ULTRA- HIGH- FREQUENCY AIRPORT TRAFFIC CONTROL

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ULTRA-HIGH-FREQUENCY AIRPORT TRAFFIC CONTROL

SUMMARY

In this report are presented the results of an investigation conducted on ground-to-aircraft transmission for airport traffic control services employing ultra-high frequencies in the band 129 to 132 megacycles A previous investigation made in this same field has established definitely the desirability of using ultra-high frequencies for this service However, only a single transmitting station was used in the previous investigation and it was considered desirable to make an additional investigation using several stations incorporating new improvements which have been discovered in the ultra-high-frequency radio art Accordingly, complete transmitting stations were installed at LaGuardia and Floyd Bennett airports in New York City and at Municipal Airport in Philadelphia The ground stations and aircraft equipment are described herein and the results of the flight tests discussed

As a result of this investigation, it is concluded that adoption of ultra-high frequencies for airport traffic control services in the manner described is practical and desirable and will provide performance which is superior to that of the present low-frequency services

INTRODUCTION

A dependable voice communication system between airport traffic control towers and aircraft is essential to the success of modern air transportation service Definite contact at all times for a minimum radius of 30 miles from the airport is considered a requisite At the present time, with few exceptions, the low frequency of 278 kilocycles is used for this service at airports having traffic control services Since this low-frequency assignment necessitates a low power transmission as a means of minimizing interference between adjacent airports, with consequent serious effects of atmospheric disturbances on the services, it produces a very small dependable service area

In the early part of 1937, an investigation was conducted for the purpose of determining whether ultra-high frequencies could be utilized satisfactorily for this service [1] This investigation was made using a single transmitting station operating at 125 megacycles which proved conclusively that the use of ultra-high frequencies for this purpose would give superior performance to the 278-kilocycle transmission Based upon results of the 1937 investigation, the Civil Aeronautics Administration recommended that ultra-high frequencies be adopted for airport traffic control Accordingly, the Federal Communications Commission made available several channels in the 129-132 megacycle band and specified that after January 1, 1941, all airport radio stations would have to provide ultra-high-frequency facilities in addition to 278 kilocycles, which would continue in use during a reasonable period of transition

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[1] W E Jackson and J C Hromada, "Report on 125-Megacycle Airport Traffic Control Tests at Indianapolis," Civil Aeronautics Authority, Technical Development Report No 2, January 1938

Since only one station had been used in the 1937 investigation, it was considered advisable to conduct another series of tests using three stations located at various distances from each other, employing various frequency separations, and incorporating in the equipment design all important improvements which had subsequently been developed

In order to conduct these tests three sets of transmitting equipment, three transmitting antennas, and six aircraft receivers conforming to Civil Aeronautics Administration Specifications CAA-11, CAA-254, and CAA-13, respectively, were obtained from the Radio Receptor Company One set of transmitting equipment was installed at each of the following airports. LaGuardia and Floyd Bennett Airports in New York City, and the Municipal Airport at Philadelphia One receiver was installed in the Civil Aeronautics Administration Stinson airplane NC-80, which was used for flight tests Another receiver was installed in the Administration's Boeing airplane NC-11, which was used for demonstration flights These tests were completed, and in the fall of 1940 the three-station experimental system was demonstrated to the Radio Technical Committee for Aeronautics Following the demonstration, the FCC amplified its rules to accommodate a comprehensive national system of airport stations specifying standardized operating channels, and a definite schedule governing establishment of service on ultra-high frequencies at various categories of airports

It is the purpose of this report to describe the equipment used and to discuss the test results obtained

GROUND EQUIPMENT

Transmitter

The transmitter is crystal-controlled and is capable of delivering 100 watts of power to the antenna at any frequency between 129 and 132 megacycles The crystal unit is provided with a thermostatically controlled heater and operates at a fundamental frequency which is one twenty-fourth of the transmitting frequency A type 807 tube is used as a fundamental crystal oscillator and frequency quadrupler This is followed in the buffer amplifier stage by another type 807 tube which is used as a frequency doubler Following this, the first intermediate power amplifier stage uses a type 35TG tube operating as a neutralized fundamental amplifier The second intermediate power amplifier stage uses two type 35TG tubes in a push-pull tripler circuit The power amplifier is a fundamental Class C push-pull amplifier using two type 75T tubes The output stage operates into an adjustable coupling circuit which connects to a balanced 2-wire transmission line having an impedance of 140 ohms

The power amplifier is plate-modulated by a push-pull audio amplifier using type 805 tubes A low level audio-amplifier stage and a push-pull audio-driver stage precede the modulator The audio amplifier is provided with an adjustable 600-ohm "L" pad The range of adjustment is such that input levels from plus 15 decibels to minus 15 decibels may be used Three rectifiers are used in the transmitter to supply the necessary plate and bias voltages Circuit breaker switches and overload relays are used instead of fuses A switch is provided on the control panel for reducing the voltage of the high-voltage rectifier to 70 7 percent, thereby reducing the radio-frequency power output to 50 percent An automatic voltage regulator, rated at 1,600 watts is used to compensate for line voltage fluctuations in the 115-volt, 60-cycle power supply.

A monitor meter is provided on the transmitter for indicating both the percentage modulation and the amplitude of the radio-frequency carrier at the input terminals of the transmission line

Figures 1 and 2, are photographs of the transmitter Figure 3 is a block diagram of the transmitter

Transmitting Antenna

The antenna radiates a horizontally polarized signal having an essentially circular field pattern in the horizontal plane It consists of two crossed "folded" dipoles arranged to provide currents in phase quadrature and is commonly known as a "turnstile" type antenna One dipole is made shorter than one-half wavelength and the other longer than one-half wavelength in order to obtain a 90° phase shift between the two dipoles The shorter unit is capacitive and draws current that is leading the feeder voltage by 45° The longer unit is inductive and draws current that lags the feeder voltage by 45° A sleeve type construction at the folded section of the dipoles provides for the adjustment of their lengths to vary the shape of the field pattern An inductance coil having low loss characteristics is connected across the end of the matching section to tune out the stray shunt capacity of the feed through insulators The impedance of the dipoles connected in parallel is approximately 300 ohms A quarter-wave transmission line section of 205 ohms impedance is used to match the antenna to the 140-ohm 2-wire transmission line The antenna assembly is mounted on a 3-inch diameter galvanized steel pipe which is 18 feet long and is provided with a mounting and steel braces Figure 6 is a photograph of the antenna

Speech Amplifier

The speech amplifier operates between the microphone and the transmitter and is capable of providing an output of zero level when the input level is minus 60 decibels The amplifier uses two stages of amplification and is provided with a gain control and an overload magnetic type circuit breaker Figure 5 is a photograph of the unit

Microphone and Monitor Unit

The microphone is a Western Electric induction type No 632 and is mounted on a stand having a control switch The monitor unit is designed for mounting near the operator's position and is provided with a monitor meter and two pilot lamps The remote monitor meter connects in parallel with the monitor meter on the transmitter The two pilot lamps connect in parallel with the filament and plate indicating lamps on the transmitter

Factory Tests

Complete tests were conducted on all equipment prior to its installation at the airports A general summation of the important electrical characteristics which resulted from these tests is shown in figures 4, 7, 8, 9, and 10

AIRCRAFT EQUIPMENT

The aircraft equipment used in the tests consisted of a type RUH aircraft receiver, a 125-megacycle horizontal loop type receiving antenna, a 3-channel filter-control unit having a full-wave copper oxide rectifier unit, and an Esterline-Angus type AW 5-milliampere recorder Flight tests were made in the Civil Aeronautics Administration's Stinson airplane NC-80 Figure 11 is a photograph of the installation in the plane

Type RUH Aircraft Receiver

The receiver uses a triple detector ("double superheterodyne") circuit and is provided with manual tuning on two frequency bands, 60-66 megacycles and 123-132 megacycles Crystal-controlled reception is provided at any two spot frequencies in the higher frequency band, and in this case crystals were supplied for reception at 125 and 130 3 megacycles The receiver is designed for the general application of both voice and radio range reception and is equipped with switches and controls for these services All controls are located on a remote control unit designed for mounting near the instrument panel A total of 17 tubes is used, including the rectifier Figures 12, 13, 15 and 16, are photographs of the receiver and remote control unit, and figure 17 is a block diagram of the receiver The performance characteristics for 123-132 megacycle operation are shown in figures 18 to 25, inclusive

Airplane Antenna

A standard 125-megacycle horizontal loop-type antenna[2] was used for receiving all signals during the tests The antenna was tuned to 130 3 megacycles for all tests Figure 14 is a photograph of the antenna on the plane

INSTALLATION

During the installation of the equipment at the three airports, an effort was made to make all three installations identical This feature was found impractical, however, because of the differences in buildings, available space, and existing low-frequency equipment Some difficulty was encountered in providing parallel operation of the equipment with the existing low-frequency equipment, and each installation was found to require a different circuit arrangement The antennas were mounted on the roofs of the buildings at the most practicable locations to give clear areas for the radiated fields The heights of the antennas above ground at the Floyd Bennett, LaGuardia, and Philadelphia airports, respectively, are 73 feet, 82 feet, and 46 feet Figures 26, 27, and 28 are photographs of the three antenna installations Figures 29, 30, and 31 are photographs of the Philadelphia transmitter, antenna, and control tower installations

TEST PROCEDURE AND MEASURING EQUIPMENT

The phenomena particularly observed were transmitting and receiving field patterns, interference at various carrier frequencies, propagation, and service range at various altitudes Since the operation of airport traffic control transmitting equipment is normally for intermittent voice transmission, it was necessary to provide a different method of operation in order that measurements of the transmitting characteristics could be made To accomplish this, each transmitter was provided with an audio oscillator and arranged for continuous operation The frequencies of the three tone signals were widely separated as a means of simplifying the measuring equipment in the airplane The frequencies selected were for the Philadelphia station, 460 cycles, for the Floyd Bennett station, 1020 cycles, and for the LaGuardia station, 4300 cycles The tone signals in all cases were adjusted to give approximately 90 percent modulation of the radio-frequency carrier A few tests were also made using voice transmission Provision was made for changes in the transmitting frequencies by means of several plug-in type crystal units For the tests requiring voice signals, a recording of speech was made which provided a continuous voice transmission of nearly two hours All flight tests were made in the Administration's Stinson airplane NC-80 Figure 32 is a map of the area covered in the flight tests.

The installation of the receiver, the recorder, and the filter-control unit in the airplane is shown in figure 11 The remote control unit for the receiver was mounted on the right side of the co-pilot's seat The cathode circuit of the first intermediate-frequency amplifier and the output circuit of the receiver were each connected to the filter-control unit The former circuit is controlled by the

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

automatic volume control action of the receiver and was used for indicating relative field strengths of the received signals. This intermediate-frequency current could either be recorded on the recorder or observed on the milliammeter which was mounted on the filter-control panel A calibration of the intermediate-frequency current versus microvolts input was made prior to the field testing The milliammeter was also used as a voltmeter for measuring the battery voltage to the receiver Three band-pass filters, together with several selector switches, jacks, and level controls, were provided in the filter-control unit and so connected that it was made possible to monitor or record the received tone signals either together or separately, as desired Separate attenuation controls were provided in each filter circuit for adjusting the recording or headphone levels A block diagram of the filter-control unit is shown in figure 33 The characteristics of the copper oxide rectifier are shown in figure 34

FLIGHT TEST RESULTS

Receiving Antenna Characteristic

It was necessary to determine the horizontal pattern of the receiving antenna on the airplane before proceeding with the measurement of the transmitting patterns This characteristic was derived from recordings made during several flights at points located 20 to 25 miles from the Floyd Bennett station and at altitudes between 1,000 and 2,000 feet The receiver volume control was on manual position for these tests and the transmitter was modulated with a 1020-cycle tone signal

Figure 35 shows the receiving antenna pattern obtained when the airplane was in level flight over a fixed point at various headings and constant altitude Also shown in this figure are the results of recordings made during left- and right-hand turns with wings leveled

Figure 36 shows the plot of a recording made during left- and right-hand turns in a 40° bank Figure 37 shows the antenna patterns during a left- and a right-hand turn with the wings banked 15°.

The pattern obtained in level flight over a fixed point is considered to be correct for this condition All other patterns are subject to error mainly because of the unavoidable change in position when the airplane is flying a circle. It will be seen that for the pattern obtained over a fixed point the front and rear of the airplane show less than a 1 5-1 variation for more than a 45° section at both front and rear

It will be seen from figure 36 that the receiving pattern in the vertical plane of the airplane will have a large variation It was not possible to obtain a measurement of the vertical characteristics during the testing of this equipment An indicated pattern in the vertical plane, however, will be shown later in this report

Transmitting Horizontal Field Pattern

No accurate measurements were made of the transmitting horizontal field patterns However, the result of a recording made on a flight around the Floyd Bennett station at a 5-mile radius and 2,000 feet altitude is shown in figure 38 The field versus distance curves in figures 51 and 52 show that the pattern of figure 38 is subject to considerable variation because of the rapid change in the field strength due to varying apparent heights of the antenna at various azimuth positions Figure 39 shows the results of a recording of the LaGuardia station This pattern is likewise subject to large variations Figure 40 shows the results of recordings made during identical flights before and after the transmitting antenna had been rotated 45°

Propagation and Service Range

Flight tests were made to determine the relative field strength of the Philadelphia and Floyd Bennett stations on a course between the two stations at an altitude of 2,000 feet Figure 41 shows the result of this measurement The automatic volume control current of the receiver indicated the relative field strength The same method of measuring was used to obtain the data illustrated in figure 42, which shows the change in relative field strength of the Floyd Bennett station with change in altitude This observation was made during a test flight over Bay Shore, L I

Figure 43 shows the change in receiver output signal of the Philadelphia station with change in altitude as recorded during a flight test over the Floyd Bennett airport The receiver volume was controlled manually during this test It is interesting to note that the slopes of the curves of figures 42 and 43 are practically the same

Figure 44 shows the result of recordings of the Philadelphia tone signal between Philadelphia and New York City at altitudes of 2,000 and 8,000 feet Automatic volume control was used in the receiver for this test Figure 45 shows the result of a similar recording of the Floyd Bennett signal between Philadelphia and New York City at an altitude of 2,000 feet

Figures 46 and 47 show the result of recordings made of signals from the Floyd Bennett station with the transmitter operating at 33 and 100 watts output The flight was made from the Floyd Bennett airport to Center Moriches, L I , at an altitude of 1,000 feet For this test, recordings were made alternately of the tone signal from the output of the 1020-cycle filter and of the tone signal plus noise to the input of the filter The receiver was operated with automatic volume control for this test

Flight tests were conducted at each of the three stations with voice signals being transmitted For these tests, the transmitters were modulated with recorded voice signals and the receiver was operated with automatic volume control The flights were made on a 30-mile radius at an altitude of 1,000 feet Clear, intelligible reception was obtained at all points at this radius and altitude As will be seen from a survey of the curves of figures 43 to 47, reception at greater distances is obtainable

Field Versus Distance Curves

Field versus distance curves were obtained from recordings made during flights across each station at a constant altitude Figure 48 shows a copy of a portion of an actual recording of signals from the Floyd Bennett station during a flight test in a southwest to northeast direction at a constant altitude of 2,000 feet with the receiver volume controlled manually Figures 49, 50, and 51 are plotted curves of this recording These curves are the resultant of the station's vertical field characteristics and the airplane's nose-to-tail vertical receiving characteristics Figures 52 and 53 are curves obtained from a recording of signals from the Floyd Bennett station This flight test was made in a north to south direction at an altitude of 2,000 feet Figure 54 is a field versus distance curve of the Floyd Bennett station obtained from a recording made on a flight from a northwest to southeast direction at an altitude of 2,000 feet Figure 55 is a curve of the Floyd Bennett station obtained from a recording made during a flight from east to west at an altitude of 1,000 feet Figures 56 and 57 are field versus distance curves of transmissions from the Philadelphia and LaGuardia stations, respectively, obtained from recordings made at an altitude of 2,000 feet Figure 58 shows curves of the outer maximum and minimum areas of the Floyd Bennett and Philadelphia stations obtained from recordings made at an altitude of 2,000 feet.

Interference Patterns

Interference patterns were obtained from recordings made during flights on a radial across two stations at constant altitude The receiver was tuned to either station and operated with automatic volume control during these tests The tone signals from the output of the band-pass filters were recorded The transmitters were operated at 100 watts output To assist in the interpretation of the recorded interference patterns, the field versus distance curves of the Floyd Bennett and LaGuardia stations are shown on figures 59A and 59B, respectively These recordings were made at 2,000 feet altitude with the receiver volume controlled manually and only one station operating during each recording Figures 59C and 59D are recordings of the Floyd Bennett and LaGuardia tones, respectively, which were made at 2,000 feet altitude with both stations operating simultaneously at a frequency separation of 16 7 kilocycles The distance between the two stations is approximately 13 miles The Floyd Bennett crystal frequency was adjusted so that the carrier beat note was above audibility The measured frequencies of the two signals were LaGuardia 130 2979 megacycles, and Floyd Bennett, 130 3146 megacycles Figure 59E is a recording of the La Guardia tone made at an altitude of 5,600 feet with both stations operating simultaneously at a frequency separation of 16 7 kilocycles It will be seen from these recordings that the relative field strength of the two stations at any one point determine the amplitude of the recorded tone Figures 60A and 60B are recordings of the LaGuardia and Floyd Bennett tones, respectively, made at 2,000 feet altitude with both stations operating simultaneously at a frequency separation of 100 kilocycles The receiver was tuned to 130 3 megacycles and was operating with automatic volume control Figure 60C is a recording made under the same conditions as the 60B recording except that the LaGuardia station was turned off Under the latter condition, the receiver was operating at maximum sensitivity, and as a result, a relatively strong signal was recorded Figure 60D is a recording made under the same conditions as 60C except that the frequency separation was 200 kilocycles This recording shows a small interference area in the immediate vicinity of the Floyd Bennett station Figure 60E is a recording of the LaGuardia tone made at 2,000 feet altitude with both stations operating simultaneously at a frequency separation of 300 kilocycles Figure 61A is a recording of the LaGuardia and Philadelphia tones made at 2,000 feet altitude at a frequency separation of 16 7 kilocycles The distance between the two stations is approximately 95 miles Figure 61B is a recording made under conditions similar to those for figure 61A except that the altitude was 5,000 to 8,000 feet and the direction of flight was reversed A comparison of these two recordings shows the cross-over rate of the two tones to decrease with increase in altitude and the interference areas to increase with increase in altitude Figure 60C is a recording of the Philadelphia and Floyd Bennett tones made at 5,000 to 8,000 feet altitude at a frequency separation of 100 kilocycles In this test the receiver was tuned alternately to each station and was operating on automatic volume control The distance between the two stations is approximately 86 miles

Miscellaneous Flight Tests

Figure 62 is a recording of the LaGuardia tone made at 2,000 feet altitude while the airplane was circling the LaGuardia station at a radius of 7 miles For this test, only the LaGuardia station was operating and the receiver was on automatic volume control

Figure 63 is a recording of the Floyd Bennett tone made at 2,000 feet altitude when the airplane was flying from the Floyd Bennett airport to Englishtown, N J , a distance of 33 miles The receiver was operating on automatic volume control for this test

Figure 64 is a recording of the Floyd Bennett tone obtained at 1,400 feet altitude on a flight up the west side of the Hudson River For this test, only the Floyd Bennett station was operating and the receiver volume was controlled manually

Following the completion of tests on the three stations, the ultra-high-frequency equipment was arranged for parallel operation with the low-frequency transmitting equipment at the three airports The frequencies of the ultra-high-frequency and the low-frequency equipment were, respectively, for LaGuardia Airport, 130 3 megacycles and 362 kilocycles, for Floyd Bennett Airport, 129 78 megacycles and 278 kilocycles, and for the Philadelphia Airport, 131 42 megacycles and 278 kilocycles Several flights were made in airplane NC-80 at various directions and altitudes in order to compare the reception of the transmission from each airport when operating under actual service conditions. A standard commercial type aircraft receiver was used for receiving the low-frequency transmissions. It was found, however, that because of the high noise pick-up caused mainly by the airplane's ignition system, reception of the low-frequency transmission was limited to a distance of approximately 30 miles. The results of the ultra-high-frequency transmission are shown in the following tabulation.

Floyd Bennett - 129.78 Megacycles

Bay Shore, L. I.	35 miles	1,000 ft. altitude	excellent
Islip, L. I.	37 miles	" " "	excellent
Patchogue, L. I.	48 miles	" " "	last usable
Terryville, L. I.	48 miles	" " "	fair
Brentwood, L. I.	36 miles	" " "	excellent
New Brunswick, N. J.	32 miles	" " "	excellent
New Brunswick, N. J.	32 miles	600 ft. altitude	fair
Rocky Point, L. I.	54 miles	1,000 " "	just audible
Norwalk, Conn.	44 miles	500 " "	just audible

LaGuardia - 130.3 Megacycles

New Brunswick, N. J.	37 miles	1,000 ft. altitude	excellent
New Brunswick, N. J.	37 miles	600 " "	last usable
Islip, L. I.	35 miles	1,000 " "	last usable
Terryville, L. I.	44 miles	1,000 " "	fair
Rocky Point, L. I.	50 miles	1,000 " "	just audible
Norwalk, Conn.	35 miles	500 " "	fair

Philadelphia - 131.42 Megacycles

Over Floyd Bennett	86 miles	4,500 ft. altitude	fair

In recognition of the great interest shown in this investigation by private, municipal, and Government groups, the Civil Aeronautics Administration arranged and gave a demonstration of the complete system operating under actual service conditions. The demonstration was made at the LaGuardia Airport during the period of November 12 to 16, 1940. Among the groups which witnessed the demonstration were airport managers and operators, and Army, Navy, Coast Guard, and Federal Communications Commission personnel. All demonstration flights were made in the Administration's Boeing 247-D airplane, which was equipped to receive both low-frequency and ultra-high-frequency transmissions. Each passenger's seat was provided with headphones and a switch to select either transmission. Flights were made from the LaGuardia airport to a point near Philadelphia and return. Although the demonstration was definitely a success and confirmed the results obtained during the flight testing, unfortunately it did not bring out one of the most important advantages to be realized by the use of ultra-high frequencies, which is nearly complete elimination of static interference caused by thunderstorms and other atmospheric disturbances. The low-frequency radio reception was exceptionally good during the demonstration period.

DISCUSSION OF FLIGHT TESTS

At the outset of this project it was realized that, because of the inherent propagation characteristics of ultra-high frequencies, the transmitting antennas should be located as high as practicable above the ground level if long-distance transmission at low altitudes was to be achieved. Thus, in the case of the Floyd Bennett antenna, located 73 feet above the ground level, the maximum optical path at an altitude of 1,000 feet is approximately 48 miles, whereas under the same conditions except with the transmitting antenna at ground level, the maximum optical path is approximately 38 miles.

The use of highly elevated transmitting antennas in ultra-high-frequency transmission results in another inherent characteristic becoming an important factor This characteristic appears in the form of loops having maximum and minimum points in the transmitted vertical field pattern These points are commonly known as "peaks" and "nulls " The theory of this phenomenon has been thoroughly covered in several published articles on the subject of ultra-high-frequency propagation and only a brief explanation of it will be given here

It has been shown that the field from a transmitting antenna at a point in space, not beyond line of sight, may be considered to be due to the combination of a direct and a reflected ray The path difference of the two rays determines the number and location of the peaks and nulls in the transmitted field and is proportional to the height of the transmitting antenna above ground The amplitude of the peaks and nulls is determined by the coefficient of reflection of the reflecting medium The coefficient of reflection K is in general a complex quantity, the value of which is determined by the conductivity, σ , the dielectric constant, ϵ , of the reflecting medium, and the angle of incidence of the reflected ray For horizontal polarization and the same reflecting medium the reflection coefficient increases with the decrease in the angle of incidence and approaches a value of unity at grazing incidence As a result, for a perfectly reflecting medium the reflection coefficient can theoretically affect the transmitted field at points in space to the extent that the null points will approach a value of zero and the peak points a value of twice the direct ray It will be realized that the occurrence of such a condition would be very undesirable A survey of the field versus distance curves of figures 50 to 57, inclusive, shows that several fairly deep null points were recorded and indicates a good reflecting medium at these points The curves of figure 58 were obtained from recordings where a special effort was made to obtain accurate measurements of the outermost null and peak points The indicated reflection coefficients ranged as high as 0 97 Although undesirable, this condition can easily be compensated for by a suitable receiver having automatic volume control features As will be observed from the recording of figure 63, the maximum decrease in receiver output is slightly greater than 6 decibels when transmissions are received over salt water with the receiver operating on automatic volume control

The recording of figure 62 shows that the received signal fluctuated very rapidly in the vicinity of the George Washington bridge and near Hudson Heights The sharpness and uniformity of occurrence indicate that very strong reflected signals were being received from bridges or high buildings at these points

The field versus distance curves obtained during flights on the north side of the Floyd Bennett station, figures 51, 52, and 55, indicate a close approach to the theoretical pattern of an antenna located in free space The antenna at this station was located on top of the control tower within a few feet of the north side of the building Figure 65 is the theoretical field versus distance curve of this station, assuming the antenna to be in free space and based on the ground conditions as indicated It will be seen that the locus of the peak points for a reflection coefficient of unity varies inversely as the distance to the antenna

For the attenuation beyond the outermost peak the rate of decrease in field strength rapidly becomes proportional to the square of the distance or greater This fact is confirmed in figures 50 and 55 The close agreement between the position of theoretical and measured peaks and nulls should be noted

The type of field versus distance curve obtained at the LaGuardia station is believed to be due entirely to the fact that the building acts as a highly elevated counterpoise The antenna is located directly over an air-conditioning room which is comprised largely of sheet metal air ducts The theoretical field versus distance curve of this station, assuming an antenna in free space, is similar to that shown in figure 65, except that two additional nulls and three additional peaks are added with the point directly over the antenna having a null

The field versus distance curves of the transmitting stations indicate to some degree the effect of obstructions in the path of the reflected ray and of differences in the reflecting medium Figure 54 shows how buildings in the path of the reflected ray will affect the field The recording of figure 64 indicates the effect of diffraction on field strength measurements The recording has notation of points on Manhattan Island that are in direct line with the Floyd Bennett station The altitude was such that direct line of sight was maintained The effect of the high building area is indicated by a decrease in the received signal, and the position of the Empire State Building is clearly shown

The determination of interference areas between stations operating simultaneously with various frequency separations was an important feature of the tests The reproduced recording of figure 60D indicates that a frequency separation of 200 kilocycles is sufficient to give no appreciable interference areas between the Floyd Bennett and LaGuardia stations when a receiver having characteristics comparable to the type RUH receiver is used Similarly, the recording of figure 61C indicates that a frequency separation of 100 kilocycles is sufficient between the Philadelphia and Floyd Bennett stations Since airport traffic control transmitting equipment is operated intermittently, that is, with carrier off when no transmissions are being made, the interference between stations must be considered on this basis Because of this fact, the interference areas between stations which are not operating on the same frequency are determined by the receiver's usable sensitivity, the receiver's selectivity, and the field strength of the interfering signal For stations operating on the same frequency, the factor of receiver selectivity is not considered An approximation of the service range of a transmitting station having an antenna 70 feet high may be obtained from the chart in figure 66 The line-of-sight curve will approximate the limit of intelligibility, as is confirmed by figure 47 The chart also shows the angle from the station to the aircraft for various altitudes and distances.

Figure 67 is a copy of a portion of a recording obtained with the LaGuardia and Floyd Bennett stations operating simultaneously with a frequency separation of 16 7 kilocycles Figure 68 shows the results of the analysis of this recording The Floyd Bennett transmitted signal E_{FB} is plotted for values of E_{REC} and E_{LGR} obtained from the recording and E_{LG}, the LaGuardia field strength which is assumed to vary as $1/d^2$ at the distance given The resultant curve indicates a high value of reflection coefficient for the reflecting medium acting on the Floyd Bennett field received at this position A change of the reflection coefficient to a lower value would in this case lower the peaks of the recorded pattern E_{LGR} and result in a smooth curve approaching $1/d$ for reflection coefficient values approaching zero, where d is the distance to the LaGuardia transmitter

In connection with the receiver used in flight testing, it should be pointed out that the maximum sensitivity of the unit could not be used because of the noise pickup, which was caused mainly by the airplane's ignition system It is estimated that the maximum sensitivity of the receiver could have been reduced five to one without affecting the results of these tests

The indicated receiving pattern of the airplane NC-80 has been determined from the theoretical field versus distance curve of the Floyd Bennett station, figure 65, and the curves obtained from the recordings shown in figures 50 and 51 Figure 69 shows the indicated vertical receiving pattern from nose-to-tail of airplane NC-80

CONCLUSIONS

On the basis of the results obtained during the tests conducted, it is concluded that

1 An airport traffic control transmitting system greatly superior to the present low-frequency system has been realized by the application of ultra-high frequencies to this service

2 A reliable service range greater than 30 miles radius at an altitude of 1,000 feet will be obtained

3 An automatic volume control in the receiver will smooth out the signal variations caused by the high angle lobes

4 A transmitter delivering 100 watts of power to a crossed dipole antenna erected 50 to 90 feet above ground level will provide sufficient signal at 30 miles and 1,000 feet altitude so that service may be rendered to all types of aircraft even though there may be high inherent noise levels

5 On the basis of a receiver selectivity comparable to the RUH receiver, the following frequency separations between stations will be sufficient

Stations Separated	Frequency Separation
0 to 60 miles	200 kilocycles
60 to 200 "	100 "
200 to 500 "	15 "
500 and greater	0 "

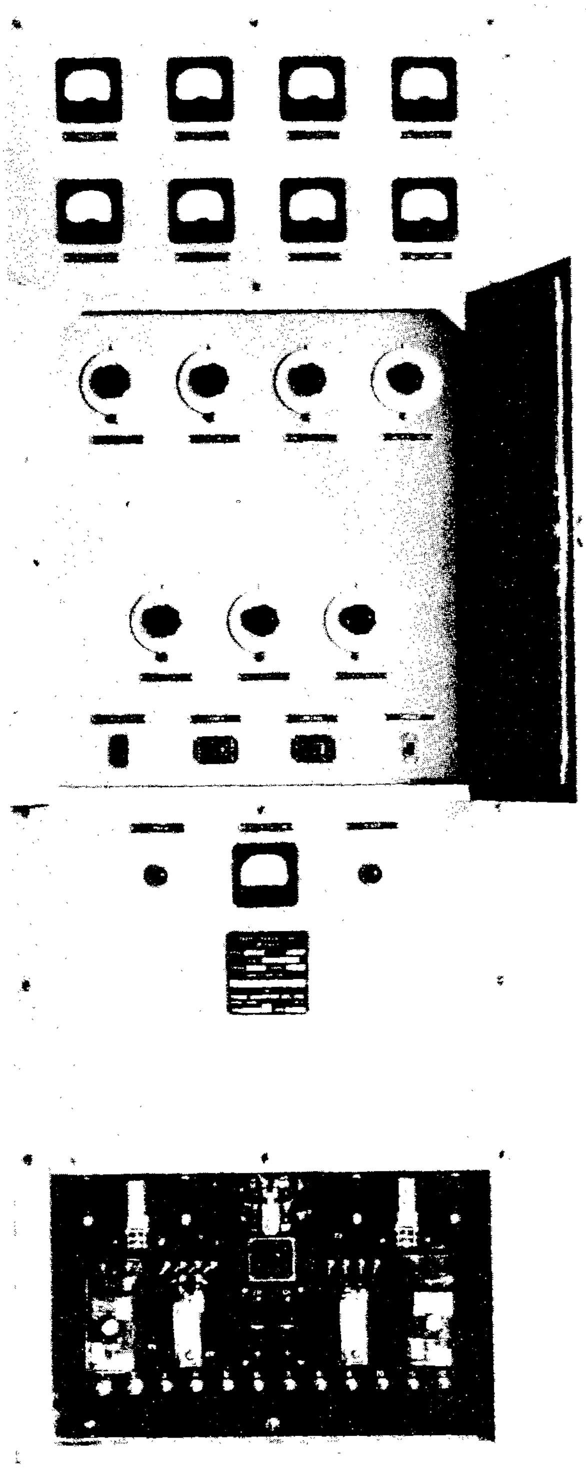


Figure 1. Transmitter - Front View.

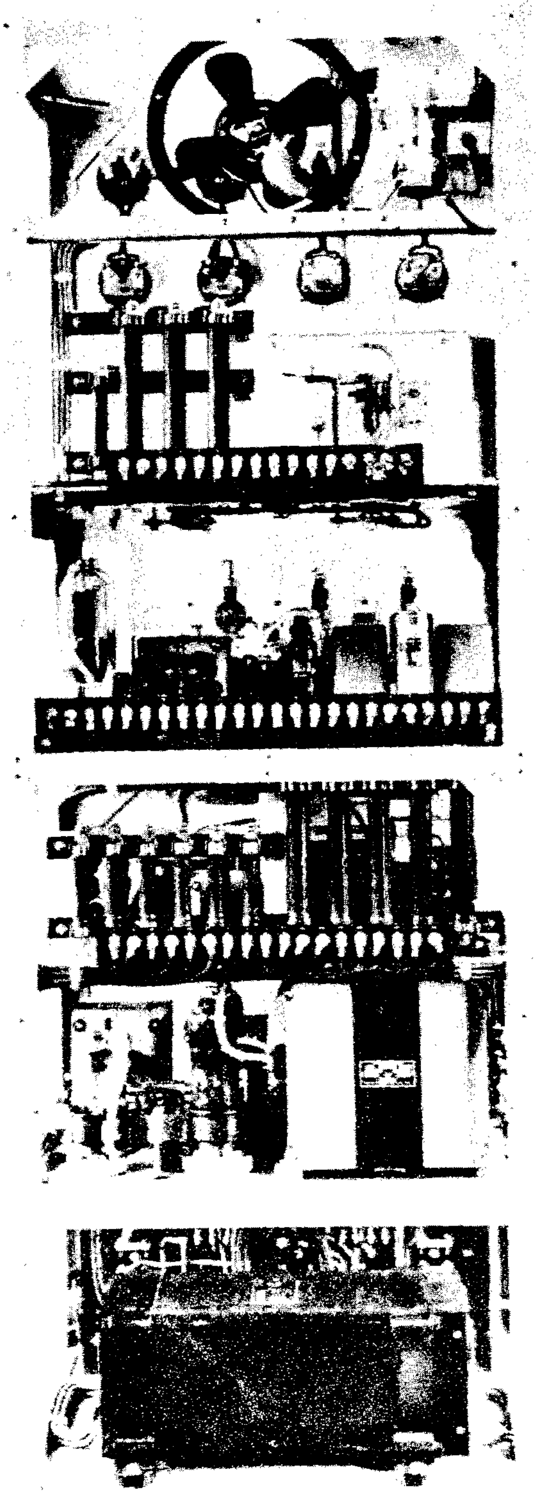


Figure 2. Transmitter - Rear View.

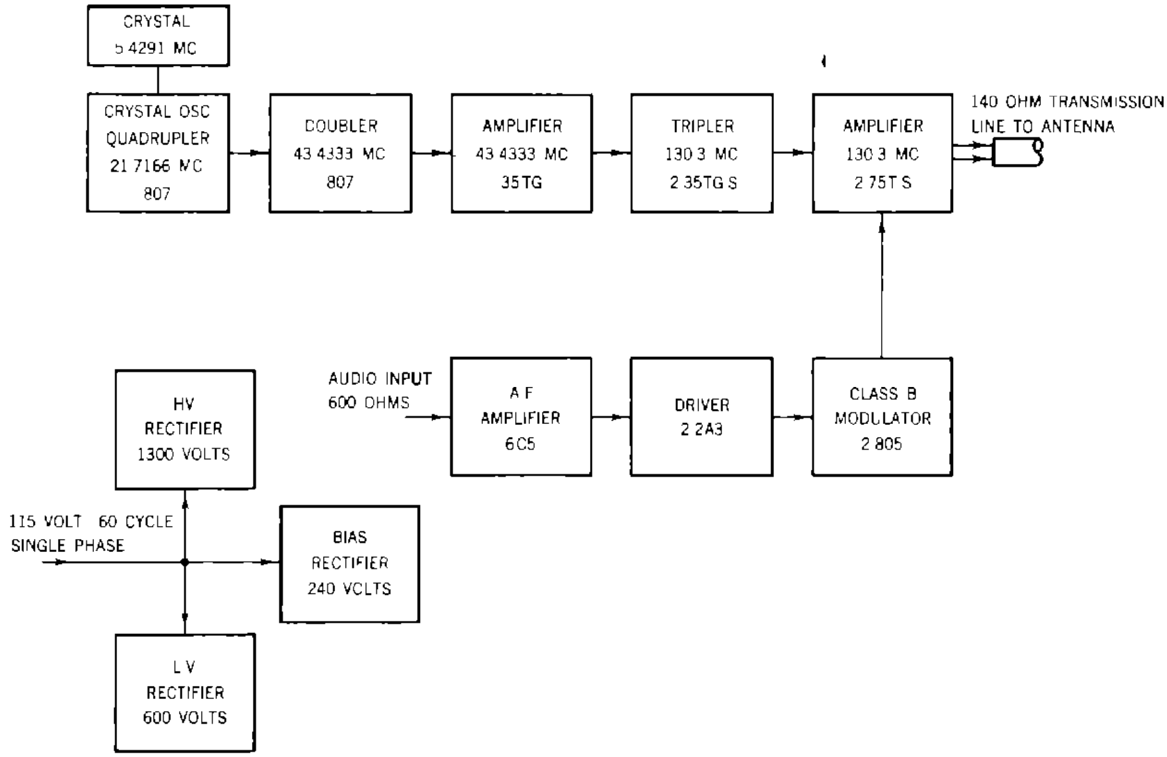


Figure 3 Block Diagram of TUD Transmitter (130 3 Megacycles)

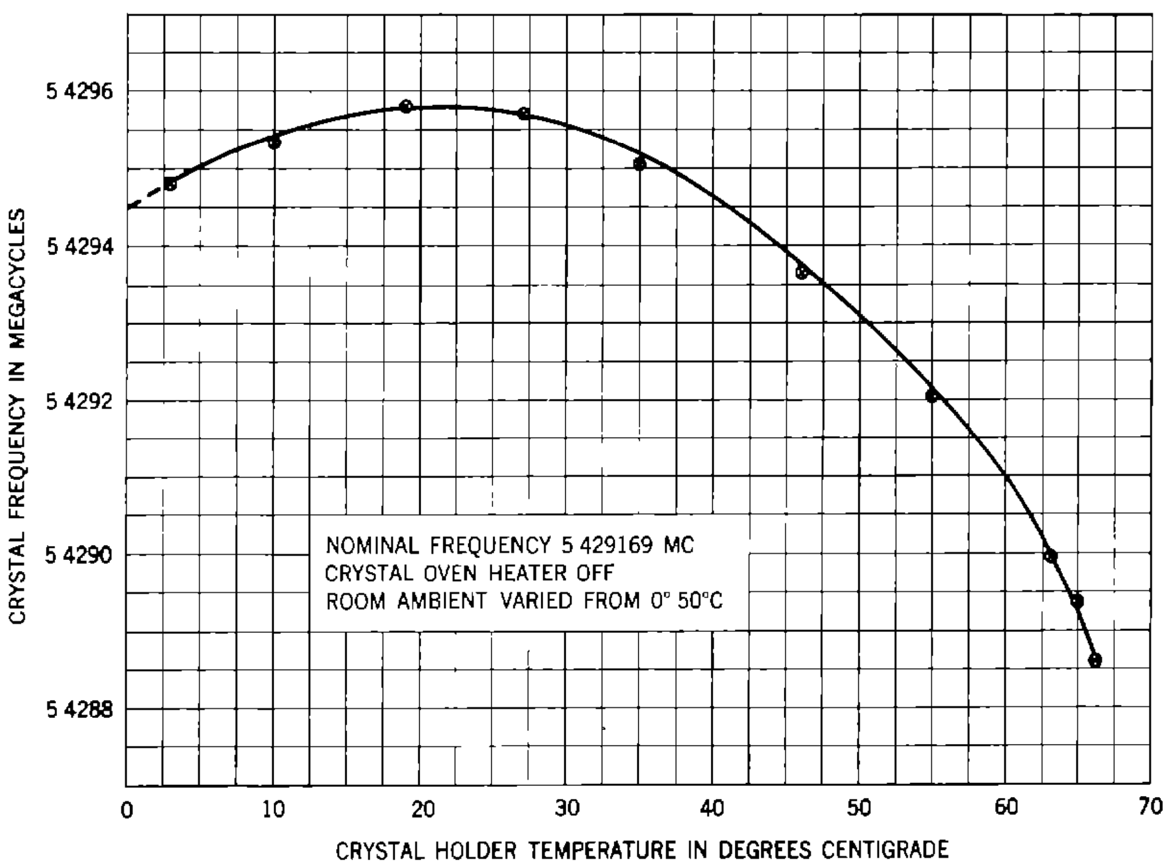


Figure 4 Crystal Frequency vs Holder Temperature with Transmitter Operating at Full Output

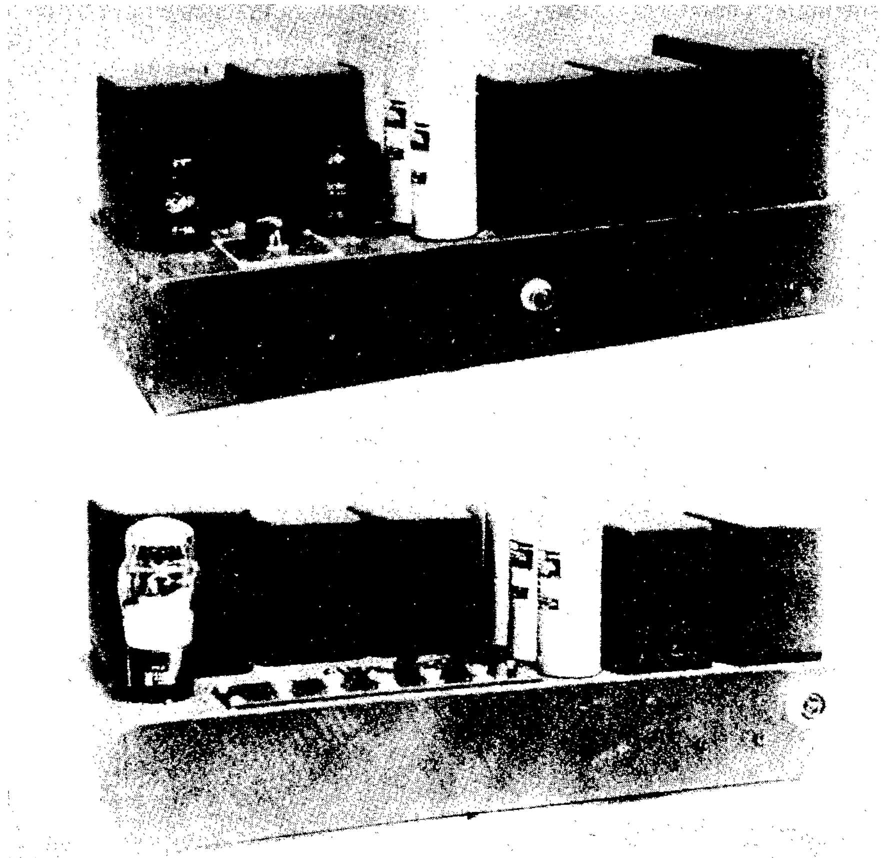


Figure 5. Speech Amplifier.

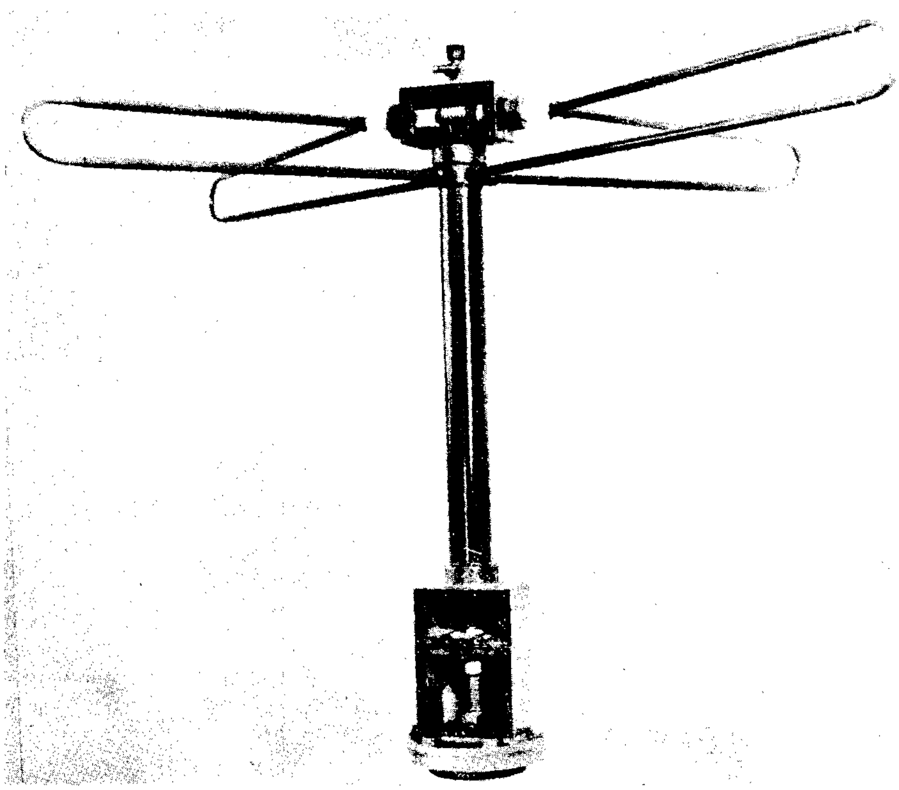
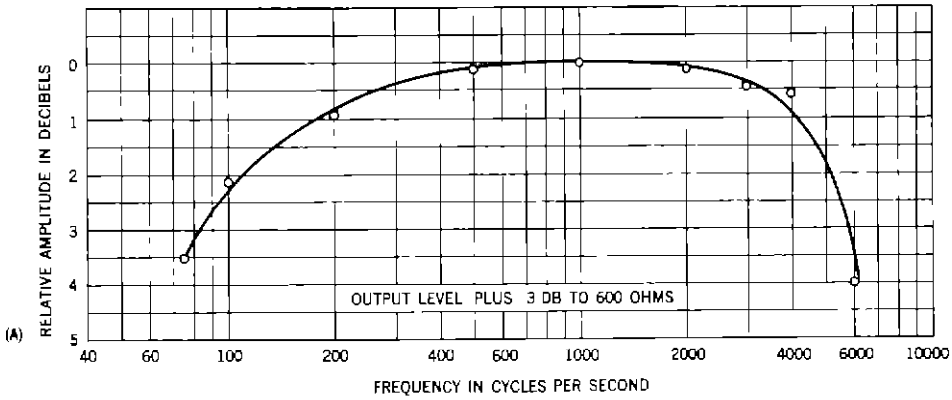


Figure 6. Transmitting Antenna.



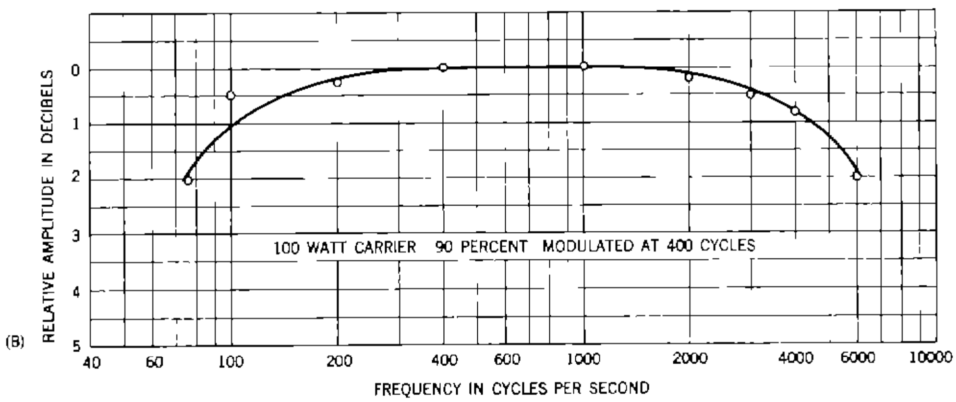


Figure 7 Audio Characteristics, A-Speech Amplifier, B-Transmitter

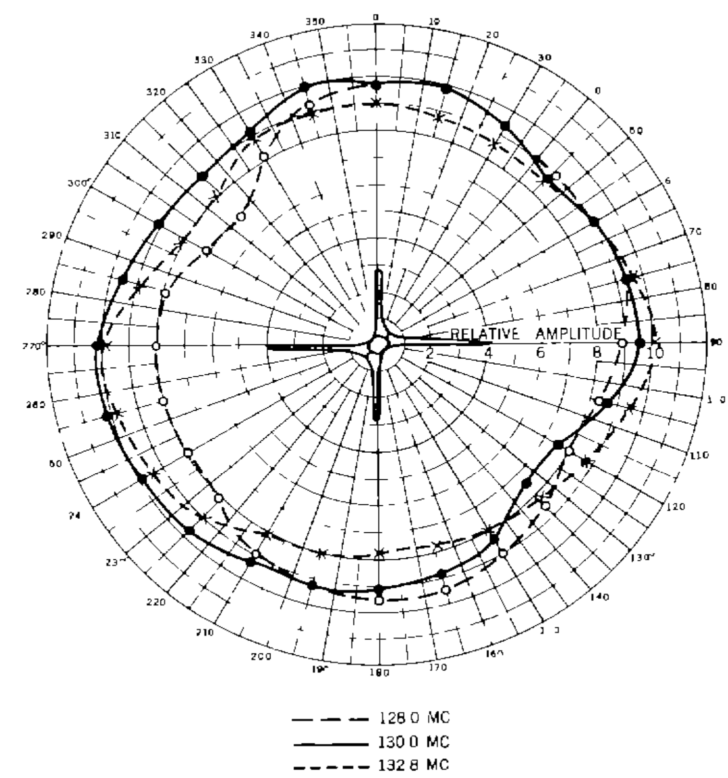


Figure 8 Antenna Field Patterns Taken on Ground at 100 Feet Distance

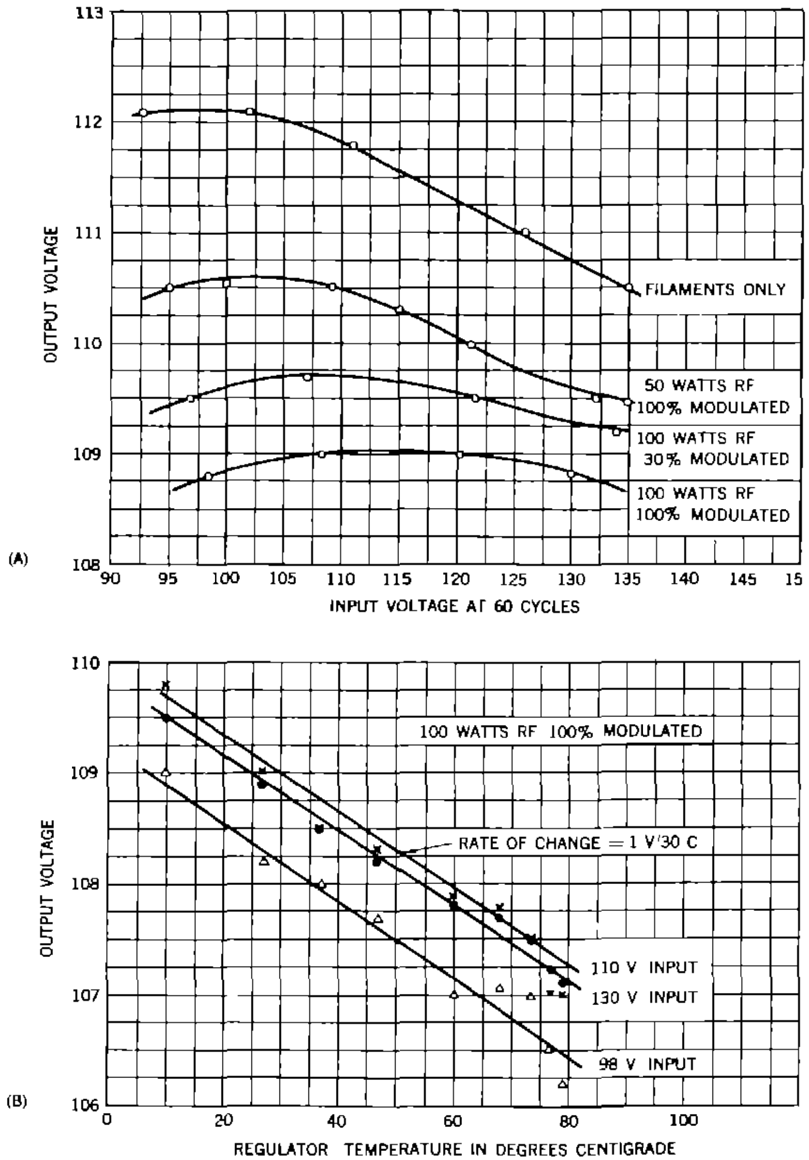


Figure 9 Voltage Regulator Characteristics, A-Output vs Input for Various Loads, B-Output vs Temperature for Various Input Voltages

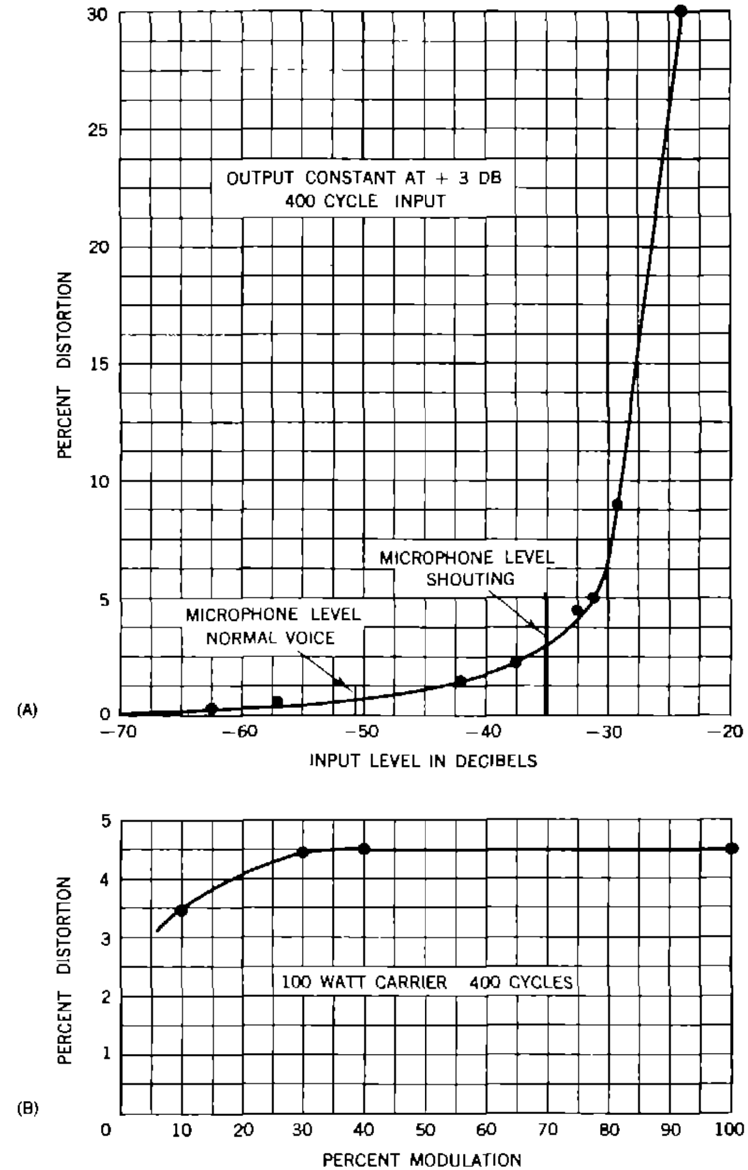


Figure 10 Distortion Characteristics, A-Speech Amplifier, B-Transmitter

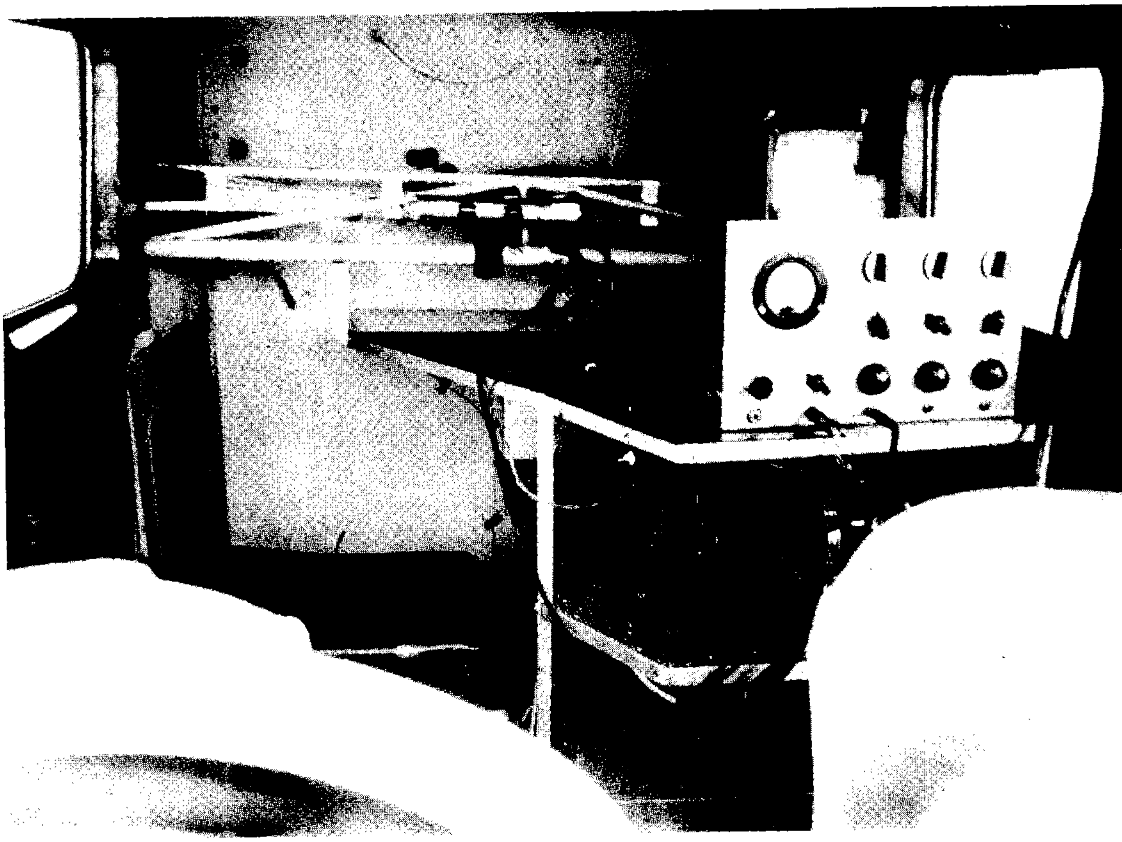


Figure 11. Installation of Receiver and Test Equipment in Airplane NC-80.

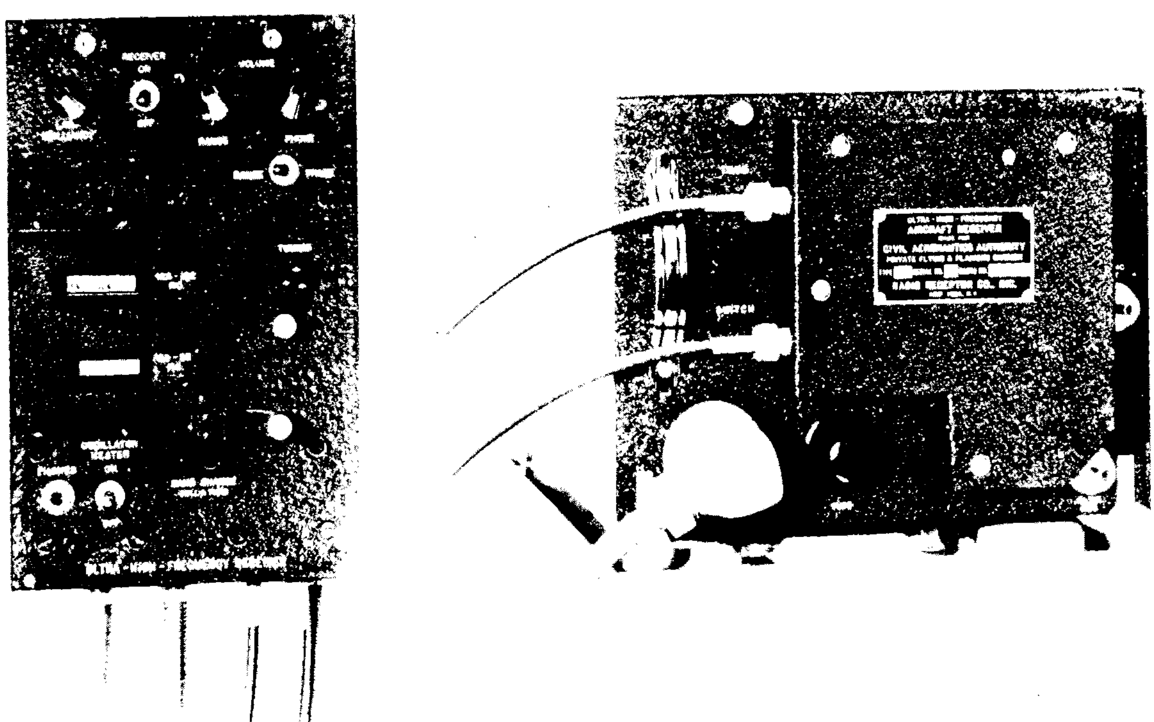


Figure 12. Receiver and Remote Control Unit.

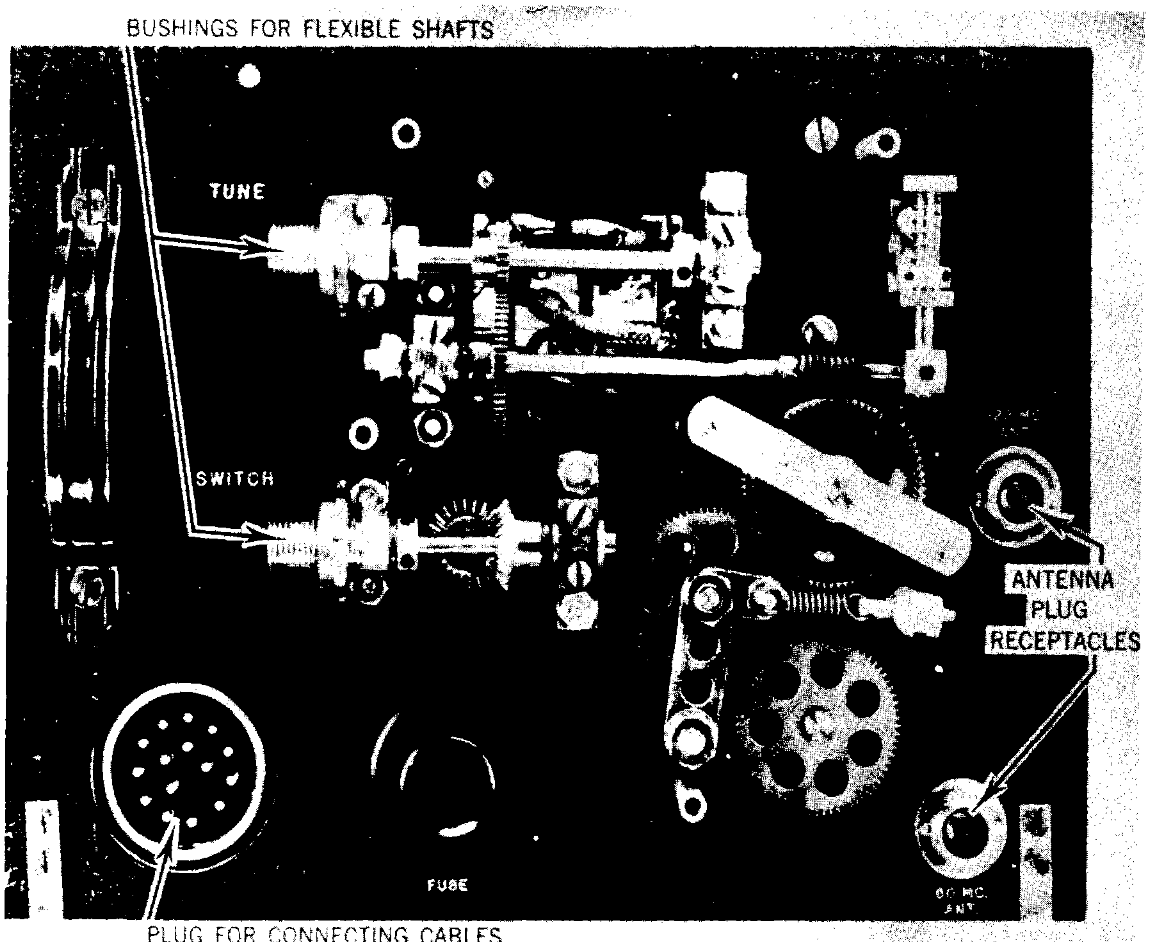


Figure 13. Receiver - Front View.

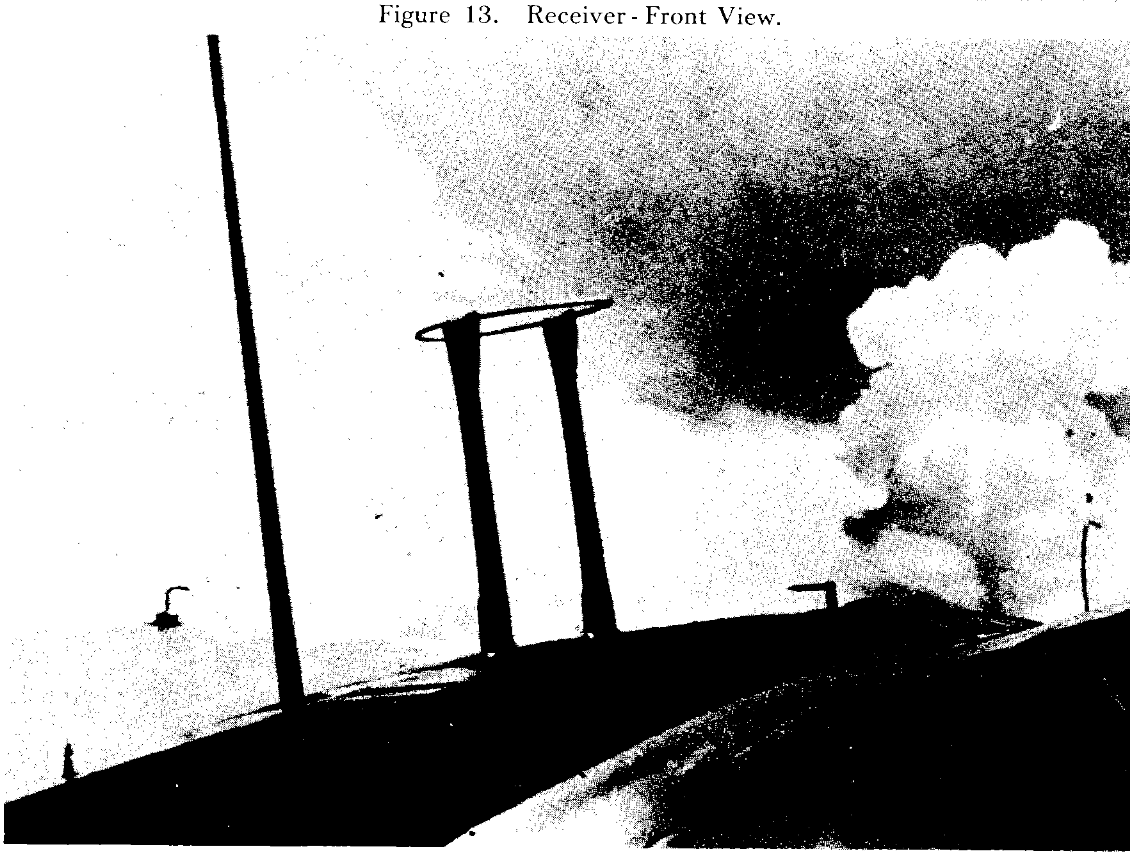


Figure 14. Receiving Loop Antenna on Airplane NC-80.

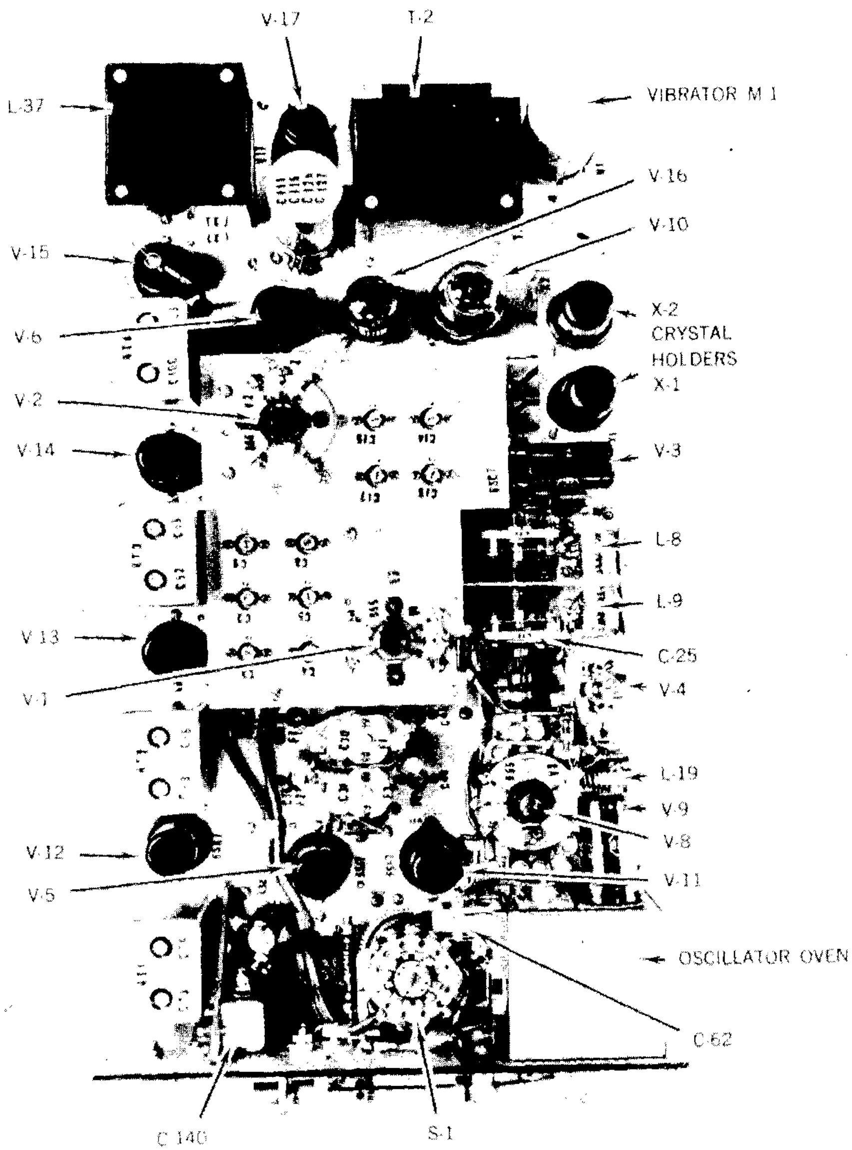


Figure 15. Receiver - Top View.

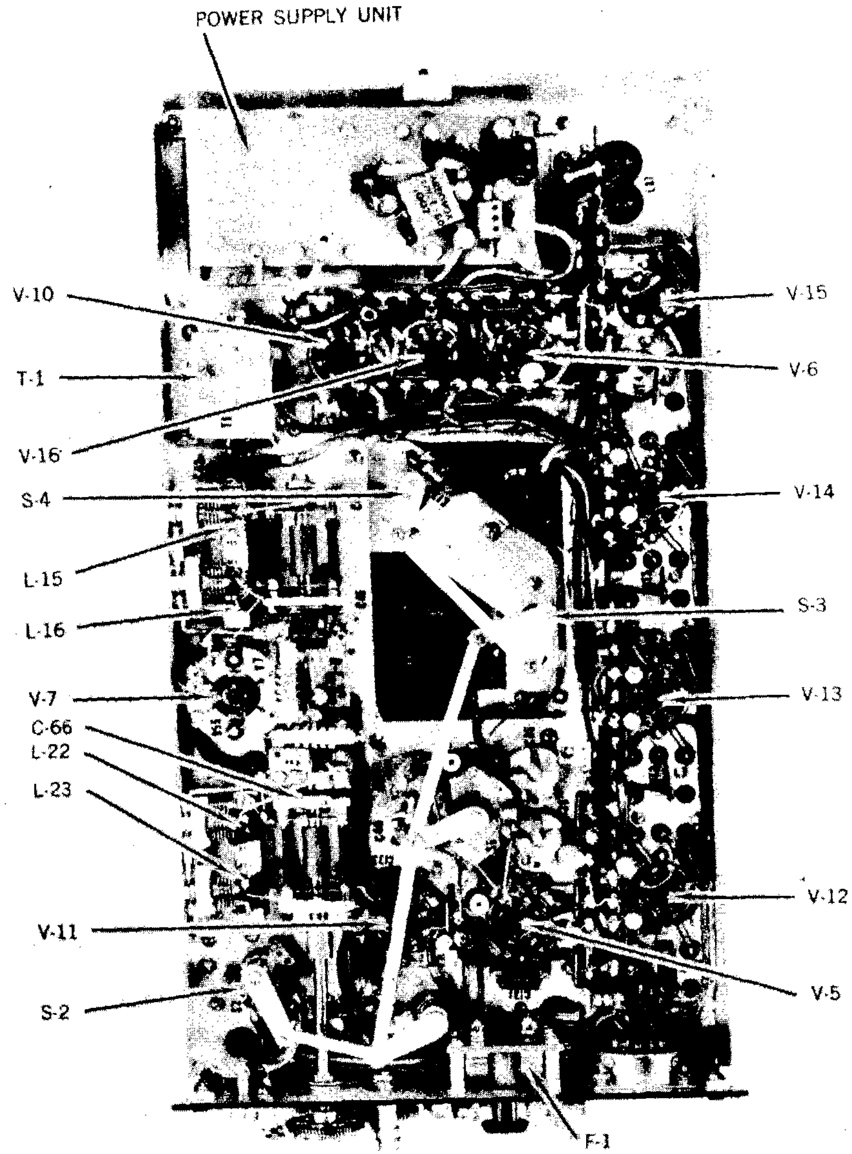


Figure 16. Receiver - Bottom View.

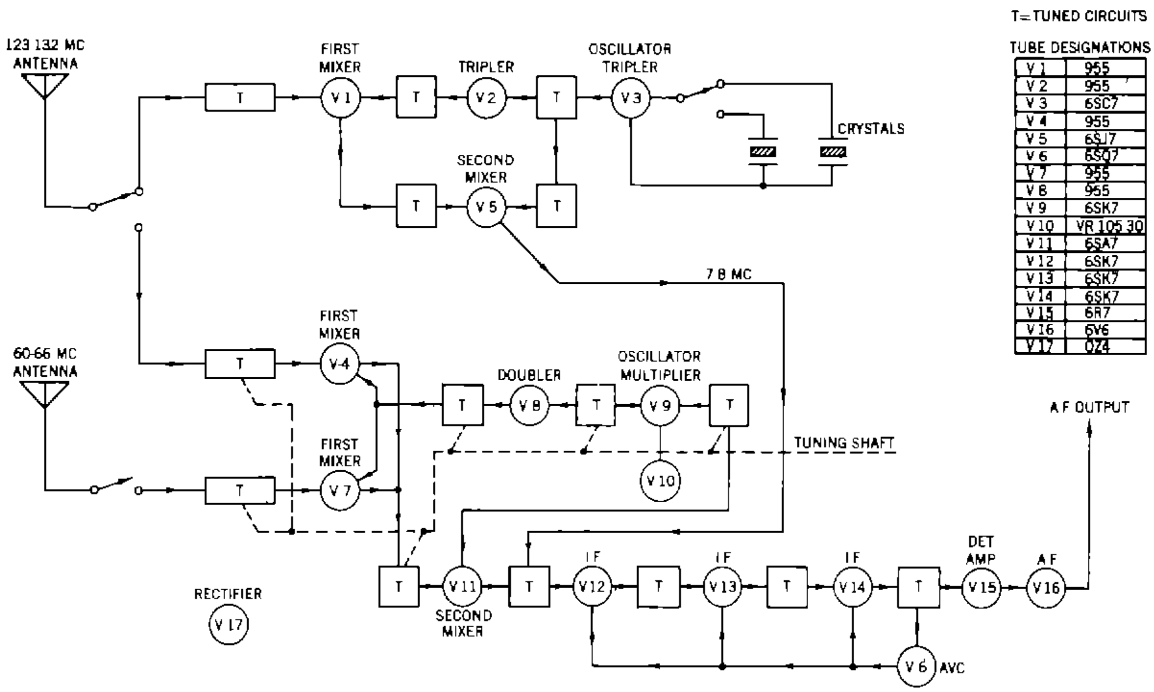


Figure 17 Block Diagram of Receiver

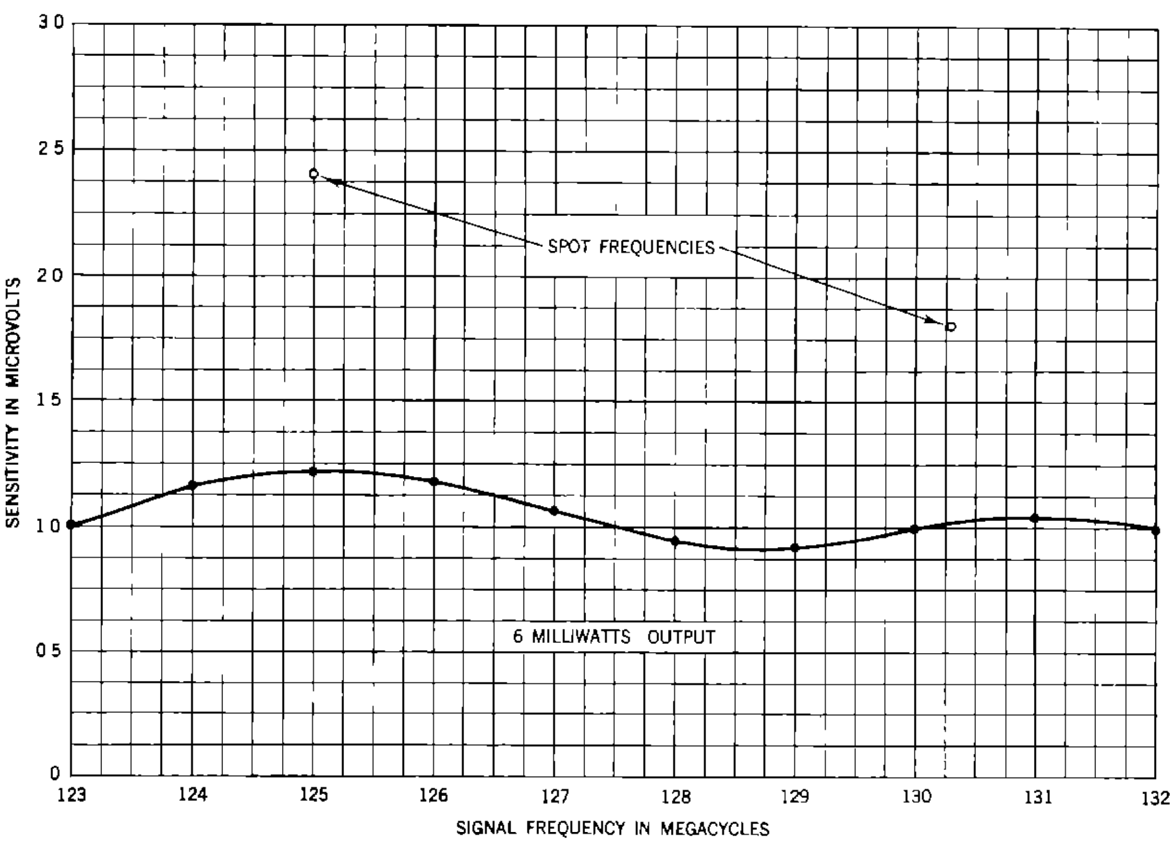


Figure 18 Receiver Sensitivity Curve for 123 to 132 Megacycle Band

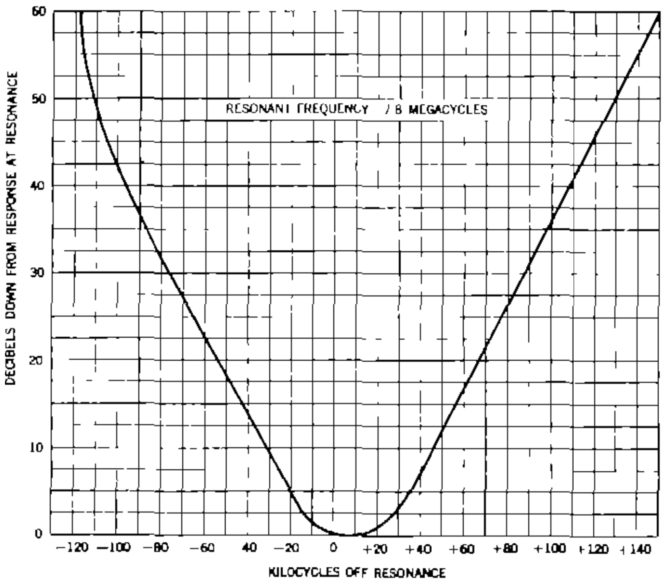


Figure 19 Selectivity Curve of Receiver Intermediate Frequency system

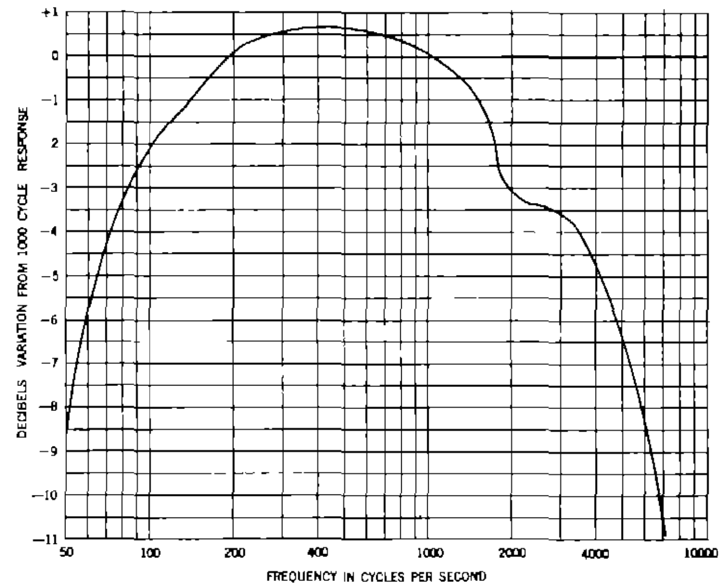


Figure 20 Receiver Audio Frequency Response Curve

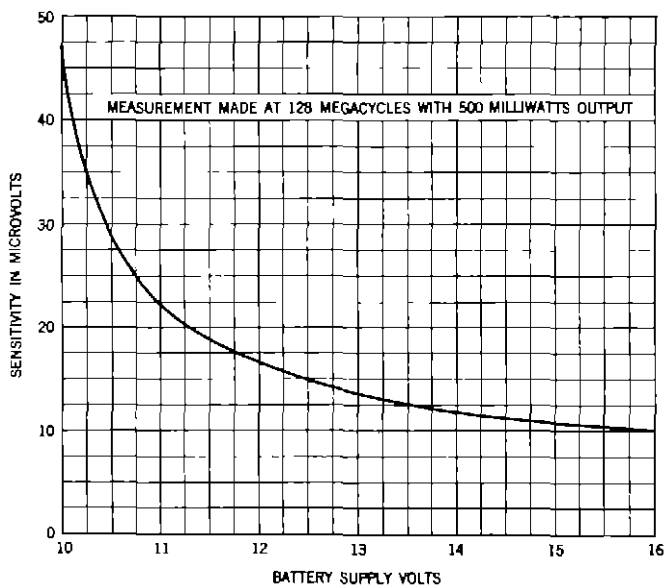


Figure 21 Receiver Sensitivity Variation with Battery Voltage

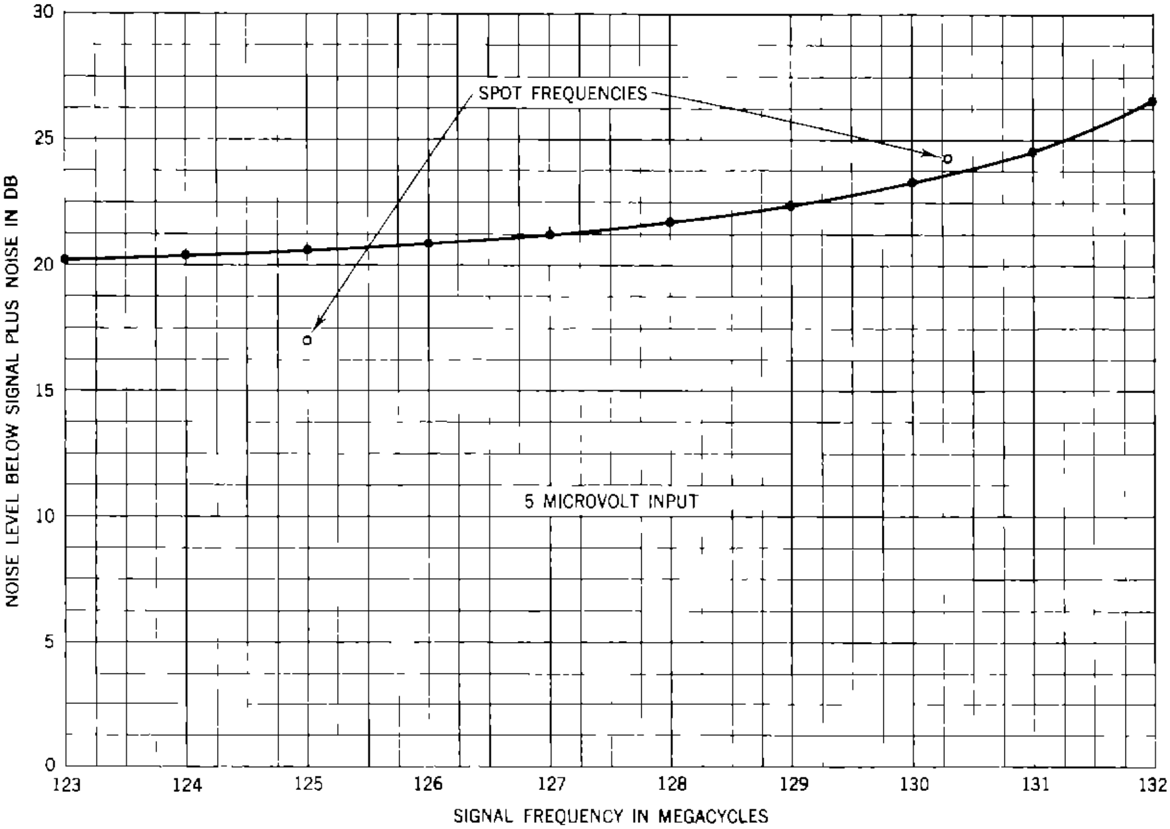


Figure 22 Receiver Typical Signal to Noise Ratio for 123 to 132 Megacycle Band

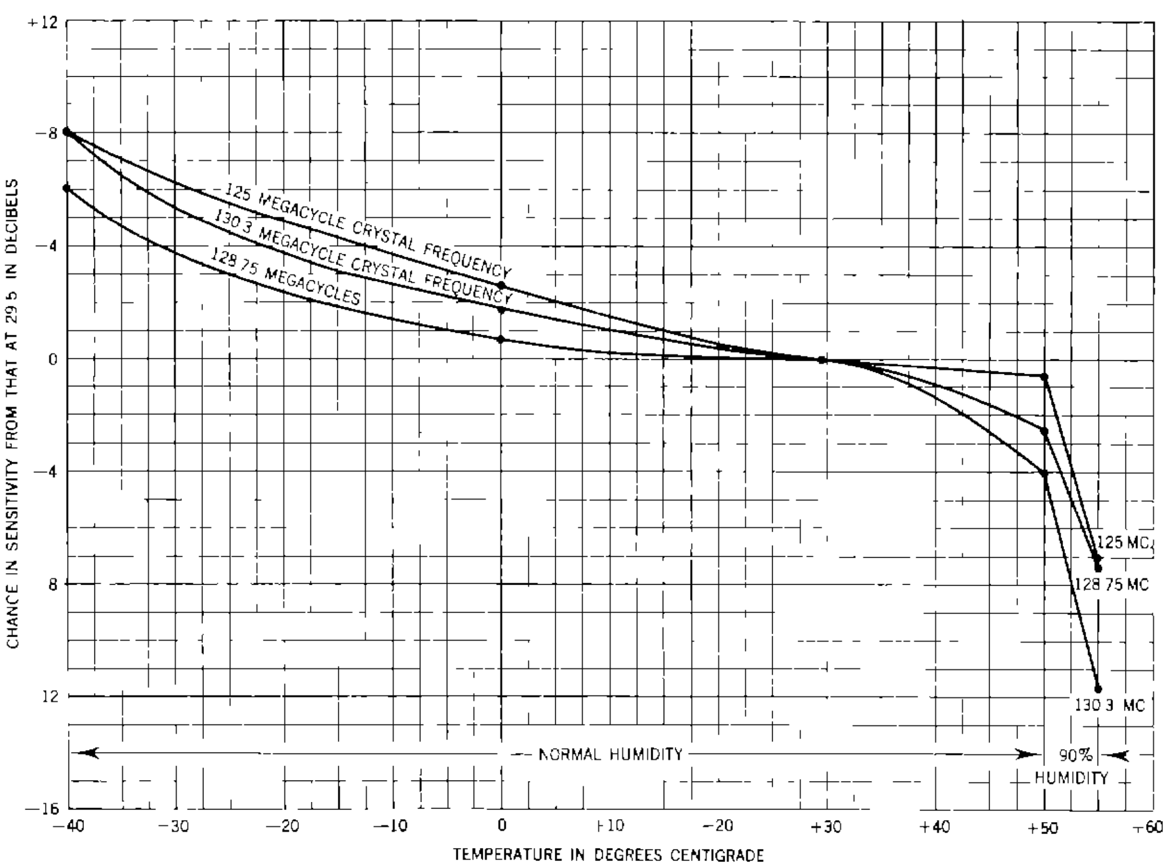


Figure 23 Receiver Sensitivity Variation with Temperature and Humidity,

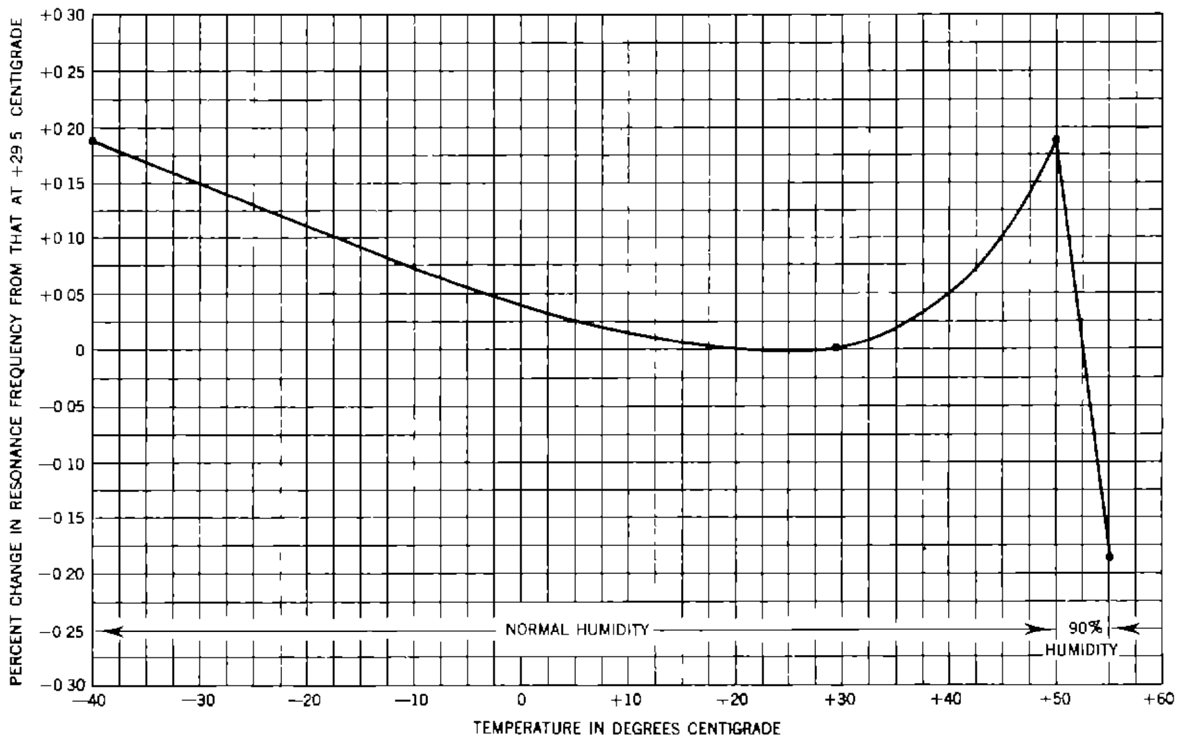


Figure 24 Receiver Resonance Frequency Variation with Temperature and Humidity

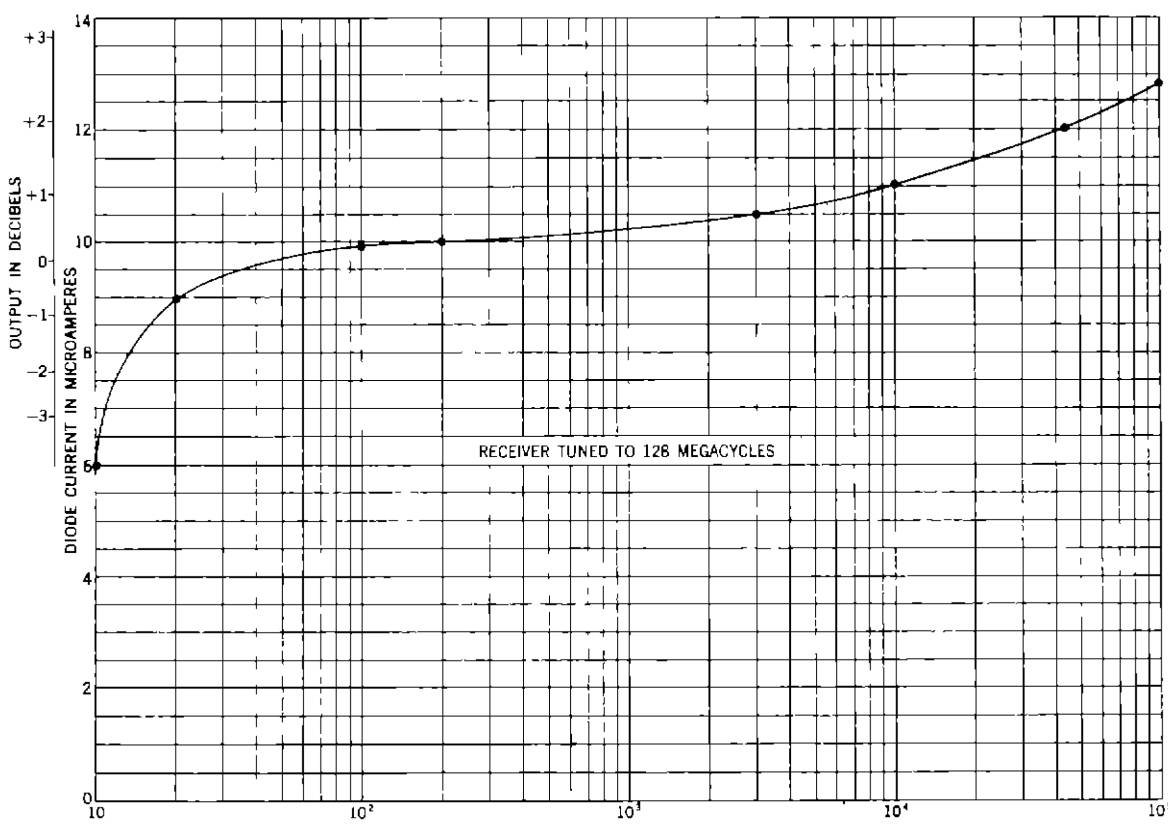


Figure 25 Typical Receiver Automatic Volume Control Characteristic

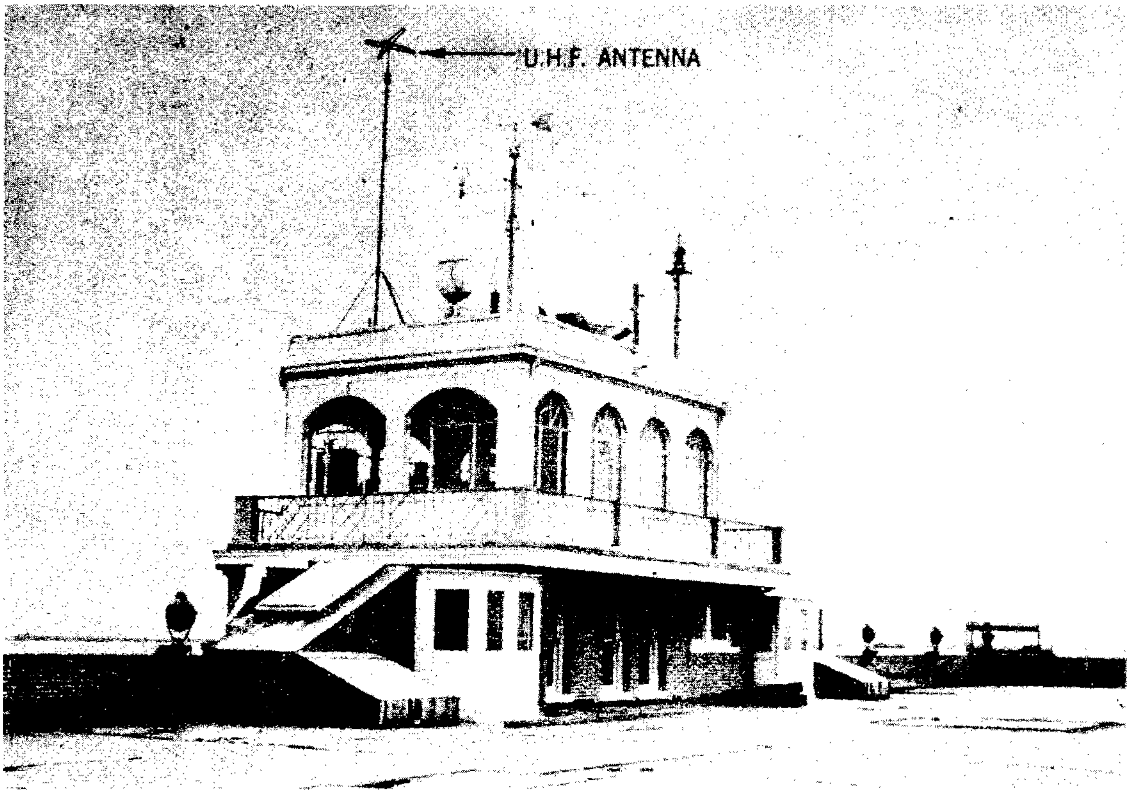


Figure 26. Floyd Bennett Transmitting Antenna Installation.

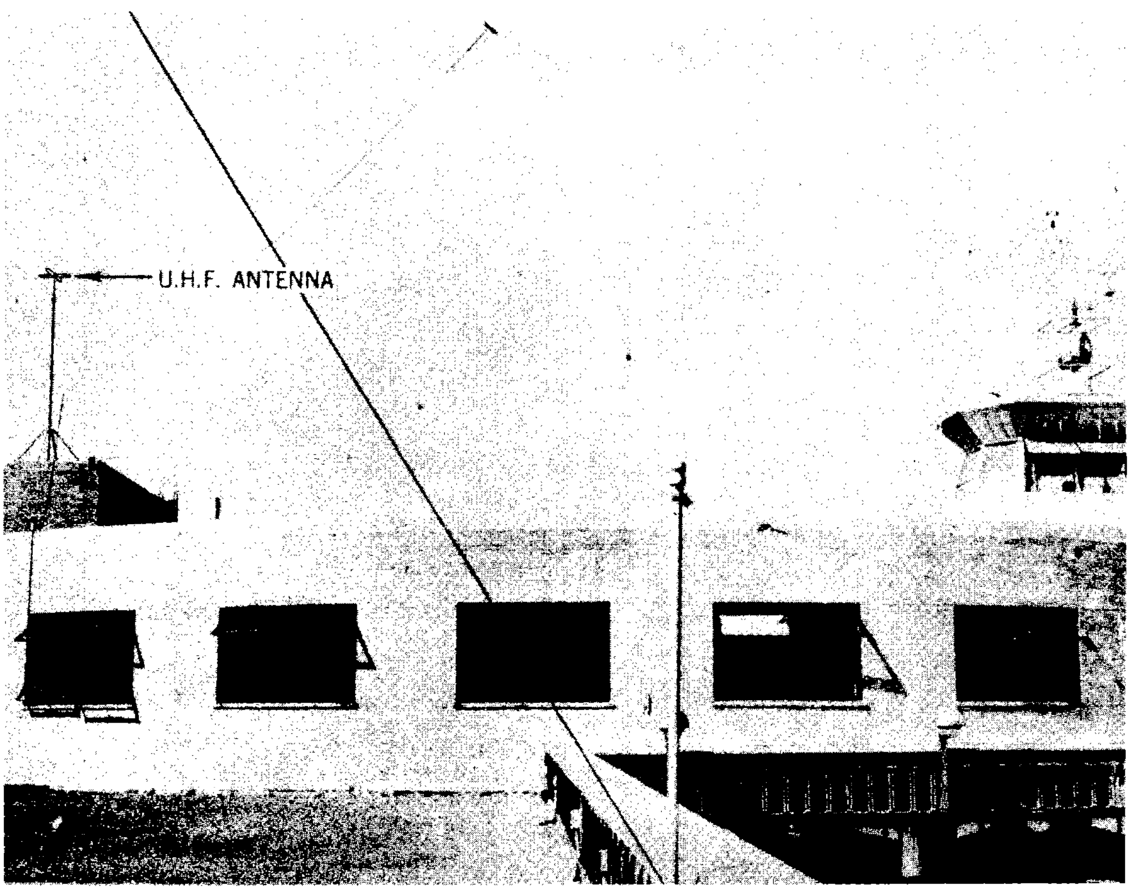


Figure 27. LaGuardia Transmitting Antenna Installation.

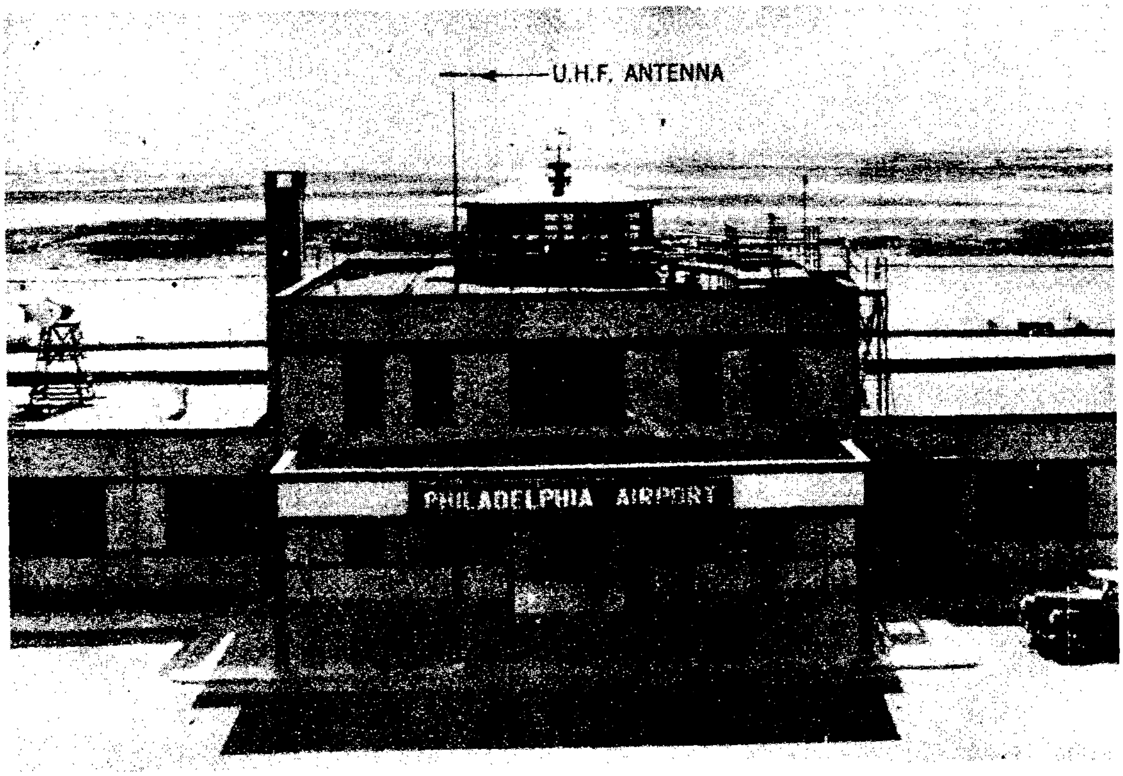


Figure 28. Philadelphia Transmitting Antenna Installation.

Figure 29. Philadelphia Monitor Installation.

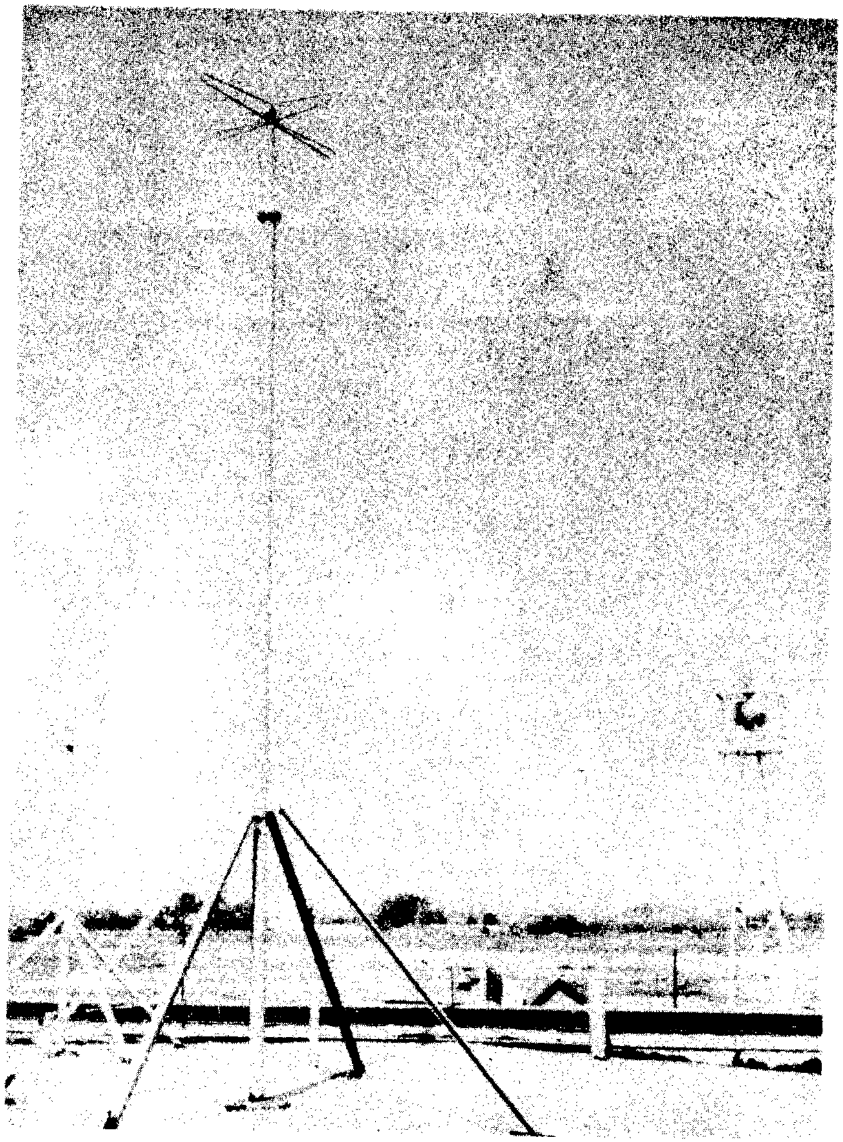


Figure 30. Close-Up View of Philadelphia Transmitting Antenna.

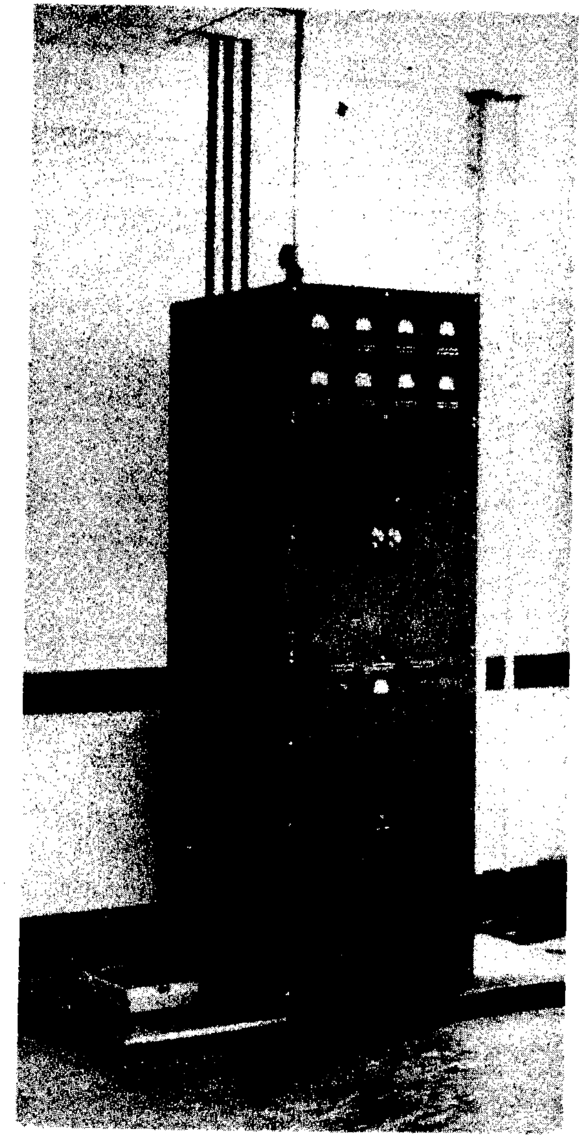


Figure 31. Philadelphia Transmitter Installation.

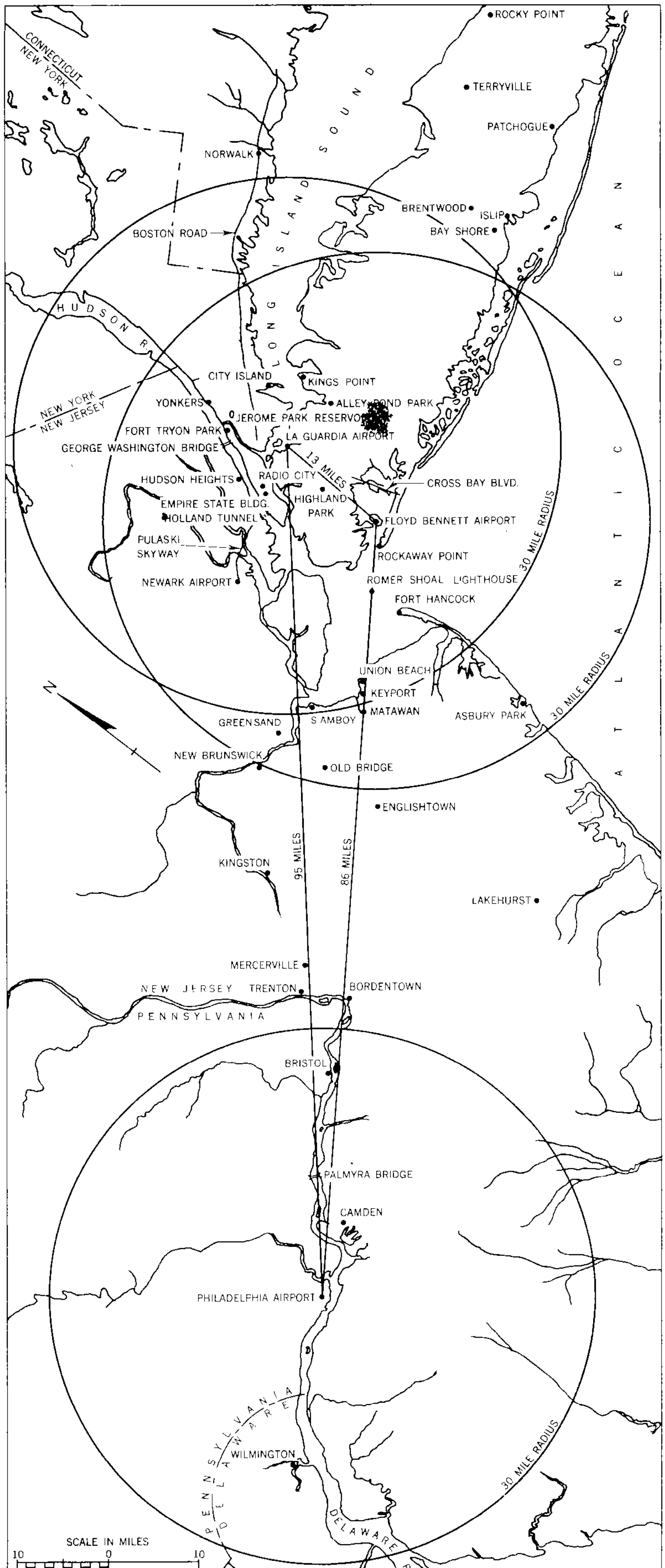


Figure 32. Map of Area Covered in Flight Tests.

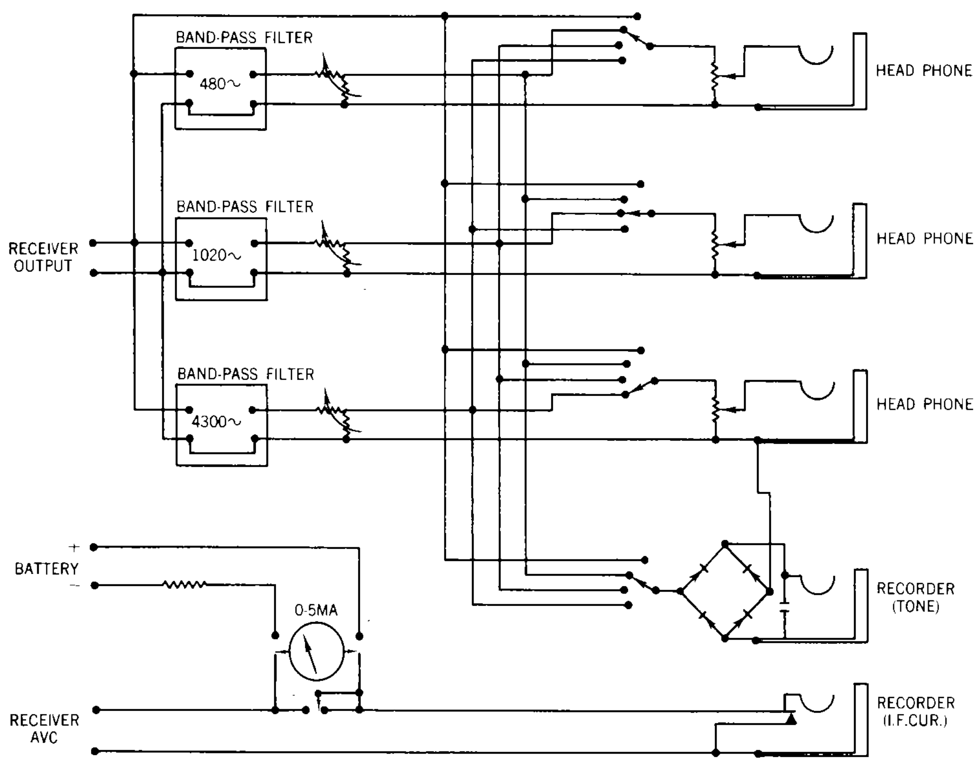


Figure 33. Schematic Diagram of Filter-Control Unit,

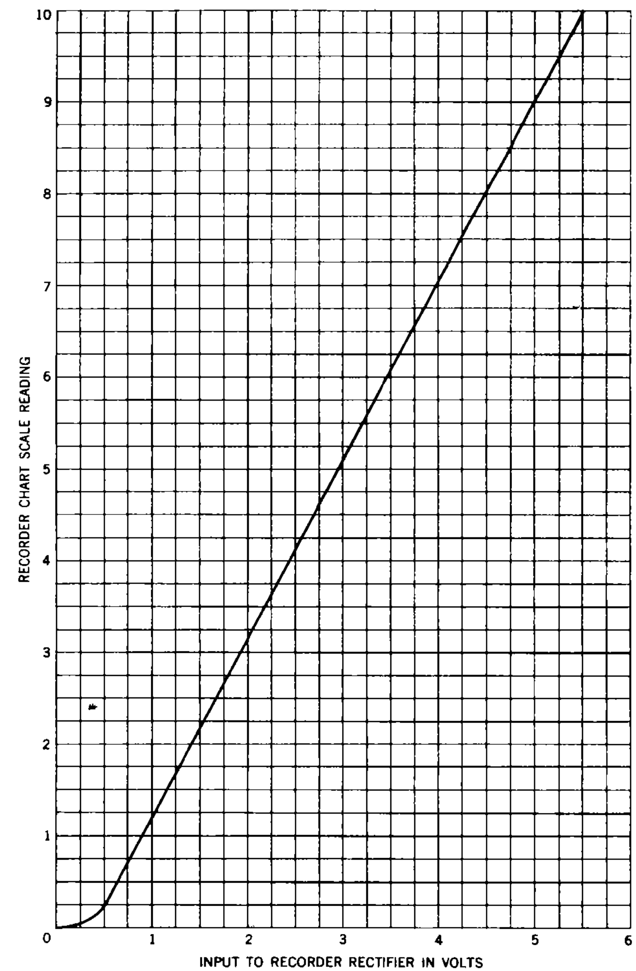
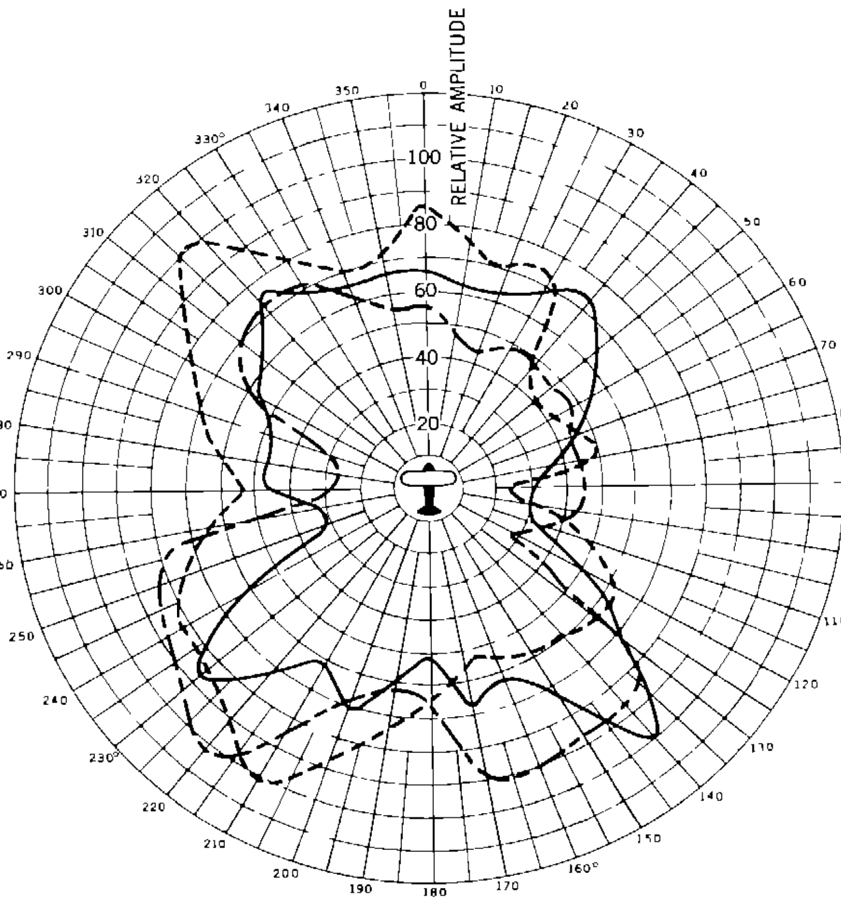


Figure 34. Copper-Oxide Rectifier Characteristic.



LEVEL FLIGHTS OVER FIXED POINT AT VARIOUS HEADINGS

COMPLETE TURN WITH WINGS LEVEL FOR EACH READING (RIGHT)

COMPLETE TURN WITH WINGS LEVEL FOR EACH READING (LEFT)

Figure 35 Receiving Antenna Patterns for Level Flights

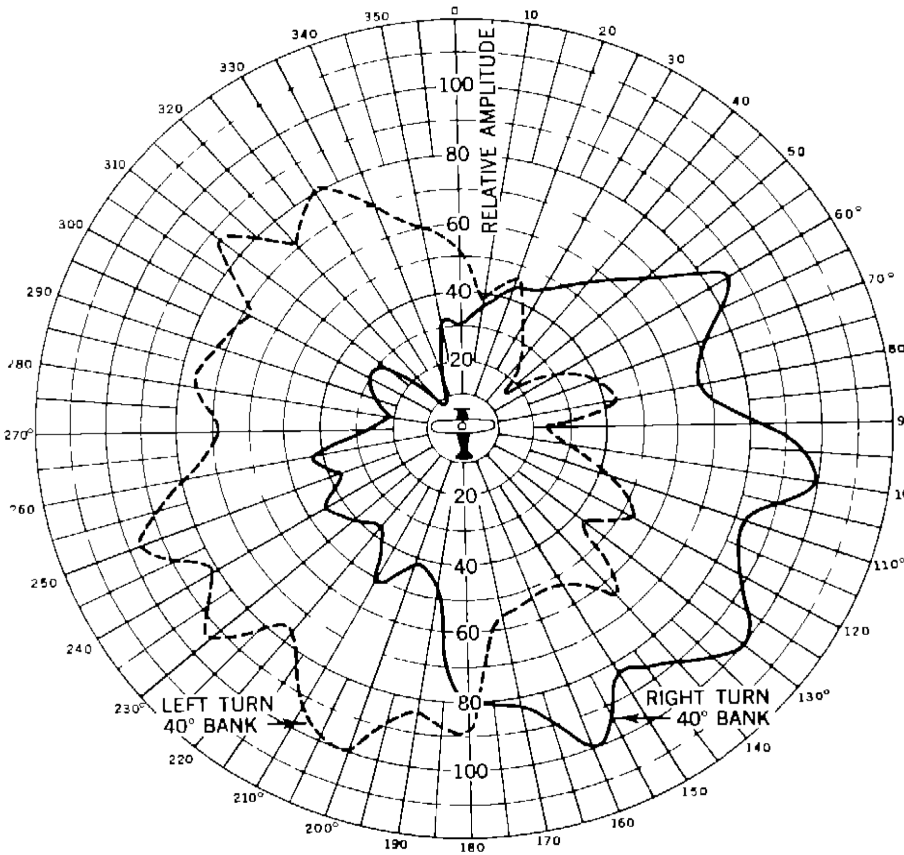
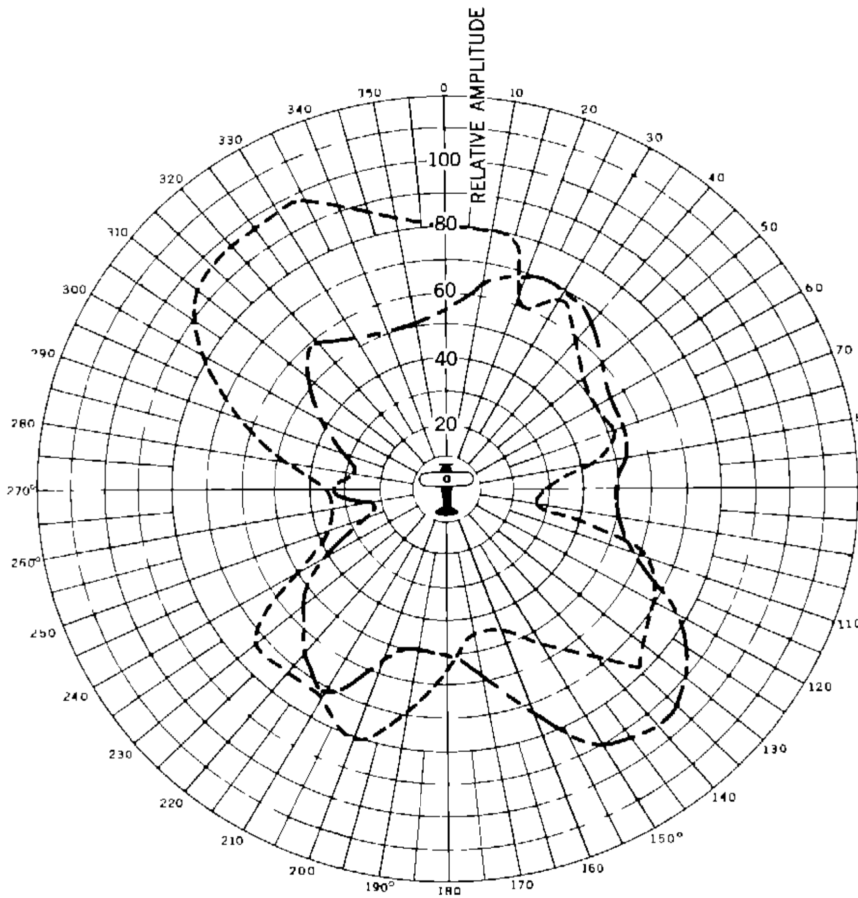


Figure 36 Receiving Antenna Patterns for 40° Banks



— — ——— — — AVERAGE OF 2 COMPLETE TURNS (15° RIGHT BANK)

- - - - - - - - - AVERAGE OF 2 COMPLETE TURNS (15° LEFT BANK)

Figure 37 Receiving Antenna Patterns for 15° Banks

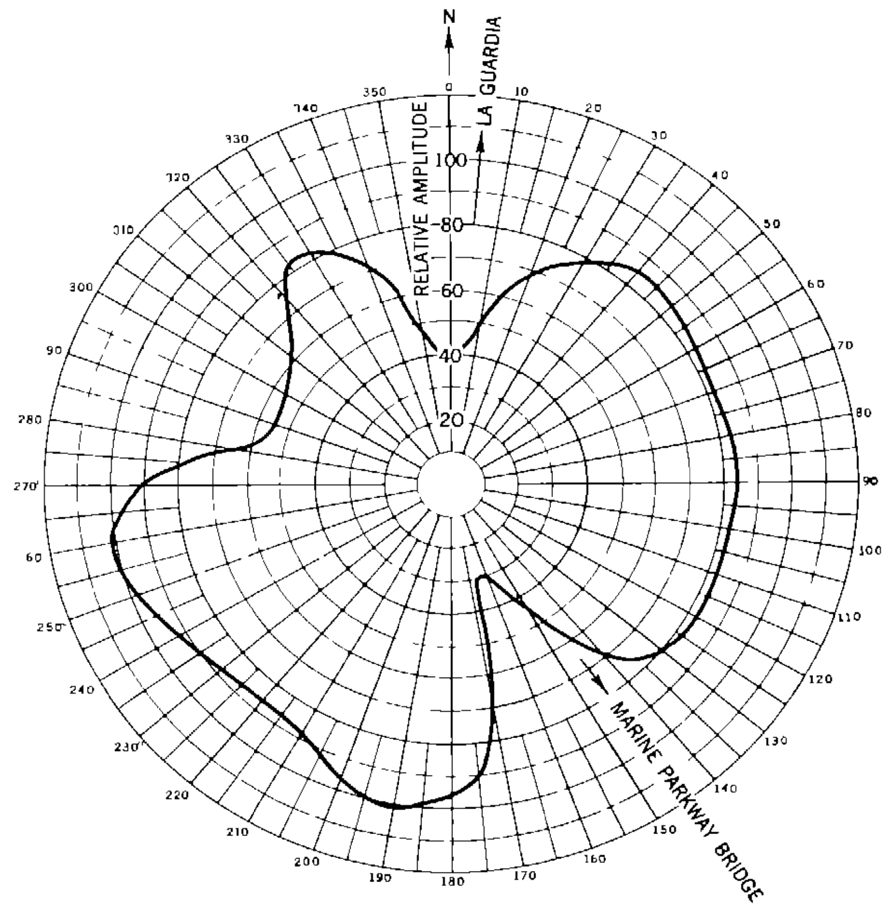


Figure 38 Horizontal Field Pattern of Floyd Bennett at 5-mile Radius and 2,000 Feet Altitude

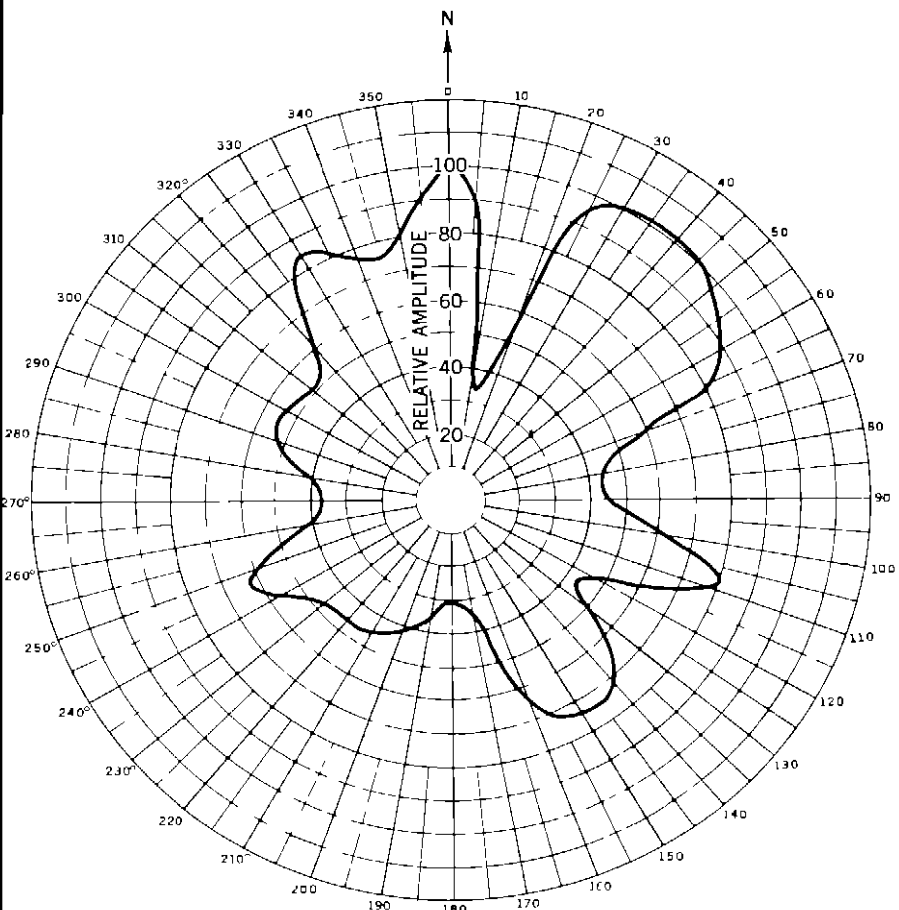
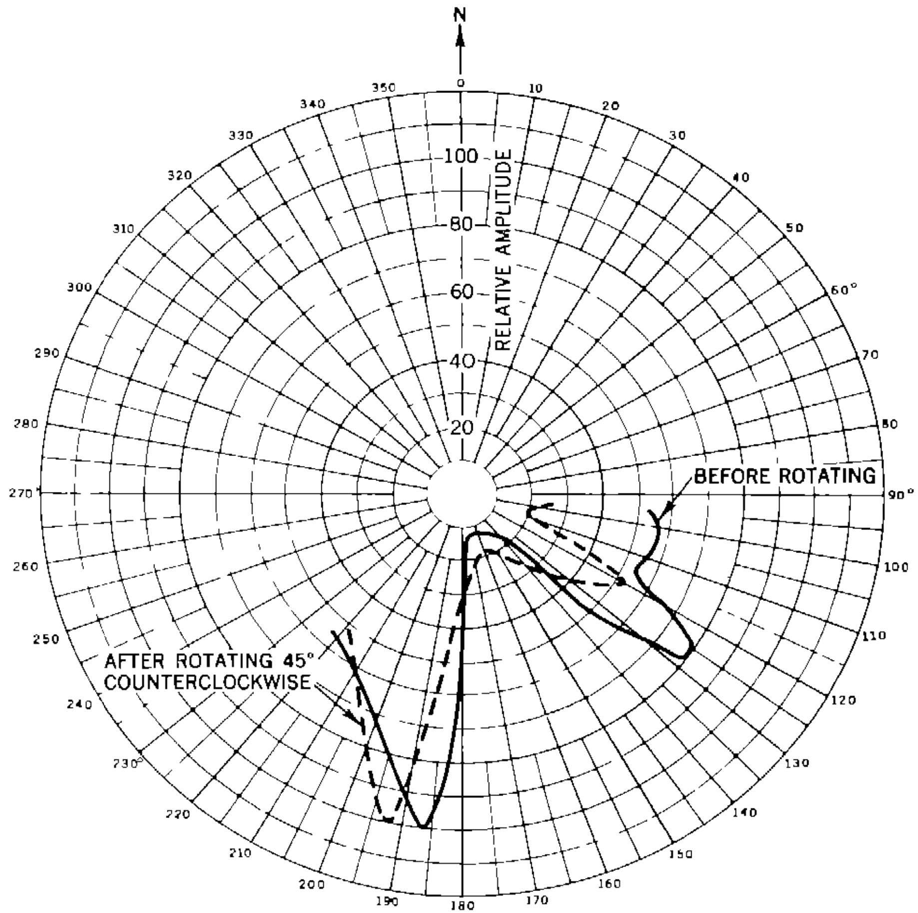


Figure 39 Horizontal Field Pattern of LaGuardia at 13-Mile Radius and 2,000 Feet Altitude



FLIGHT FROM ROCKAWAY BEACH TO ROCKAWAY POINT ALTITUDE 600 FEET

Figure 40 Horizontal Field Patterns of Floyd Bennett Before and After Antenna Rotation of 45°

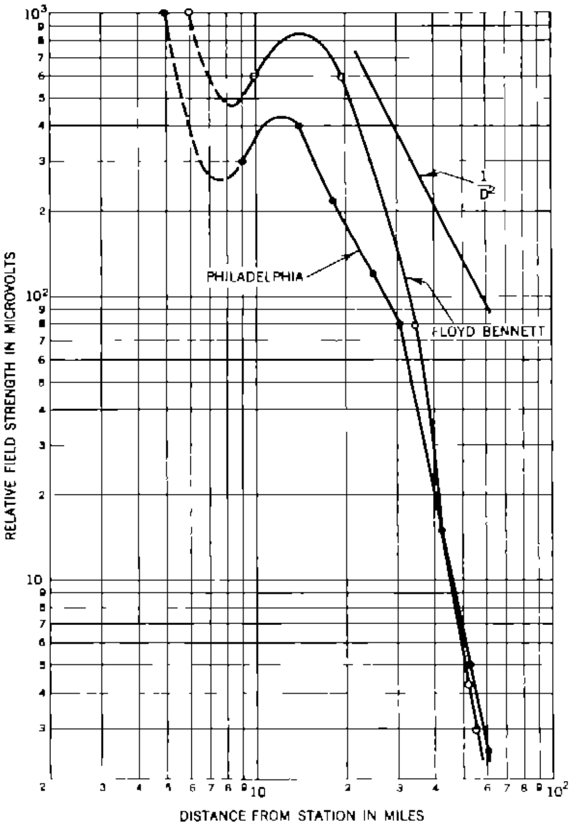


Figure 41 Field Strength vs Distance of Floyd Bennett and Philadelphia Signals at 2 000 Feet Altitude

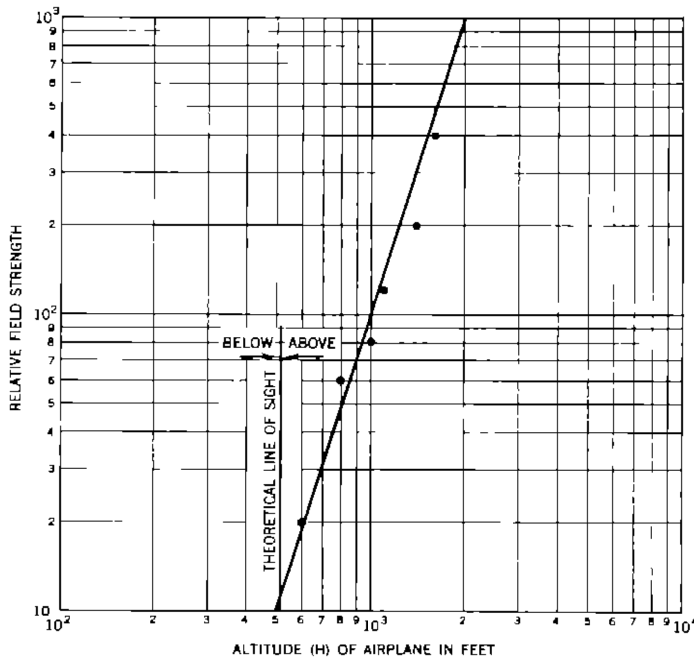


Figure 42 Field Strength vs Altitude of Floyd Bennett Signal at 35 Miles Distance Over Bay Shore L I Frequency 130 3 Megacycles and Power 100 Watts

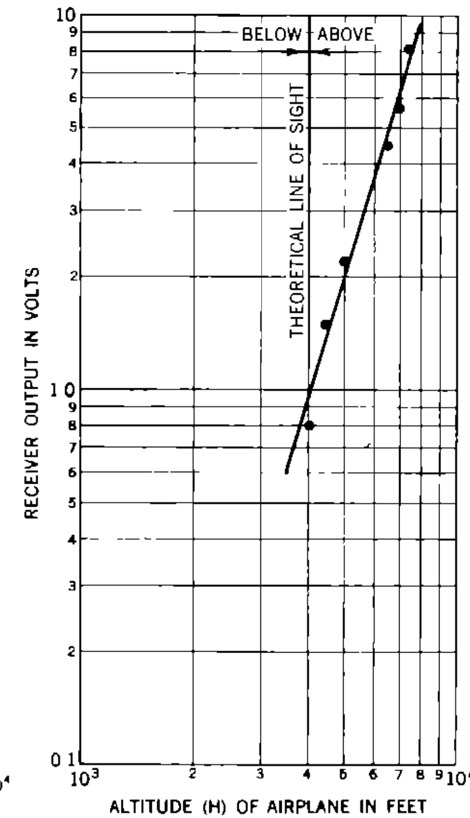


Figure 43 Receiver Output vs Altitude of Philadelphia Signal at 86 Miles Distance Over Floyd Bennett Airport Frequency 130 3 Megacycles, Power 100 Watts and Receiver on Manual Volume Control

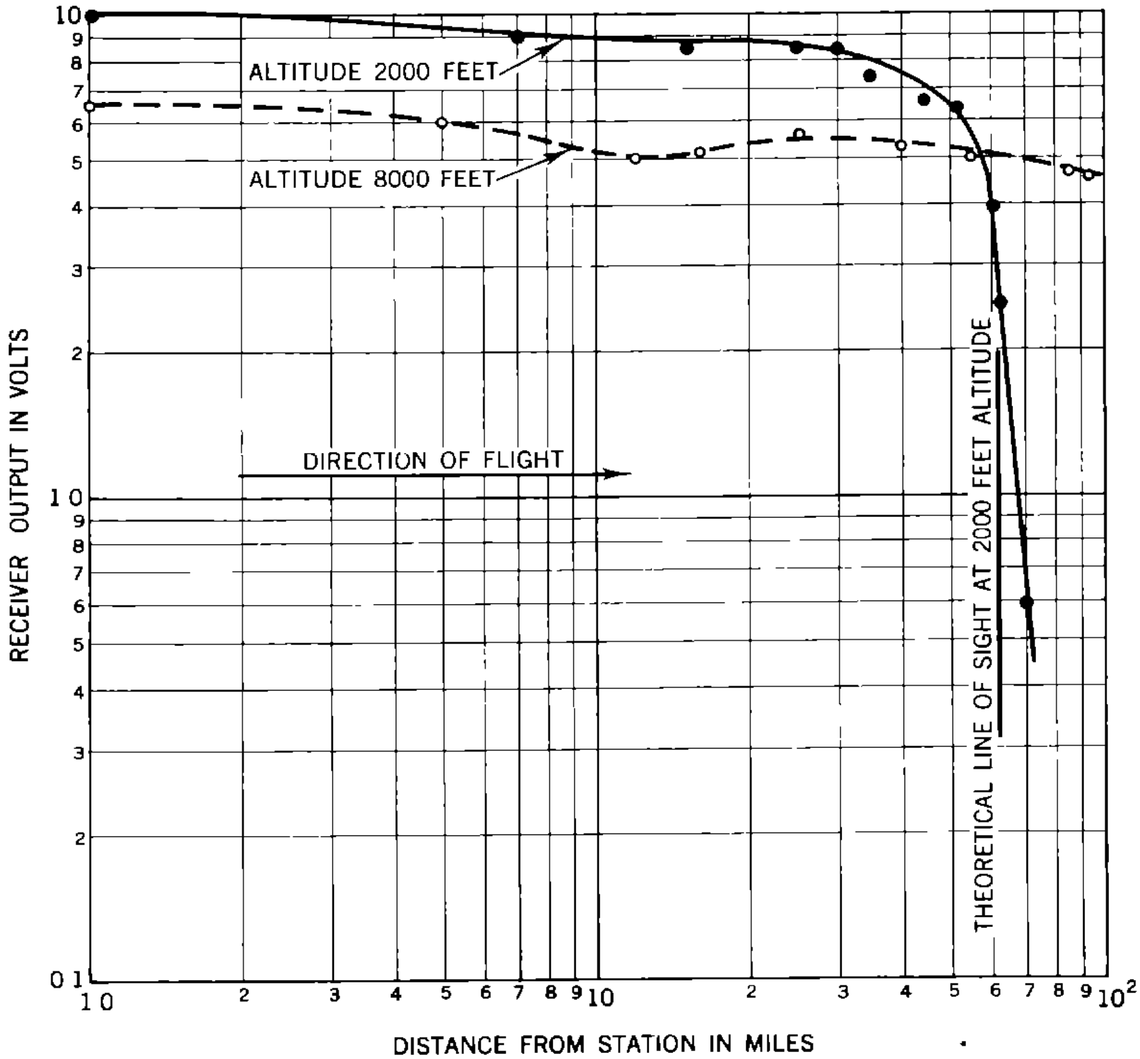


Figure 44 Receiver Output vs Distance and Altitude of Philadelphia Signal Frequency 130 3 Megacycles, Power 100 Watts and Receiver on Automatic Volume Control

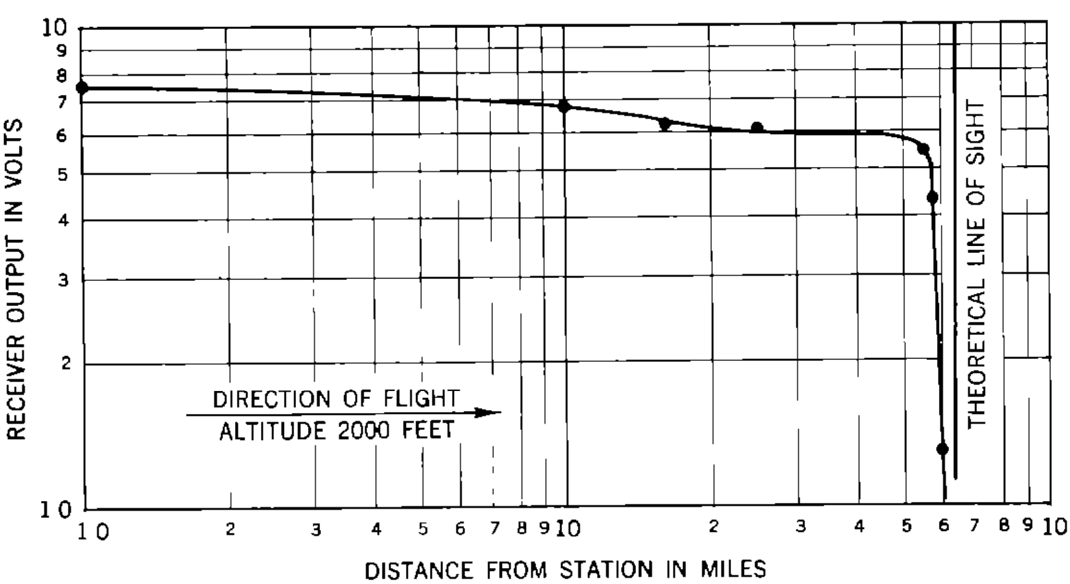


Figure 45 Receiver Output vs Distance of Floyd Bennett Signal Frequency 130 4 Megacycles, Power 100 Watts and Receiver on Automatic Volume Control

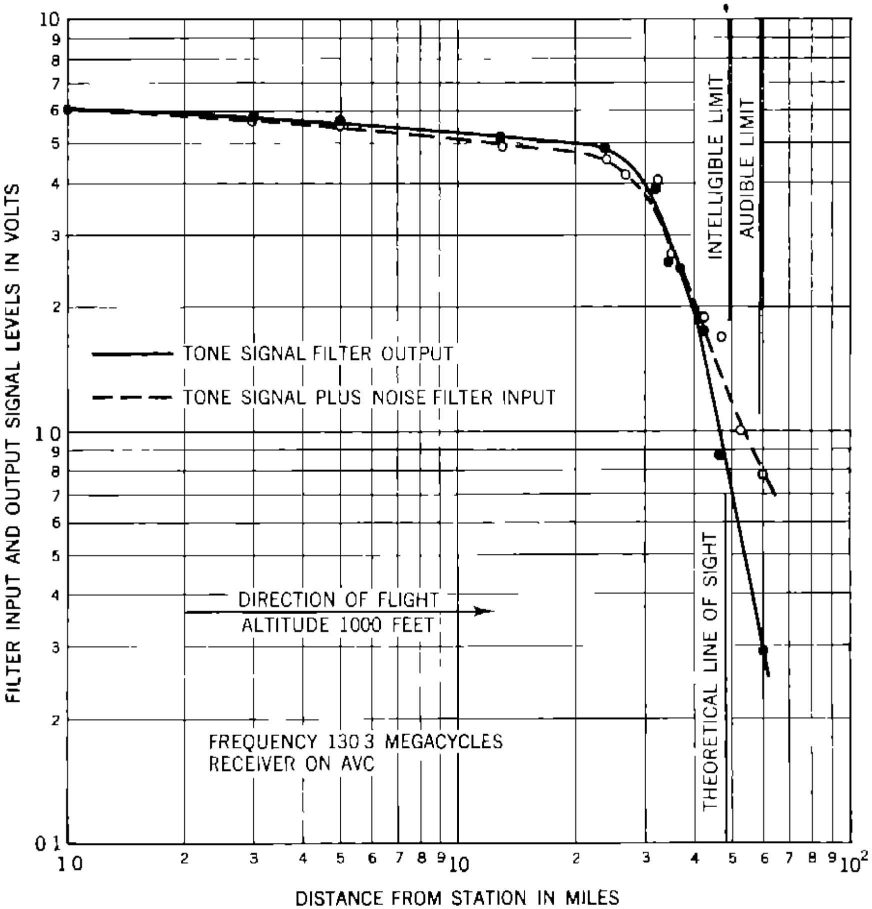


Figure 46 Tone Signal vs Distance and Tone Signal Plus Noise vs Distance of Floyd Bennett Signal Power 33 Watts

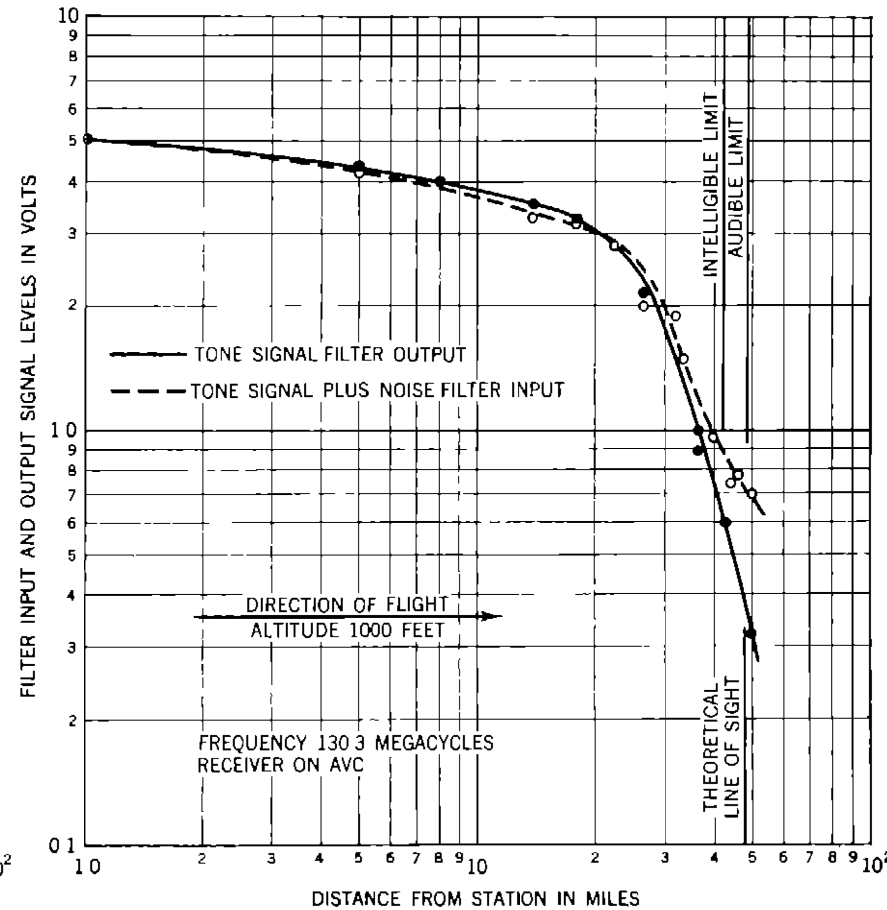


Figure 47 Same as 46 Except 100 Watts

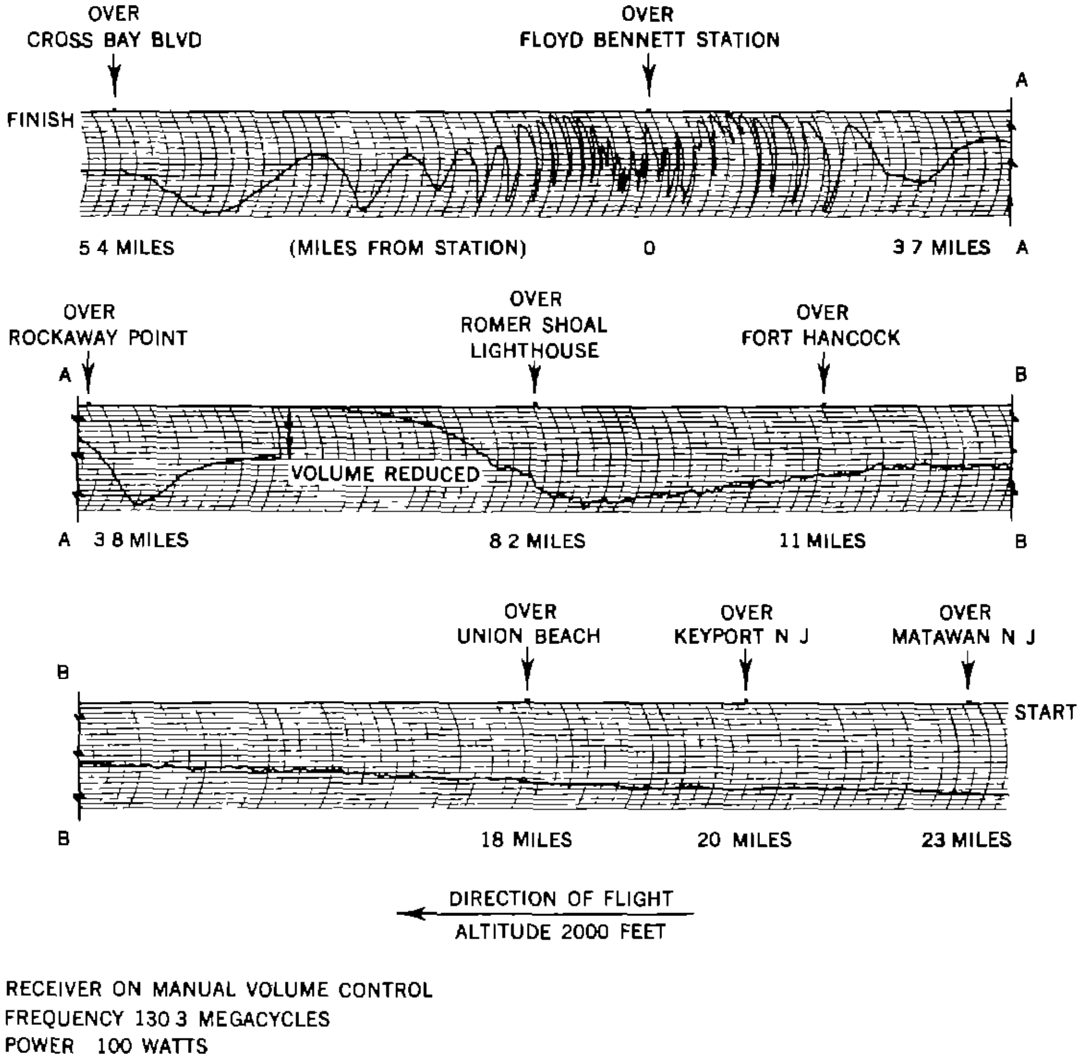


Figure 48 Recording of Floyd Bennett Tone on Flight from Matawan, N J to Cross Bay, Boulevard, L I

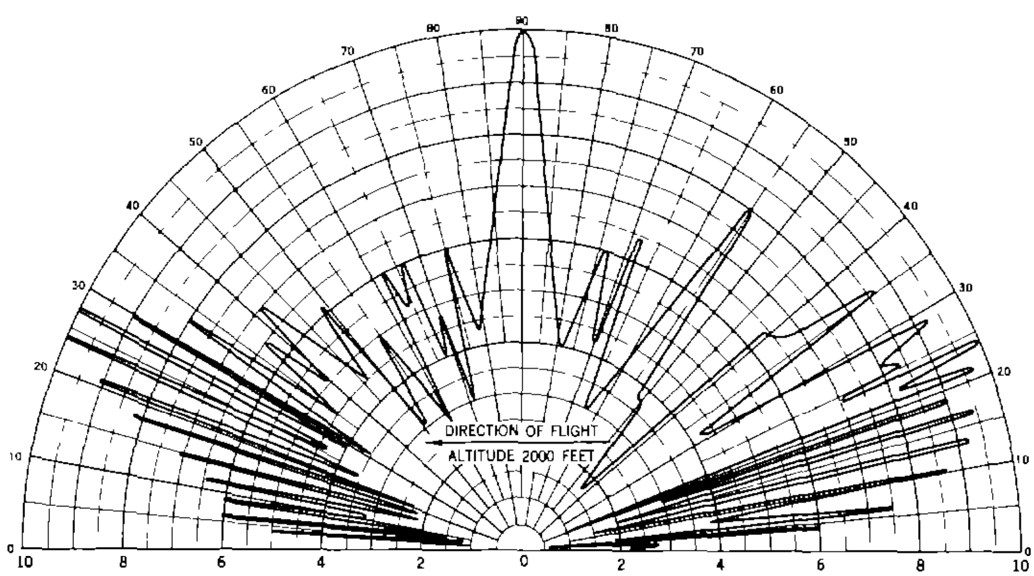


Figure 49 Floyd Bennett Observed Field vs Angle to Airplane

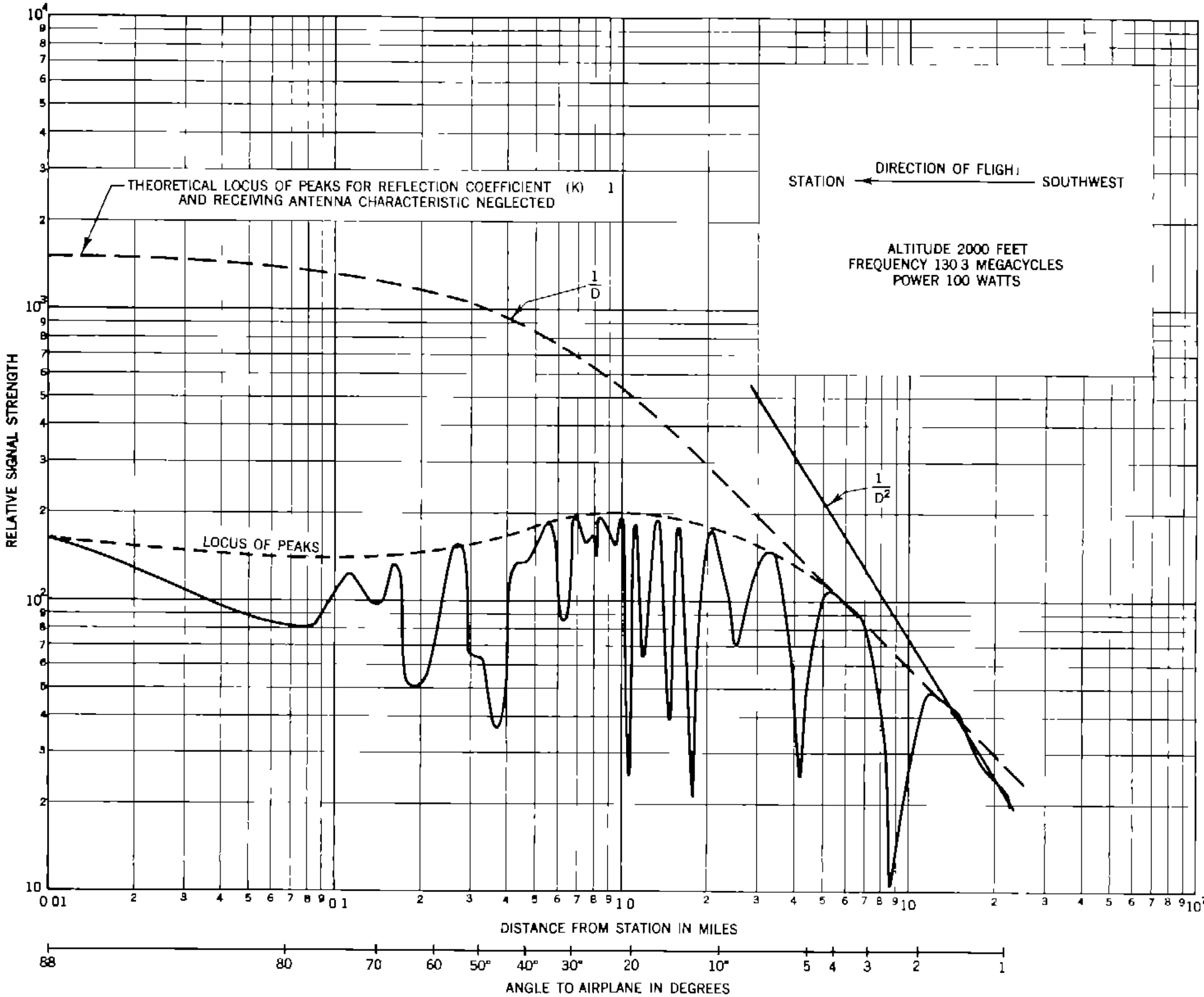


Figure 50 Floyd Bennett Observed Field vs Distance Southwest of the Station

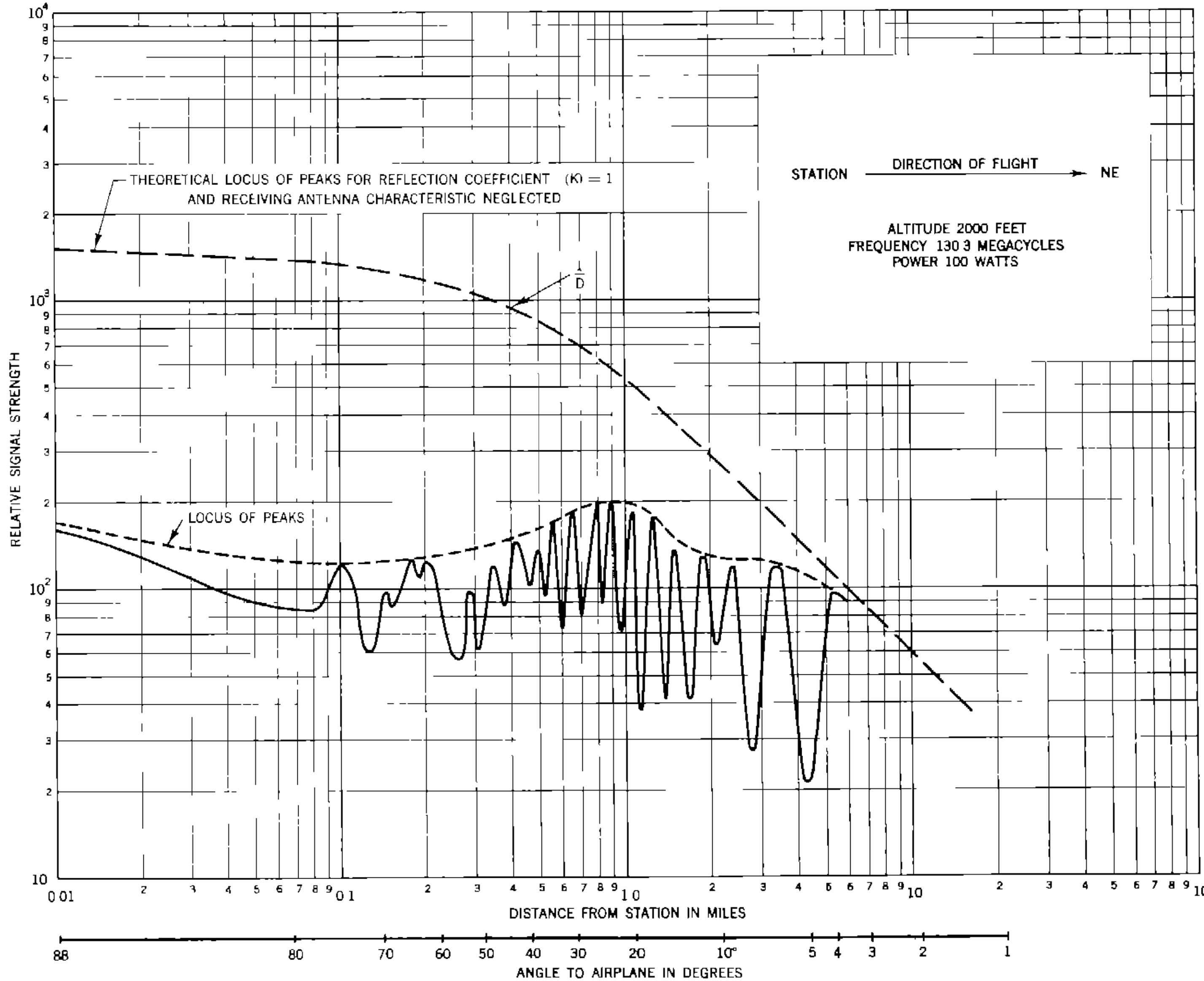


Figure 51 Floyd Bennett Observed Field vs Distance Northeast of the Station

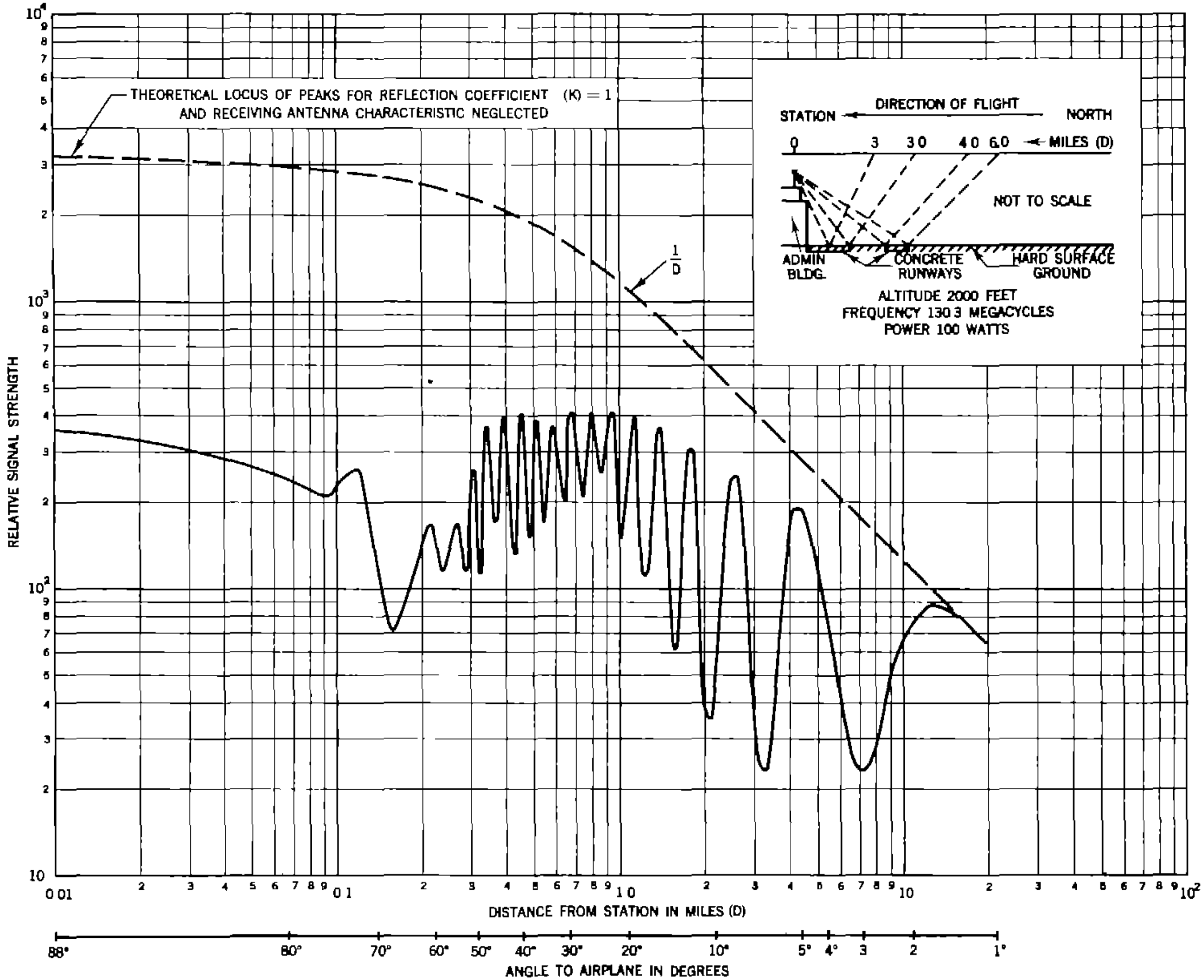


Figure 52 Floyd Bennett Observed Field vs Distance North of the Station

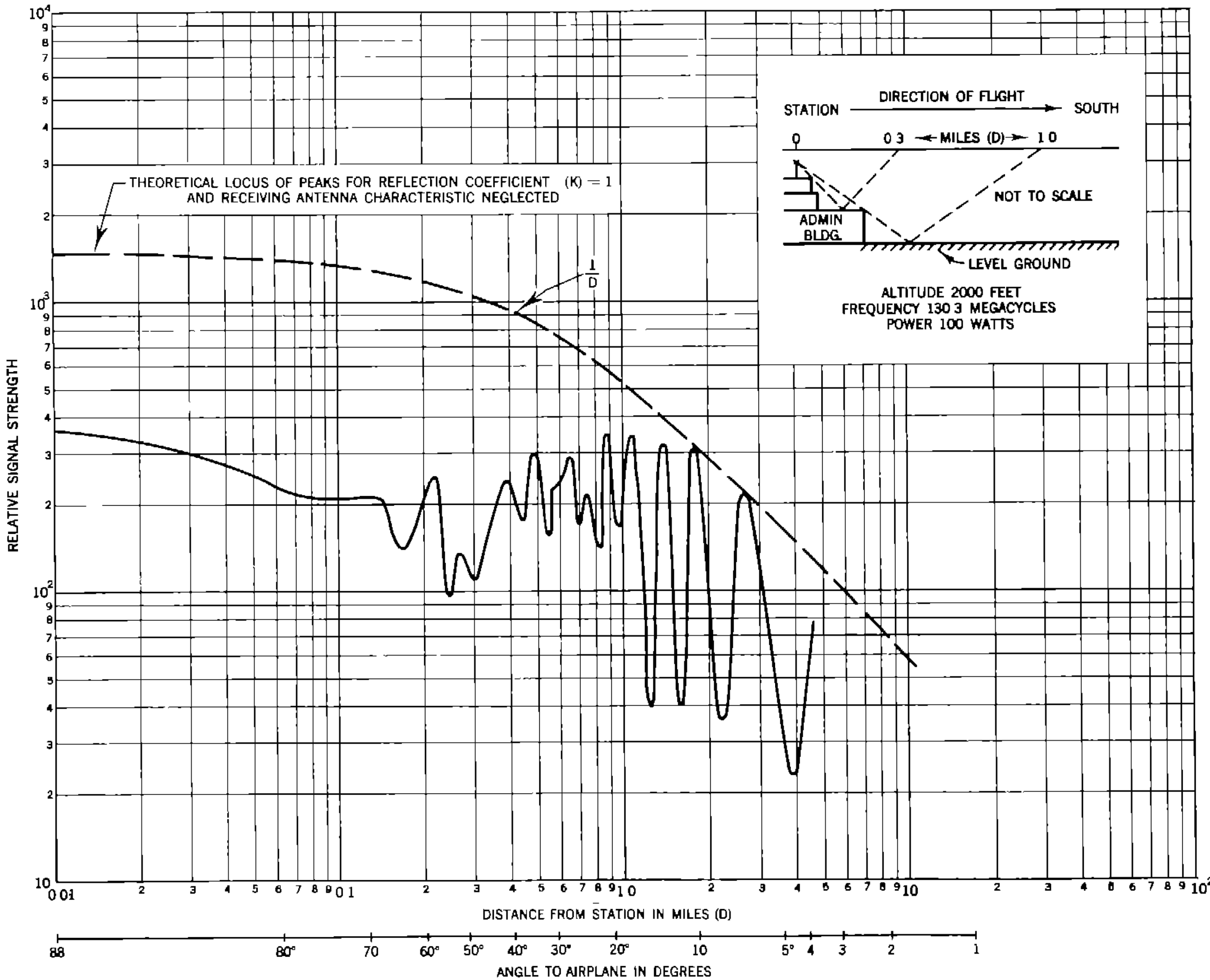


Figure 53 Floyd Bennett Observed Field vs Distance South of the Station

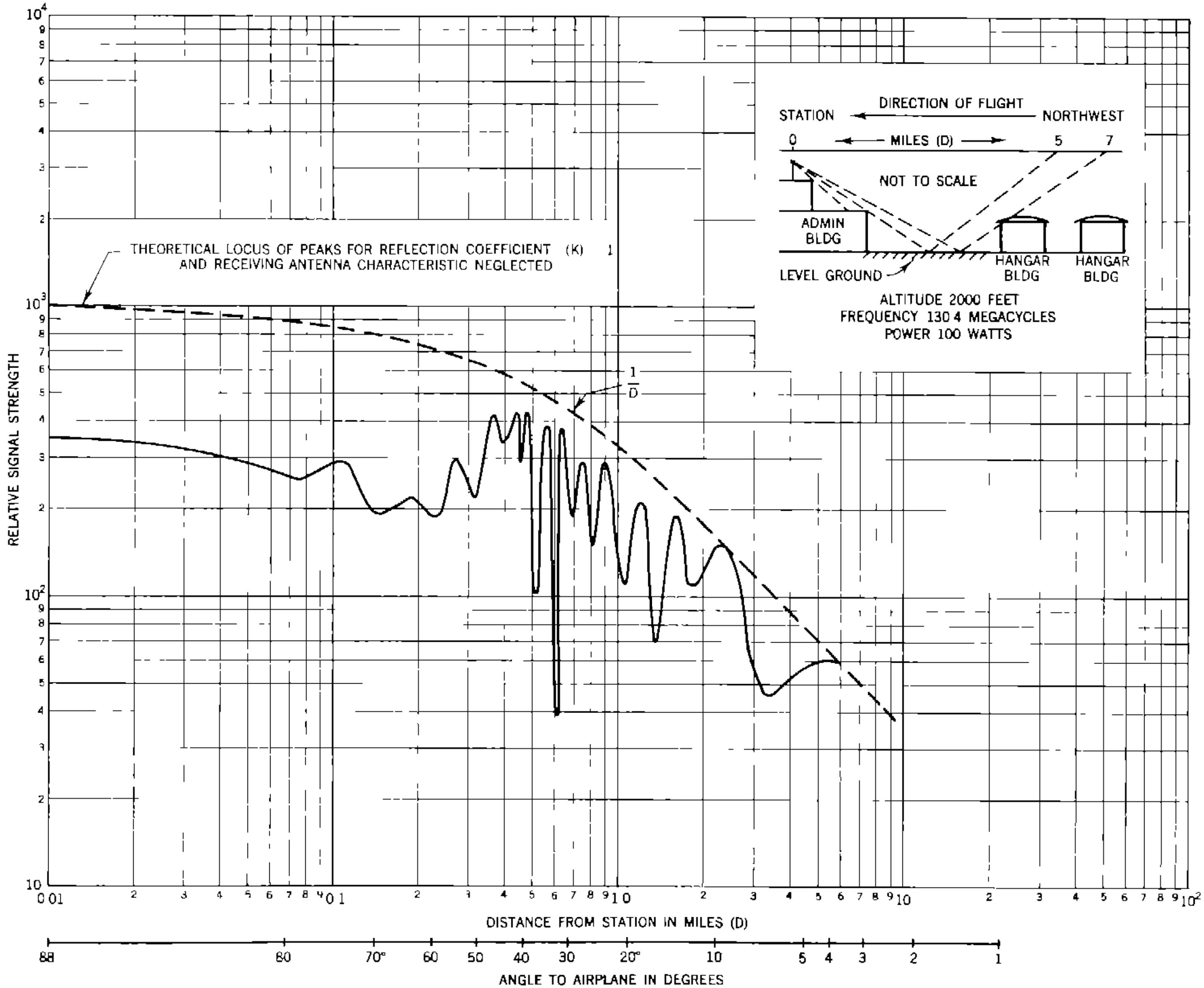


Figure 51 Floyd Bennett Observed Field vs Distance Northwest of the Station

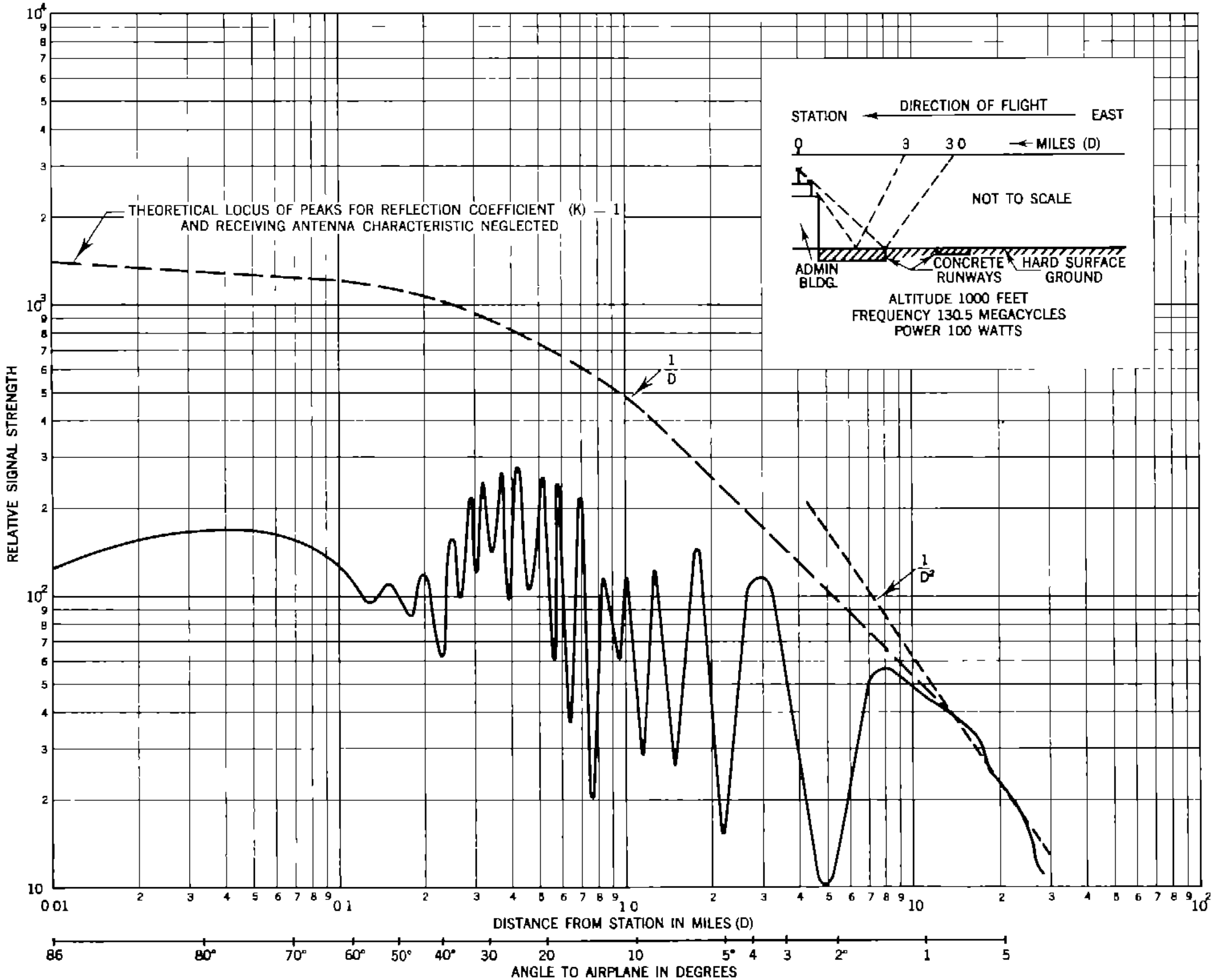


Figure 55 Floyd Bennett Observed Field vs Distance East of the Station

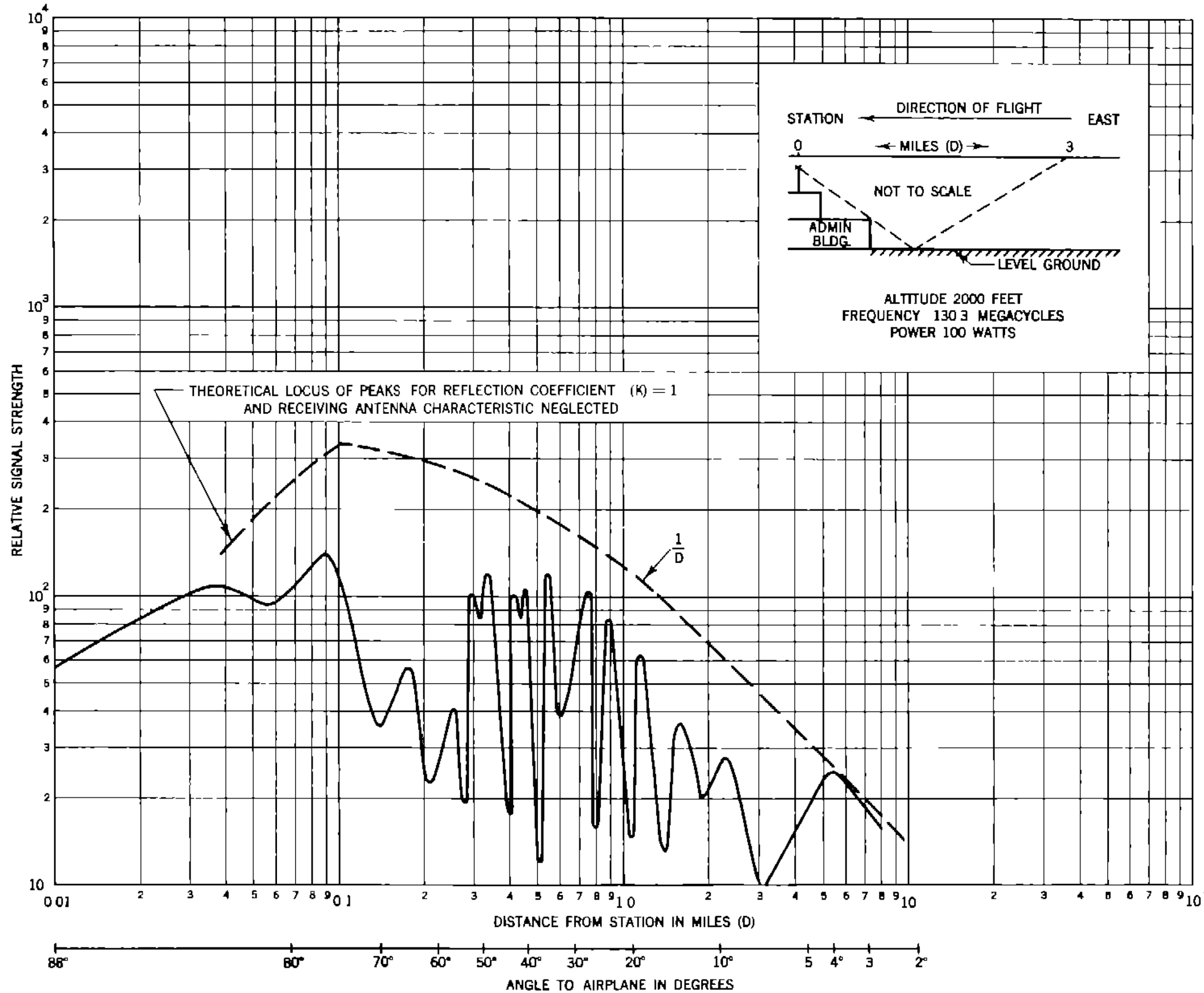


Figure 56 Philadelphia Observed Field vs Distance East of the Station

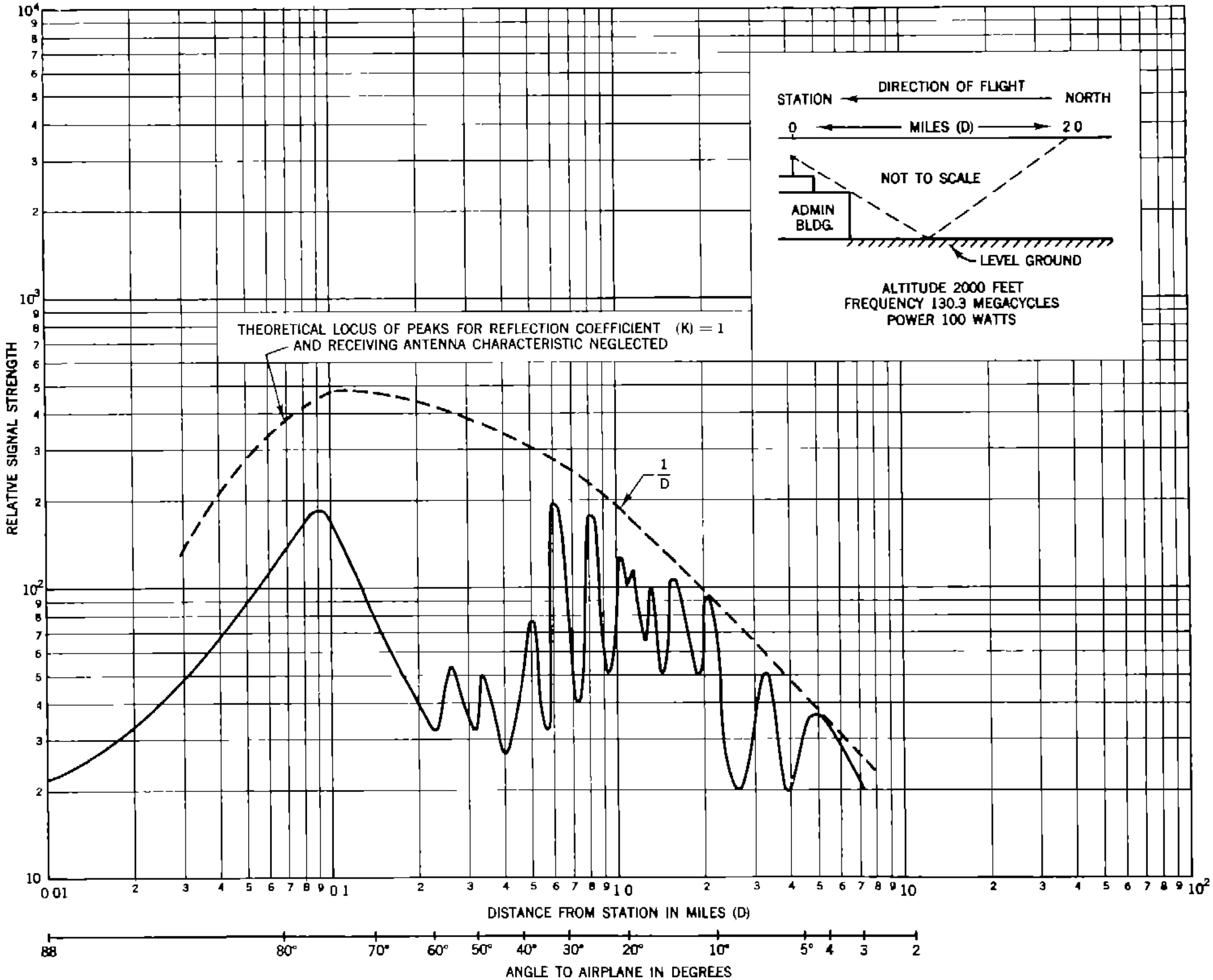


Figure 57 LaGuardia Observed Field vs Distance North of the Station

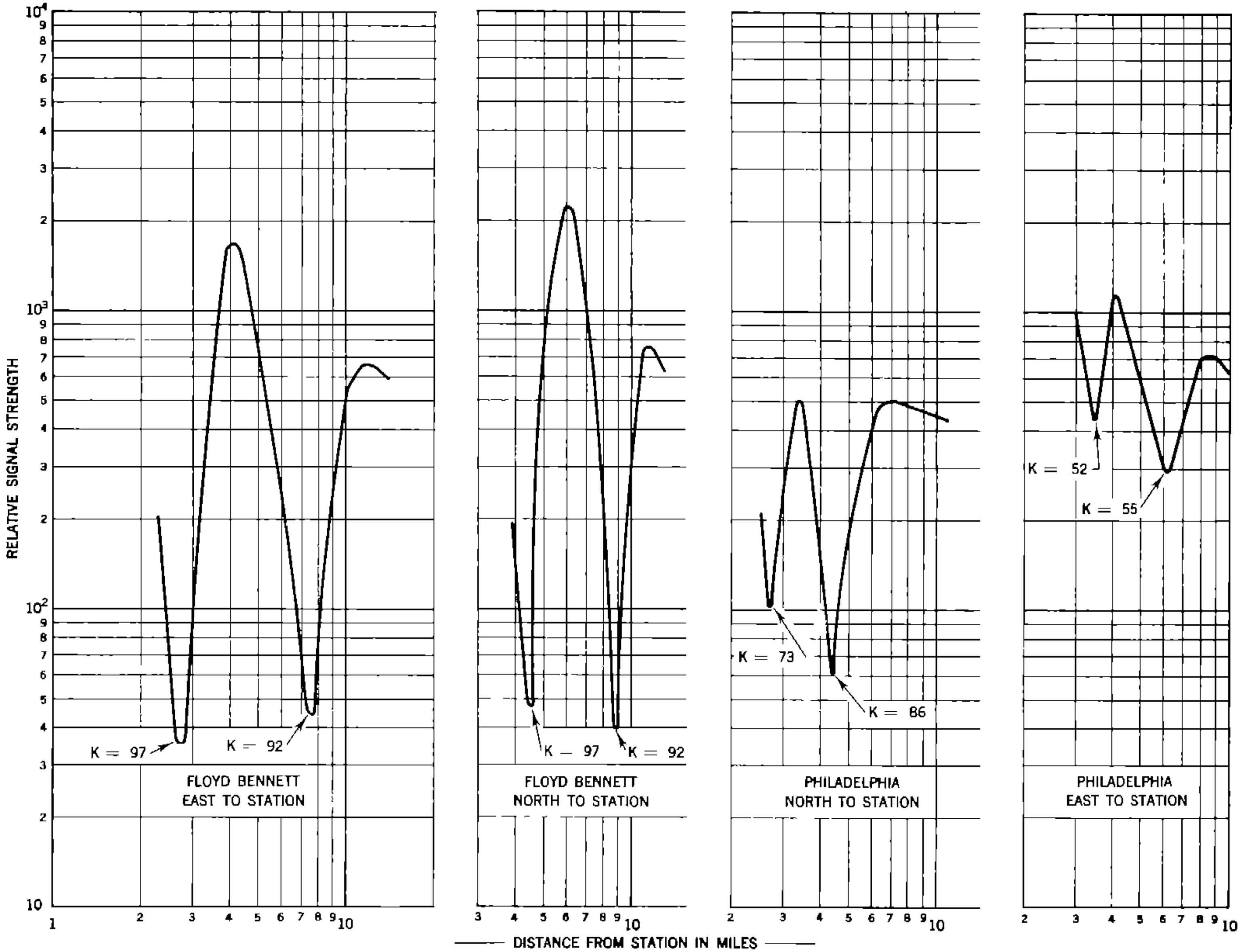


Figure 58 Floyd Bennett and Philadelphia Outer Maximum and Minimum Areas at 2,000 Feet Altitude

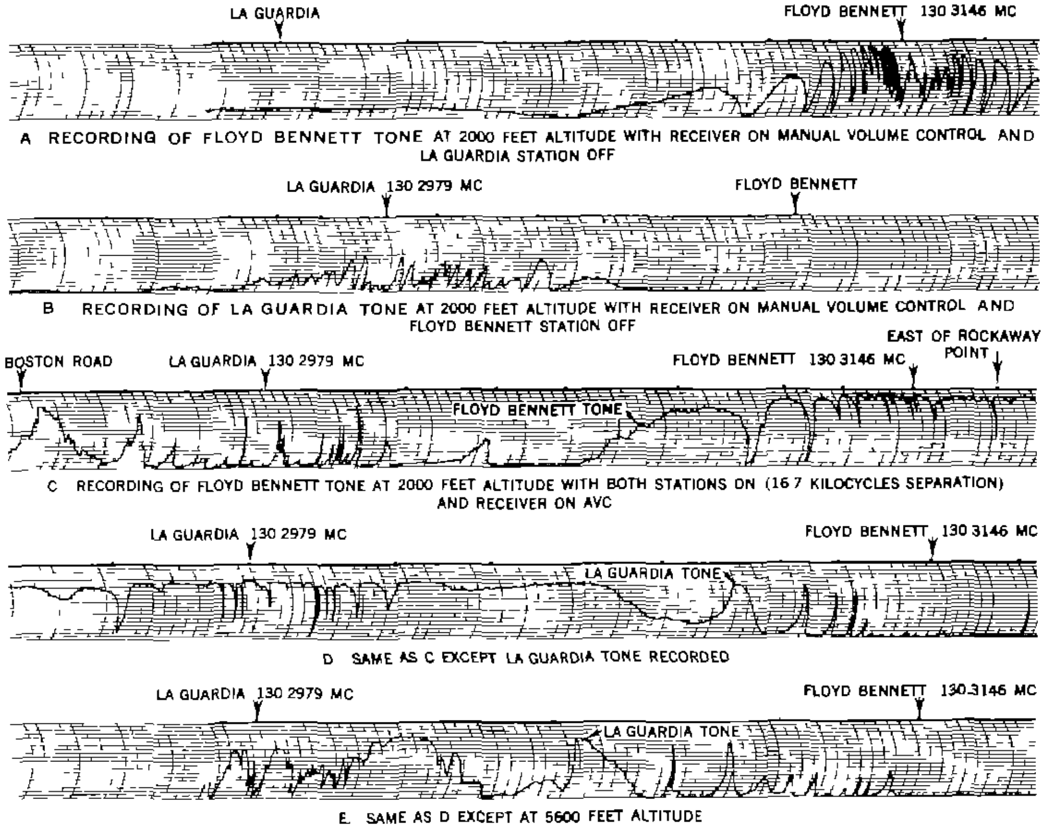


Figure 59 Recordings Showing Field vs Distance and Interference vs Distance Between LaGuardia and Floyd Bennett Stations

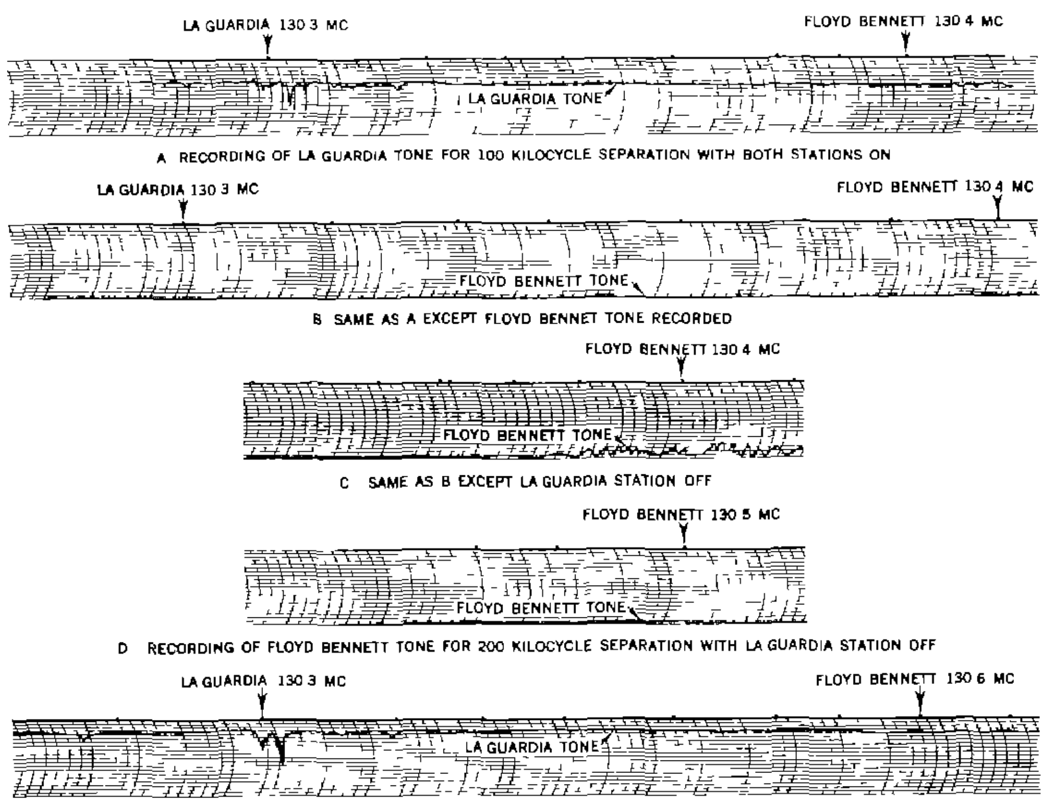


Figure 60 Recordings Taken at 2,000 Feet Altitude Showing Interference Between LaGuardia and Floyd Bennett Stations Receiver Tuned to 130 3 Megacycles and on Automatic Volume Control

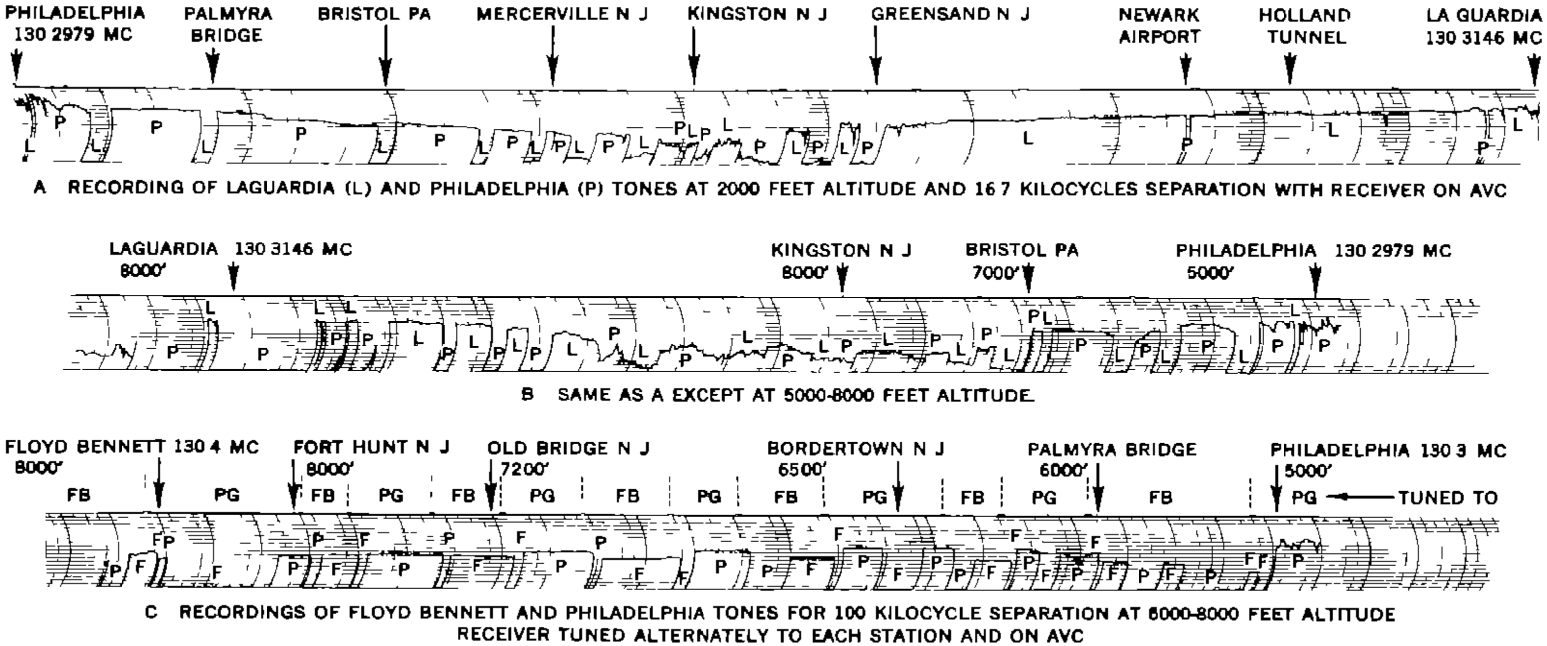


Figure 61 Recordings Showing Interference Between Philadelphia and LaGuardia, and Philadelphia and Floyd Bennett Stations

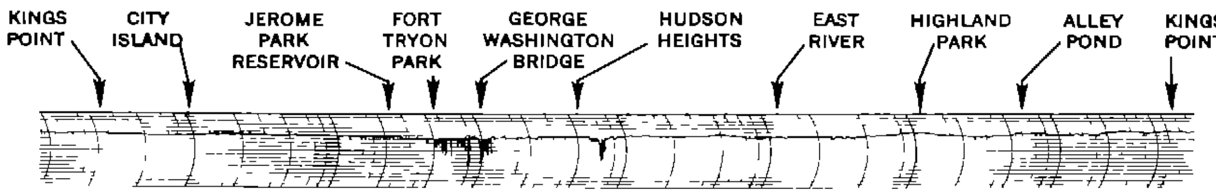


Figure 62 Recording of LaGuardia Tone at 2,000 Feet Altitude While Circling LaGuardia at Radius of 7 Miles Receiver on AVC

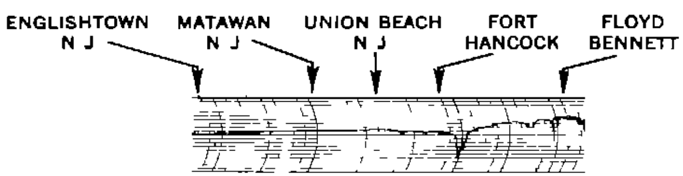


Figure 63 Recording of Floyd Bennett Tone on Flight to Englishtown, N, J at 2,000 Feet Altitude Receiver on Automatic Volume Control

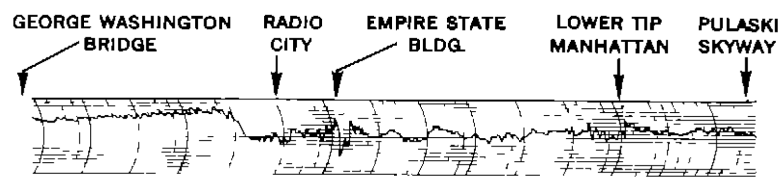


Figure 64 Recording of Floyd Bennett Tone on Flight Up West Side of Hudson River at 1,400 Feet Altitude Receiver on Manual Volume Control

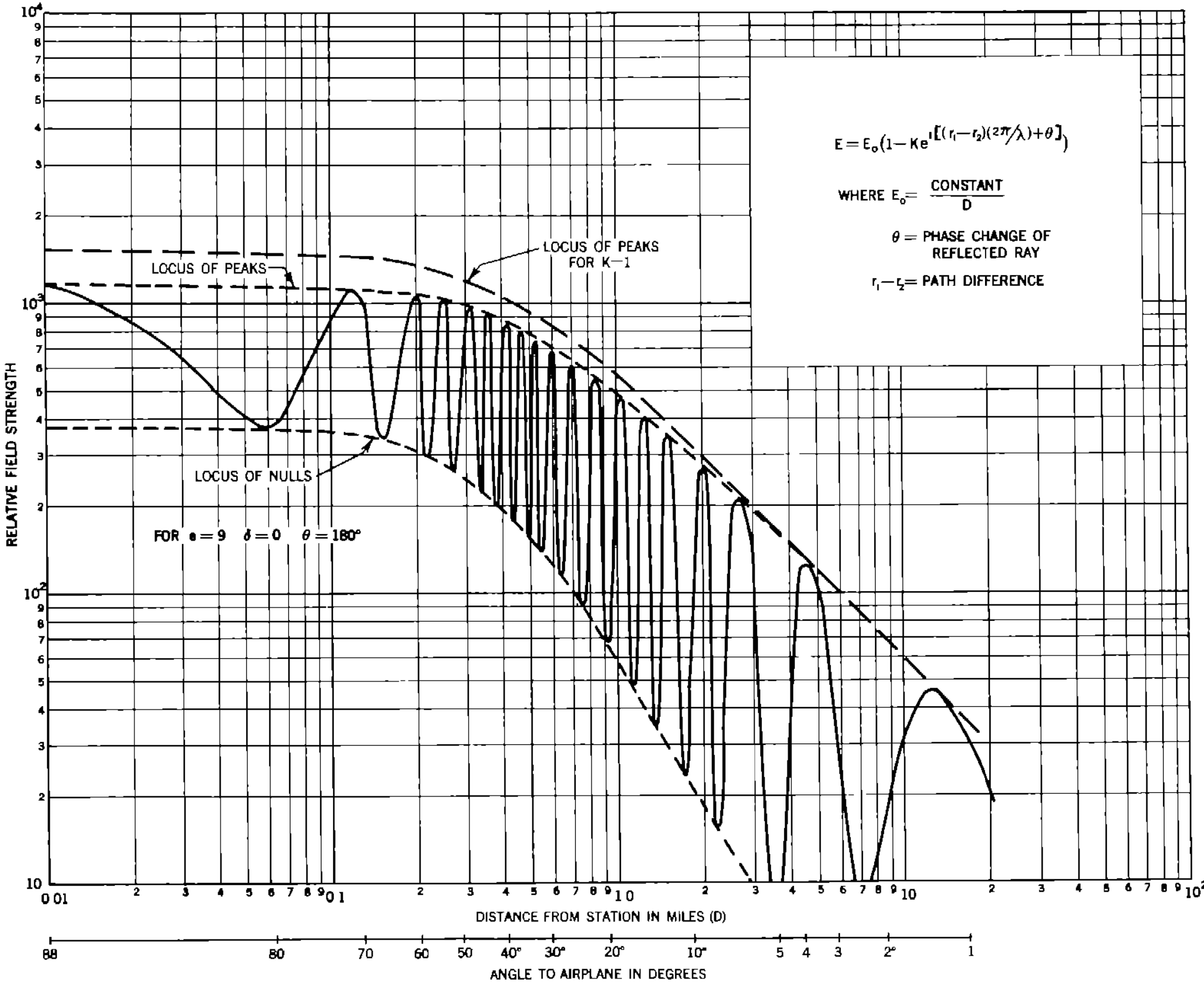


Figure 65 Theoretical Field vs Distance of Floyd Bennett Station at 2,000 Feet Altitude and 130 3 Megacycles

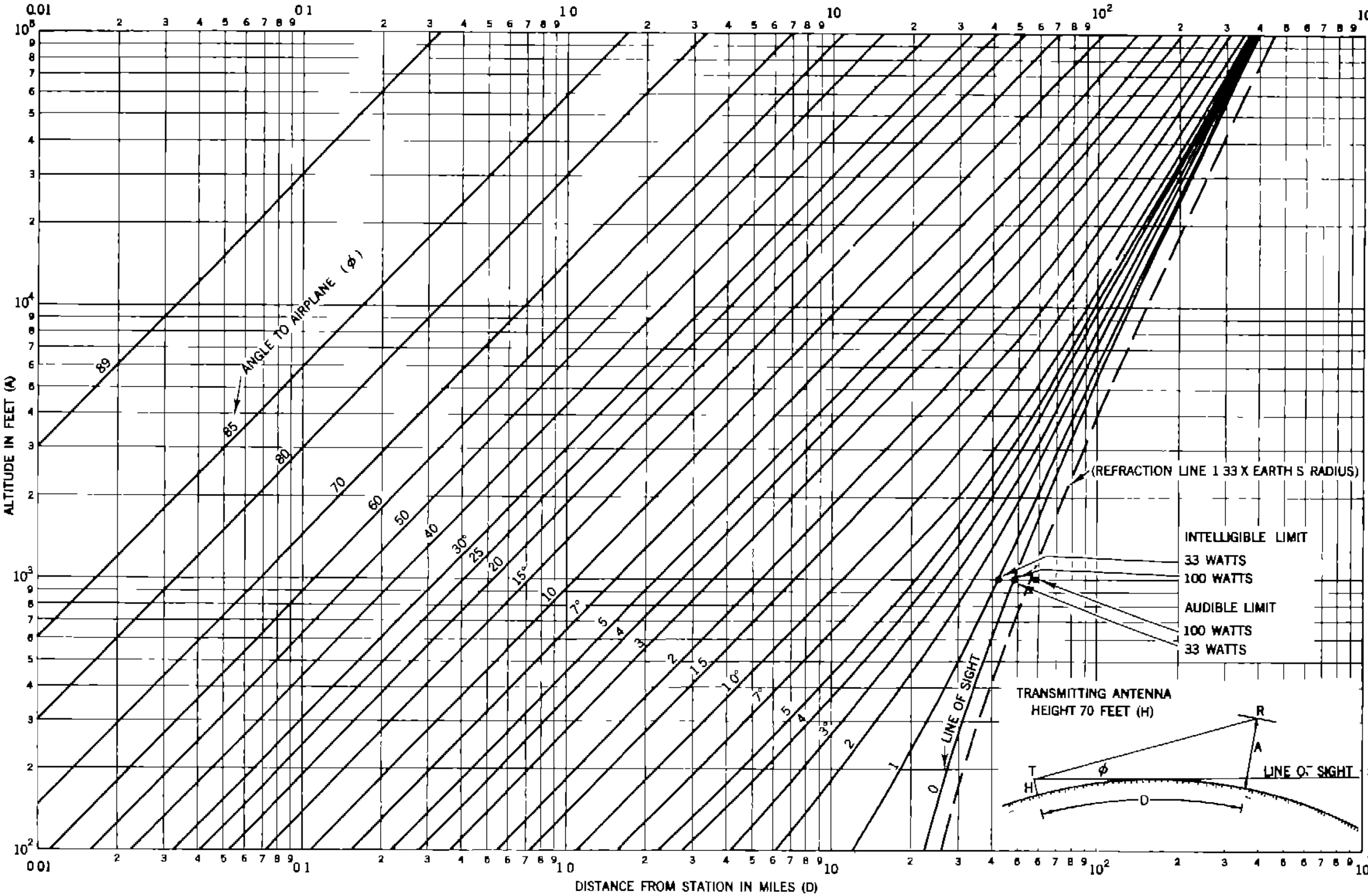


Figure 66 Service Range Chart of Transmitting Station

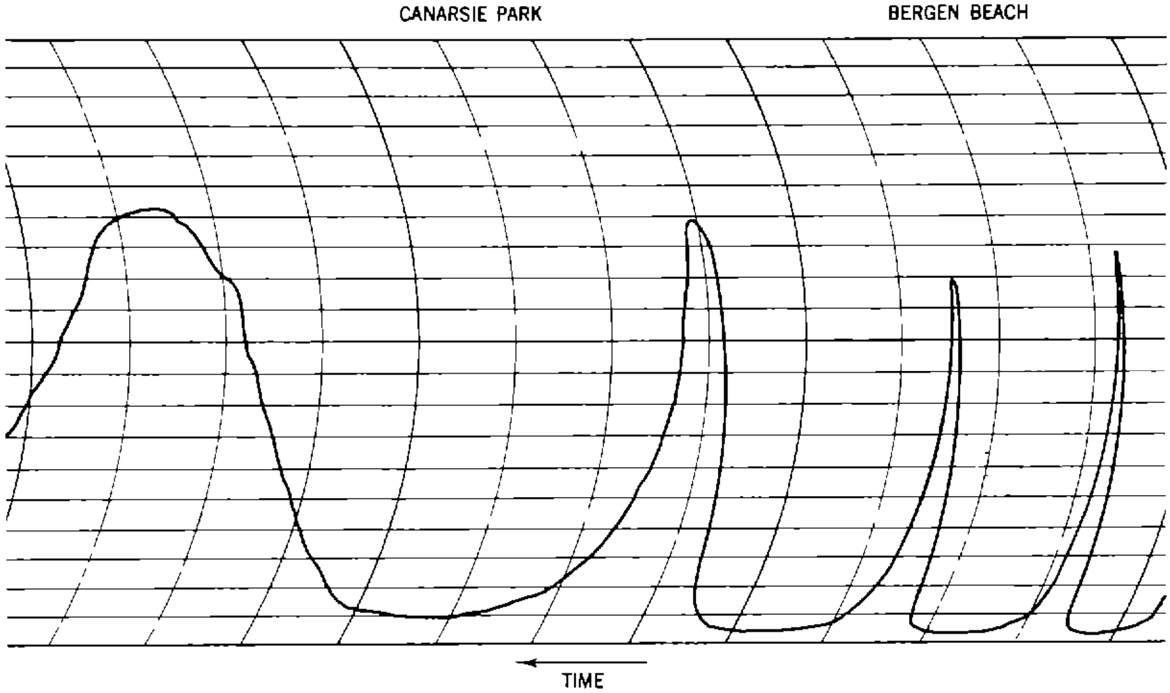


Figure 67 Recording of LaGuardia Tone at 2,000 Feet Altitude With LaGuardia and Floyd Bennett Stations Operating Simultaneously on 130 3 Megacycles (16 7 Kilocycles Separation) Receiver on Automatic Volume Control

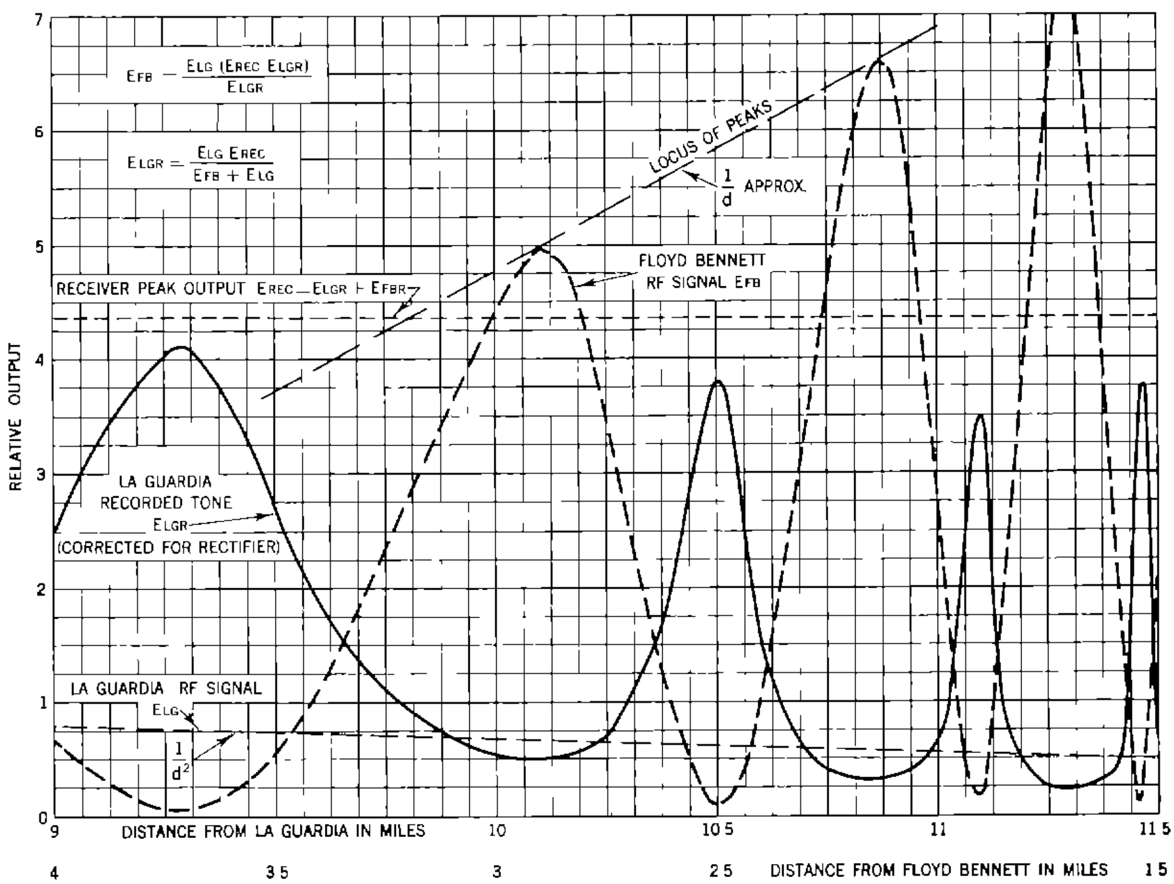


Figure 68 Analysis of Recording of Figure 67

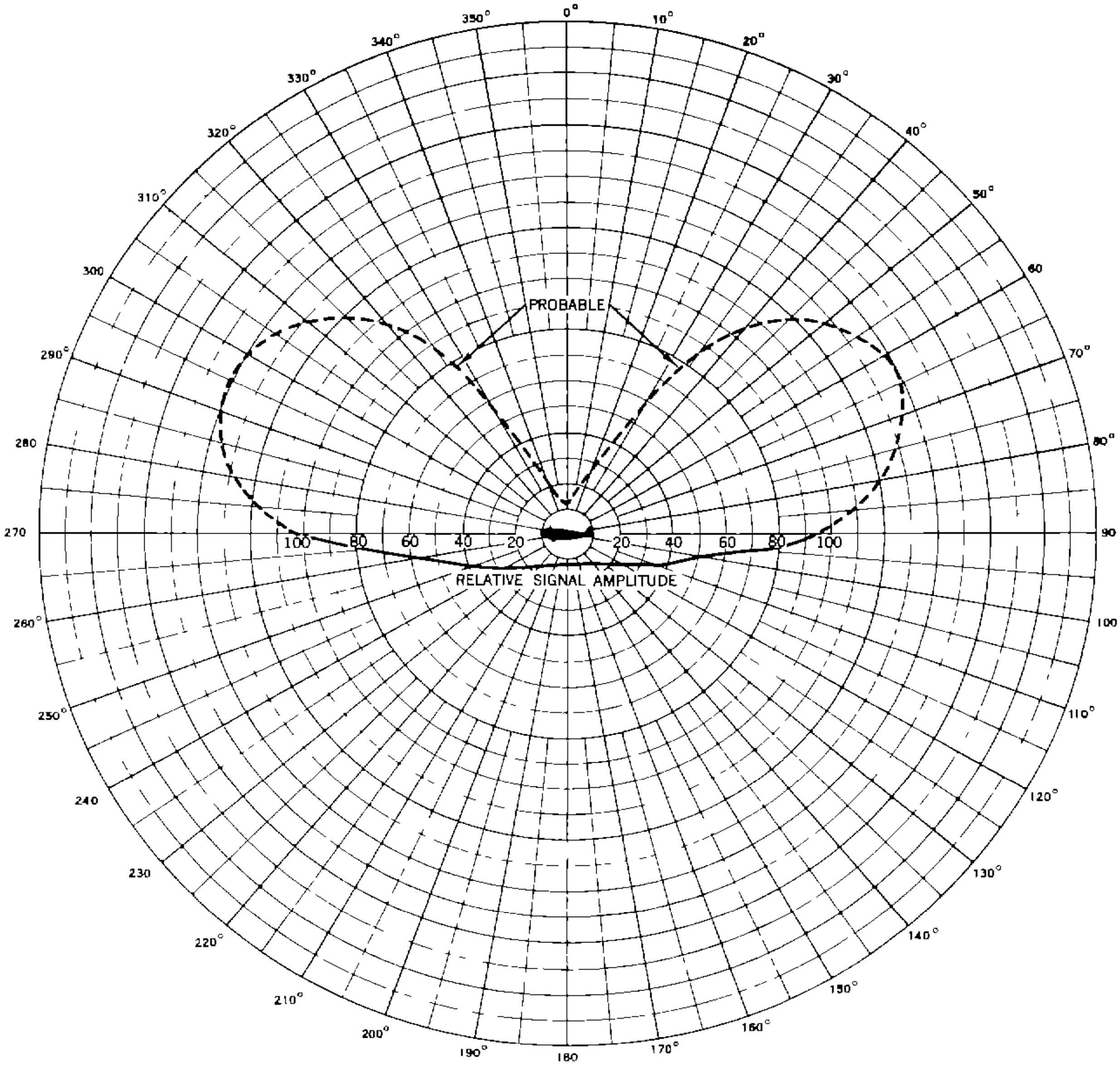


Figure 69 Indicated Vertical Receiving Characteristic of Airplane NC-80 at 130 3 Megacycles