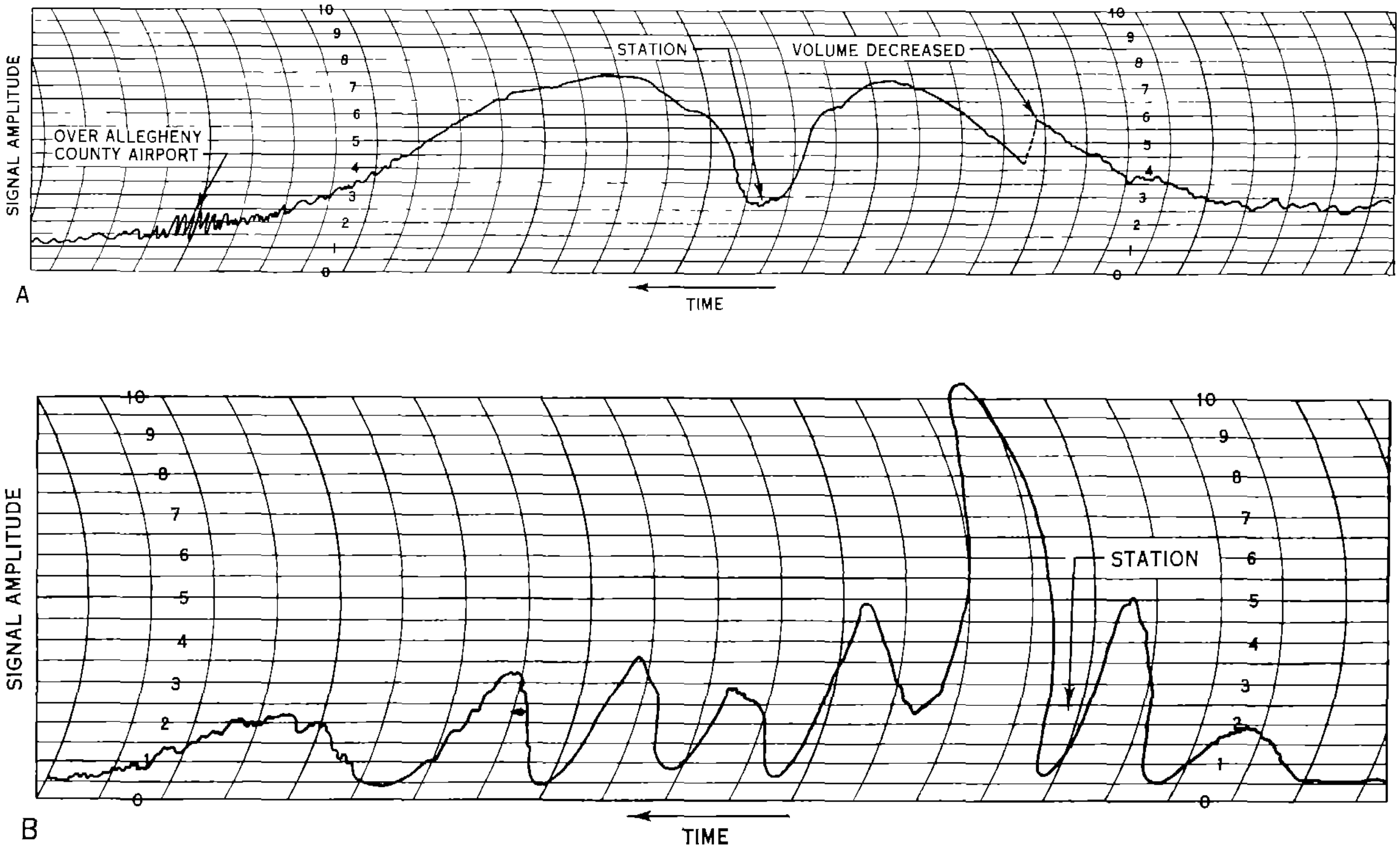


Figure 40 Comparison of Cone-of-Silence With and Without Counterpoise

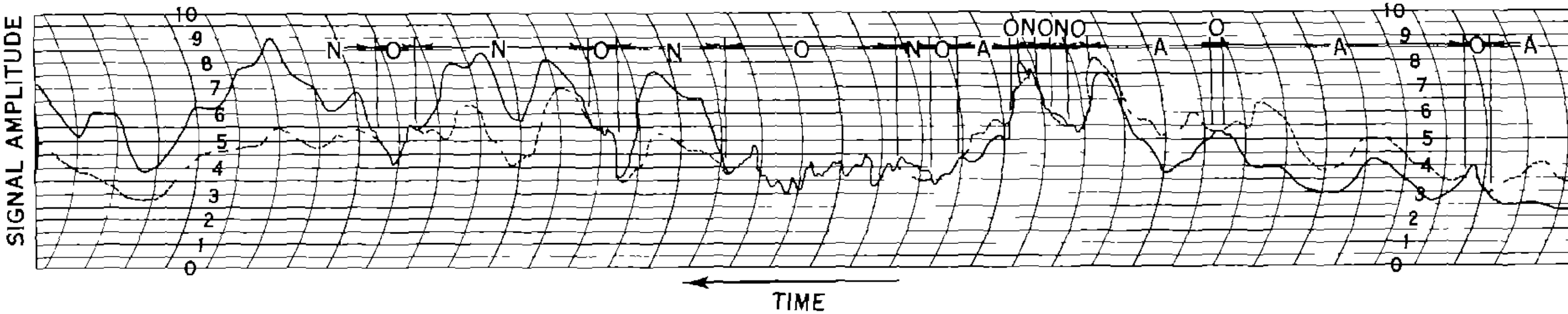


Figure 41 Recordıng of Cross-Course Flıght Over Herndon, Va , on the 125-Megacycle Horızontal Crossed-Dıpole Range Installed on 125-Foot Tower at Washıngton, D C

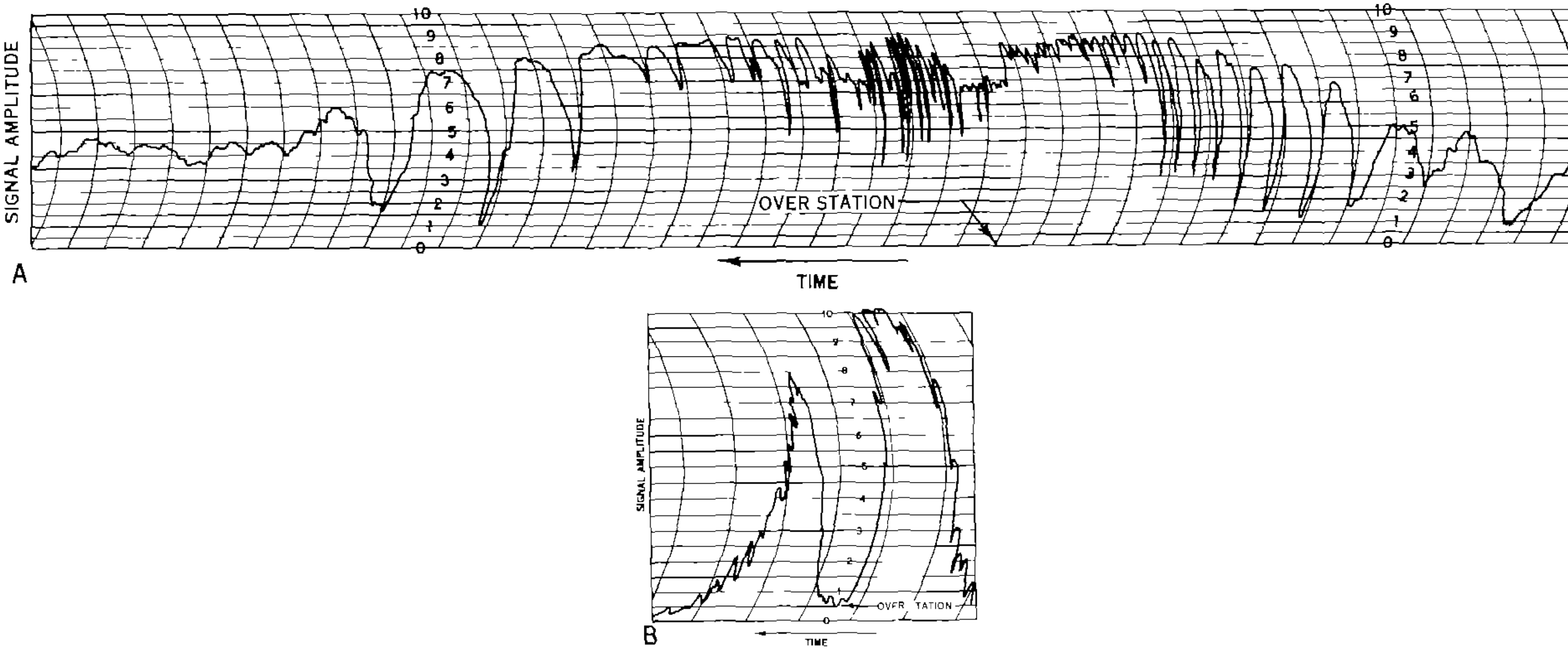


Figure 42 Cone-Of-Sılence Recordıngs of the 125-Megacycle Horızontal Crossed Dıpoles on the 125-Foot Tower at Washıngton, D C , A, Wıthout Counterpoıse, B, Wıth Counterpoıse

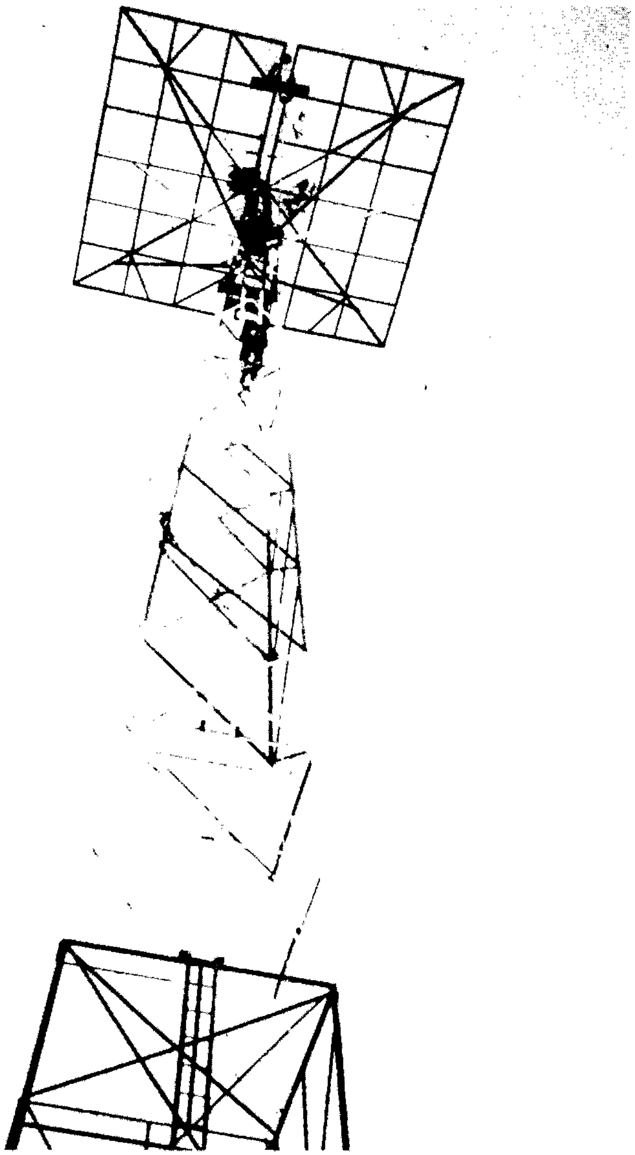


Figure 43. 125 Foot Tower and Counterpoise at Washington, D. C, The Horizontal 125-Megacycle Crossed-Dipole Antenna is One-Half Wave Above the Counterpoise.

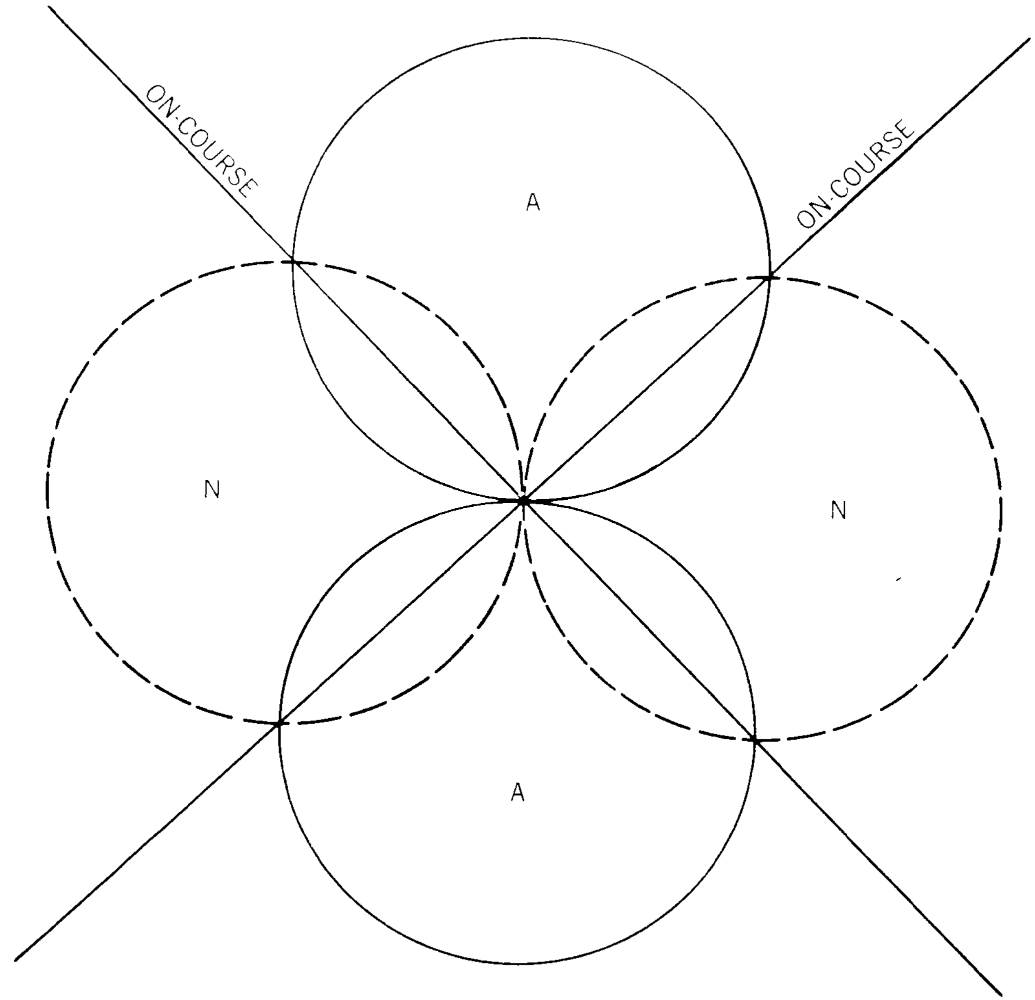


Figure 44. Theoretical Horizontal Field Pattern of a Four-Course Radio Range.

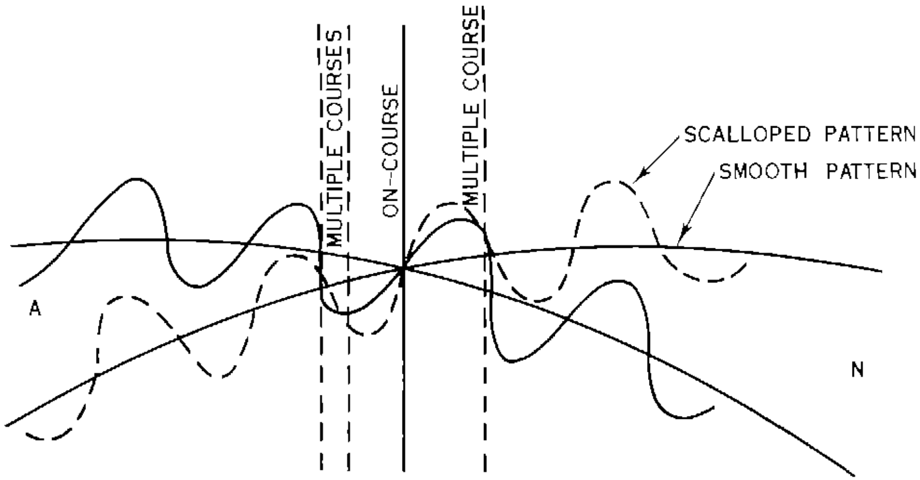


Figure 45A A Sector of Figure 44 Showing How Scalloping of the Patterns, Due to Reflections, Causes Multiple Courses to Appear

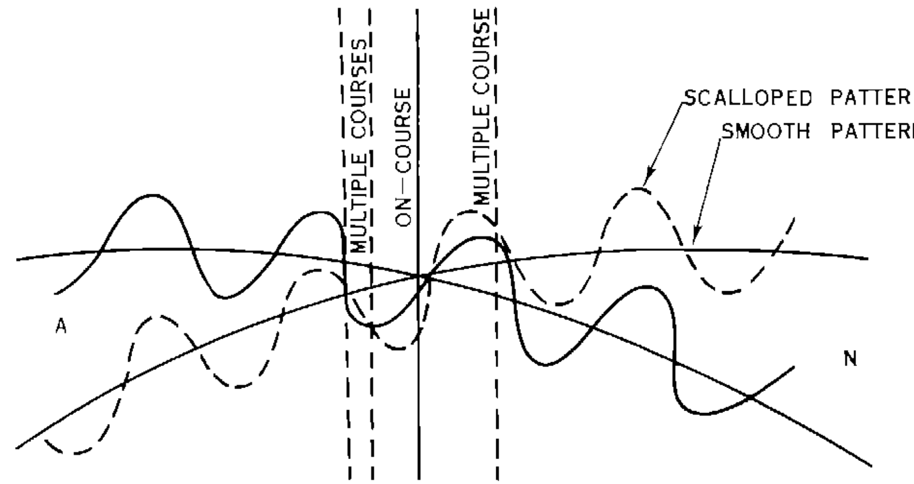


Figure 46A Multiple Courses Produced by Scalloped A and N Patterns

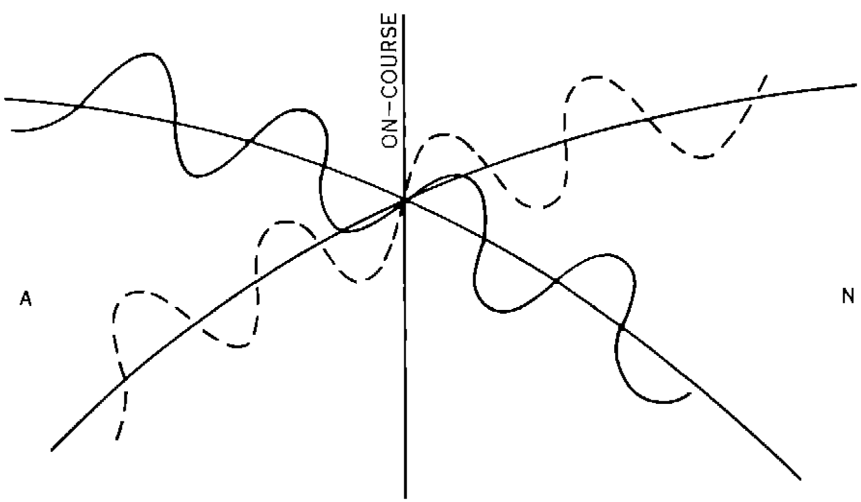


Figure 45B Same as A Except Course Sharpness Increased, Removes the Multiple Courses

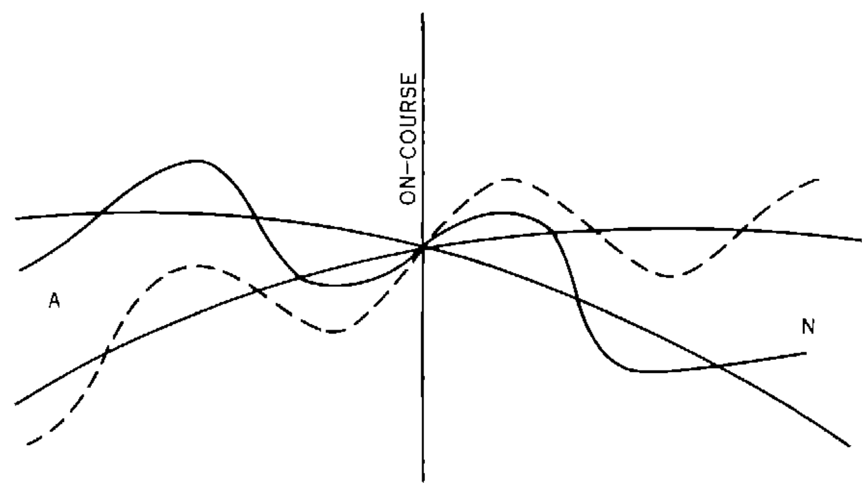


Figure 46B Showing How a Reduction of the Frequency Removes the Multiple Courses

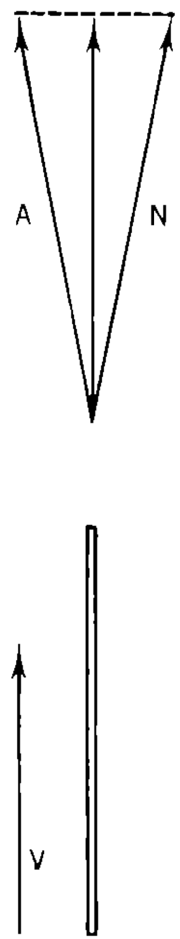


Figure 47A Vertical Dipole On-Course Response Midway Between the A and N Vectors

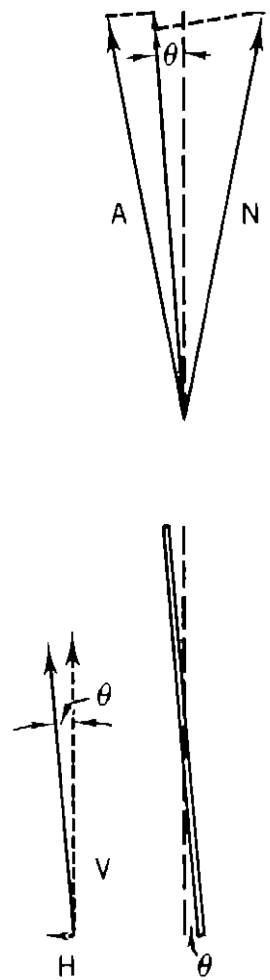


Figure 47B Tilted Dipole, Introduces Horizontal Component, Giving A Signal While Still on Course

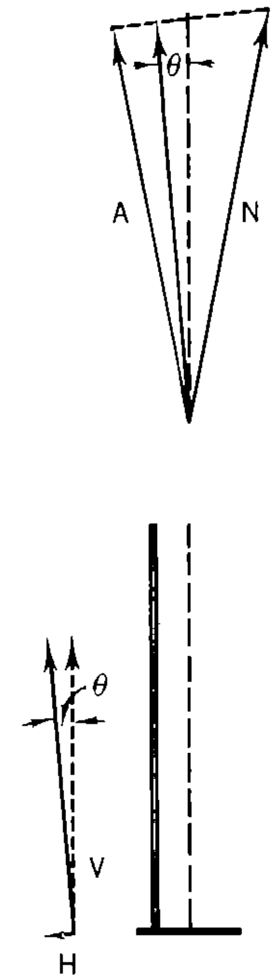


Figure 47C Unbalanced Verticle Dipole, Having Horizontal Response, Gives an On-Course Signal in the A Quadrant, an Illustration of Pushing Effect

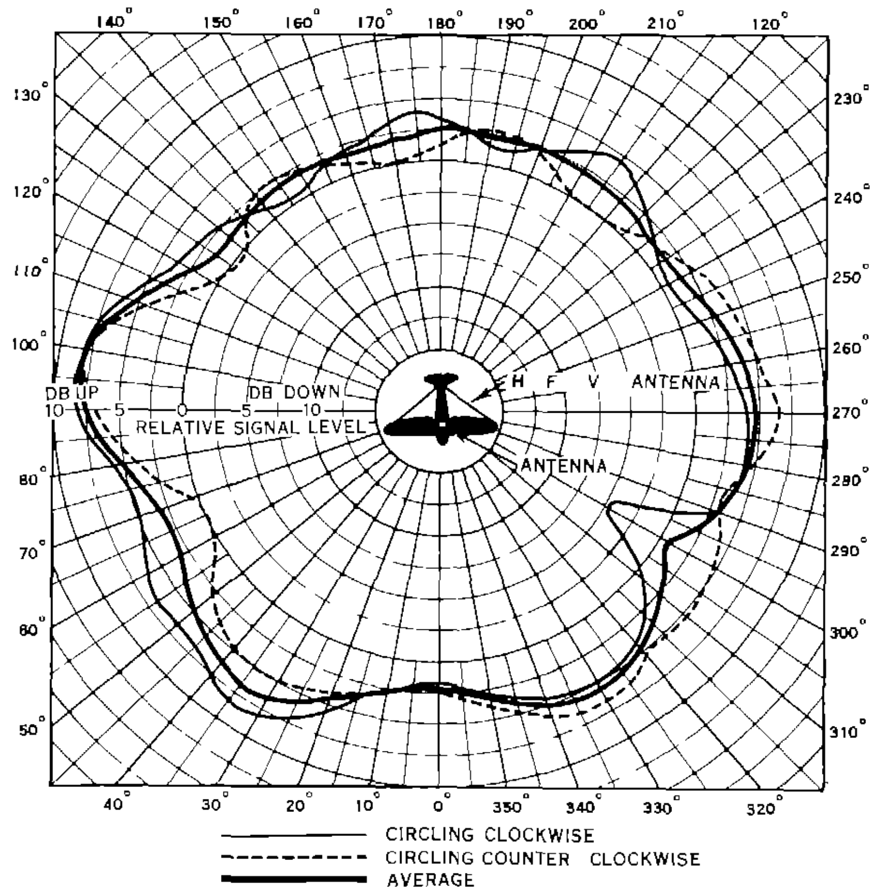


Figure 48 Field Pattern of the 63-Megacycle Whip Antenna on NC-80, With V Antenna Installed

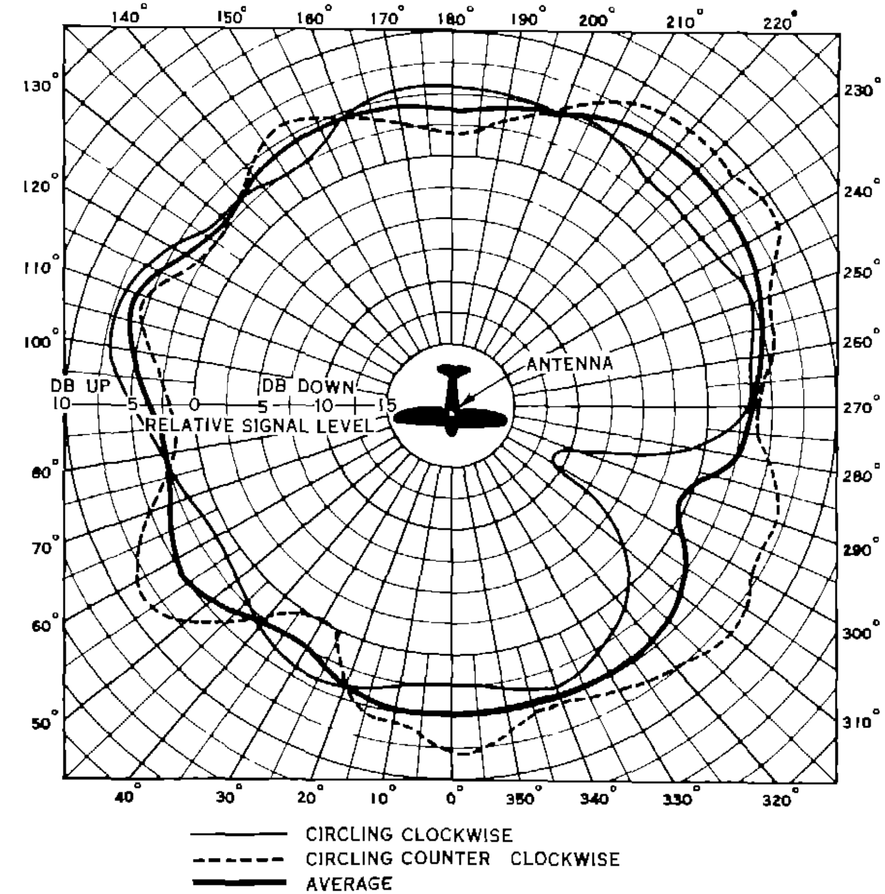


Figure 49 Field Pattern of the 63-Megacycle Whip Antenna on NC-80 High Frequency V Antenna Removed

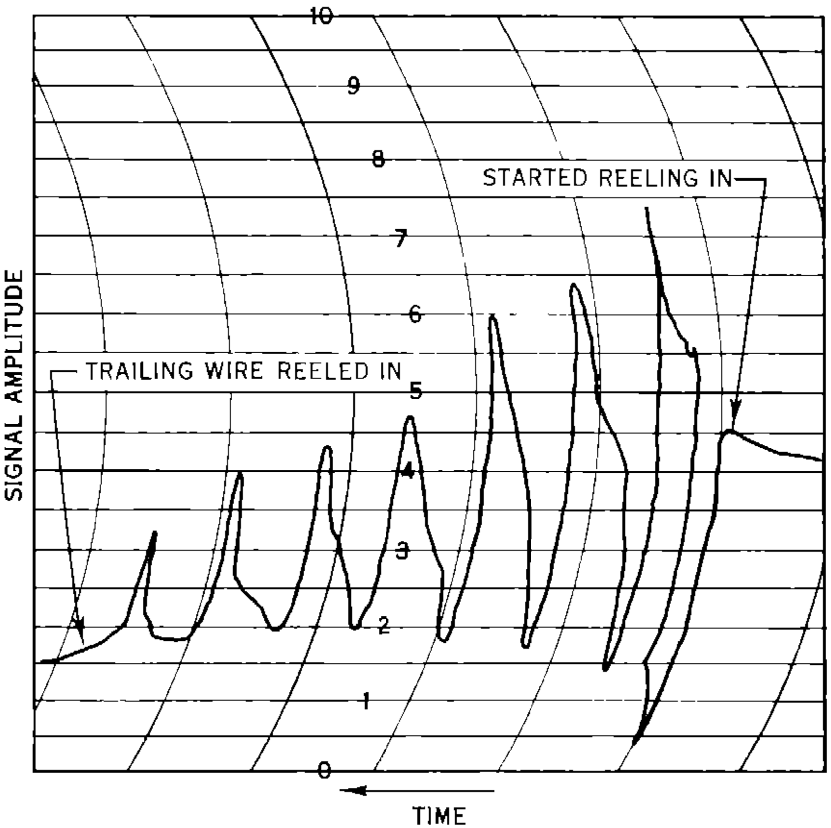


Figure 50 Recording Showing the Effect of the High-Frequency Trailing Wire on the 63-Megacycle Received Signal

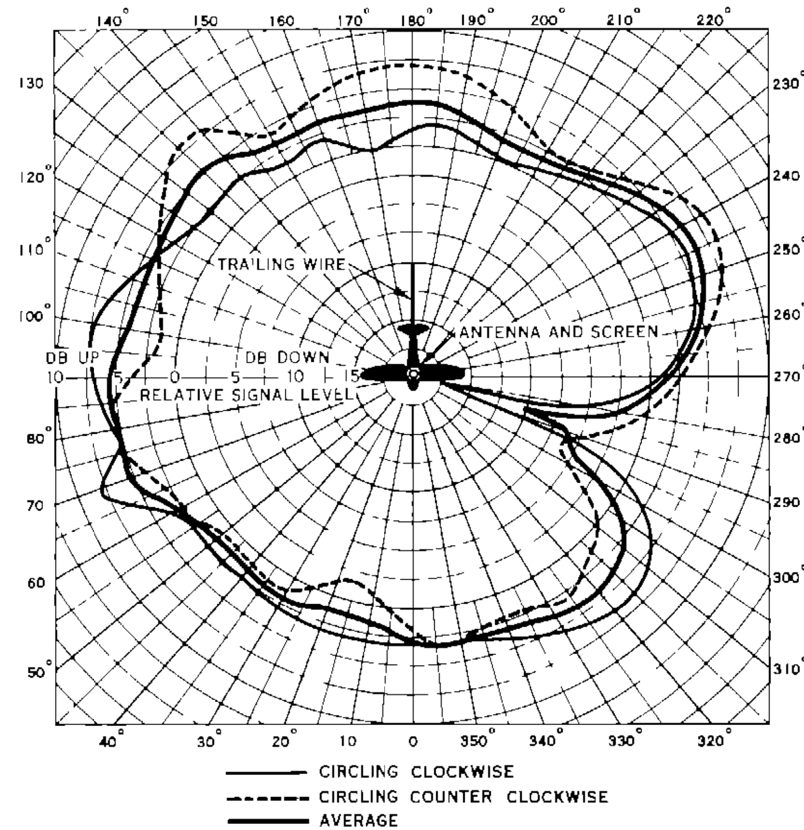


Figure 51 Field Pattern of the 63-Megacycle Whip Antenna on NC-80, With Copper "Ground" Screen and Trailing Wire Tuned off Resonance

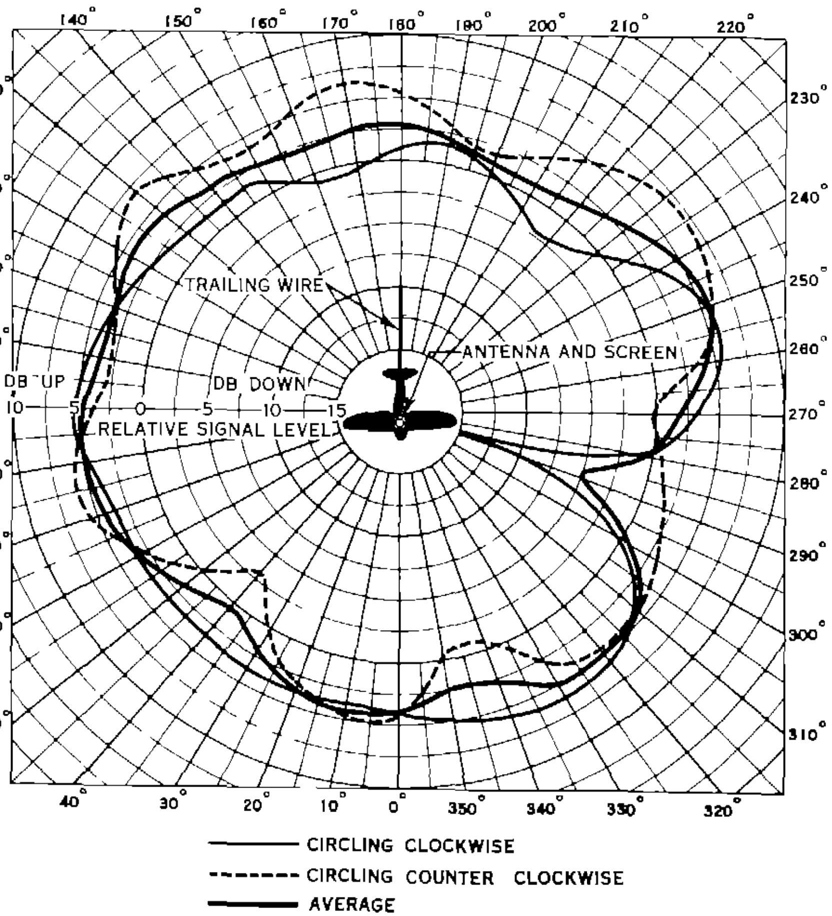


Figure 52 Field Pattern of the 63-Megacycle Whip Antenna on NC-80, With Copper "Ground" Screen, and Trailing Wire Tuned to Resonance

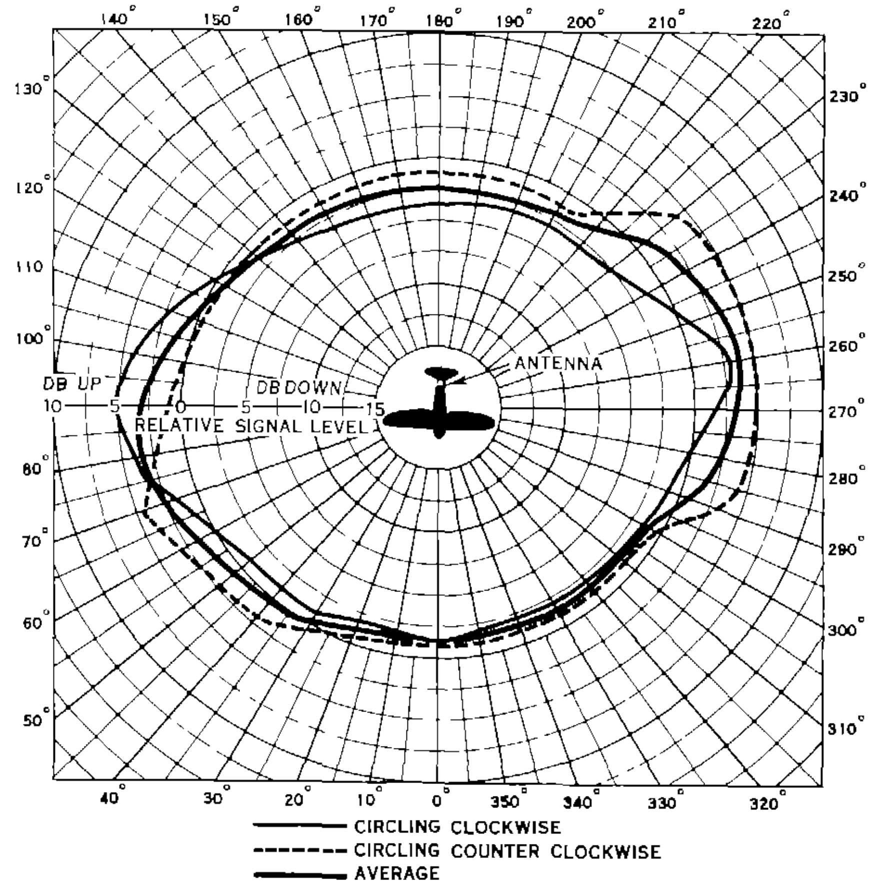


Figure 53 Field Pattern of the Half-Wave 63-Megacycle Whip Antenna on NC-80

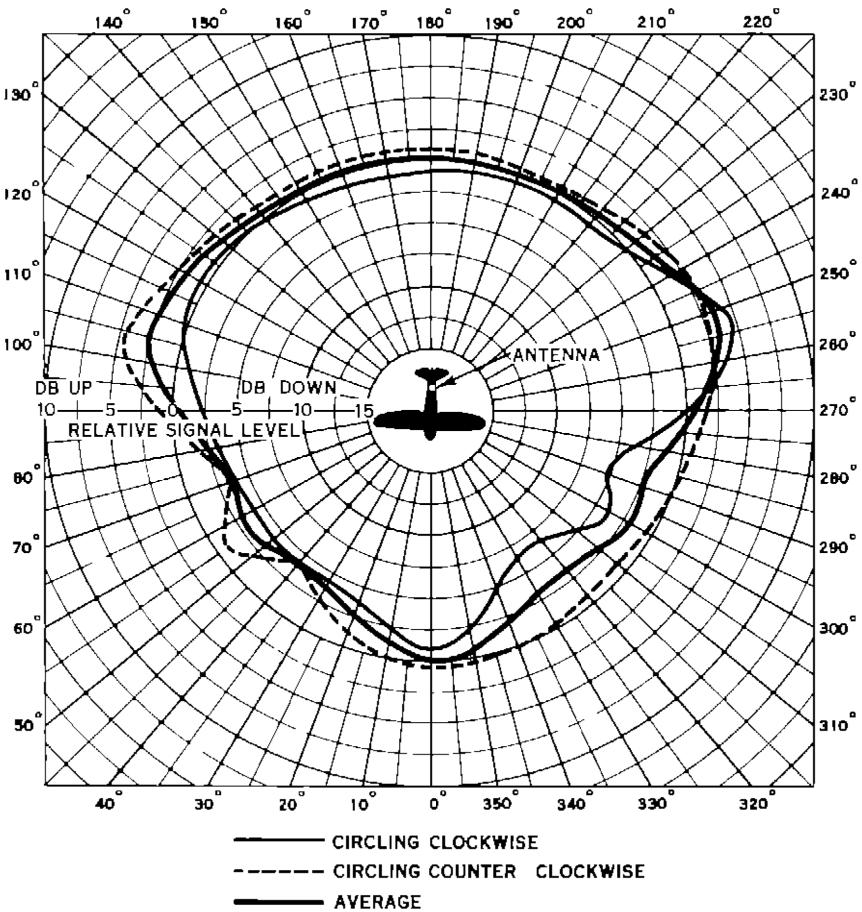


Figure 54, Field Pattern of the Quarter-Wave, 125-Megacycle Whip Antenna on NC-80

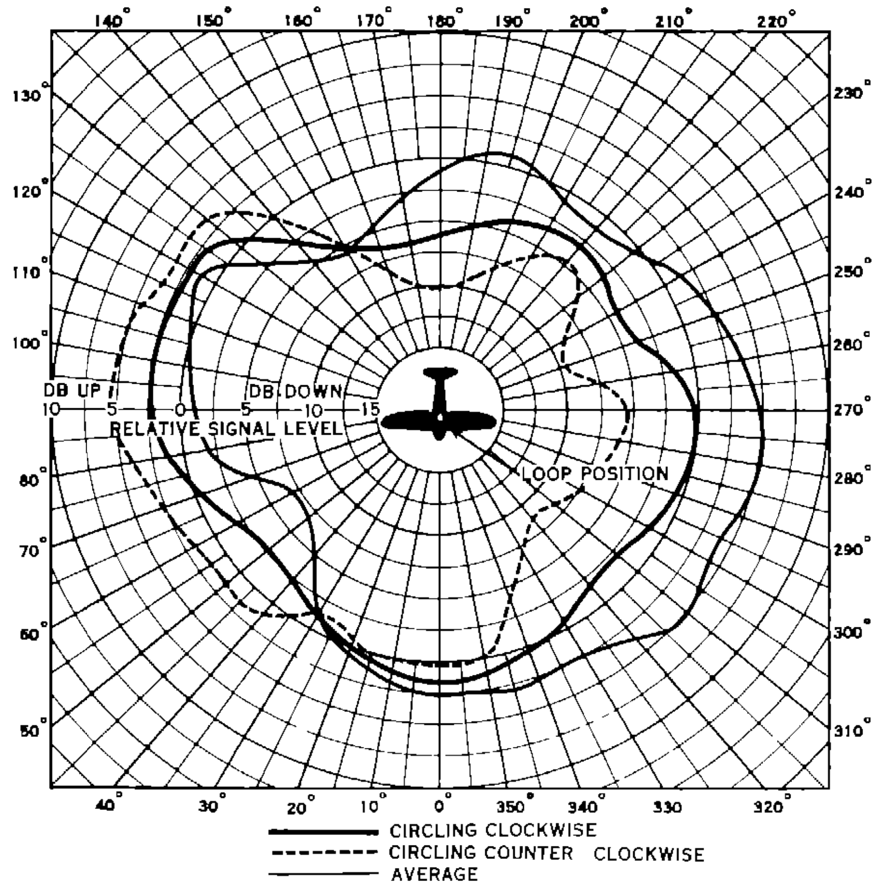
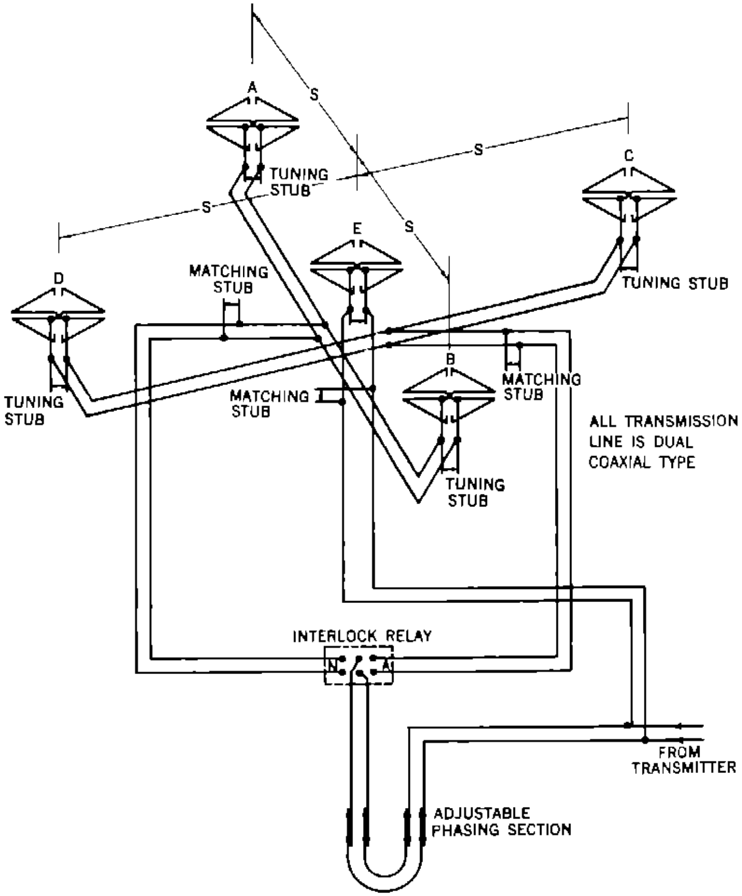


Figure 55 Field Pattern of the 125-Megacycle Horizontal Loop Installed Under Belly of NC-80



FINAL ARRANGEMENT

	3-Element	5-Element
Relative Current in Corner Loops	1 0	1 0
Relative Current in Idle Corner Loops	0	0 36
Relative Current in Center Loop	2 0	1 18
Phase Angle between Current in Center Loop and Current in Corner Loops	180°	180°
Spacing between Corner Loops (2S)	420°	360°

Figure 56 Method of Feeding the Five-Loop Radio Range Antenna

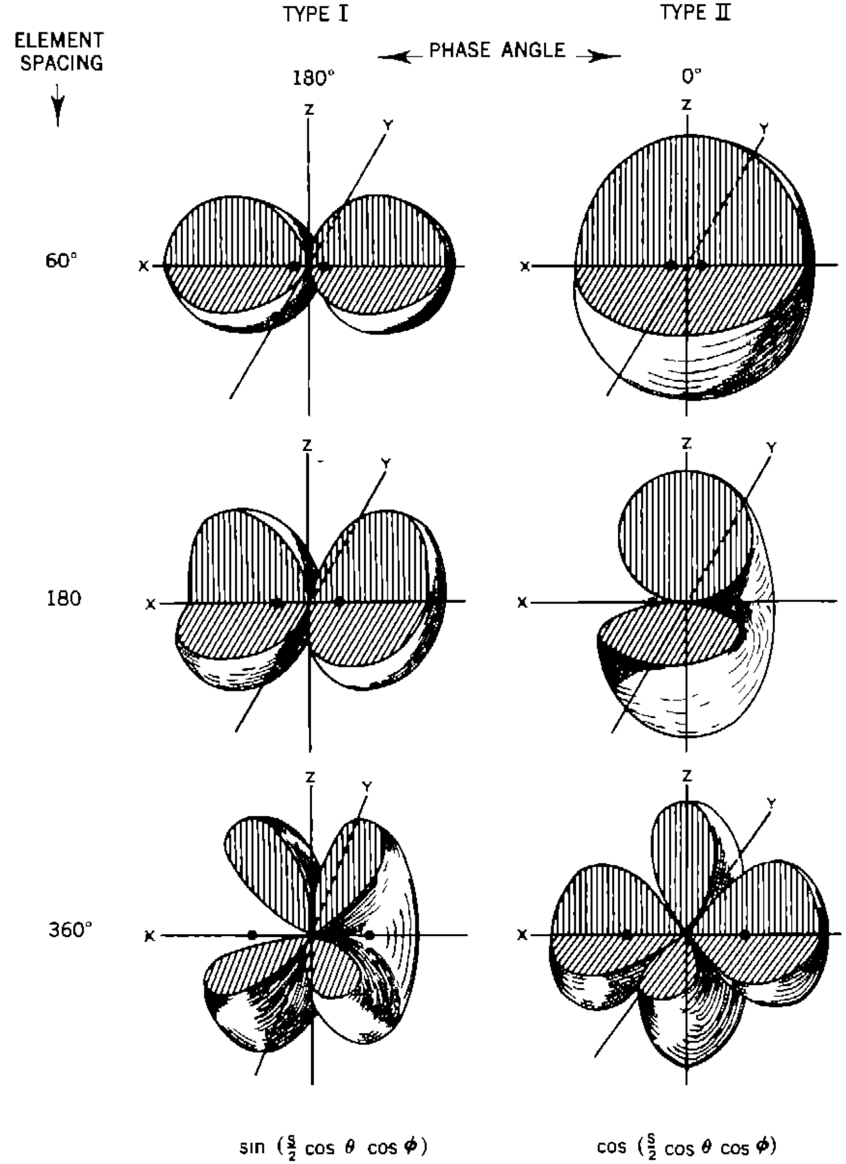
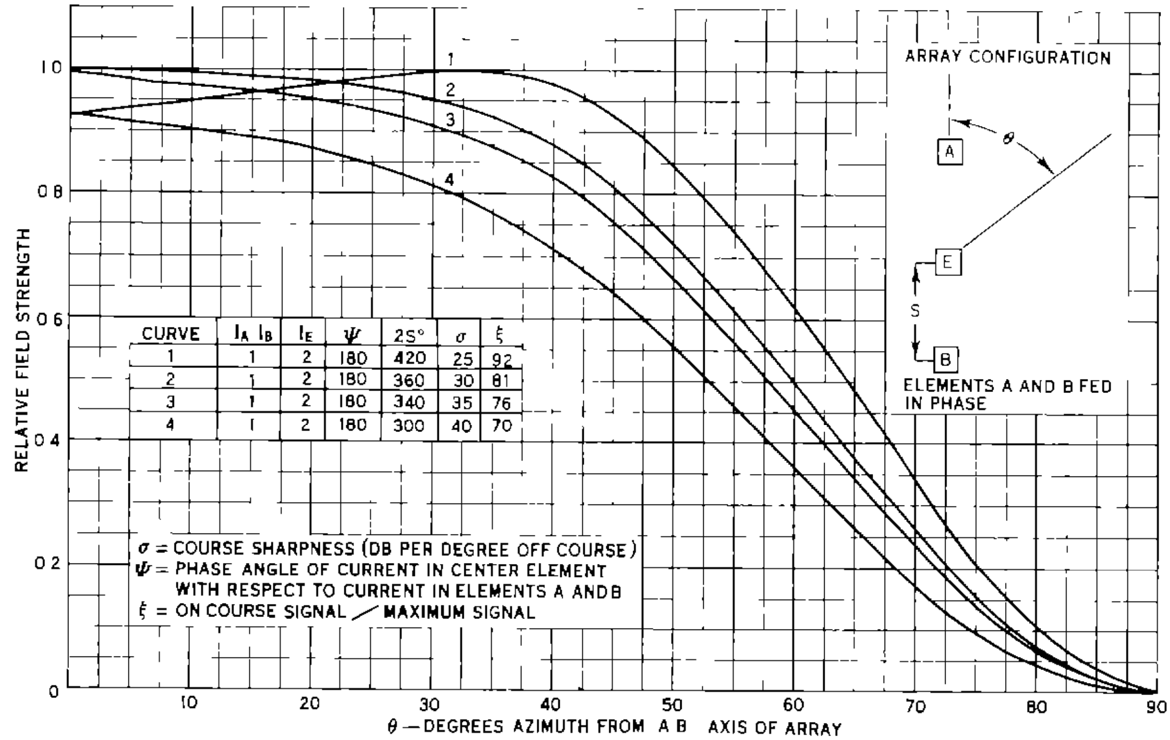
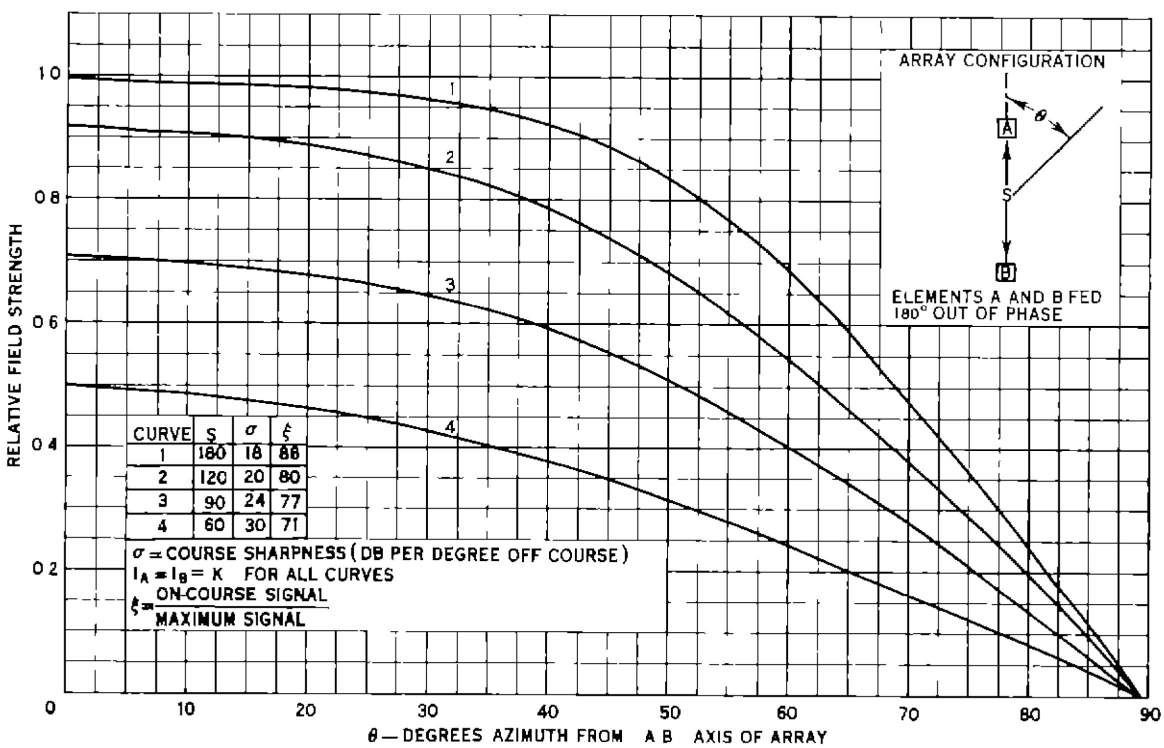


Figure 57 Free Space Field Patterns of two Point Source Radiator Elements, for Zero and 180° Phasing



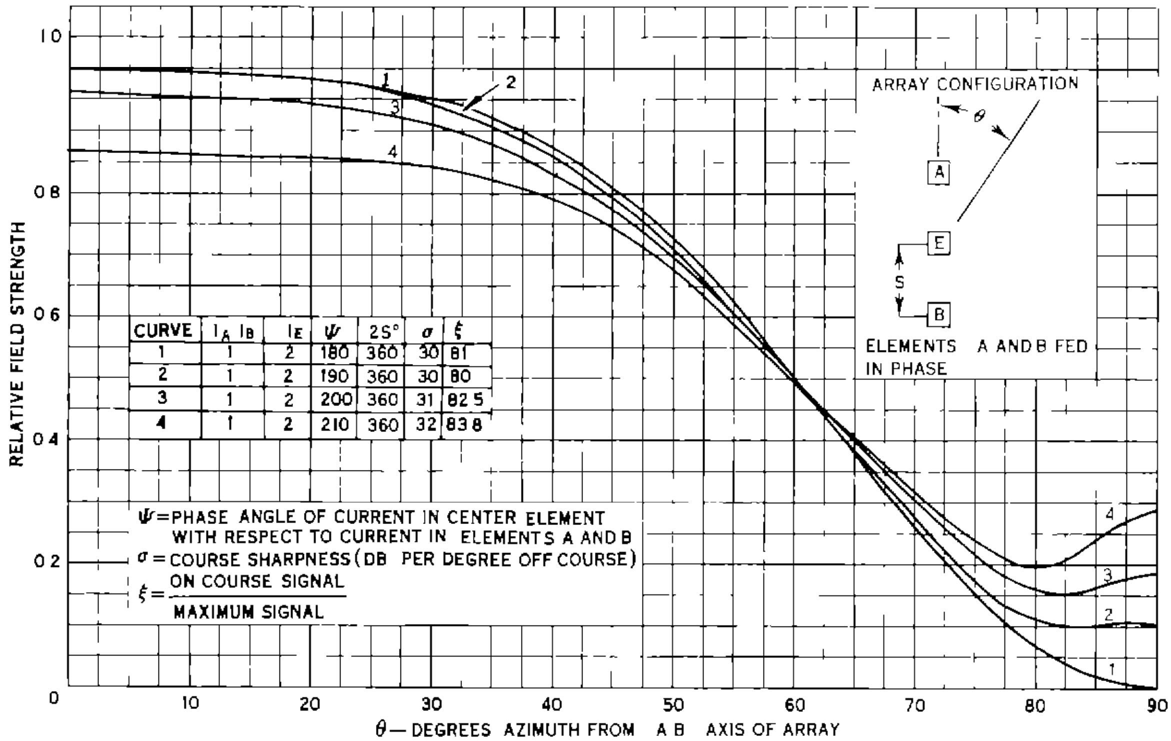
CURVE	I_A I_B	I_E	Ψ	2S°	σ	ξ
1	1	2	180	420	25	92
2	1	2	180	360	30	81
3	1	2	180	340	35	76
4	1	2	180	300	40	70

Figure 58 Horizontal Field Pattern of a Three-Element Array as a Function of Spacing



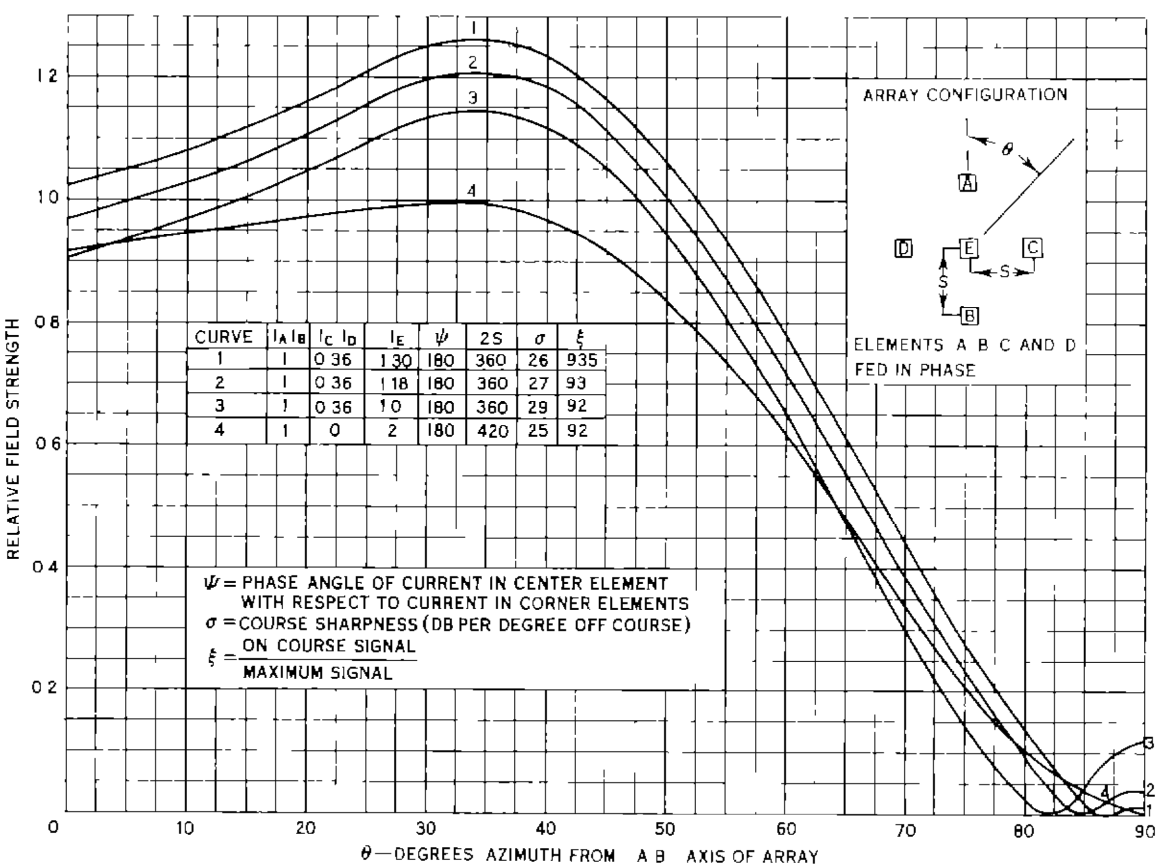
CURVE	S	σ	ξ
1	180	18	88
2	120	20	80
3	90	24	77
4	60	30	71

Figure 59 Horizontal Field Patterns of a Two-Element Array as a Function of Spacing



CURVE	I_A I_B	I_E	Ψ	2S°	σ	ξ
1	1	2	180	360	30	81
2	1	2	190	360	30	80
3	1	2	200	360	31	82 5
4	1	2	210	360	32	83 8

Figure 60 Horizontal Field Patterns of a Three-Element Array as a Function of Phasing



CURVE	I_A I_B	I_C I_D	I_E	Ψ	2S	σ	ξ
1	1	0 36	1 30	180	360	26	935
2	1	0 36	1 18	180	360	27	93
3	1	0 36	1 0	180	360	29	92
4	1	0	2	180	420	25	92

Figure 61 Horizontal Field Patterns of a Five-Element Array as a Function of Current Ratios

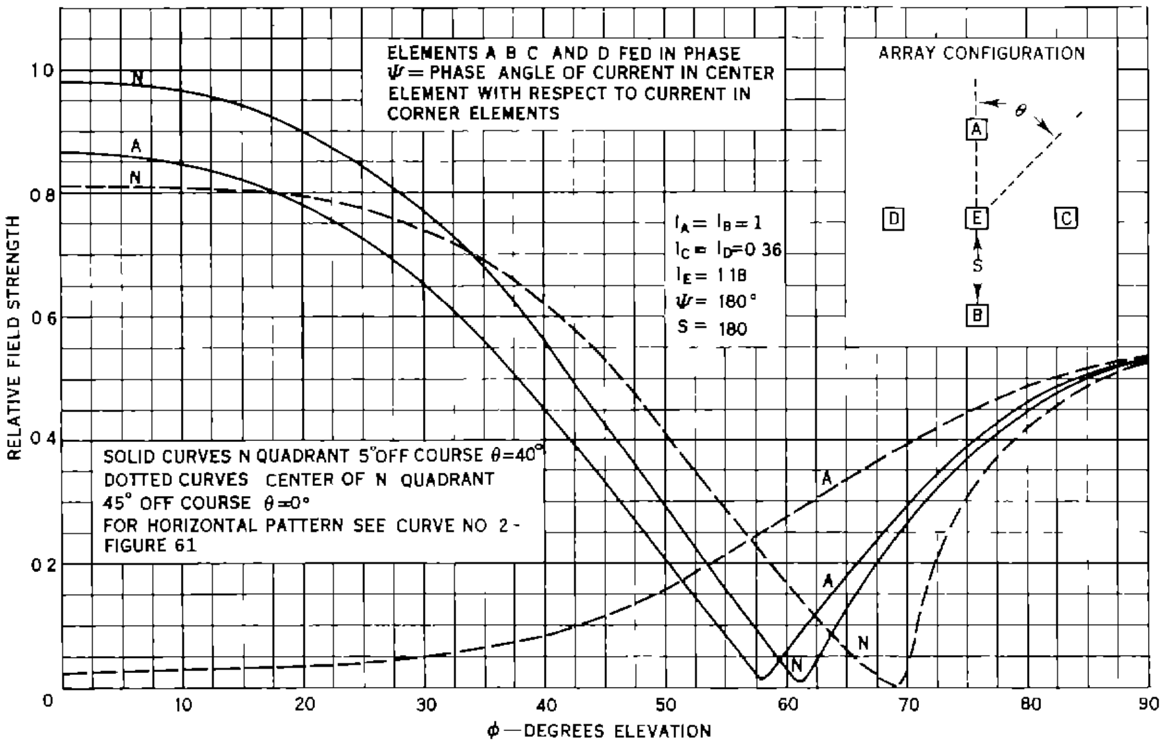


Figure 62, Free Space Point Source Sections of the Vertical Field Pattern of a Five-Element Array

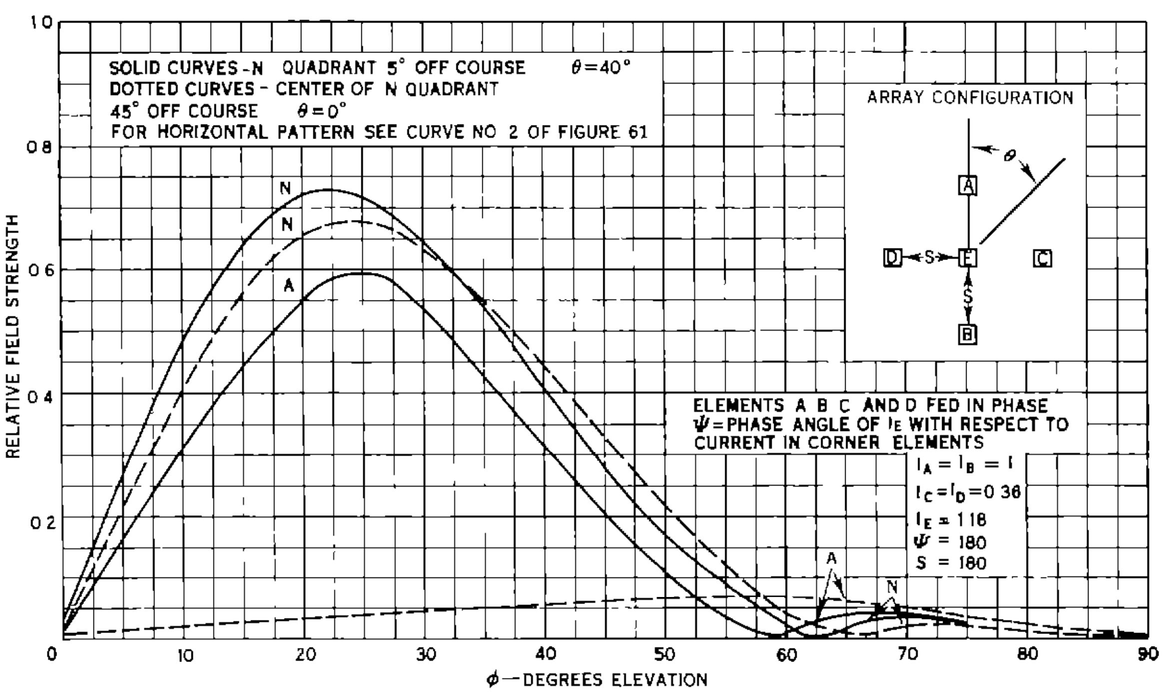


Figure 63 Sections of the Vertical Field Pattern of a Five-Loop Radio Range Antenna, One-Half Wavelength above Ground

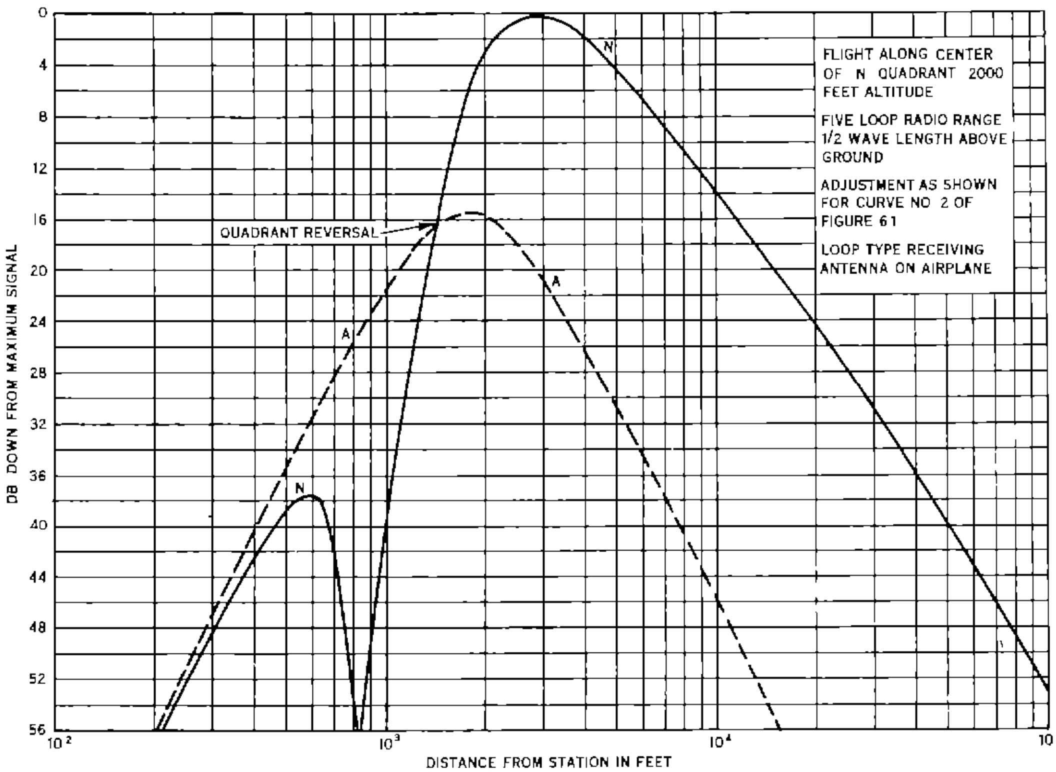


Figure 64 Received Signal Strength vs Distance from Station for Five Element Array, Showing Quadrant Reversal (Computed)

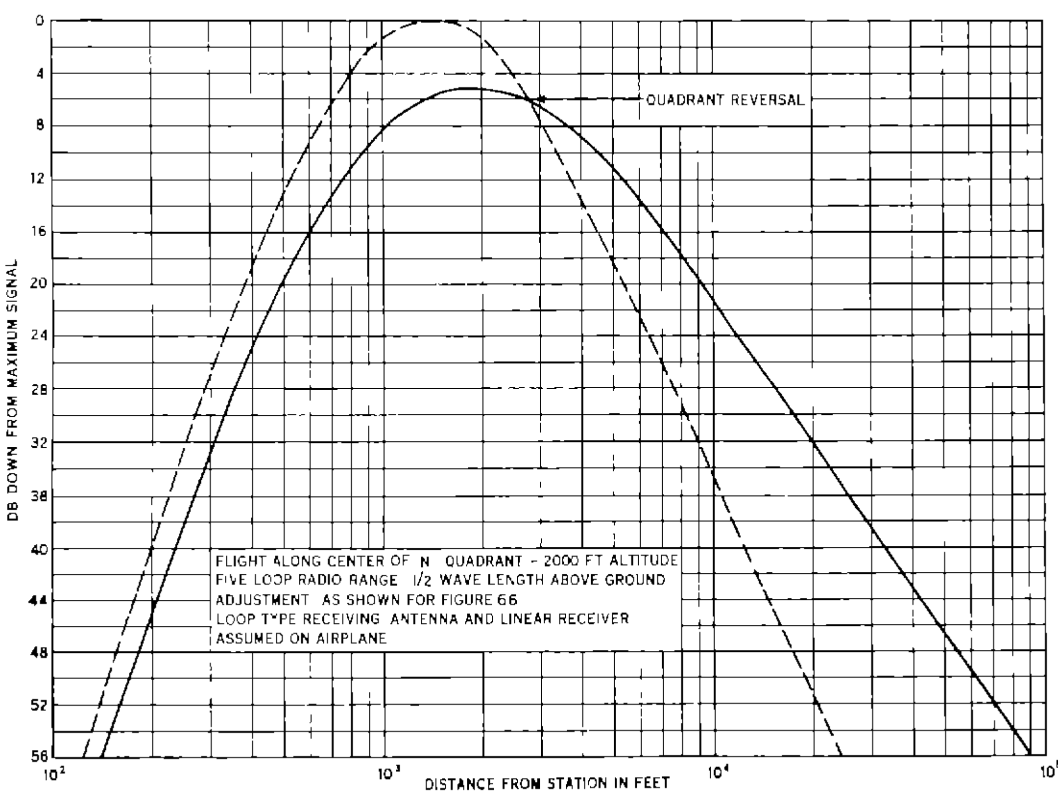


Figure 65 Received Signal Strength vs Distance from Station for Three-Element Array, Type II, Showing Quadrant Reversal (Computed)

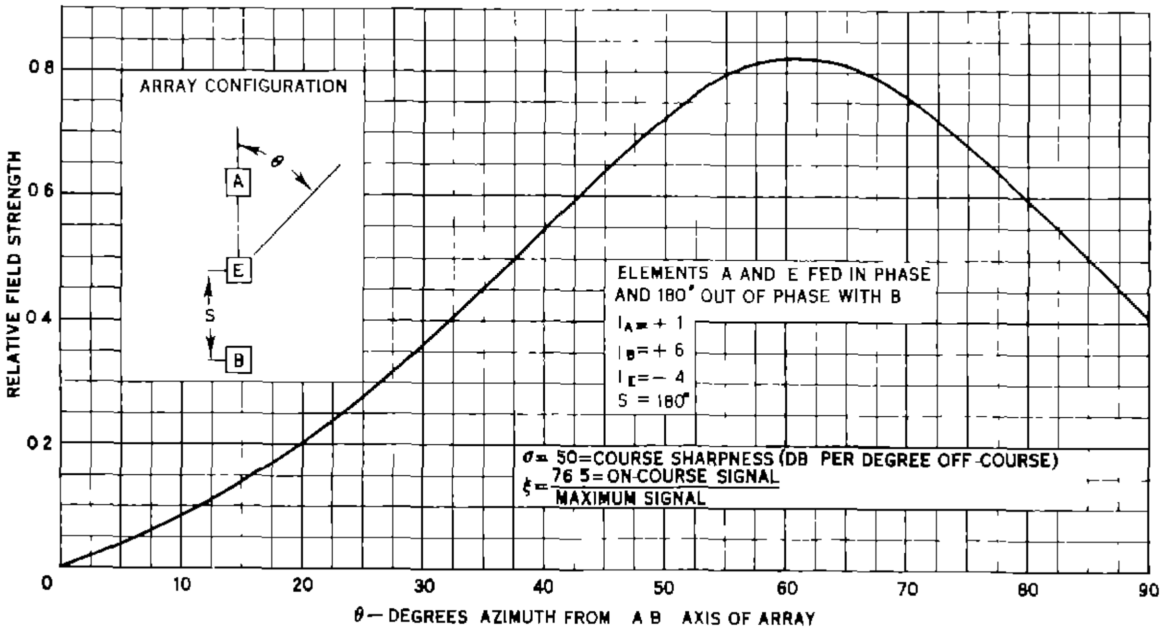


Figure 66 Horizontal Field Patterns of a Three-Element Array

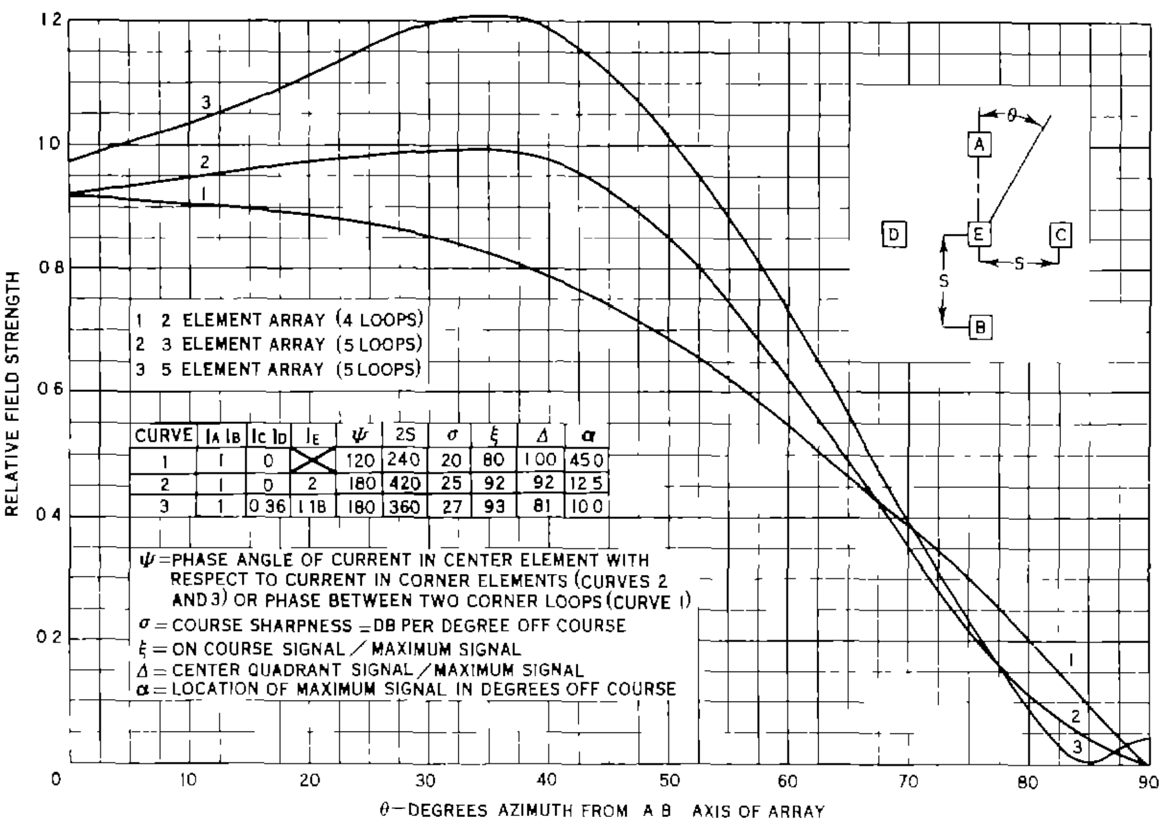


Figure 67 Horizontal Field Patterns of Two-, Three-, and Five-Element Arrays

Figure 68. View of the 125-Megacycle Range Station at Indianapolis, Using Pure Horizontally Polarized Ultra-High-Frequency Loop Antennas.

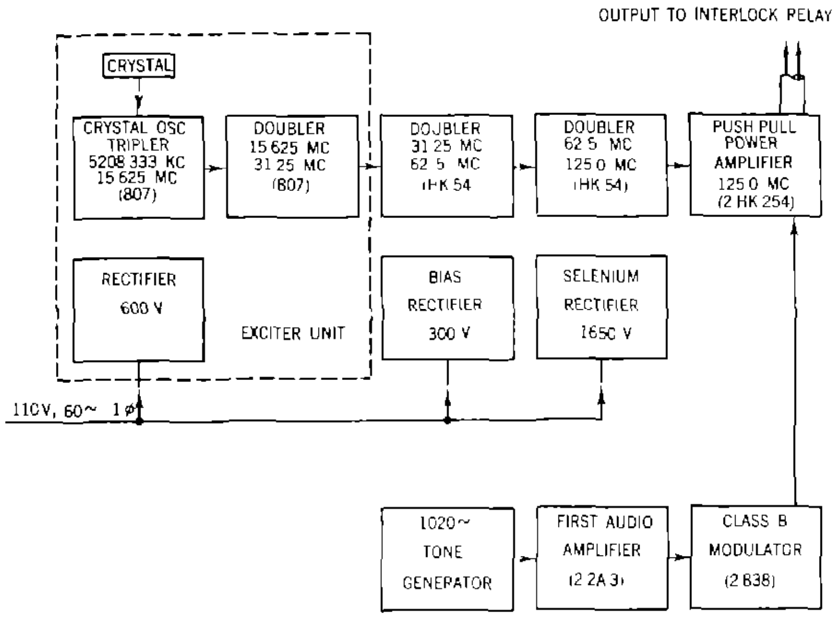


Figure 69 Block Diagram of the Modified TXI Transmitter Used on 125-Megacycles

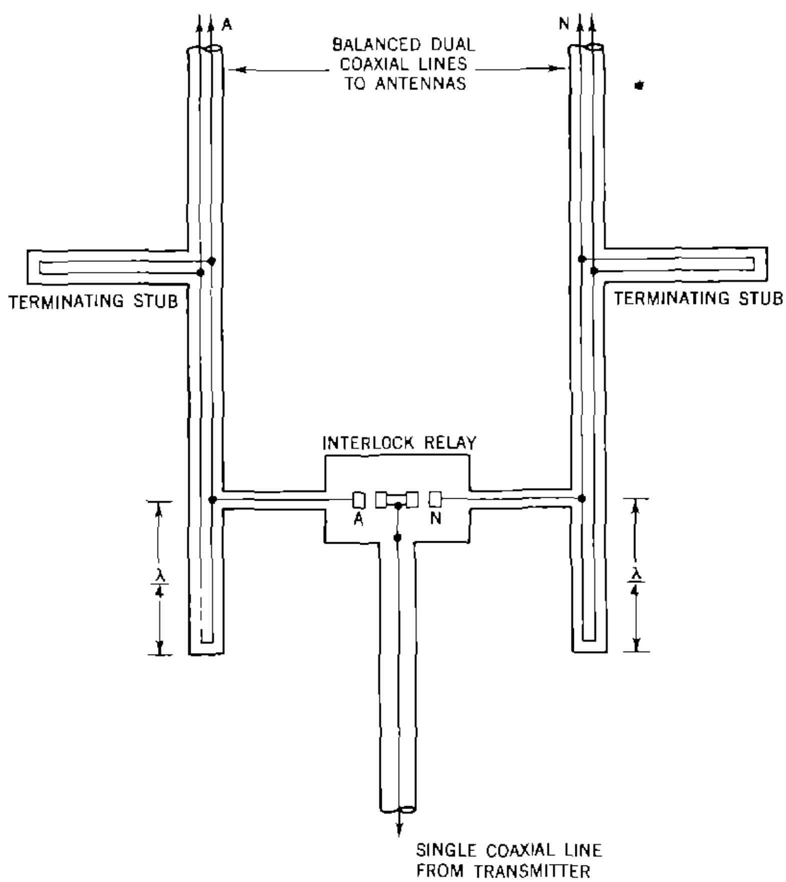


Figure 70 Diagram Showing the Balancing Network Used for Tranforming from Single Coaxial to Balanced Dual Coaxial Lines

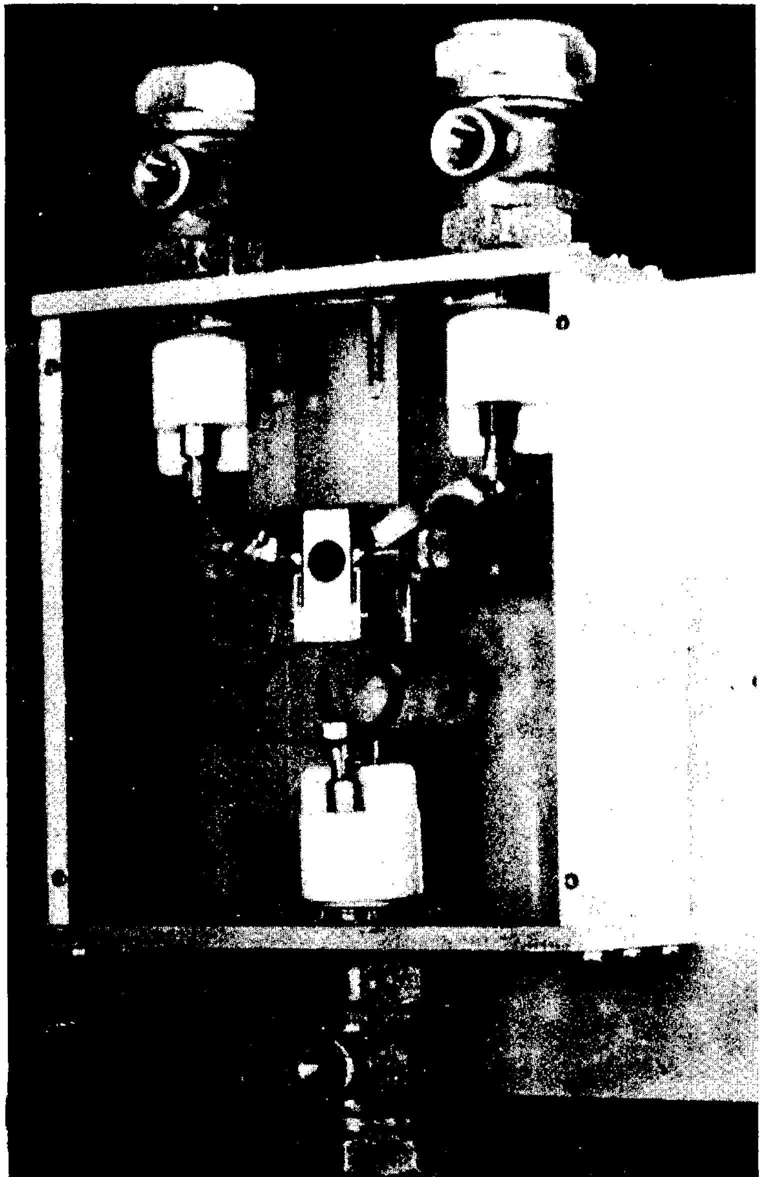


Figure 71. Close-Up View of the Modified Contact Arrangement of the Interlock Relay for use with Balanced Dual Coaxial Lines.

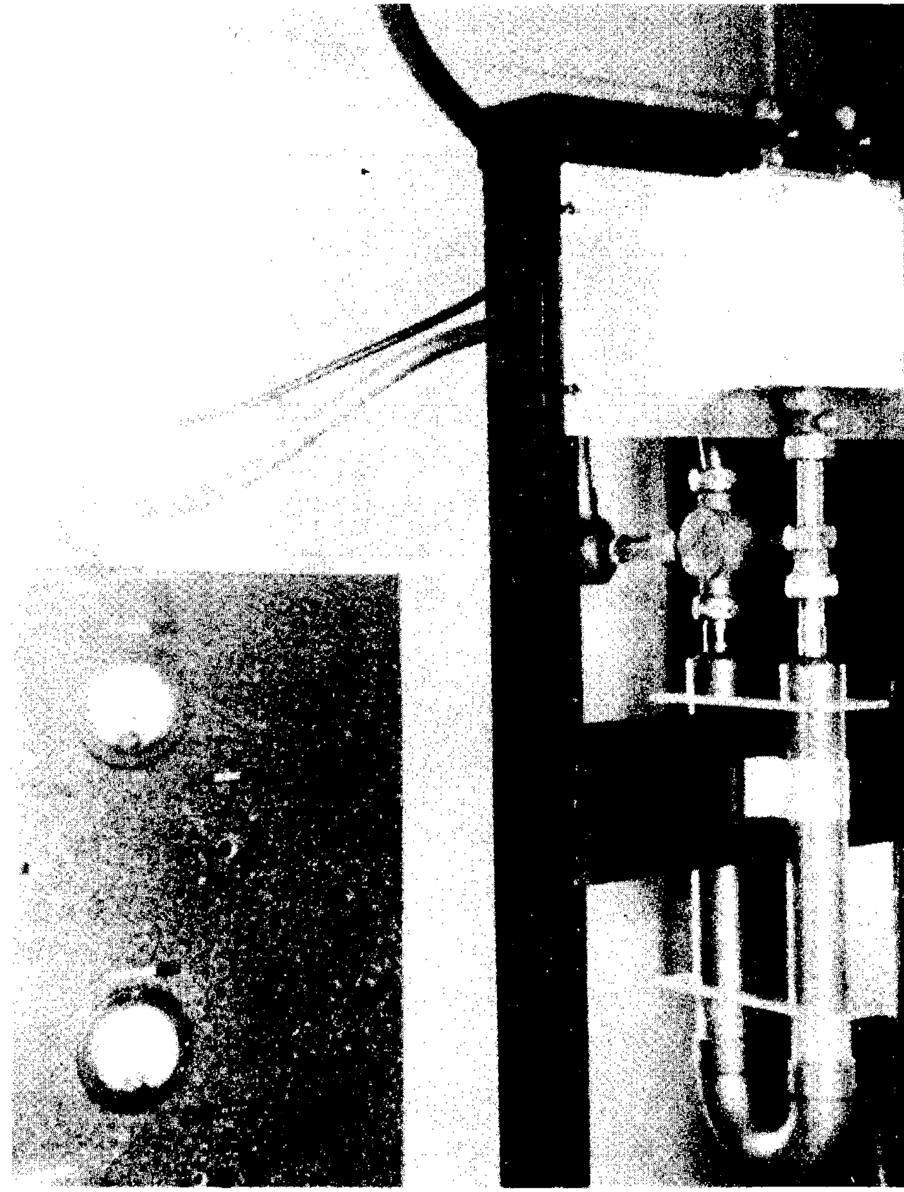


Figure 72. View of the Adjustable Trombone Phasing Section and the Shielded Interlock Relay.

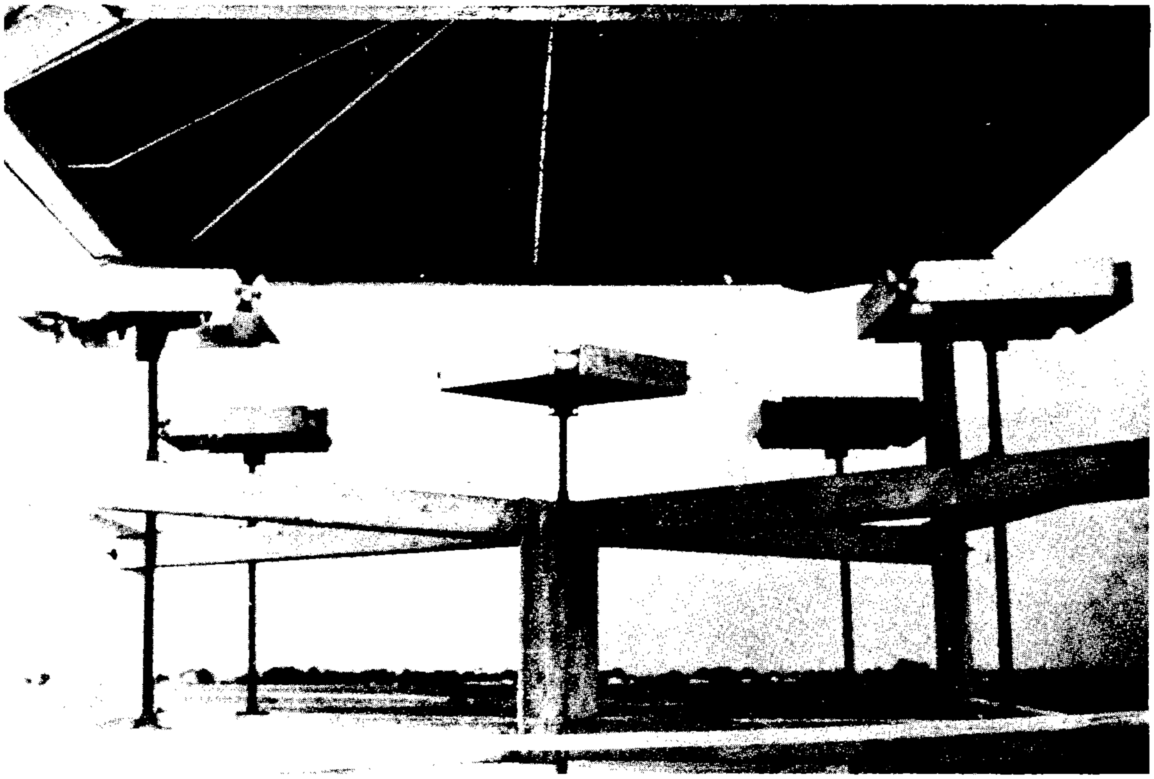
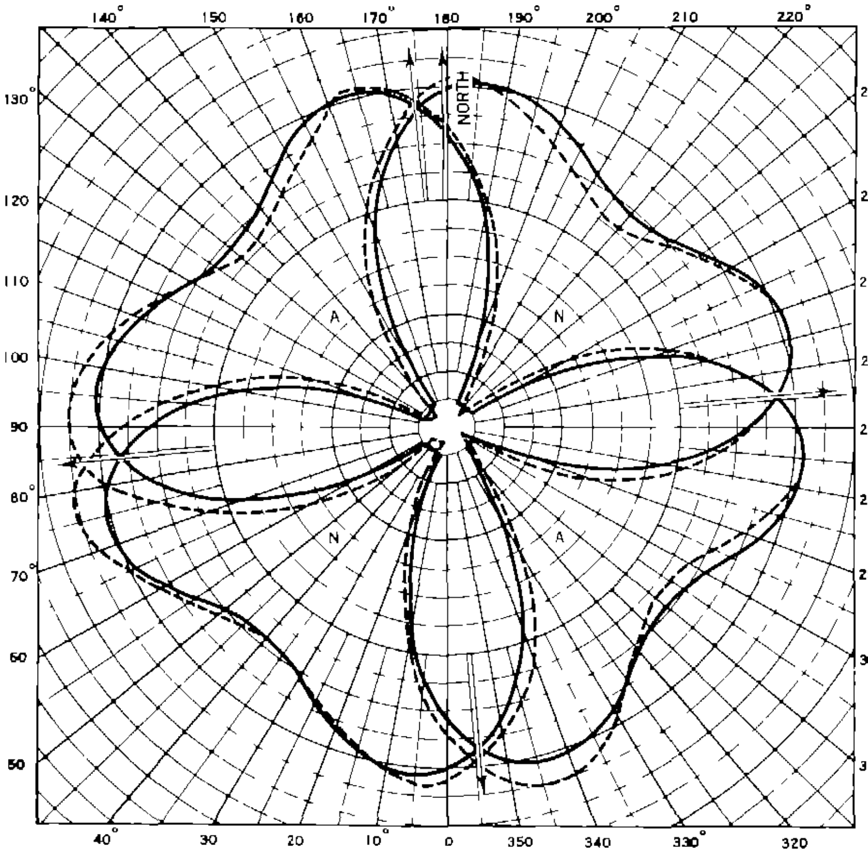


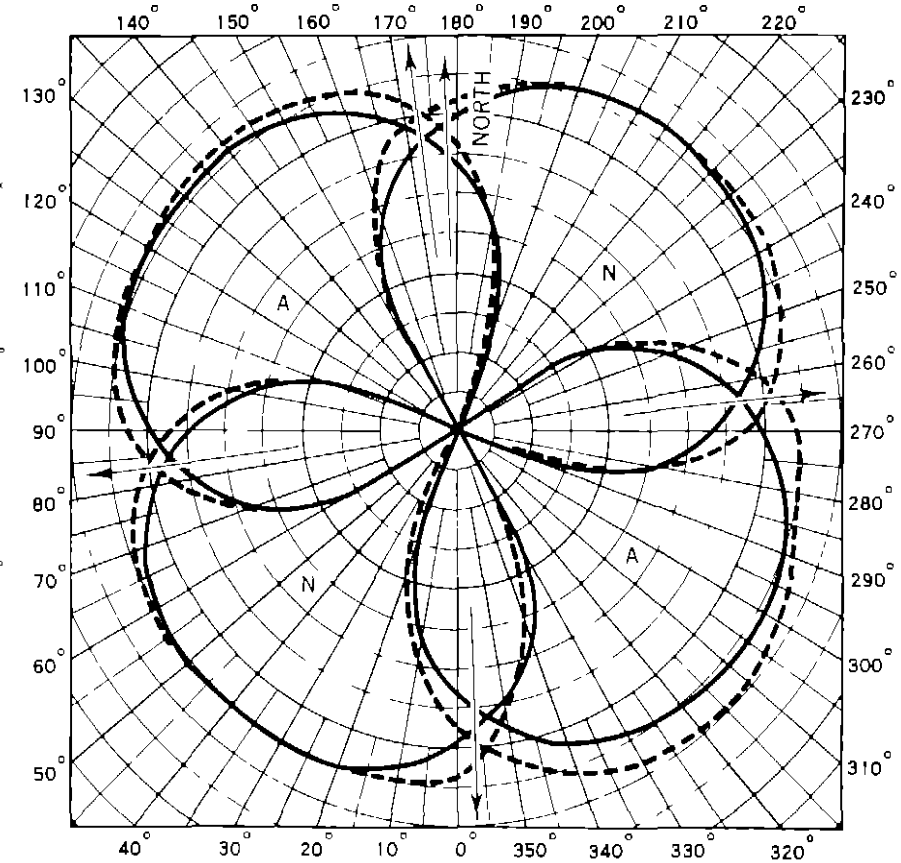
Figure 73. View of the Five-Loop Antenna Array on Top of the 30-Foot Counterpoise.

Figure 74. View of the Ultra-High-Frequency Loop Receiving Antenna Mounted Above the Fuselage of Civil Aeronautics Administration Stinson NC-80.



SOLID CURVE CALCULATED CORRESPONDS TO CURVE NO 2
OF FIGURE 61 DOTTED CURVE MEASURED AT 240 FOOT RADIUS

Figure 75 Measured and Calculated Horizontal Field Pattern of the Five- Loop Antenna



SOLID CURVE CALCULATED CORRESPONDS TO CURVE NO 2 OF FIGURE 59
DOTTED CURVE - MEASURED AT 240 FOOT RADIUS

Figure 76 Measured and Calculated Horizontal Field Pattern of the Four- Loop Antenna

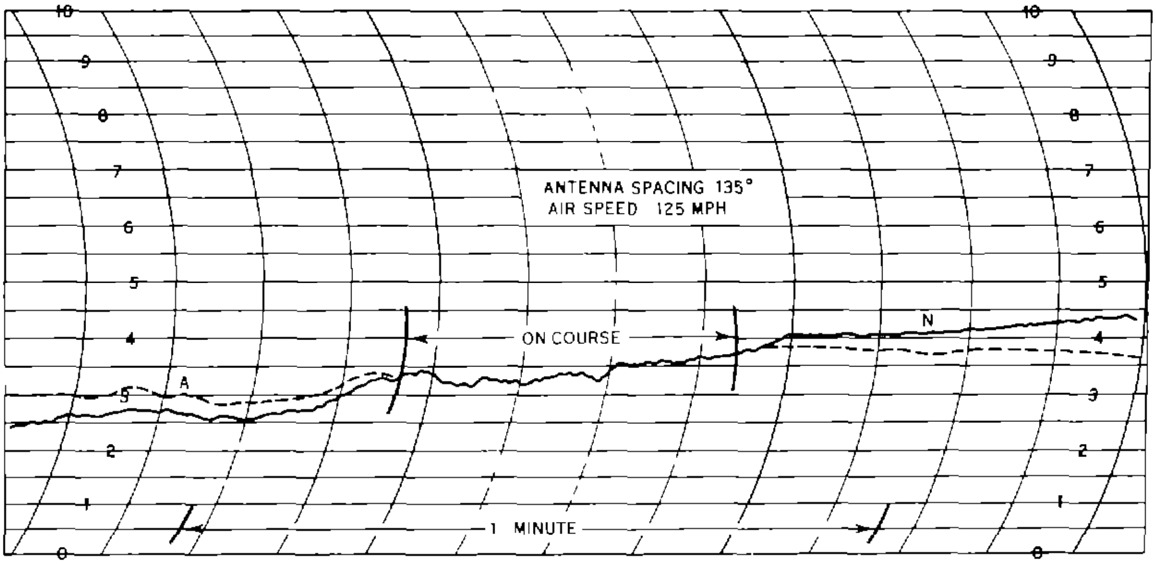


Figure 77 Envelope of Recording of Cross-Course Flight for Four-Loop Antenna Taken at 15 Miles and 5,000 Feet Above the Ground

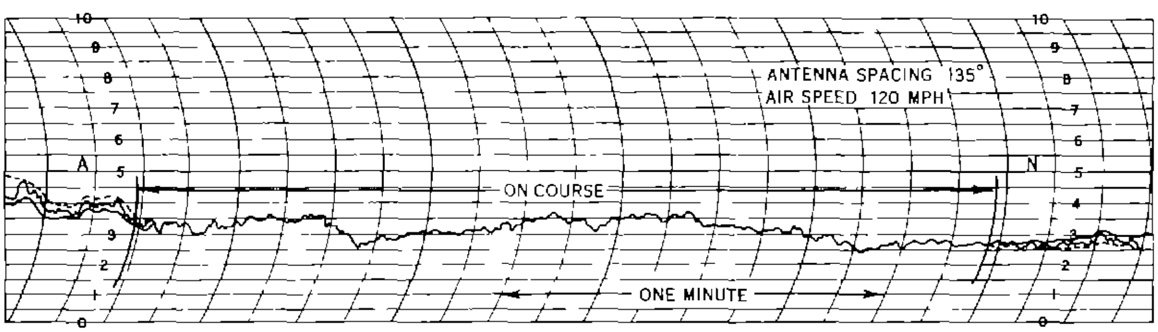


Figure 78 Envelope of Recording of Cross-Course Flight for Four-Loop Antenna Taken at 31 Miles and 4,000 Feet Above Ground

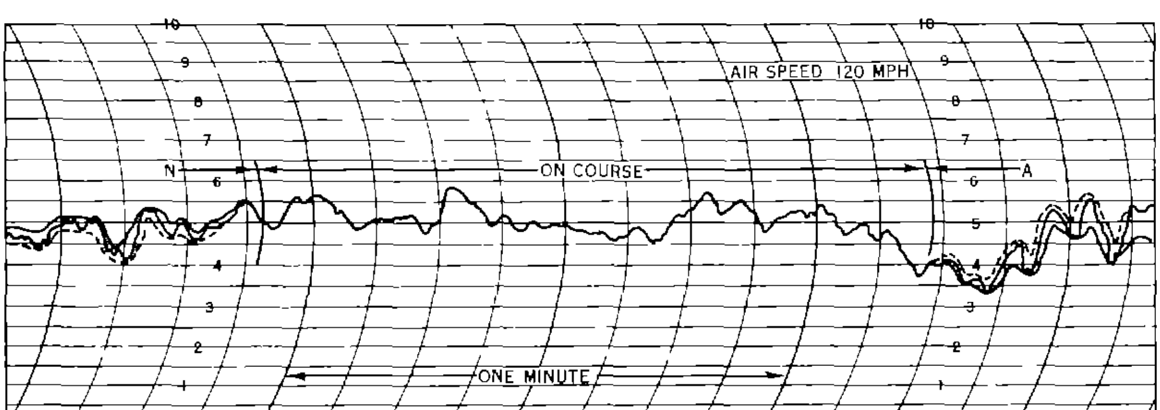


Figure 79 Envelope of Recording of Cross-Course Flight for Five-Loop Antenna Taken at 30 Miles and 2,000 Feet Above Ground

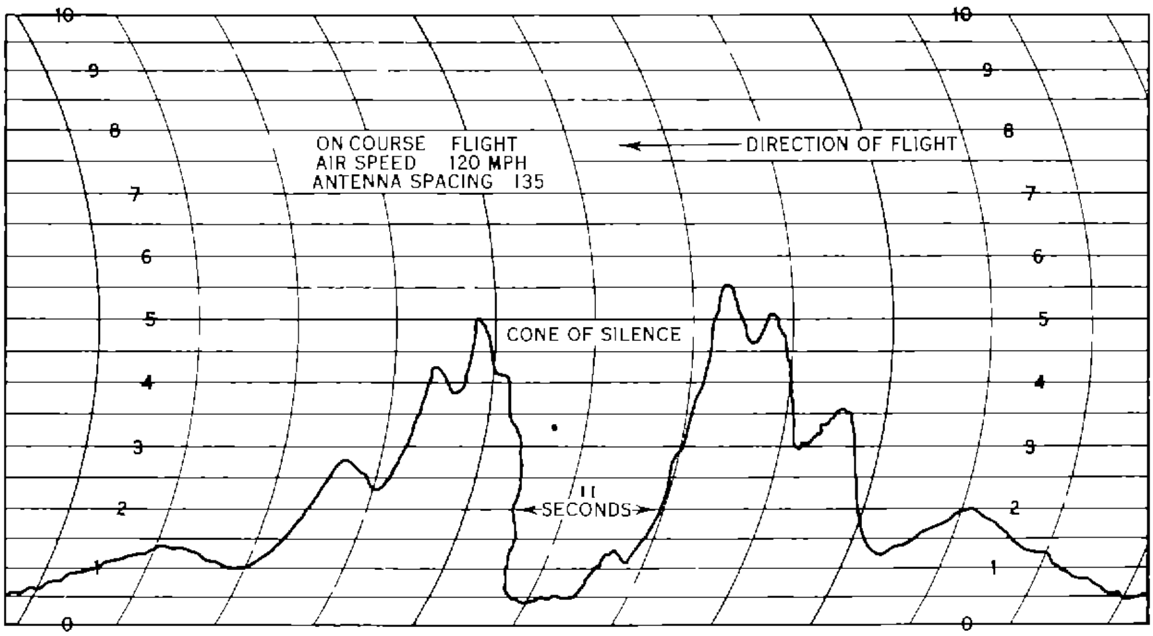


Figure 80 Cone-Of-Silence Recording Taken at 1,000 Feet Above Ground for the Four Loop-Antenna

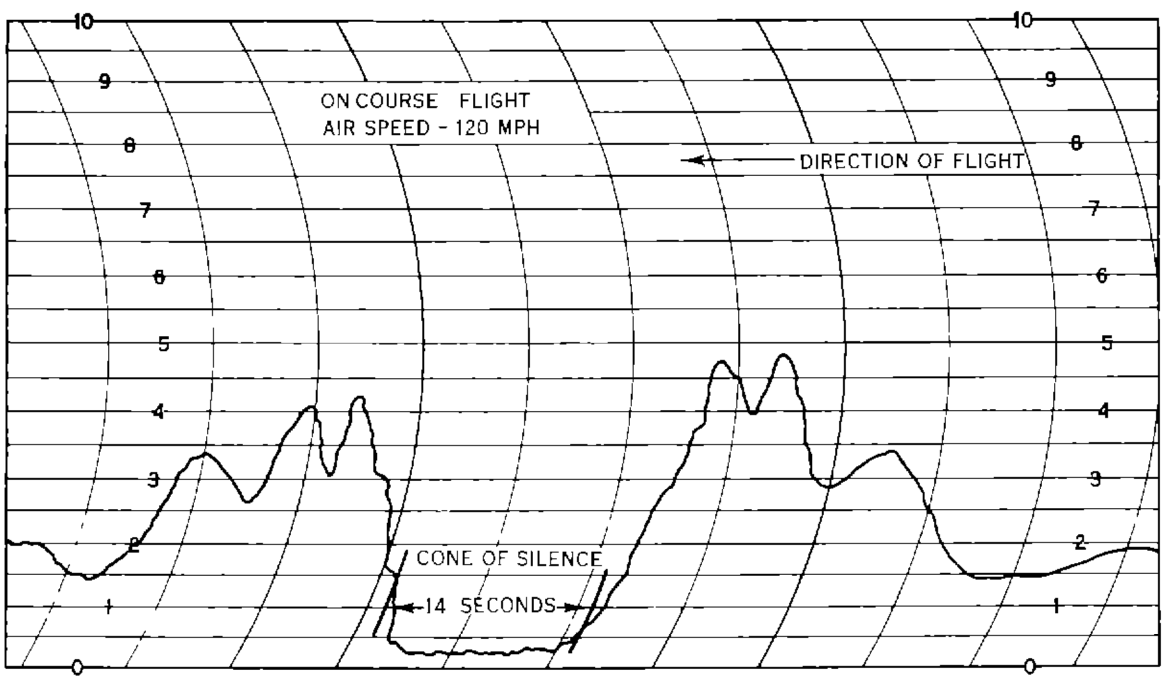


Figure 81 Cone-of-Silence Recording Taken at 1,000 Feet above Ground for the Five-Loop Antenna

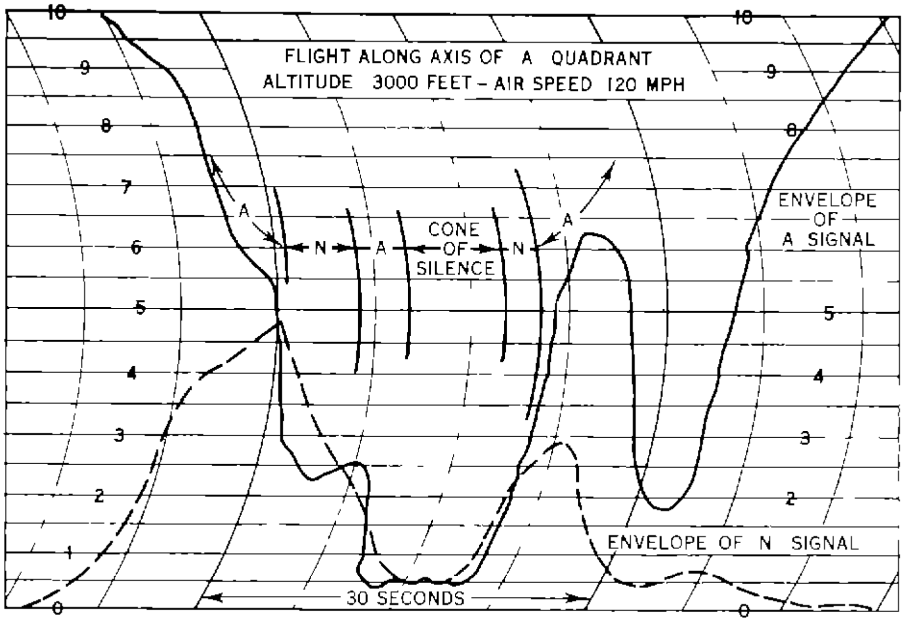


Figure 82 Cone-of Silence Recording for Five Loop Antenna Illustrating Quadrant Reversal Effects

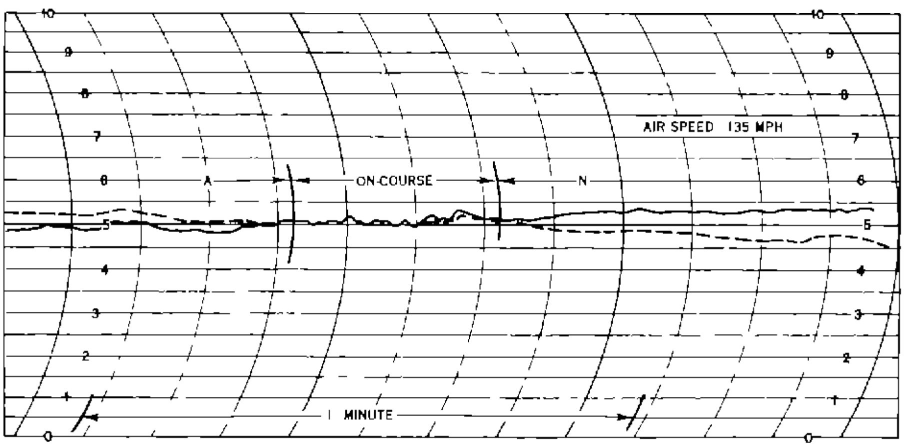


Figure 83 Envelope of Recording of Cross Course Flight on Indianapolis 266 Kilocycle Range at 15 Miles and 1 000 Feet Altitude

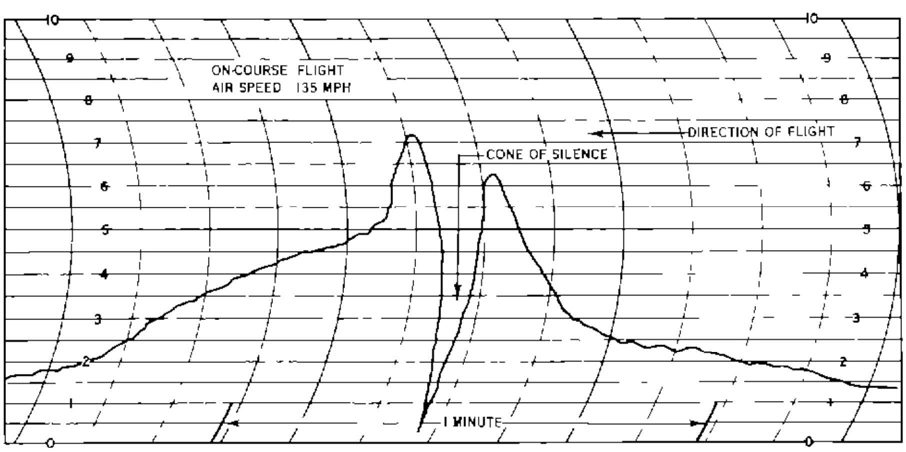


Figure 84 Cone of Silence Recording of the Indianapolis 266 Kilocycle Range at an Altitude of 1 000 Feet