THE CAA LOW FREQUENCY OMNIRANGE

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SUMMARY

A low frequency omnirange suitable for long-distance air navigation has been constructed and tested at Avon, Indiana, approximately seven miles northwest of the Experimental Station. In principle this range operates the same as the VHF omnirange now being installed on the Federal Airways

As in the VHF system, the low frequency omnirange produces in the aircraft receiving system two 30-cps signals, one of which is constant and the other variable in relative phase for various azimuthal angles around the station The receiver incorporates a conventional superheterodyne circuit followed by suitable audio amplification, a phase-splitting circuit to drive the omnibearing selector, and a phase discriminator circuit to operate the course-deviation indicator

The ground station is a standard 400-watt AN (Adcock) radio range, except for the addition of a rotating, inductive goniometer The station operates on a frequency of 194 kc

A course-width of 10°, twice as sharp as that of the VHF omnirange is used, and flight tests indicate good performance free of attitude or other similar effects within the service area Although guidance has been observed as far as 600 miles, the final service area is dependent upon output power, atmospheric interference, and ability to use the night-time sky wave, all of which are to be studied in the continuation of the project In this experimental installation, using standard 133-foot towers, the antenna input power was 400-watts, some of which is lost in the feeding and tuning networks Distance checks, therefore, are not to be considered conclusive

INTRODUCTION

Following successful preliminary tests on a VHF omnirange system at the Experimental Station, plans were made to develop a similar system for operation at low frequencies

Two methods of transmitting the reference and variable signals were considered

In the first method two carriers of different frequency were radiated. The reference carrier was amplitude modulated at 60-cps, while the variable signal carrier was modulated at 60-cps, in space, by the output of the sideband generator and its associated radiators

The second method uses a single carrier The reference signal is produced by amplitude modulation of the carrier by a 210-cps subcarrier which in turn was frequency modulated at 30-cps The variable signal is produced by space modulation of the carrier at 30-cps

After consideration of the two plans of transmitting the reference and variable phase signals, the method using the two carrier frequencies was placed in operation in December 1945. The constant, or reference phase signal was radiated on 172 kc, and the variable phase signal was radiated on 194 kc Two airborne receivers were used for reception of the signals

At the completion of numerous tests designed for the collection of data, to investigate the basic principles of this type of system, the omnirange was converted from the two-frequency to the single-frequency type in September 1946

THEORY OF OPERATION

The omnirange system now in use was designed to produce in the receiving equipment, two 30-cps voltages the phases of which have a definite relationship depending upon the azimuth angle from the station One 30-cps voltage, commonly referred to as the "variable phase signal," results from a field pattern rotating at a 30-cps rate, which produces in the receiver a 30-cps voltage with a phase depending upon the azimuthal position from the station This rotating field is made possible by the use of a goniometer driven by an 1800-rpm synchronous motor The second 30-cps voltage, commonly referred to as the "reference phase signal," has a fixed phase in all directions To avoid cross modulation in the receiver between the reference and variable 30-cps signals the reference 30-cps signal is imposed by frequency modulation on a 210-cps subcarrier and this combination then amplitude modulates the carrier. A typical AN range Adcock antenna installation with 133-foot towers was used in these experiments.

GROUND EQUIPMENT

Transmitter

The transmitter, illustrated in Fig. 1,

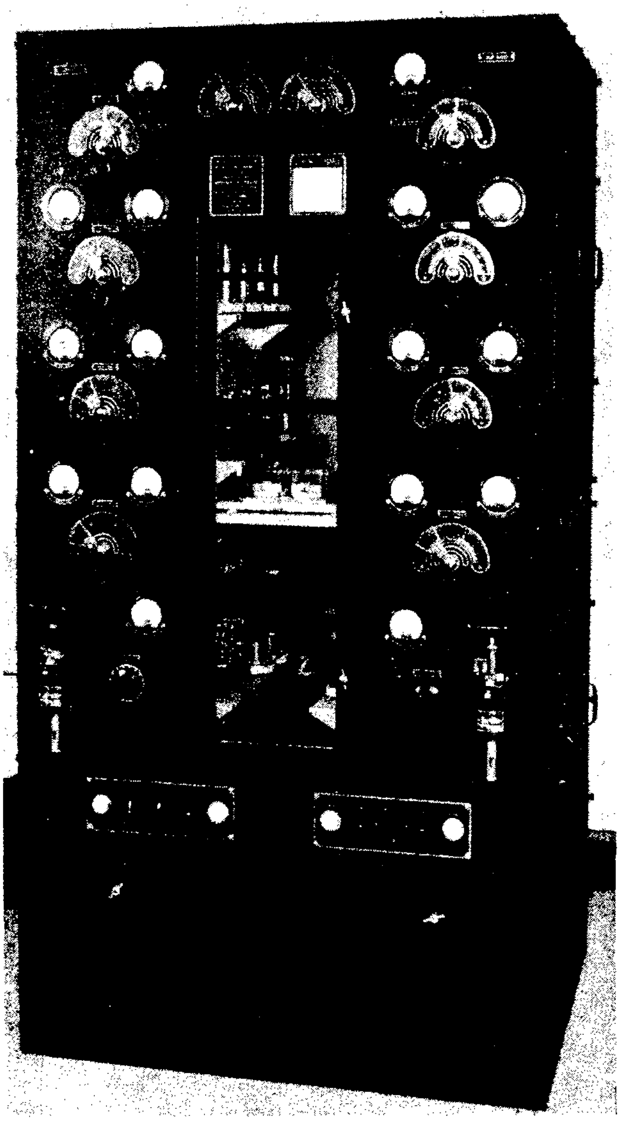


Fig. 1 Transmitter

is a self-contained unit in which are assembled all the control circuits, power supply, radio frequency, and audio circuits necessary to provide a carrier channel output of 400-watts and a sideband channel output of 275-watts. The control circuits provide either local or remote control of the transmitter.

Plate voltage for the vacuum tubes is obtained from two rectifier systems. One supplies power to the smaller tubes in the equipment at a potential of 500 volts. The second supplies power to the larger radio and audio frequency tubes at a potential of 1400 volts.

The radio frequency system of the transmitter consists of two separate and distinct channels. One channel, known as the sideband channel, provides an output of 275-watts. The second channel is known as the carrier channel and provides an output of 400-watts. Each channel consists of an untuned crystal controlled oscillator, buffer amplifier, two intermediate amplifiers, and the power amplifier. The audio system consists of two stages of Class A amplification feeding a modulator stage operating as a Class B push-pull amplifier.

The normal frequency range of the dual transmitter unit is 200 to 400 kc. Because the assigned frequency of 194 kc is below the normal tuning range, modification of the tuned circuits was necessary to bring them into resonance. The only modification necessary in the transmitting unit was a circuit change in the exciter section of the sideband channel. In this section the oscillator and buffer-amplifier were removed. An rf network in the carrier channel provides power to drive the intermediate amplifiers of the sideband channel. This in turn provides rf excitation to two separate power amplifiers from a single crystal source and rf phase control of the amplifiers.

Antenna Array

The antenna array used in the low frequency omnirange is similar to that used on all low frequency four-course simultaneous radio ranges. The radiation of energy is effected by means of five vertical tower radiators, one tower located on each of the four corners of a square, with a diagonal distance of approximately 600 feet, and the fifth tower in the center of a square. The towers are of the self-supporting insulated base type. The total height is 133 feet, and the distance above the insulators is 124 feet. (See Fig. 2).

Each tower is equipped with a tuning unit containing means for properly tuning the tower and for effecting impedance trans-

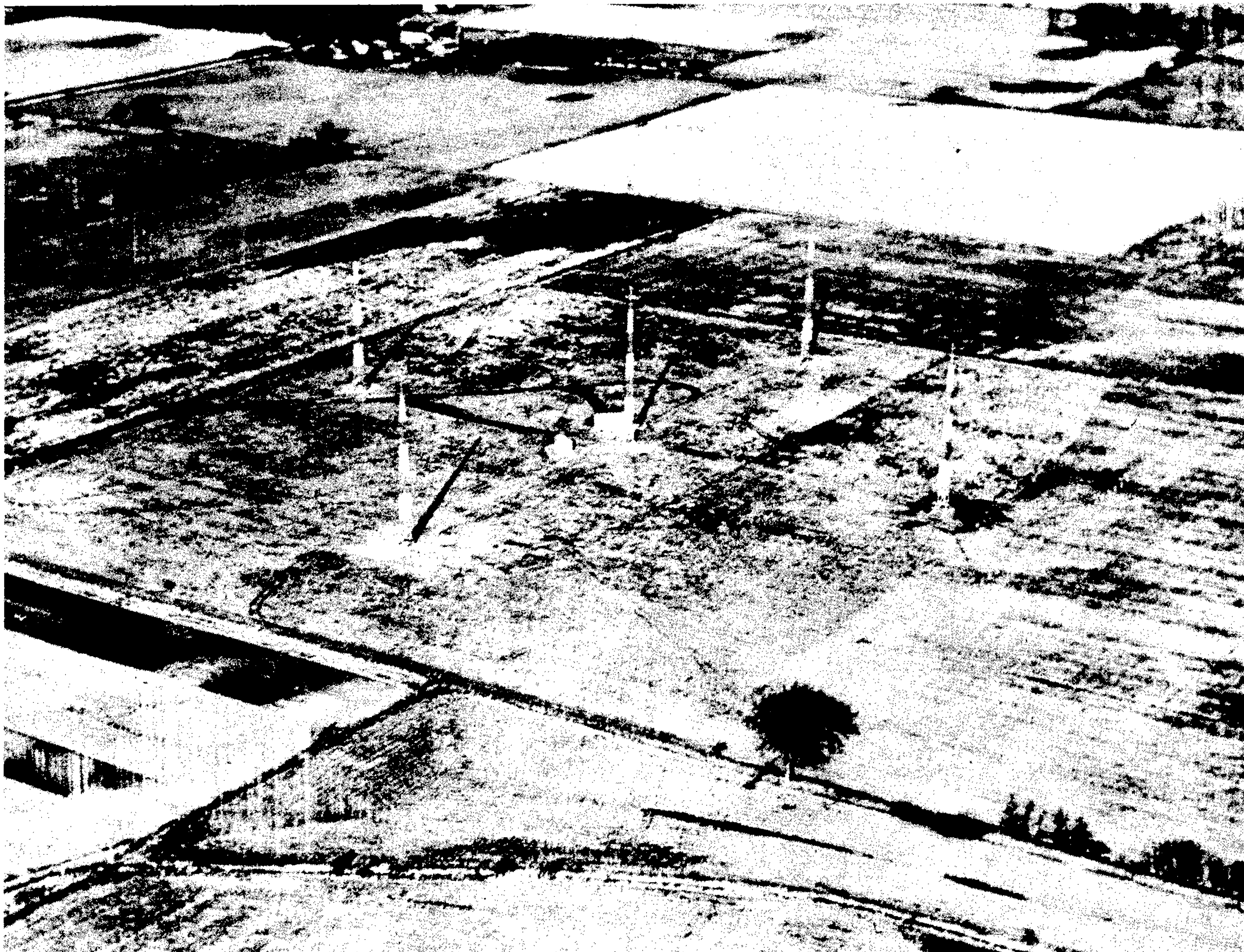


Fig. 2 Aerial View of Transmitter Site

formations Fig. 3 is a schematic diagram of the antenna tuning network used in tuning the tower radiators Each tower is energized by means of a coaxial transmission line of approximately 70 ohms characteristic impedance, and all four corner tower lines are of equal length The sending end of the lines from diagonally opposite towers are connected in parallel to one of the goniometer secondary windings The other secondary winding similarly energizes the second pair of diagonally opposite towers The towers of each pair are connected 180 electrical degrees out of phase. When each pair of opposite towers are energized, a signal having a "figure-of-eight" space pattern in the horizontal plane is radiated.

Goniometer

The sideband generator, shown in Fig 4, is an inductive type goniometer[1] and is comprised of one rotating primary winding and two fixed secondary windings Each winding may be tuned from 190 to 400 kc The rotating primary is driven at 1800 rpm by direct coupling to a synchronous motor Coupled to the opposite end of the motor shaft is a tone wheel which generates the reference subcarrier signal

[1]H F Keary, "A Rotating Goniometer for the Low Frequency High Power Omnirange," T. D. Report No. 70, March 1947.

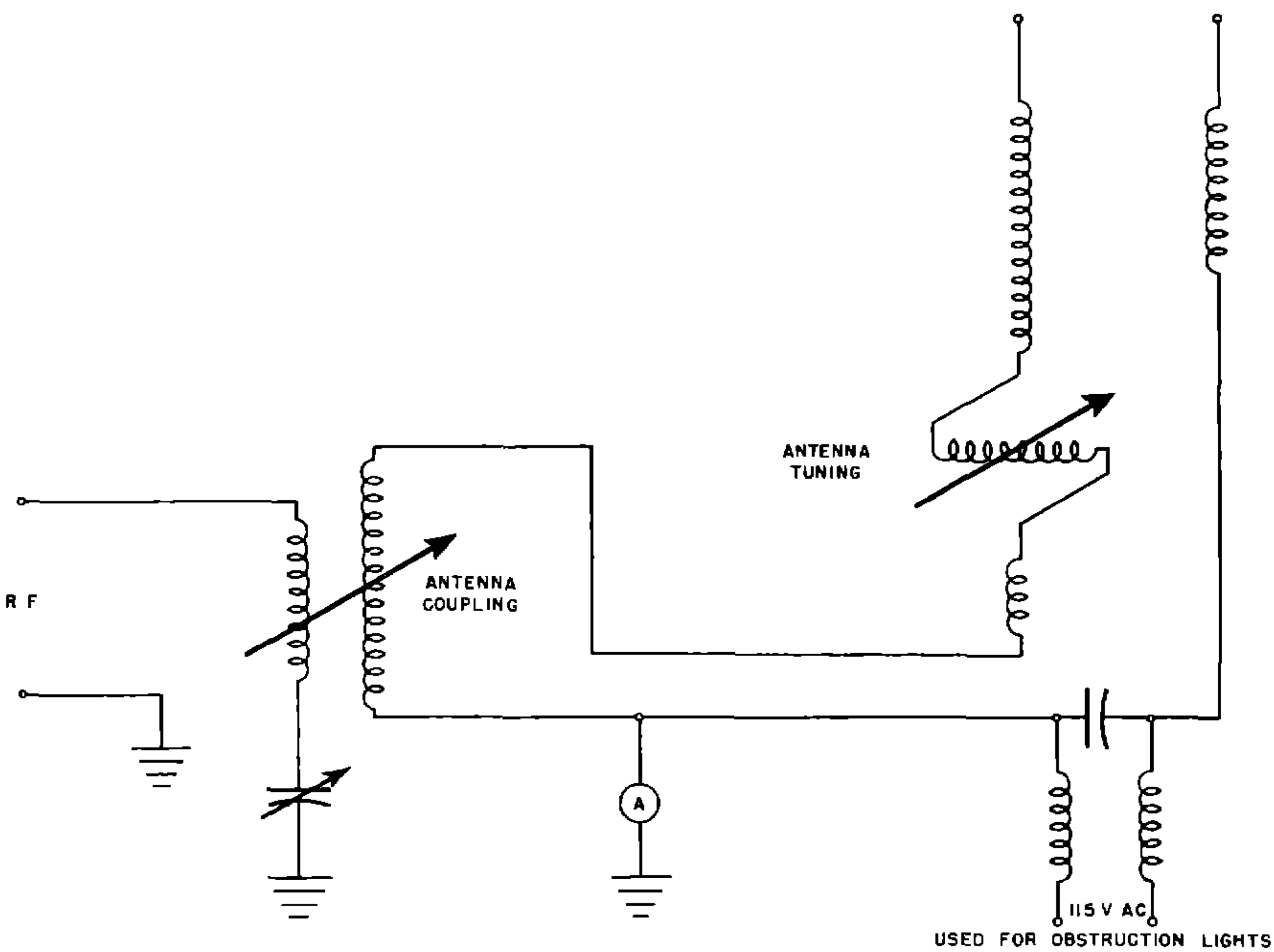


Fig 3 Antenna Tuning Network

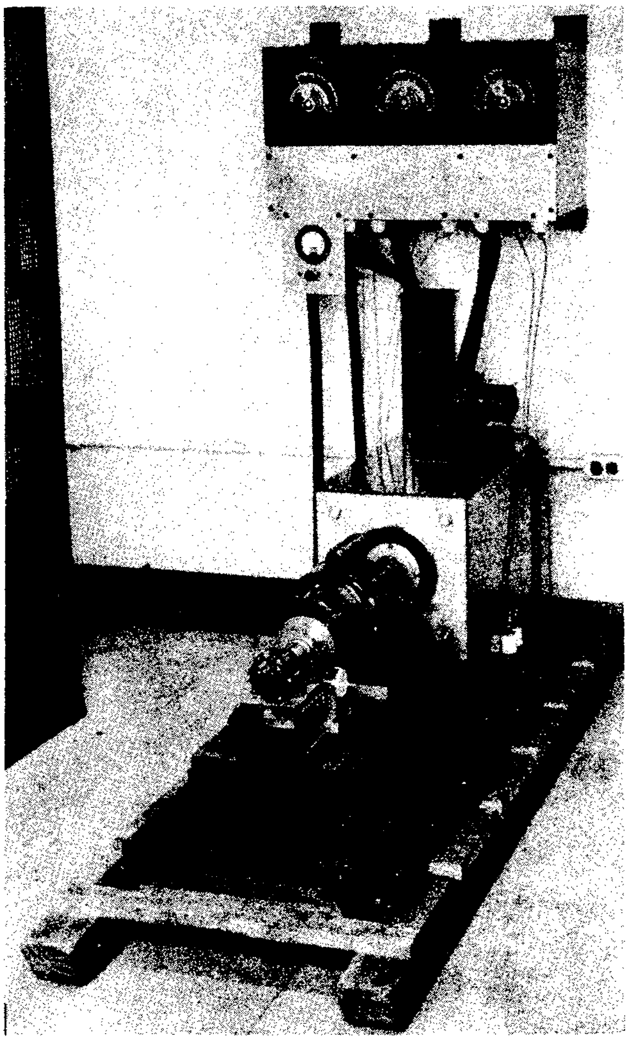


Fig. 4 Goniometer and Subcarrier Generator

Characteristic curves of the goniometer in actual operation are shown in Fig. 5. These curves show the input voltage to the primary and the output voltage of the two secondaries, as the primary is rotated through 360°.

Subcarrier Generator

The reference phase signal is generated by an electromagnetic pick-up in proximity to a rotating tone wheel. This tone wheel is an iron disc with seven teeth. The tooth spacing varies with angular displacement to produce a varying frequency. When the tone wheel is rotated at 1800 rpm, the pick-up generates a 210-cps signal, frequency modulated at a 30-cps rate with a deviation ratio of one.

Antenna Tuning

The tuning of the antenna system is directly responsible for the accuracy of the omnirange. This tuning procedure is described in the two sections, general tuning procedure, and rf phase and amplitude correction.

(1) General tuning procedure

The general procedure for tuning the five tower radiators is identical to that employed on a standard four-course AN radio range. This procedure may be obtained from any simultaneous radio range and broadcast equipment instruction book and will not be described in detail here. Briefly, with the aid of a substitution type impedance box, the antenna tuning network is adjusted to make the reflected impedance exactly 70 ohms and purely resistive. Special precautions are taken to make sure that the antenna towers are tuned for high stability and that they will maintain this stability. Standard phase stability tests are made and curves plotted to check the accuracy of this preliminary tuning.

The accuracy of the omnirange is not assured at the completion of the general tuning procedure. It is quite common for an omnirange checked at this point to reveal an error of the order of plus or minus 6°.

The following conditions must be met before the antenna system can be considered properly tuned.

(a) The current in diagonally opposite pairs of corner towers must be 180° out of phase.

(b) The rf currents in diagonally opposite corner towers must be equal.

(c) The two diagonal pairs of corner towers must be tuned inphase.

(d) The center tower current must be in quadrature with that in the corner towers.

(2) Rf phase and amplitude corrections

The conditions (a) and (b) are satisfied when the nulls produced by the figure-of-eight pattern of a diagonally opposite pair of corner towers lie on a line perpendicular to the

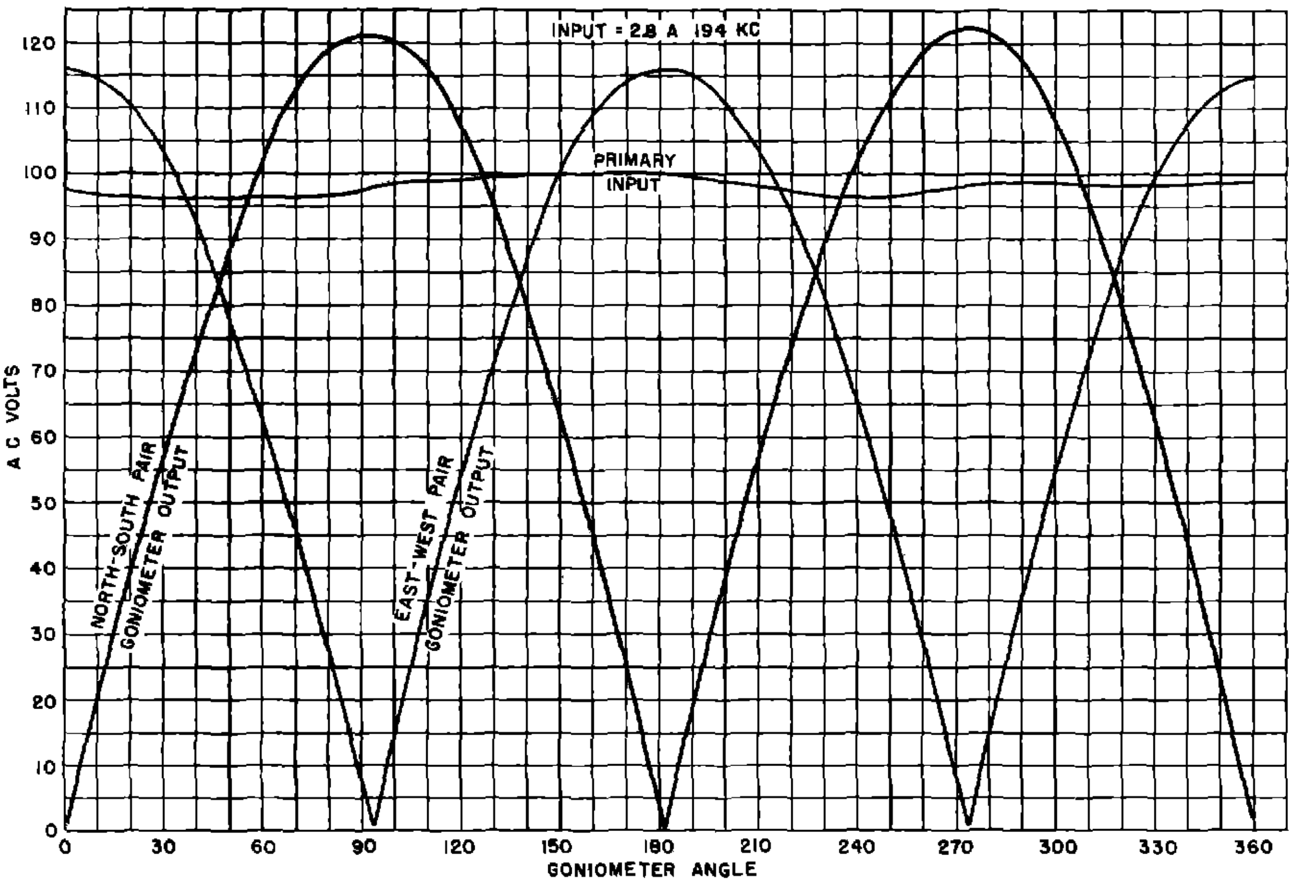


Fig 5 Goniometer Characteristics

towers The position of the nulls may be determined with the aid of a field intensity meter

The position of the field meter during these measurements depends on local conditions at the range site. Power lines in proximity to the range will reradiate the signals and give false null indications if the field meter is used too close to the range station.

If the nulls are not in the proper position, the antenna coupling control in the antenna tuning network (Fig. 3) should be adjusted to give proper null position This adjustment can be made in either of the corner towers, however, it should be made in the particular tower which will result in proper null position and also equal corner tower antenna currents

In order to determine if the conditions (c) and (d) have been complied with a sampling loop and oscilloscope are used to measure the rf phase of the five radiators A small portion of rf energy, from the transmitter, is fed through a calibrated phase shifter and applied directly to one set of plates of the oscilloscope. Rf energy induced in a sampling loop at the antenna is fed through a coaxial cable to the other set of plates The same sampling loop and length of coaxial cable is moved from tower to tower and the rf phase measurements made and recorded. The proper phasing of the center tower with respect to the corner towers is controlled by the phasing network in the transmitter between the common crystal source and the sideband amplifier.

If condition (c) is not satisfied, an artificial line of the proper electrical length must be inserted to bring the diagonally opposite pairs of towers into the same phase

AIRBORNE EQUIPMENT

Receiver

A block diagram of the airborne receiving equipment is shown in Fig 6 The receiver used in the airplane for low frequency omnirange reception was a modified aircraft radio receiver, Model ARB, tuned to 194 kc The modification consisted of adding an AVC amplifier circuit together with an associated bias oscillator to provide improved AVC action

The detector output of this receiver is fed into a converter unit, and after passing through a common amplifier, the signal is separated into its two component parts by filters The 30-cps variable signal taken directly from the common amplifier, is isolated through a low-pass filter, amplified, and fed into a phase discriminator circuit

The frequency modulated, 210-cps, reference signal is fed through a 180-240 cps band-pass filter to an amplifier stage. The output is limited and fed into a frequency discriminator circuit, where the 30-cps reference phase signal is detected. This is again filtered to remove 210-cps components, and fed through a phase-splitter circuit and amplifier stage to provide two equal voltages which have a phase difference of 90° These voltages are connected to the stators of a phase shifting device called an omnibearing selector The phase of the voltage on the rotor of the omnibearing selector can be continuously varied through 360°, and this rotation is indicated on the dial scale in degrees of azimuth This provides a means of selecting on-course indications at any azimuth angle The output from the rotor of the omnibearing selector is fed through an amplifier stage to a phase discriminator circuit, where it is mixed with the variable phase signal to obtain plus or minus dc indications The amplitude and polarity of this current depends upon the amplitude and phase relationship of the two voltages

The output of the phase discriminator is connected to a zero center type instrument called a course-deviation indicator which is located on the instrument panel of the aircraft

Indicators

The indicators used in conjunction with the omnirange receiving equipment are as follows

(1) A course-deviation indicator, the pointer of which, when centered, indicates an on-course position (Fig 7)

(2) An omnibearing selector, the pointer of which is rotated manually to center

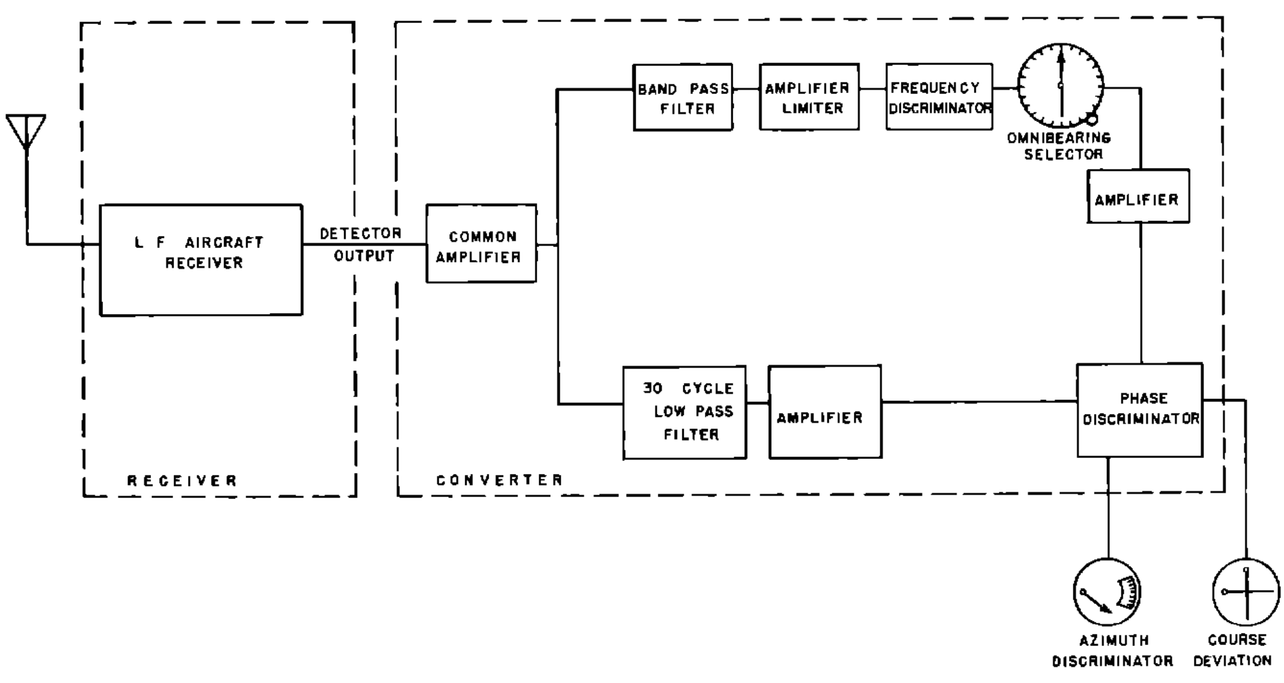


Fig 6 Block Diagram - Low Frequency Omnirange Receiving Equipment

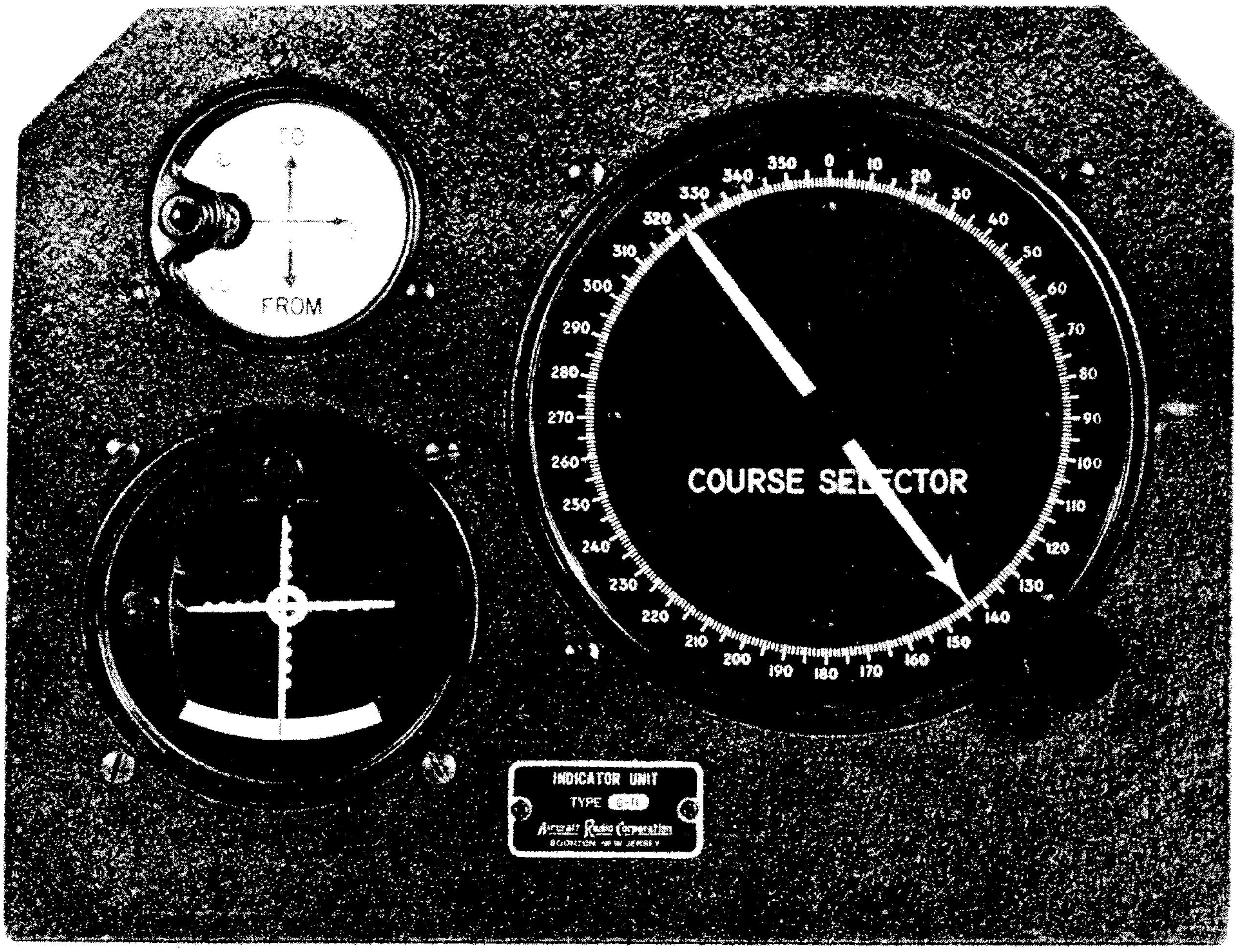


Fig. 7 Receiver Indicating Instruments

the course-deviation indicator needle or to select a predetermined course. It indicates the true bearing of the aircraft either to or from the station. (Fig. 7).

(3) A zero-center type instrument located near the omnibearing selector to provide ambiguity and loss of signal indications. It is mounted so that the pointer deflects up or down. The word TO is at the top of the meter scale and the word FROM is at the bottom. (Fig. 7).

When flying on-course to the station with the TO-FROM indicator pointing to TO the omnibearing selector will indicate the true bearing of the station from the aircraft. The sensing will be correct or normal, such that if the aircraft deviates to the right of the course, the deviation indicator will deflect to the left. In order to return the needle to center the pilot must fly to the left or "fly to the pointer." If the aircraft continues in a straight line over the station, and is now flying from the station, the course-deviation indicator will still show on-course, the TO-FROM indicator needle will point to FROM, and the omnibearing selector will indicate the bearing of the aircraft from the station. The pilot must again fly to the pointer in order to remain on course.

When first tuning in the station, and the azimuth is unknown, the pointer of the omnibearing selector is rotated until the course-deviation indicator pointer is centered and the TO-FROM indicator points to TO. The selector will then indicate the bearing of the station from the aircraft.

Receiving Antennas

The antenna used with the receiver on the airplane is a long wire type extending from nose to tail with shielded coaxial cable lead in

TESTS

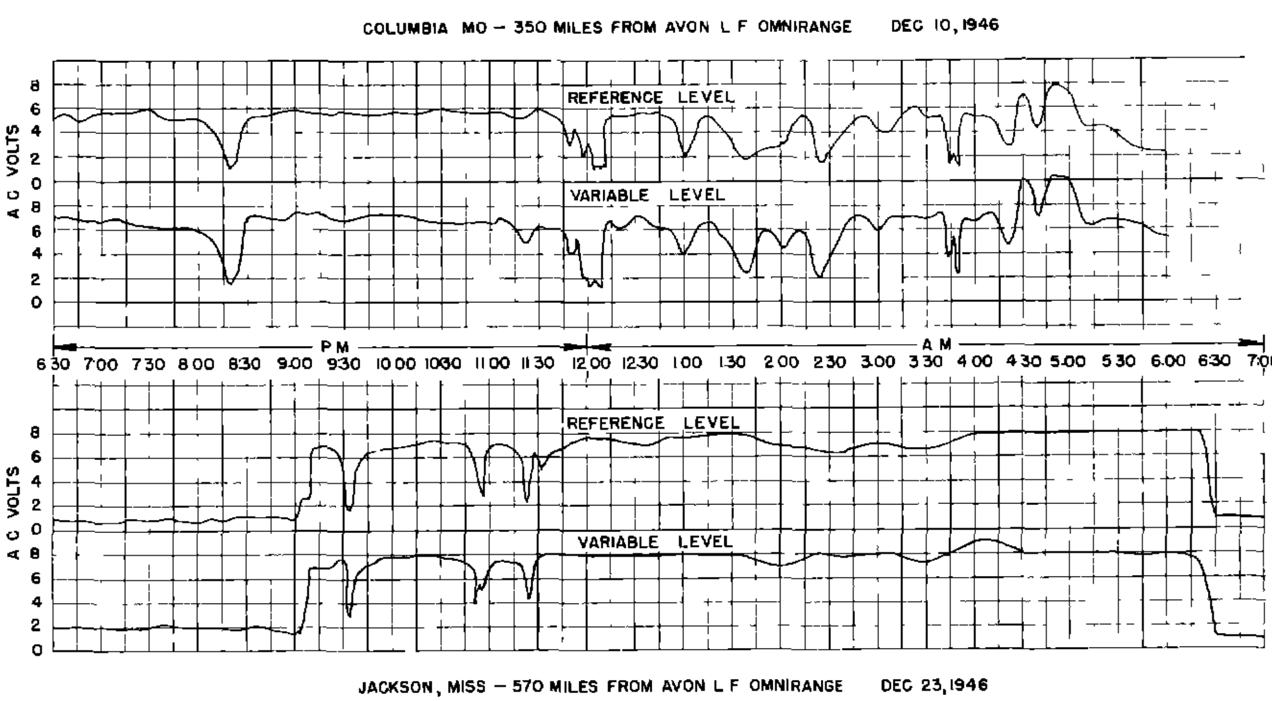
Night Effect

There has been considerable conjecture as to the extent of interference which may be encountered with the omnirange due to night effect. This anomalous transmission is caused by the reflection of signals by the ionized gas layer located above the surface of the earth, often referred to as the Kennelly-Heaviside layer, but more properly known as the ionosphere. This effect is observed for the most part at sunset and after nightfall

Numerous tests were made during the past year and a half to determine the influence of night effect on the omnirange signals Over-night recordings were made on the two-frequency omnirange at distances from 100 to 600 miles Similar recordings were made on the single frequency omnirange There were recorded, as expected, several instances in the two-frequency omnirange where one frequency would fade alternately with respect to the other This constituted one reason for a change to the single frequency omnirange

In the recordings of the single frequency omnirange there is no evidence of selective audio frequency fading As long as the necessary input signal to operate the receiver AVC circuits is available, sufficient reference and variable signal levels will be obtained to provide normal operation of the receiving equipment

Fig 8 shows receiver reference and variable signal levels plotted from over-night recordings which were at the distances of 350 miles and 570 miles on the single frequency omnirange The reference and variable levels, in volts are shown during the time from 6 p m. in the evening until 6 a m in the morning Variations in signal amplitude and frequency of fading are evident at the different distances and, at the distance of 570 miles, the recording shows no signal received at all until 9 p m., at which time strong signals were received and continued until sun-up the next morning The antenna power input at the omnirange station during these



OVERNIGHT RECORDED VARIATIONS IN REFERENCE AND VARIABLE SIGNAL LEVELS

Fig 8 Night Effect Graphs

tests was approximately 400-watts From this, it can be seen that night effect does not introduce any noticeable audio selective fading.

Measured Error Curve

The calibration consists of recording the movement of the course-deviation indicator in an airplane as it circles the omnirange station at a distance of approximately six miles The omnibearing selector is advanced in 10° steps to keep the course-deviation indicator on scale and to present, at center scale, the indicated position in azimuth from the station This indicated azimuth is checked against the absolute azimuth which is measured by a theodolite operated on the ground at the station, the information being relayed to the airplane by VHF radio communication.

The error curve, shown in Fig 9, represents the over-all error of the entire system, which includes the receiver and transmitting station The receiver itself is known to have had an error of ±1° at the time of this calibration. The receiving antenna used during calibration was the long wire nose-to-tail horizontal antenna on airplane NC-181, a Douglas DC-3

Attitude Effect Tests

To check for attitude effect, extremely steep-banked turns were made in all directions, and the wings were rocked while on radial flights There was no evidence of any type of attitude effect in these tests.

During the flights, tests were made to determine the extent of pushing and pulling Specific landmarks were crossed on two or more headings and always resulted in the same azimuth recording. No pushing or pulling was detected.

Radial Flights

On-course flights, following a straight ground track across the station, were made on many different headings. The results are considered satisfactory in that a straight course was continued as the aircraft passed over the station, flying on the same heading

CONCLUSIONS

The development of the low frequency omnirange provides a long-range air navigational aid which is simple to install, maintain, and operate It is unique in its presentation of information to the pilot

The pilot, without assistance, may use this navigational aid in two ways

1. By rotating the omnibearing selector until the course-deviation indicator is centered, the pilot has available a course to or from the station

2. By successively centering the course-deviation indicator on two different omnirange stations, a fix may be plotted using the two bearings thus obtained

From the flight tests and theoretical considerations, it appears that the low frequency omnirange possessed exceptionally good flight characteristics and, when operated at high power with adequately high antenna towers, presents a solution to the long-range aircraft navigational problem

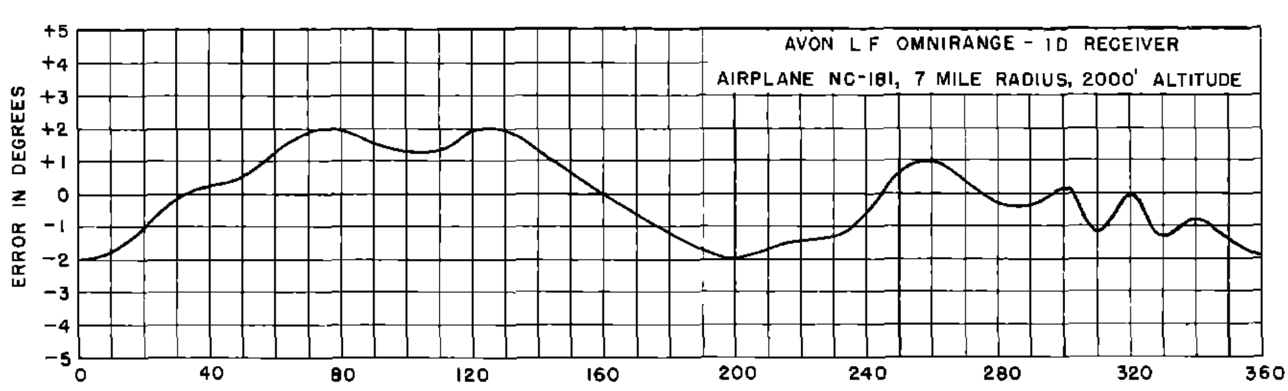


Fig 9 Measured Error Curve