

A SIMULTANEOUS RADIOTELEPHONE AND VISUAL RANGE BEACON FOR THE AIRWAYS

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ABSTRACT

Increased use of the airway radio services by transport operators has resulted in a demand for continuous range-beacon service. At the same time the weather broadcast information has increased in importance and the interruptions to the beacon service have become more frequent. To eliminate difficulties arising from this conflict a transmitting system has been developed which provides simultaneous transmission of visual range-beacon and radiotelephone signals.

This system is designed to employ existing equipment so far as possible. By combining two transmitting sets into one the cost of buildings and antenna equipment is reduced. Continuous check on the operation of both systems can be obtained with less personnel than required at present.

The transmitting set consists of a 2-kw. radiotelephone transmitter operating into a nondirective antenna system and an additional set of amplifier branches supplying power through a goniometer into two loop antennas. The two antenna systems are symmetrically disposed with respect to each other, and coupling effects are balanced out to prevent distortion of the space pattern. The phase of the currents in the different antenna systems is controlled by a phase shift unit and means for checking the adjustment of this phase relationship continuously is provided.

The equipment on the airplane to receive this service is changed only by the addition of a small filter unit which keeps the low-frequency reed voltages from reaching the head telephones and the voice frequencies from the reed indicator.

Numerous flight tests on the system have shown it to provide very satisfactory service under adverse interference conditions.

The distance range is the same as that provided by the present visual range-beacon service.

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I. INTRODUCTION

In order to facilitate traffic over the airways of the United States, the Department of Commerce provides two types of radio aids to navigation. The first to be employed was the broadcast of weather information at regular intervals and later the radio range beacon marked out a radio path for the airplane to follow.

For some time the weather information was broadcast on a different frequency than the range-beacon service, but this required constant tuning of the receiving set on the part of the pilot. At the request of the operating companies the weather broadcast from a given field was transmitted on the same frequency as the range-beacon service from that field. In order to do this the length of the broadcast was reduced to a minimum and the range beacon shut down during this period. The cessation of the range-beacon signals informed the pilot that the weather information was due and the voice broadcast aided in identifying the station from which he was receiving guidance. This latter point is of great importance where several range-beacon stations are located close together. Such identifying means as are now employed on the aural beacon service, for instance, a characteristic code letter transmitted at regular intervals, would not be readily applicable to the visual beacon transmitter. Because of this the voice broadcast is relied upon to a great extent for identification.

This second scheme operated fairly well until pilots began to depend upon the range-beacon signals to locate their landing field. If the signals ceased when near the field, it frequently meant missing the field entirely and a loss of time in reorientation. Furthermore, when a great number of airways converge at a field, the time taken up by the weather broadcast is a considerable percentage of the entire time, and in such installations some new scheme was imperative. As itinerant fliers begin to equip their airplanes with radio, the problem becomes even more important. The intermediate frequency phone station is the one which will handle messages from and to such itinerant pilots. If this traffic reaches any considerable size, the time during which the range-beacon service is available would be very short indeed.

In order to provide these services satisfactorily, the research division, Aeronautics Branch, of the Department of Commerce, commenced a research program for the development of a transmitting set which would furnish visual range-beacon signals and speech modulation simultaneously without interruption of either service.

Such a system has been developed at the experimental flying field of the National Bureau of Standards, and is described in this paper. It supplies the pilot with continuous signals of the visual range-

beacon type, and allows voice communication with the pilot at any time with no interruption to the range service.

This is accomplished with no changes in the installation in the airplane except the addition of a small filter unit to separate the speech frequencies from the reed frequencies. No new method of operation is required and no extra strain is imposed upon the pilot.

This system presents additional advantages over the present method of transmission. By combining the two transmitters into one unit, the total amount of equipment required is greatly reduced. The same building is employed for both services, and much of the rotating machinery is used simultaneously on both portions of the transmitter. Since a radio operator is constantly on duty at the phone station, the combined system insures a constant monitoring of the beacon operation which at the present time can only be done with additional personnel. Many similar advantages are readily apparent and, consequently, from an economic viewpoint, the combined transmission is very desirable.

II. PRELIMINARY WORK

During the preliminary development of the 12-course visual range beacon in January, 1929, the idea of a simultaneous radiophone and range-beacon transmitter first appeared. When the three amplifier branches of this type of radio range are excited with the radio-frequency in time phase, the resultant carrier is suppressed by the goniometer and loop antenna system. The reason for this is readily apparent. Considering only the carrier current in each goniometer stator, these produce three figures-of-eight separated in space by 120° . If the carrier currents are in time phase, the resultant field will be the sum of three equal vectors with 120° space phase. The resultant of three such vectors is zero at any point in space. The side bands, being of different frequencies, will not combine but will appear as true figures-of-eight at 120° space phase, giving the conventional space pattern. In order to utilize this signal, it is necessary to resupply the carrier, and it was proposed to erect a suitable open antenna symmetrically located with respect to the loop antennas and radiate carrier from this. It was suggested at this time that the carrier might well be modulated with voice for identification purposes and general communication with the pilots.

However, as work on the 12-course system progressed it was found a simpler matter to use a 120° time-phase displacement in the beacon amplifiers to avoid suppression of the carrier. The need for a simultaneous transmission was not apparent at this time, so no further work was done along this line.¹

In the fall of 1929 the necessity for providing continuous range-beacon service became apparent, and preliminary experiments were conducted to determine the feasibility of a simultaneous transmitting system. In order to secure some test data, with as little change in existing apparatus as possible, the 12-course experimental beacon was employed for this work.

The modulated amplifiers of this beacon were redesigned to receive a direct voltage on their plates in place of the alternating voltage

¹ H. Diamond and F. G. Kear, A 12-Course Radio Range for Guiding Aircraft With Tuned Reed Visual Indication, B. S. Jour. Research, 4; March, 1930.

previously supplied from the modulation frequency alternators. Each amplifier was provided with a Heising choke and the alternating voltage applied across this choke. This voltage was so proportioned as to give a 50 per cent modulation of the radio-frequency instead of the previous 100 per cent.

The master oscillator of this beacon employed two 50-watt tubes in parallel. A modulating amplifier consisting of four 50-watt tubes in parallel was applied to this oscillator and the grids of these tubes excited from a 3-stage speech amplifier. This combination modulated the carrier to a maximum of about 40 per cent.

This voice-modulated carrier was fed to each amplifier branch where it was further modulated by the reed frequencies and then radiated through the loop antenna system. The reed frequency side bands still maintained their figure-of-eight pattern while the voice side bands were radiated circularly in the same manner as the carrier.

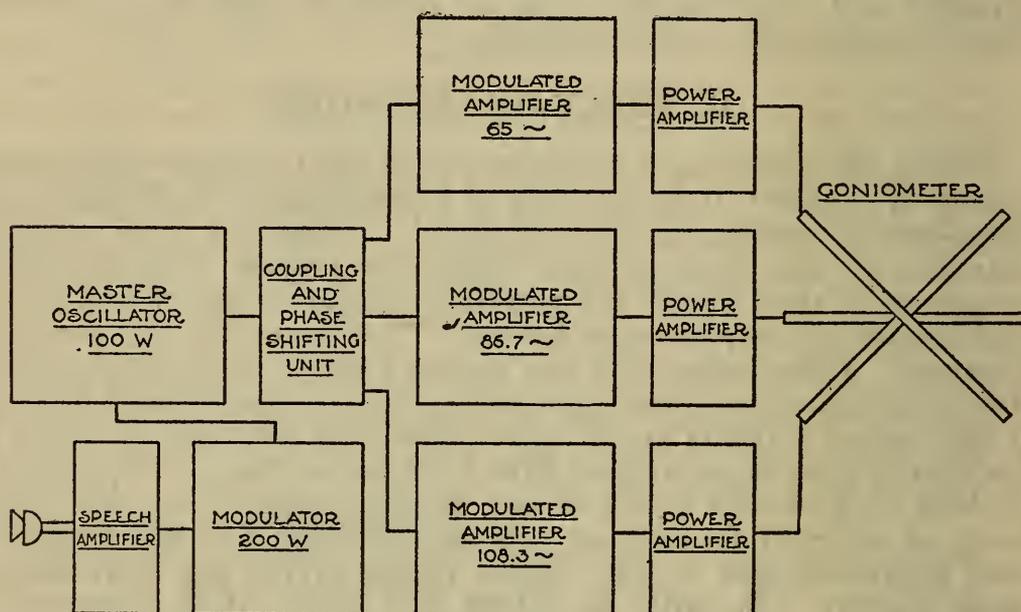


FIGURE 1.—Schematic circuit arrangement of 12-course radio range beacon with radiotelephone modulation

Figure 1 shows the schematic circuit while Figure 2 shows details of the modulation units and intermediate amplifiers.

It is obvious that such a modulation system would produce a great number of extraneous frequencies as a result of cross modulation; however, it afforded a simple way of getting a rapid check on the possibilities of the project.

In the latter part of 1929 field tests were made on this system. The reed indicator operated with very little irregularity and the voice quality was much better than would have been expected.

Having found this scheme to be practicable, work was begun upon a transmitter which would reduce the number of extraneous audio-frequencies and thereby improve the operation.

Two methods of attack were conceived at this time. The first required applying the voice modulation to the modulated amplifiers in series with the reed frequency modulation already present. By properly proportioning the relative voltages, any desired modulation ratio could be obtained. This would reduce the number of unwanted

frequencies to those introduced by the class C power amplifiers and it was felt that they would not be of serious magnitude.

The second method was that of a separate radio-frequency amplifier stage which received the voice modulation. This was to be of the balanced-amplifier type and so connected as to suppress the carrier and supply only the voice side bands to an open antenna system symmetrically disposed within the loop antenna structure. This last means would eliminate all the cross modulation frequencies and, in addition, would provide a simple control of the modulation ratio.

It was evident that any system in which the major portion of the power was radiated by the loop antennas must be a highly inefficient solution and would require too great a loss of power to be practical as a final product. Therefore, instead of trying out these last two methods experimentally, it was decided that the tests already made had shown the idea to be practical, and, a transmitter should be

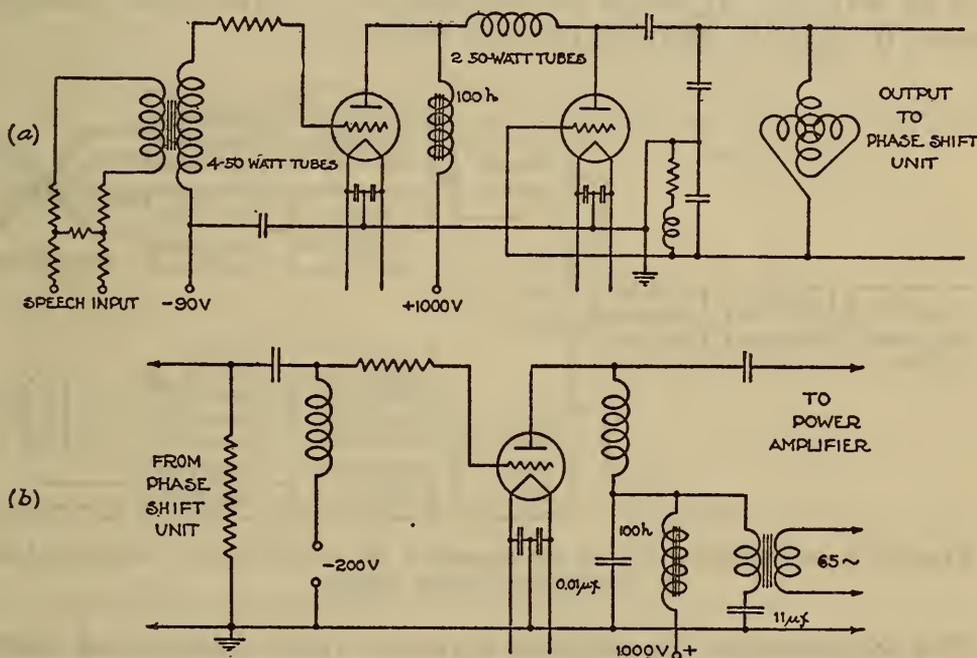


FIGURE 2.—Electrical circuit details of 12-course radio range beacon with radiotelephone modulation

developed of a design which could be employed along the airways. In a conference with members of the Bell Telephone Laboratories, a schematic circuit arrangement of a suitable transmitter was developed. This is illustrated in Figure 3. This circuit arrangement formed the basis of an investigation which has resulted in the development of a suitable transmitting system. This system has proven eminently satisfactory and provides simultaneous transmission of voice and radio-range signals with a minimum of expenditure and alteration to existing stations. It is with this transmitter that the paper is most concerned.

III. THE TRANSMITTING PROBLEM

1. FACTORS INFLUENCING THE DESIGN

In the design of the new transmitting system, it was not possible to start from purely theoretical considerations and so develop what would be, in the light of present radio technique, an ideal unit. Cer-

tain limiting factors entered and circumscribed the sphere of development.

The first consideration was that of power rating. The present range beacons and phone transmitters have demonstrated that they provide adequate service on the airways; hence any new unit must provide, as a minimum requirement, the same received-signal voltages at a given point as the existing equipment.

The ratio of speech side band to range beacon side band is fairly well fixed. The present reed course indicator requires approximately 6 milliwatts of power or about 0 db absolute level. (This zero level of 6 milliwatts is commonly used in telephony and radio broadcasting). In order to insure intelligible speech in the airplane, the phones must have available 60 milliwatts or +10 db. This ratio must be attained in the field strength pattern at any point in space.

The antenna system was restricted in size on account of its location near an airport. It would be undesirable to increase the obstruction hazard in order to increase antenna efficiency.

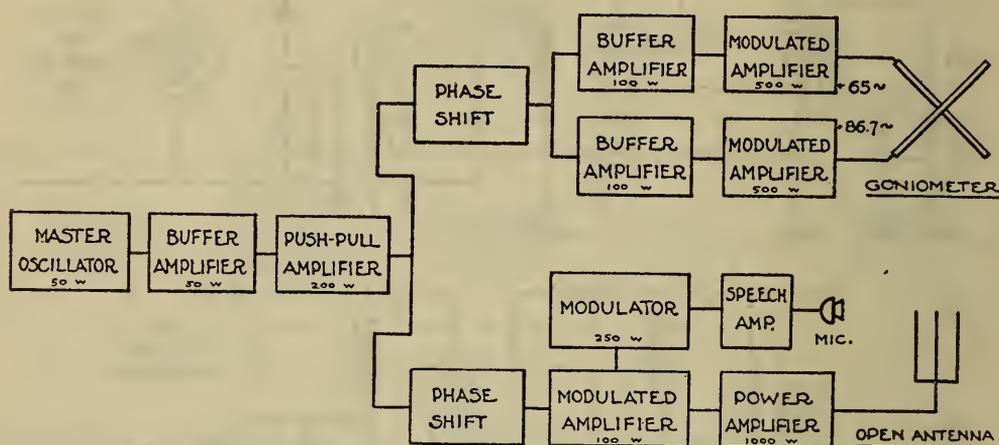


FIGURE 3.—Schematic circuit arrangement of simultaneous radiotelephone and visual range beacon

The equipment of the airplane to receive range-beacon and weather broadcast information has reached a fair degree of standardization. Any system of communication requiring much additional apparatus or considerable change in present equipment would meet with great opposition from the operating companies. The ideal solution would be one requiring no change in existing installations.

The civil airways at the present time are rather comprehensively covered with a network of radiophone and range-beacon installations. This equipment represents a considerable investment, and to adopt a design which would render all existing stations obsolescent would be economically poor. The new system must employ a maximum amount of existing equipment in its design.

Finally, much of the apparatus employed will be operated by remote control. This necessitates a design of great inherent stability and freedom from variations due to changing weather conditions. These requirements are all met in the present design. The result is a unit which is well suited to the present needs of the airways.

The foundation for the preliminary design was the 2-kw radiophone transmitter which has been used on the airways for several years and has proven very satisfactory. When used with the type of antenna

structure for which it was designed, this transmitter will produce a field intensity of 6,500 $\mu\text{v}/\text{m}$ at a distance of 10 miles over average terrain. This is modulated to a peak of approximately 60 per cent by the voice frequency.

Assuming square law detection in the aircraft radio receiver, the detected voltage is proportional to the product of the percentage modulation and the square of the carrier field intensity.

$$i_d \propto mE^2$$

from which

$$i_d \propto 0.6 (6,500)^2 \\ \propto 25,000,000 \text{ approximately}$$

As mentioned before, the reed indicator requires 0 db level or 6 milliwatts for an "on-course" indication, and the head telephones with an average amount of noise present require a level of +10 db, or 60 milliwatts. This corresponds to a voltage ratio of 3.16 to 1. Consequently, if the detected speech signal is proportional to 25×10^6 , the reed signal must be proportional to approximately 8×10^6 . This factor was used in calculating the required field intensity of the beacon side bands, and flight tests have shown it to be satisfactory.

Employing this factor we find

$$i_{d, \text{reeds}} \propto mE_o^2 \\ \propto m(6,500)^2 \\ \propto 8 \times 10^6$$

whence $m = 0.19$, or 19 per cent.

The expression for a modulated carrier is

$$E = E_o \sin \theta + \frac{mE_o}{2} \sin (\theta - \varphi) + \frac{mE_o}{2} \sin (\theta + \varphi)$$

With the carrier suppressed this becomes

$$E_1 = \frac{mE_o}{2} \sin (\theta - \varphi) + \frac{mE_o}{2} \sin (\theta + \varphi)$$

If the field intensity is measured by the usual method this will be

$$E_{eff} = \sqrt{\left(\frac{mE_o}{2}\right)^2 + \left(\frac{mE_o}{2}\right)^2}$$

$$E_{eff} = \frac{mE_o}{\sqrt{2}}$$

Substituting the known values for m and E_o

$$E_{eff} = \frac{0.19 \times 6,500}{\sqrt{2}}$$

$$E_{eff} = 874 \mu\text{v}/\text{m}$$

Using loop antennas with the dimensions of those at the College Park experimental station, this field intensity is obtained with an antenna current of slightly less than 8 amperes. The loop antenna resistance being 8 ohms, the antenna power is approximately 500 watts.

The beacon amplifier branches must, therefore, be capable of delivering 500 watts of side-band power to the loop antennas to secure the proper ratio of speech to beacon field intensity with the same useful range as the present airway equipment.

It is worthy of note at this point that if the computations were made on the basis of the field intensities of the present range-beacon stations, the power required would be much less. For example, the 4-course visual radio range beacon has a carrier field intensity of $734 \mu\text{V/m}$ at 10 miles. The detected voltage assuming 100 per cent modulation would then be proportional to $(734)^2$ or 540,000. This value, being only one-sixteenth of that used in the foregoing, would mean much lower power in both beacon and phone amplifiers.

However, while this low figure is satisfactory for use with visual range-beacon signals alone, when speech is supplied on the same channel, the increased sensitivity required in the radio receiver results in a very unfavorable static to signal ratio, and the useful distance range is greatly reduced. Because of this the power calculations were made upon the basis of the radiophone transmitter performance instead of the range-beacon transmitter data.

The transmitting system requirements, from a consideration of the foregoing factors, may be, therefore, summed up as follows:

Carrier and speech supply to consist of a 2 kw phone transmitter modulated 60 per cent peak and operating into an open antenna 75 feet high with four flat top sections 80 feet long bisecting the angles of the loop antennas.

Range beacon supply to comprise two balanced amplifier branches supplied with carrier from the 2 kw unit. Modulation to be accomplished by the use of alternating current from special low-frequency alternators and the carrier to be suppressed by some suitable arrangement. The amplifier branches to operate through a conventional goniometer into two loop antennas. The antenna height to be 75 feet and the base of the loop antennas 300 feet long. Each amplifier to have sufficient capacity to deliver 500 watts of side band power to the loop antennas.

It was felt that this system would provide adequate transmission for the needs of the airways. The next problem was to construct a unit from available material and secure actual operating data.

2. THE EXPERIMENTAL TRANSMITTER

Since no equipment of the type employed on the airways was available for use in the experimental transmitter, an entirely new unit was constructed. This unit differs considerably in arrangement from the conventional type, but, all the limiting factors being considered, the relative performance is very similar.

In order to attain flexibility, the transmitter was built upon the individual unit plan. These units are as follows:

(a) A master oscillator which supplies push-pull radio-frequency power to the amplifiers. This is designed so that variations in load do not affect the frequency or balance of the push-pull amplifiers.

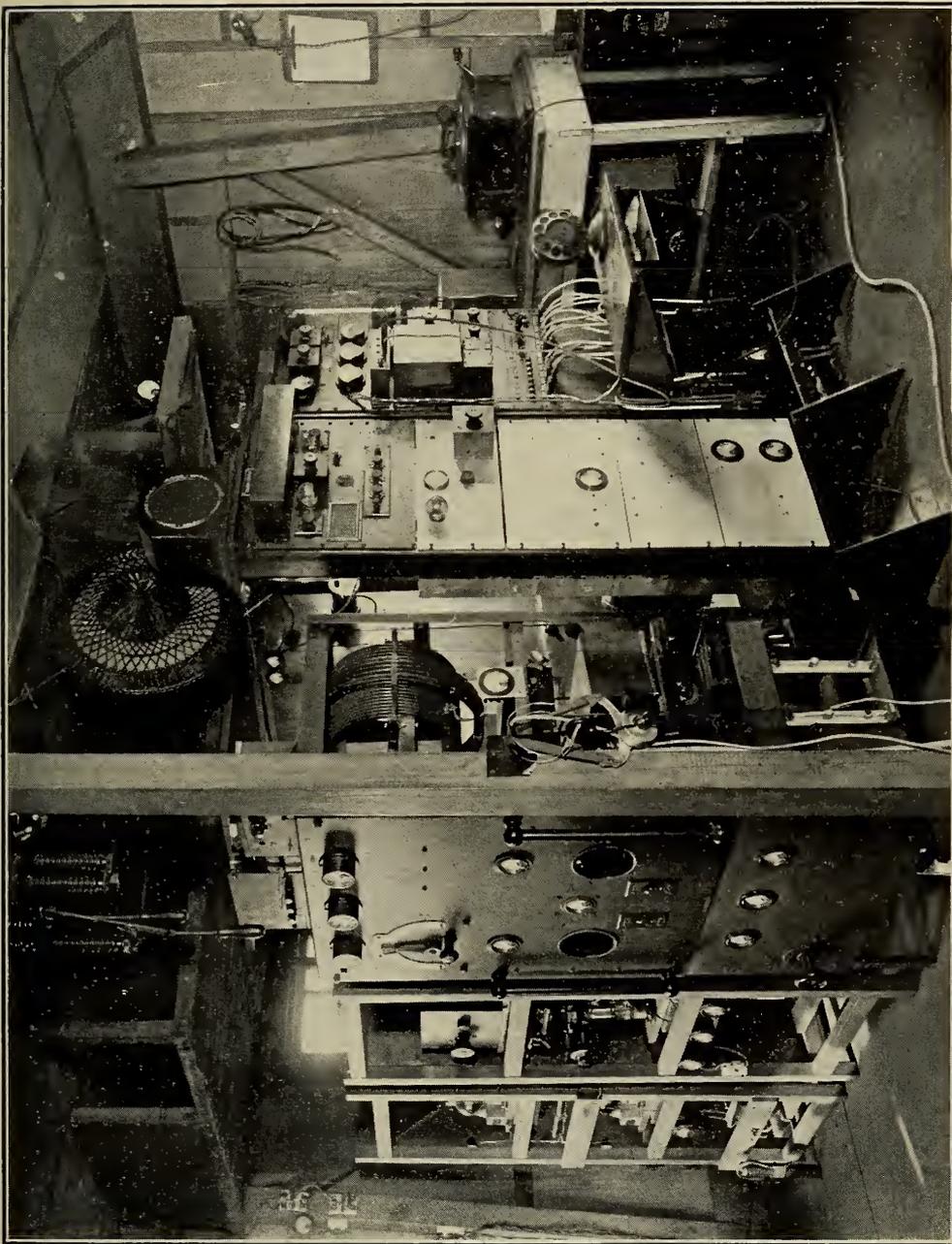


FIGURE 4.—General view of the experimental transmitting set at College Park

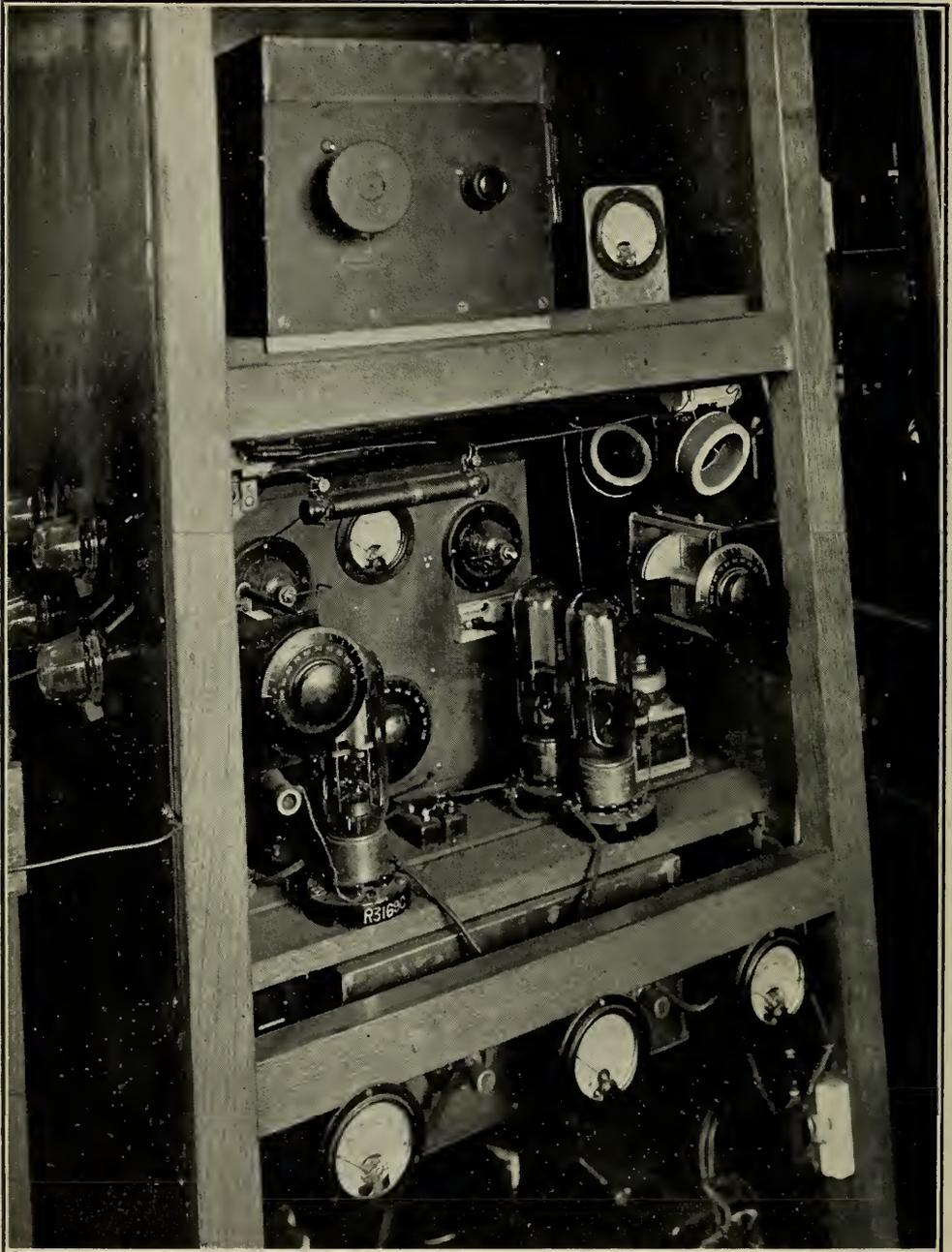


FIGURE 5.—*Front view of master oscillator unit*

(b) A phase-shifting unit to control the phase of the radio-frequency applied to the separate amplifiers.

(c) A radiophone and carrier amplifier branch which supplies carrier-frequency power to a nondirectional vertical antenna, with provision for modulating the carrier with the voice frequencies.

(d) A speech amplifier which modulates the carrier to a maximum of 60 per cent, with a flat response from 300 to 6,000 cycles, but which does not pass the low voice frequencies in the region of the reed modulation frequencies.

(e) Two beacon amplifier branches, which receive the radio-frequency from the master oscillator, modulate it with desired reed frequencies and then, having suppressed the carrier, deliver the side bands to the goniometer.

(f) An antenna system providing directional transmission from the beacon amplifiers and nondirectional transmission from the carrier and speech amplifier.

These units were constructed, tested individually, and then modified to correct such deficiencies as were found in the tests.

Figure 4 shows the installation at the College Park field station. A description of the units as finally employed follows:

(a) MASTER OSCILLATOR

The master oscillator employs a 50-watt tube with the Colpitts oscillating circuit. The frequency is adjustable by means of a variable inductor over the present aircraft beacon range of 235 to 350 kilocycles. A peizo-controlled unit has been designed to replace this in a permanent installation. This output, in turn, excites another 50-watt amplifier through a high resistance feed to prevent reaction due to change of load. The amplifier tube, through a coupling transformer, supplies a tuned circuit, the extremities of which are connected to the grids of a second amplifier, consisting of two sets of two 50-watt tubes in push-pull. These are cross-neutralized. From the plates of these tubes is obtained the push-pull radio-frequency output. This unit is complete within itself and is thoroughly shielded. It is illustrated in Figure 5.

(b) PHASE-SHIFTING UNIT

In any system of carrier suppression where both side bands are radiated it becomes necessary to resupply the carrier in the proper phase in order to prevent distortion. This may readily be demonstrated as follows:

The conventional expression for a modulated radio-frequency signal is

$$E \sin \theta (1 + m \cos \phi)$$

where

$$\theta = 2\pi f_c t$$

$$\phi = 2\pi f_m t$$

f_c being the carrier frequency, f_m being the modulating signal frequency, and m is the percentage of modulation.

This may be rewritten

$$E \left(\sin \theta + \frac{m}{2} \sin (\theta + \phi) + \frac{m}{2} \sin (\theta - \phi) \right)$$

the first term of this expression being the carrier and the last two the side bands.

In carrier-suppressed transmission the equation reduces to

$$E \left(\frac{m}{2} \sin (\theta + \phi) + \frac{m}{2} \sin (\theta - \phi) \right)$$

Assume the carrier to be resupplied at a slightly different angle α .
The transmitted wave now is

$$e_t = E \left[\sin (\theta + \alpha) + \frac{m}{2} \sin (\theta + \phi) + \frac{m}{2} \sin (\theta - \phi) \right]$$

Assuming square law detection

$$i_d = A e_t^2$$

The components of the detected signal become

$$\begin{aligned} AE^2 \left[\sin^2 (\theta + \alpha) + \frac{m^2}{4} \sin^2 (\theta + \phi) + \frac{m^2}{4} \sin^2 (\theta - \phi) \right. \\ \left. + m \sin (\theta + \alpha) \sin (\theta + \phi) + m \sin (\theta + \alpha) \sin (\theta - \phi) \right. \\ \left. + \frac{m^2}{2} \sin (\theta + \phi) \sin (\theta - \phi) \right] \end{aligned}$$

The first three terms are radio-frequencies and can be neglected.
Expanding the fourth term:

$$\begin{aligned} m \sin (\theta + \alpha) \sin (\theta + \phi) &= \frac{m}{2} \cos (\theta + \alpha - \theta - \phi) - \frac{m}{2} \cos (\theta + \alpha + \theta + \phi) \\ &= \frac{m}{2} \cos (\alpha - \phi) - \frac{m}{2} \cos (2\theta + \alpha + \phi) \end{aligned}$$

Likewise expanding the fifth term:

$$\begin{aligned} m \sin (\theta - \alpha) \sin (\theta - \phi) &= \frac{m}{2} \cos (\theta + \alpha - \theta + \phi) - \frac{m}{2} \cos (\theta + \alpha + \theta - \phi) \\ &= \frac{m}{2} \cos (\alpha + \phi) - \frac{m}{2} \cos (2\theta + \alpha - \phi) \end{aligned}$$

Expanding the last term:

$$\begin{aligned} \frac{m^2}{2} \sin (\theta + \phi) \sin (\theta - \phi) &= \frac{m^2}{4} \cos (\theta + \phi - \theta + \phi) + \frac{m^2}{4} \cos (\theta + \phi + \theta - \phi) \\ &= \frac{m^2}{4} \cos 2\phi + \frac{m^2}{4} \cos 2\theta \end{aligned}$$

Considering only the audio-frequency terms of the detected signal, we find

$$i_d = AE^2 \left[\frac{m}{2} \cos (\alpha - \phi) + \frac{m}{2} \cos (\alpha + \phi) + \frac{m^2}{4} \cos 2\phi \right]$$

or

$$i_d = AE^2 \left[m \cos \phi \cos \alpha + \frac{m^2}{4} \cos 2\phi \right]$$

Now if $\alpha = 90^\circ$, the first term of the above expression will disappear, leaving only the double frequency term. If $\alpha = 0^\circ$, the equation reduces to

$$i_d = AE^2 \left[m \cos \varphi + \frac{m^2}{4} \cos 2\varphi \right]$$

which is the usual equation for a detected signal. Consequently, if the carrier is suppressed at the transmitter and then resupplied, it must have its original phase or the detected signal components will tend to cancel each other, leaving a double-frequency term. The degree of this cancellation will increase with an increase of phase difference.

In the 4 and 12 course radio range beacons it was necessary to provide a phase shift in each amplifier to prevent carrier combination.² In the carrier-suppressed beacon this is no longer necessary. Since no carrier is radiated it can not combine to distort the space pattern. Hence, both beacon amplifiers are supplied in phase and the resultant pattern is the conventional crossed figures-of-eight.

The loop antenna introduces a phase shift of another sort. The received voltage at a given point in space is the vector sum of two voltages. One is induced by the one side of the loop antenna and one by the other. The currents in the two sides of a single loop antenna are 180° out of phase when considered with respect to a distant receiving antenna and the vector sum of the induced voltages is in quadrature with these currents regardless of the point of reception.³

Since the carrier must be resupplied in the same phase as the beacon side bands, a phase shift must be introduced at the transmitting end. The phase relations existing in the transmitter are illustrated in Figure 6. The first diagram shows the phase relations within the transmitter while the second shows those existing at the receiving point.

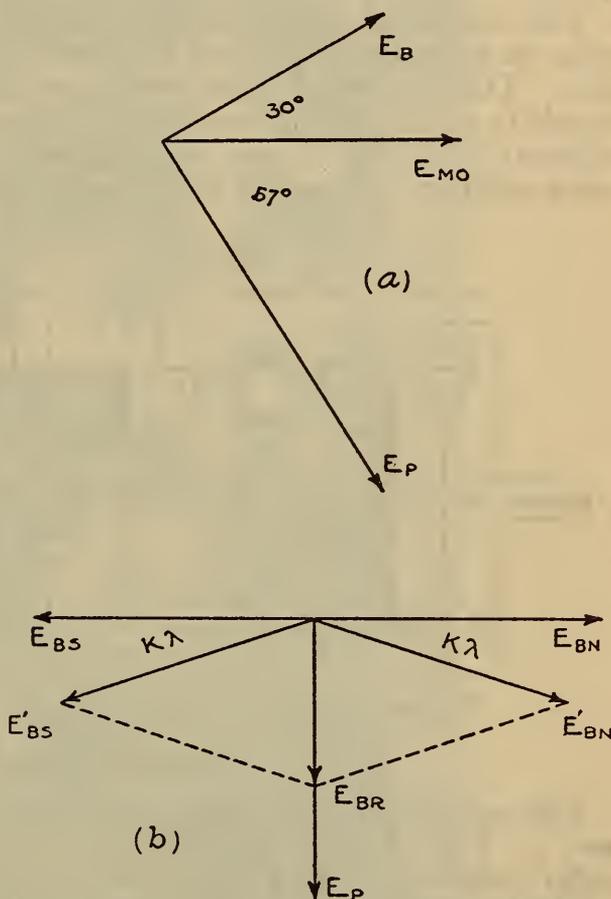


FIGURE 6.—Vector diagram showing phase relations in combined transmission

(a), phase relations within the transmitting set: E_b , voltage across beacon amplifiers; E_{mo} , voltage across master oscillator; E_p , voltage across carrier amplifiers.

(b), phase relations at point of reception: E_{bn} , voltage across north end of loop antenna; E_{bs} , voltage across south end of loop antenna; E'_{bn} , voltage across north end retarded $K\lambda$; E'_{bs} , voltage across south end advanced $K\lambda$; E_{br} , resultant voltage induced by loop antenna; E_p , voltage due to open antenna; $K\lambda$, inherent phase shift of loop antennas.

² H. Diamond, applying the Visual Double Modulation Beacon to the Airways, B. S. Jour. Research, (RP148); February, 1930; Proc. I. R. E., 17, p. 258; December, 1929.

³ J. H. Morecroft, Principles of Radio Communication, p. 709 et seq.

The 90° phase shift is accomplished in the same way as was heretofore used in the 4-course beacon. The circuit diagram (fig. 7) is self-explanatory.

(c) RADIOPHONE AND CARRIER AMPLIFIER

This amplifier receives its excitation from the master oscillator upon the grids of two 50-watt tubes in push-pull. These are operated as class C amplifiers and their grids are shunted by a relatively low resistance to insure good regulation. These tubes are the modulated amplifiers and the Heising choke is incorporated into their plate circuit.

The output of these tubes is directly coupled to two 1-kilowatt tubes in push-pull, operated as class B amplifiers to minimize distortion. The output of these tubes excites a high capacitance tuned circuit to which the antenna system is inductively coupled. One-half kilowatt of carrier power is supplied to the antenna system from this amplifier. This unit is shown in Figures 8 and 9.

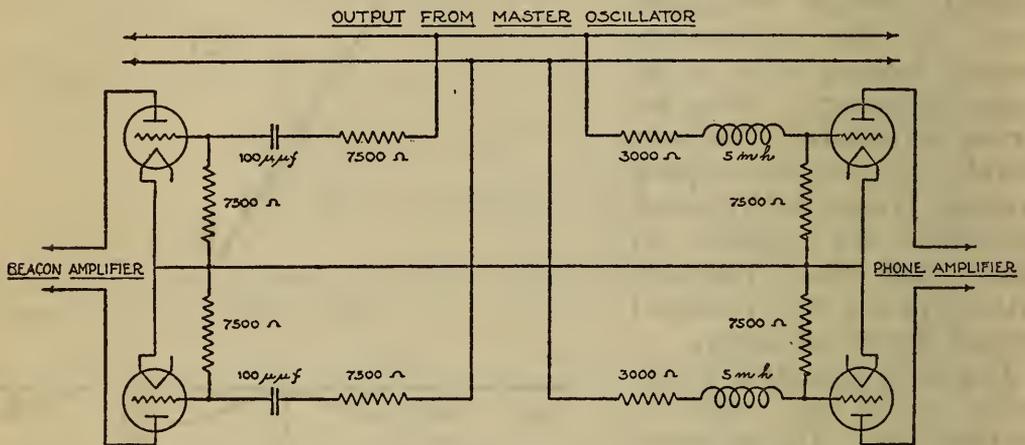


FIGURE 7.—*Electrical circuit diagram of phase-shifting unit*

(d) SPEECH AMPLIFIER

This amplifier is supplied with speech frequency at a level of 3.75 mw. (-2 db) from a conventional 2-button microphone and 3-stage audio amplifier. The first tube is a 50-watt tube which is coupled to a UV849 (250-watt modulator tube) through a filter section which rejects frequencies below 250 cycles. At an input level of 3.75 mw. the modulation is 60 per cent peak on the modulated amplifiers. The speech input equipment is shown in Figure 10.

(e) BEACON AMPLIFIERS

The beacon amplifiers are in duplicate throughout to supply power to the two stators of the goniometer. In each amplifier branch, radio-frequency from the master oscillator is supplied to the grids of two 50-watt screen grid tubes in push-pull. These tubes act only as buffer amplifiers to prevent reaction of the low reed frequencies on the speech and carrier amplifier.

These tubes are direct coupled to two $\frac{1}{4}$ -kilowatt tubes operated as class C amplifiers. The plates of these latter are fed in push-pull from transformers operated at the reed frequency. The output is taken off in parallel to the goniometer, thereby suppressing the carrier but radiating the side bands.

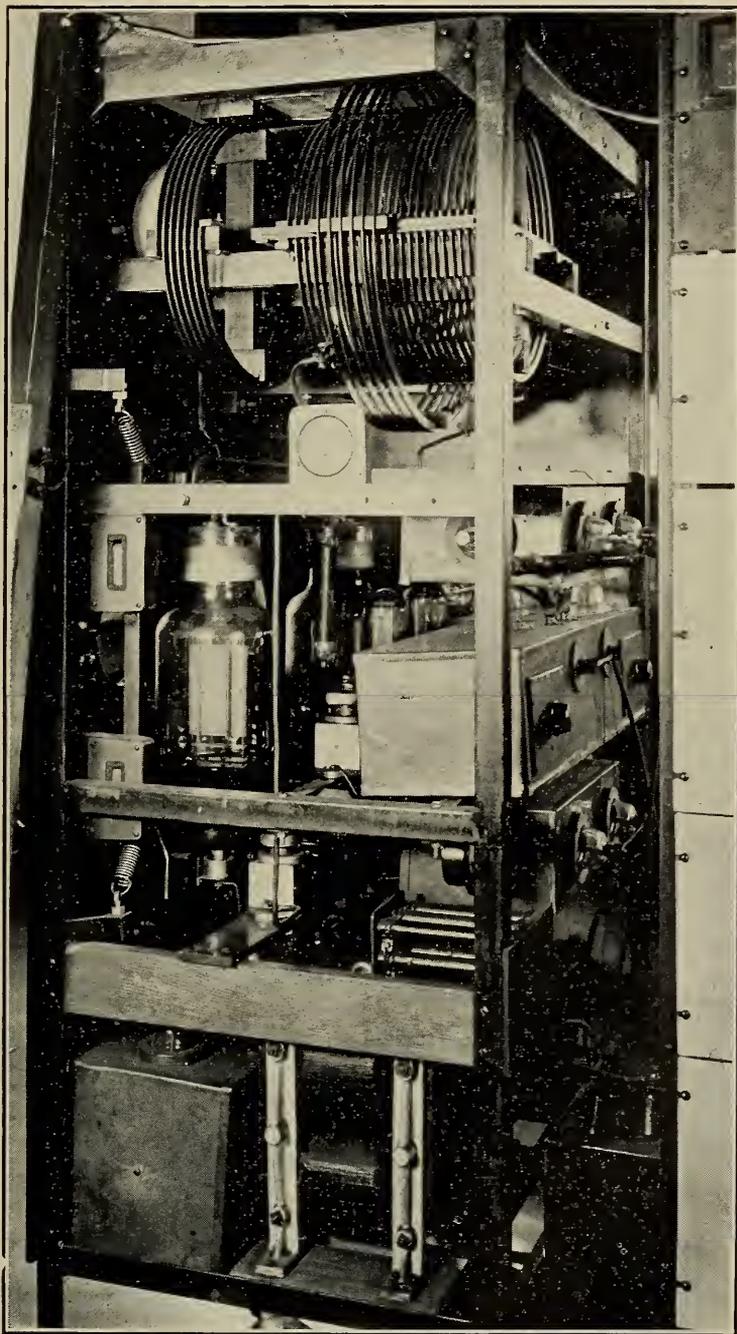


FIGURE 8.—Radiophone and carrier amplifier unit (side view)

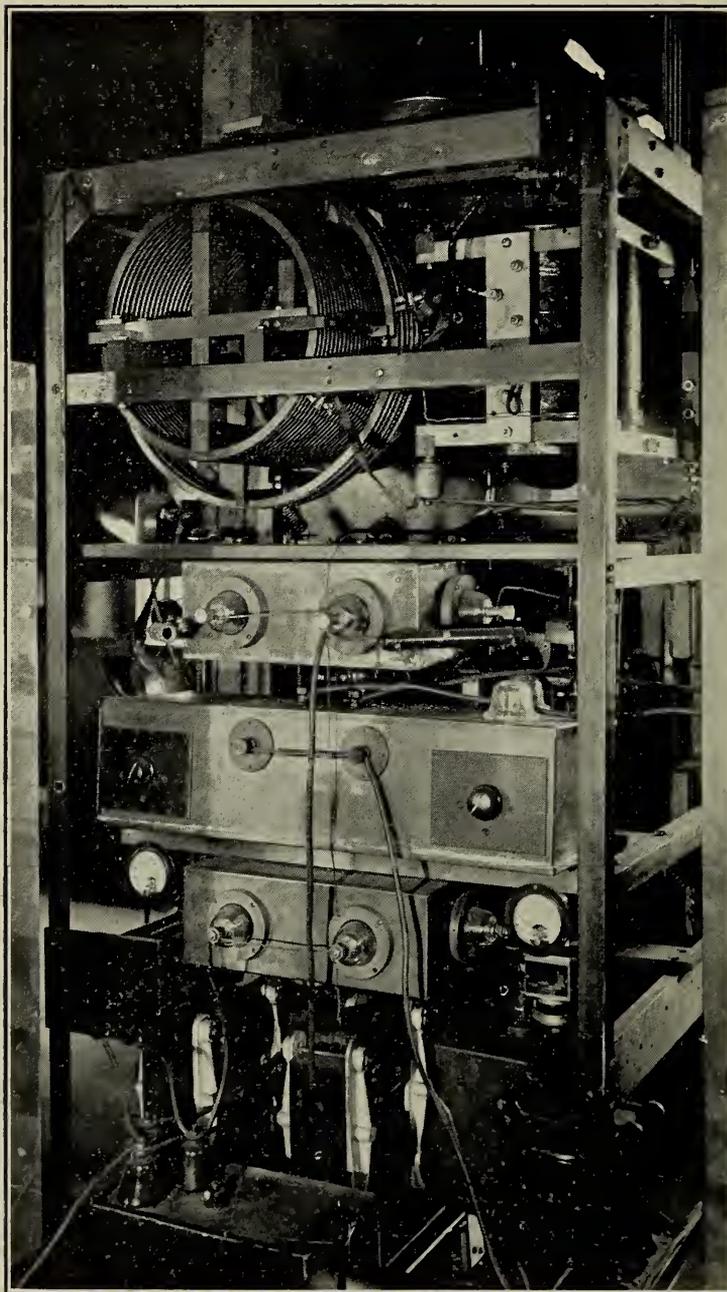


FIGURE 9.—Radiophone and carrier amplifier unit (rear view)

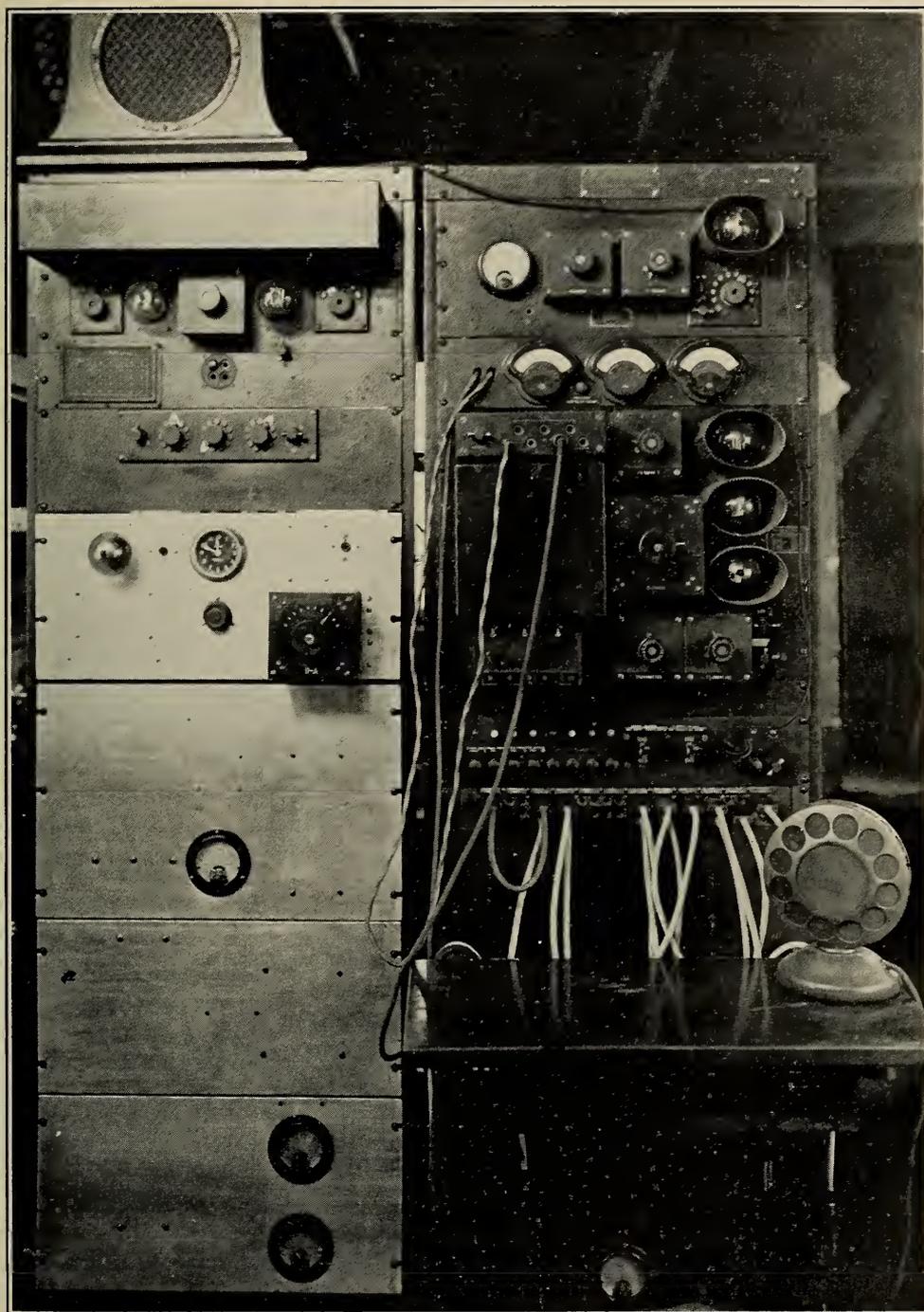


FIGURE 10.—*Speech input equipment*

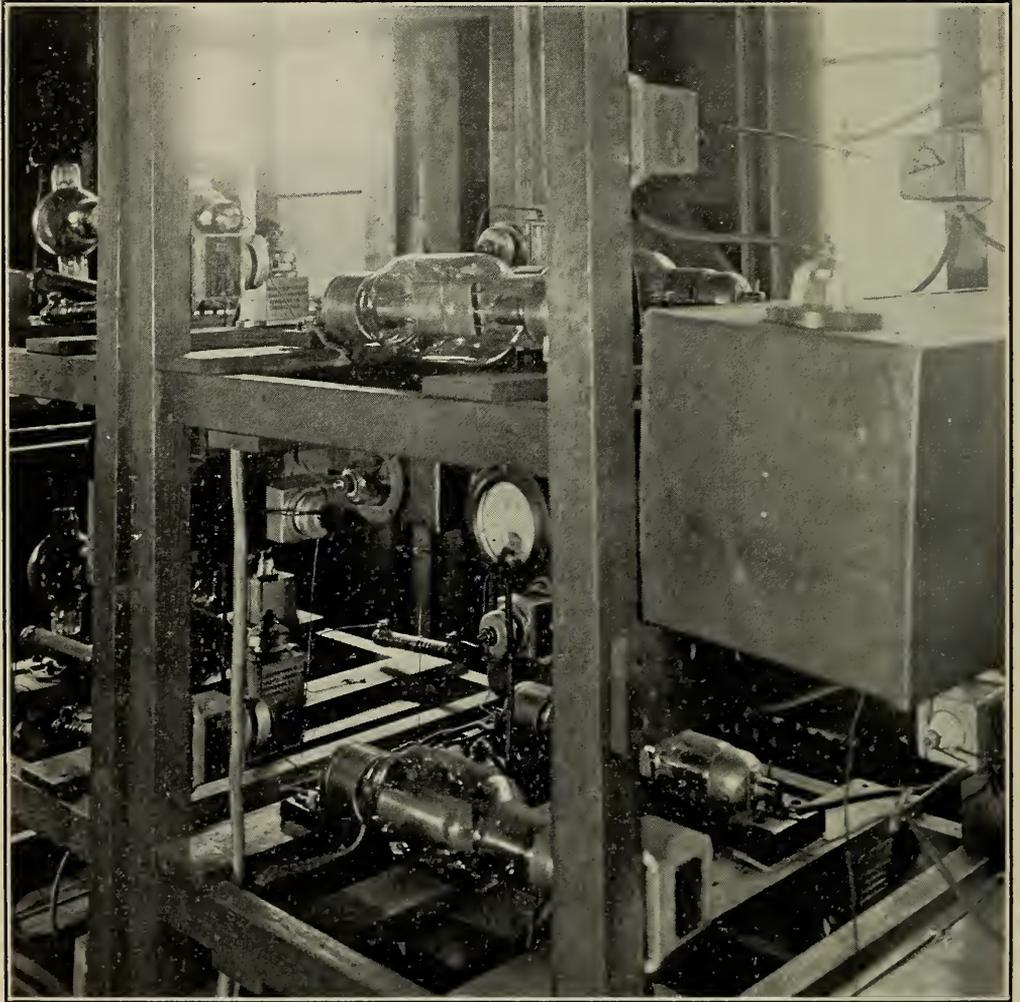


FIGURE 11.—*Range-beacon amplifiers*

On account of the poor wave shape of the alternators employed, a filter is incorporated into each transformer output. This eliminates the higher harmonics of the reed frequencies which would cause serious interference in reception of speech signals. The general arrangement of the balanced amplifier is shown in Figure 11. The upper branch carries the 86.7-cycle modulation and the lower branch, 65-cycle modulation.

(f) ANTENNA SYSTEM

Since the building housing the equipment at the College Park installation is located on the flying field and adjacent to the main runway, the antenna employed was exceedingly limited in dimensions. The loop antennas have a 300-foot base and an apex 70 feet high. This is quite satisfactory for securing the required field intensity for the beacon side bands. The open antenna used during the major portion of the work was of the umbrella type and consequently a very poor radiator. It consisted of four 60-foot vertical antennas along the main tower with four umbrella sections 30 feet long and at about a 40° angle to the vertical. This antenna radiated only about one-third as well as was necessary for satisfactory operation. Its field intensity at a distance of 10 miles from the transmitter was 1,850 $\mu\text{v}/\text{m}$ instead of the desired 6,500 $\mu\text{v}/\text{m}$. Consequently all preliminary work was done with greatly reduced loop antenna currents to maintain the proper voice to beacon signal ratio.

The later work was done with a somewhat better system. This consisted of four flat top sections, each 80 feet long bisecting the angle of the loop antennas and four 60-foot lead-in wires to the tower. This gave a field intensity of 2,500 $\mu\text{v}/\text{m}$ and resulted in proportionately greater range of transmission.

This completed the transmitter. A detailed diagram of connections is shown in Figure 12.

3. TESTS ON COMPLETED UNIT

The transmitter having been constructed, it was next necessary to carry out a comprehensive series of performance tests to determine its adaptability to the work for which it was designed. In addition to this, a system of routine tests was developed in order to enable a frequent check on the operation of the system as a whole. The more important of these tests are here somewhat briefly described.

(a) PHASE SHIFT UNIT

The problem of shifting phases has been covered quite thoroughly in recent papers on radio range beacons.⁴

On the basis of this work the phase calculations were carried out. Detailed methods of calculation and measurement of the phase displacements in various parts of the transmitter will be found in footnote 2, page 271, and footnote 4, page 273. A stabilizing resistance was employed across the grid of each tube to minimize change in phase with changing tube characteristics.

A total phase shift of 90° is required between the phone amplifiers and the range-beacon amplifiers. Since tubes of relatively low input impedance were used in the phone amplifier, the major portion of the

⁴ Jackson and Bailey, Development of a Visual Type Radio-Range Transmitter, Proc. Inst. Radio Engrs.; December, 1930. See also footnote 1, p. 263, and footnote 2, p. 271, of this paper.

phase shift (approximately 60°) was introduced into this circuit network. The remaining 30° shift was placed in the circuit network to the screen grid buffer amplifiers.

Previous work on phase adjustments had shown the input impedance of a UV-211 tube acting as a class C amplifier to be approximately 5,000 ohms. Likewise two UX-860 tubes in parallel have an input impedance of 10,000 ohms. Neglecting tube capacity, the equivalent circuit of the phone branch would be that of Figure 13 (a) and that of the range-beacon branches Figure 13 (b). In the phone branch the total resistance equals 6,000 ohms. The inductive reactance, X_2 , equals 9,100 ohms at 290 kc. The resultant phase angle (θ_1) is therefore 56° . Similarly, the beacon branches have an

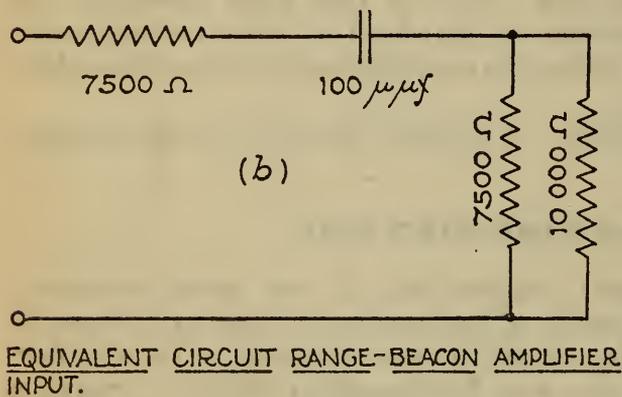
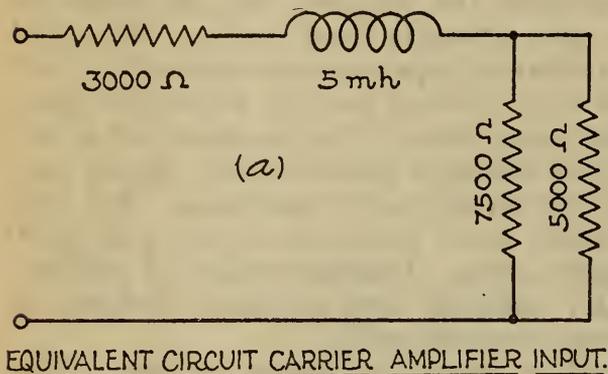


FIGURE 13.—Equivalent circuits

(a) Carrier amplifier input; (b) range-beacon amplifier input.

equivalent resistance of 9,280 ohms. The capacitive reactance, X_c , equals 5,500 ohms. The phase angle (θ_2) is therefore equal to 30° . Consequently, the total phase shift is 87° , or approximately 90° . Since the resultant detected signal varies proportionately to the sine of θ , variations of a few degrees either way make no apparent difference in signal strength.

Methods of checking these phase adjustments by measurements have been referred to previously. However, it was found more convenient to utilize a method which has not heretofore been described. Since the detected signal strength is a function of the phase relationship, the first measurements were made by observing the reed indicator deflections for various phase angles. This provided a rough check and was very valuable in securing a rough adjustment to somewhere near the desired value. However, the fact already mentioned, namely, that the variation is proportional to the sine of θ , made a close adjustment impossible by this means.

In order to secure a sharper indication, the output of the receiving set was connected to an oscillograph. As the phase changes from the optimum value, the second harmonic term begins to predominate and when the phase is 90° from the correct value, the double frequency alone will appear, as has been shown previously. Using the oscillograph in this manner, it was possible to check the previous data very closely. However, the presence of a second harmonic voltage, even at optimum conditions, made this check but little better than the use of reeds. It was noticed during these measurements that the

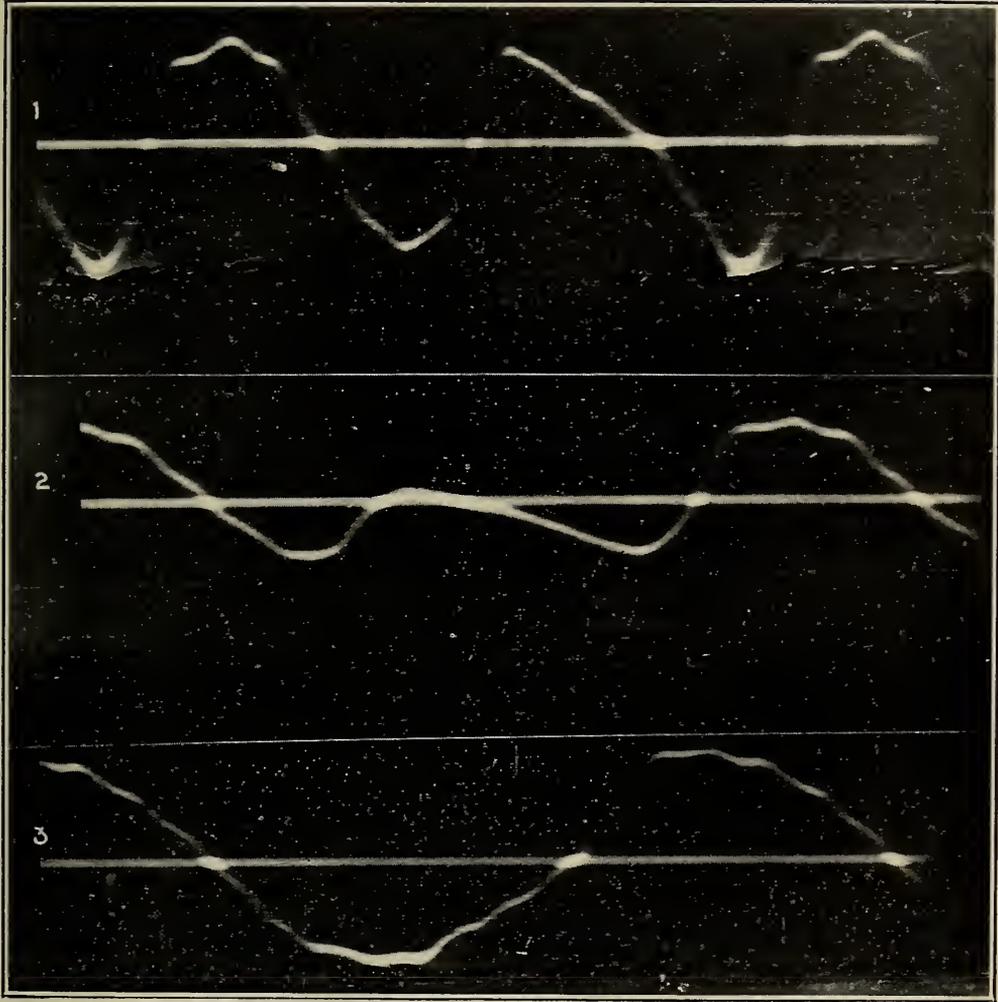


FIGURE 14.—*Oscillographs showing means of checking phase relations*
1, Carrier approximately 5° from correct phase. Successive peaks have almost same amplitude; 2, carrier 30° from correct phase. Note decided drop in center peak; 3, carrier 90° from correct phase. Center peak completely reversed.

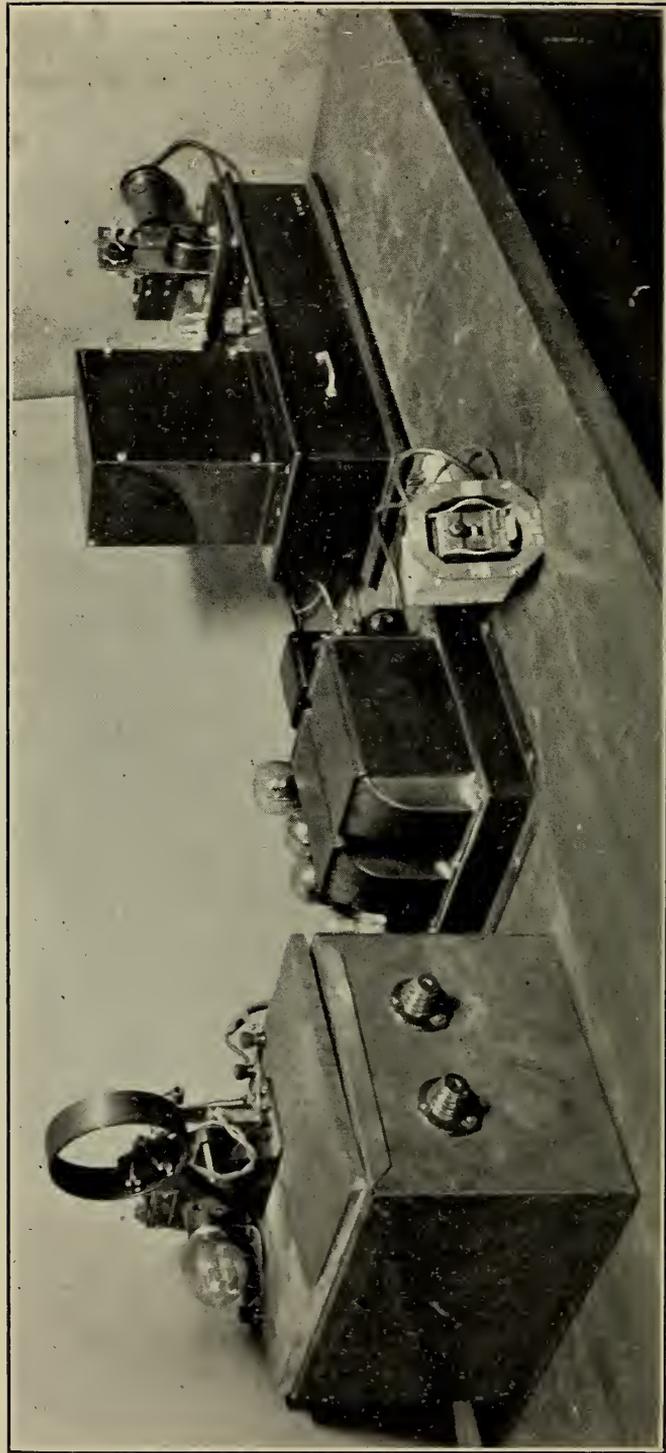


FIGURE 15.—Equipment used to check phase relations

position of poorest phase relationship was quite critical. When the phase was exactly 90° , the double frequency would be very sharply defined, but a slight shift would cause an immediate drop in the alternate voltage peaks.

It was decided to utilize this phenomenon, so a thermionic rectifier was closely coupled to the loop antenna system and to the open antenna system. Since the pick-up from the loop antenna was now purely inductive, the inherent phase shift introduced by radiation from the loop antenna already mentioned did not occur. Consequently, when the phases were so adjusted as to give maximum detected signal in a distant receiver, they were giving the minimum or double-frequency signal in the output of the local rectifier. This output was amplified and observed on an oscillograph. The indication of optimum conditions was now exceedingly sharp. This is shown in Figure 14. Three different phase adjustments are shown. The ratio of carrier to side band was very high for the conditions under which these oscillograms were taken, and the detector was considerably overloaded with carrier in order to give a reasonable vibrator deflection. However, this is not important, since the phase is not determined by the wave shape, but merely by the height of successive voltage peaks.

The equipment used to obtain these checks is illustrated in Figure 15. A detector tube shown on the left in the photograph is coupled loosely to the two antenna systems by the coil shown immediately above it. This tube is operated as a Fleming valve, and its output is amplified by means of the 2-stage power amplifier to a magnitude sufficient to operate the oscillograph. It is necessary to locate the pick-up coil with some care in order that the ratio of carrier and beacon side bands shall be satisfactory.

In beacon installations along the airways, it would not be economically possible to install an oscillograph at each station for a continuous phase check. In such cases, after the adjustment is once made for optimum relationship, a reed indicator may be substituted for the oscillograph. The reed indicator is unaffected by the double frequency and so long as the indicator does not vibrate, the phase is well within the desired limits.

(b) SPEECH AMPLIFIER AND PHONE UNIT

With the exception of a series of fidelity graphs, no special tests were made on the speech equipment. Figure 16 shows a series of fidelity measurements at different points in the system. These tests were all made by means of a variable frequency oscillator whose input to the speech equipment was held constant at 3.75 mw (-2 db), while the frequency was varied from 100 to 6,000 cycles.

Graph *A* shows the speech input equipment characteristic as determined by measurement of the voltage across the Heising choke. The action of the filter section in attenuating the low frequencies in the neighborhood of the reed frequencies is quite marked. On the other hand, the reproduction of the higher frequencies in the intelligibility range is very good indeed.

Graph *B* shows the received signal under the same conditions, employing a standard aircraft receiver. The high frequencies are now attenuated to a considerable degree. This is intentional in

the design of the receiver with the idea of reducing atmospheric noises. The intelligibility of speech is dependent to a great degree upon the fidelity of reproduction in this range, and the result is a considerable sacrifice of intelligibility in order to obtain some reduction of noise.

Graph *C* shows the received signal corrected for the poor audio-frequency characteristic of the radio receiver. The performance indicated in this graph should be the minimum requirement for aircraft receiving sets.

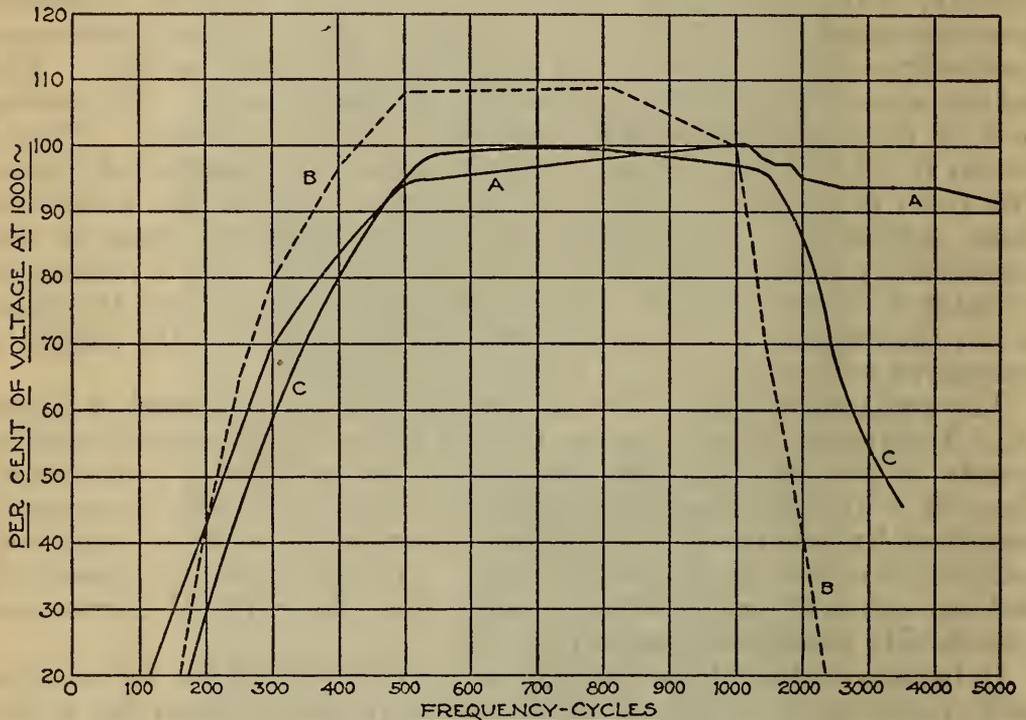


FIGURE 16.—Fidelity characteristics of speech equipment

a, characteristic of speech amplifier system; *b*, over-all received characteristic; and *c*, over-all characteristic corrected for audio-amplifier.

(c) BEACON AMPLIFIER BRANCHES

There are three major requirements for successful operation of the beacon amplifier branches. These are (1) equality of phase shift in the two branches, (2) total suppression of carrier in each branch, and (3) fidelity of reproduction of the modulation frequencies. In addition to these, the usual requirements of stability, efficiency, and freedom from parasitic oscillations must be met.

In carrier-suppressed beacon transmission it is essential that the phase of each set of side bands radiated from the loop antennas be identical. Any difference of phase introduced herein would result in a difference of phase between the resupplied carrier and one or the other sets of side bands. This would cause a change of course with variations in the phase of the carrier. Slight variations in carrier phase, due to detuning, are inevitable. Care must, therefore, be taken to prevent appreciable phase displacement between the two sets of beacon side bands. Consequently, it is necessary to insure that the amplifier branches and goniometer circuits produce the same phase shift, regardless of the goniometer position.

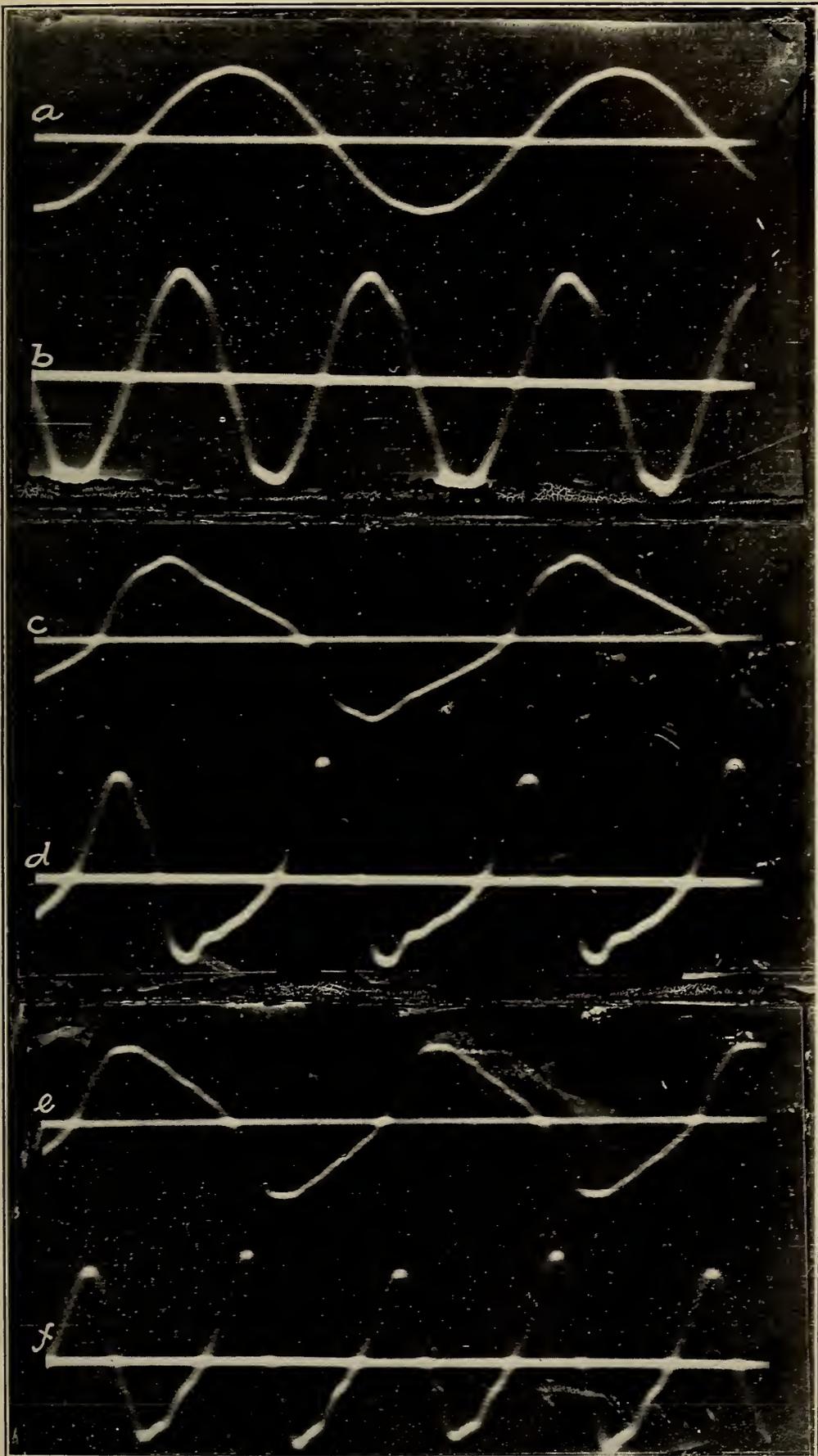


FIGURE 17.—Oscillograms showing operation of range-beacon amplifiers
a, 60 cycles from mains applied to beacon amplifier; *b*, received signal side bands only; *c*, 65 cycle alternator rated load unity p. f.; *d*, received signal side bands only; *e*, 86.7 cycle alternator rated load unity p. f.; *f*, received signal side bands only.

These phase relations are best checked by means of pick-up coils, coupled to the loop antennas and connected to a thermogalvanometer. The procedure is as follows:

With one amplifier branch excited, the goniometer is adjusted to supply current to both loop antenna systems. The coupling coils are then moved until the voltages induced by each loop antenna, as indicated by the galvanometer, are identical. The pick-up coils are then connected in series with the galvanometer, first aiding and then opposing. If the loop antenna currents are in phase, the currents in the two pick-up coils will also be in phase and in one case the current will double, while with the coils opposing no current will flow. This test may be repeated for several goniometer positions and indicates merely the proper operation of the goniometer system.

Both amplifier branches are now excited and modulated with the same reed frequency. The goniometer is set on either 0° or 90° . This directs all of the output of one amplifier into one loop antenna and all of the other into the second loop antenna. Having equalized the pick up in each coil, the currents are again measured aiding and opposing. If the reading of the meter is alternately double that due to one coil and zero, it may safely be assumed that the phase of the two amplifier branches is identical. This satisfies the first requirement. In making this test, it is necessary that the same modulation frequency be used. Since the carrier does not appear in the loop antenna, only the side-band frequencies can be compared, and these must be the same for a phase measurement to be made.

In checking the percentage of carrier suppression, an oscillograph was connected to the output of a receiving set located some distance from the transmitter and the beacon amplifiers excited one at a time with the open-type antenna disconnected. When suppression was most nearly complete, the detected signal was a pure second harmonic of the reed frequency. Any unbalance would cause alternate voltage peaks to assume different amplitudes, and when no suppression occurred, the fundamental frequency alone appeared. This test showed the amplifiers to give very good performance under wide variations of load.

The third test, that of fidelity of reproduction of modulation frequency, was also made with the oscillograph. The results of this test are shown in Figure 17. These oscillograms were taken with carrier suppressed; consequently the received signal is the second harmonic of the reed modulation frequency. Graphs *a* and *b* show the result of applying the 60-cycle line voltage to the transformers modulating the amplifier. This gives a resultant signal which has an excellent wave shape. Graphs *c* and *d* show the voltage of the 65-cycle alternator under normal load with the resultant badly distorted received signal. Graphs *e* and *f* show the 86.7-cycle alternator under the same conditions with its resultant signal.

From these oscillograms it is safe to assume that the amplifiers will produce a good wave form if supplied with a voltage of equally good wave form. A poor alternator, however, will cause audio-frequency harmonics in the transmitted signal, thereby producing frequencies which may interfere with the voice transmission. In spite of the irregular wave shape of the alternators employed in these tests, the resultant signal did not contain sufficient harmonics to

noticeably impair the speech quality. It would be very desirable, however, to use alternators with as good a wave form as possible to insure a minimum of interference with the speech reception.

The transformer output in each beacon amplifier is provided with a filter circuit to eliminate frequencies above 200 cycles. However, the major harmonics are the second and third which are below the filter cut-off point. Consequently the filter is of little value. A filter to cut-off at a lower point would require coils whose loss would be excessive. Hence, the best solution is to employ alternators whose wave form is approximately sinusoidal.

Since most of the test work on the transmitter was carried on with the inefficient umbrella type of open antenna, the output of the beacon amplifiers was proportionately reduced in order to maintain the proper voltage ratio of beacon to phone signals. The carrier field intensity of this arrangement was $1,850 \mu\text{v/m}$ at 10 miles distance from the transmitter. With a phone modulation of 60 per cent peak, the detected signal voltage is proportional to mE^2 or $0.6(1,850)^2$, giving a factor of approximately 2.05×10^6 , or only 10 per cent of that provided in the final design. To maintain the same ratio of beacon to phone signals E_1 must equal $0.19 \times E_0$, or 350 microvolts.

The corresponding field intensity is $\sqrt{\frac{350}{2}}$ or $245 \mu\text{v/m}$. This is obtained with a loop antenna current of 2 amperes. With this power output, test flights during the months of January, February, and March showed a reliable distance range for the combined transmission of 100 miles. It is estimated, however, that the equivalent distance range under summer conditions would be reduced to the order of 60 to 75 miles.

(d) ANTENNA SYSTEM

The type of antenna system employed has already been briefly described. A better idea of its construction may be gained by reference to Figure 18.

The field intensities obtained from various transmitting systems are listed in Table 1. The approximate reliable service range of each type of transmission is also included in this tabulation.

TABLE 1.—Field intensity chart (various transmitting arrangements)

Type of transmitter	Antenna system	Nominal power rating	Location	Carrier field intensity at 10 miles	Useful distance range
Radio phone.....	T, 125 feet high, 200 feet long.	<i>kw</i> 2	Hadley Field, N. J....	$\mu\text{v/m}$ 6,500	<i>Miles</i> 180
Aural radio range...	Loop \square , 40 feet high, 250 feet base.	2	do.....	800	100
Visual radio range...	Loop \square , 40 feet high, 250 feet base.	2	Detroit, Mich.....	800	150
Do.....	Loop Δ , 65 feet high, 300 feet base.	2	College Park, Md....	800	150
Simultaneous phone range.	Loop Δ , 65 feet high, 300 feet base; vertical umbrella, 60 feet high.	$\frac{3}{4}$	do.....	1,850	75
Do.....	Loop Δ , 65 feet high, 300 feet base; vertical, 75 feet high, 180-foot flat top.	$\frac{3}{4}$	do.....	2,500	100
Do.....	Loop Δ , 40 feet high, 300 feet base; vertical, 70 feet high, 160 feet flat.	3	do.....	16,000	¹ 180

¹ Estimated value if 2 kw airway radiophone transmitter was employed.

It has been shown by Smith-Rose and others⁵ that the Adcock type of antenna provides directional transmission with a marked reduction in night course shift errors over those due to the use of loop antennas.⁶ This led to some consideration of this type of antenna for use with the combined phone and beacon. However,

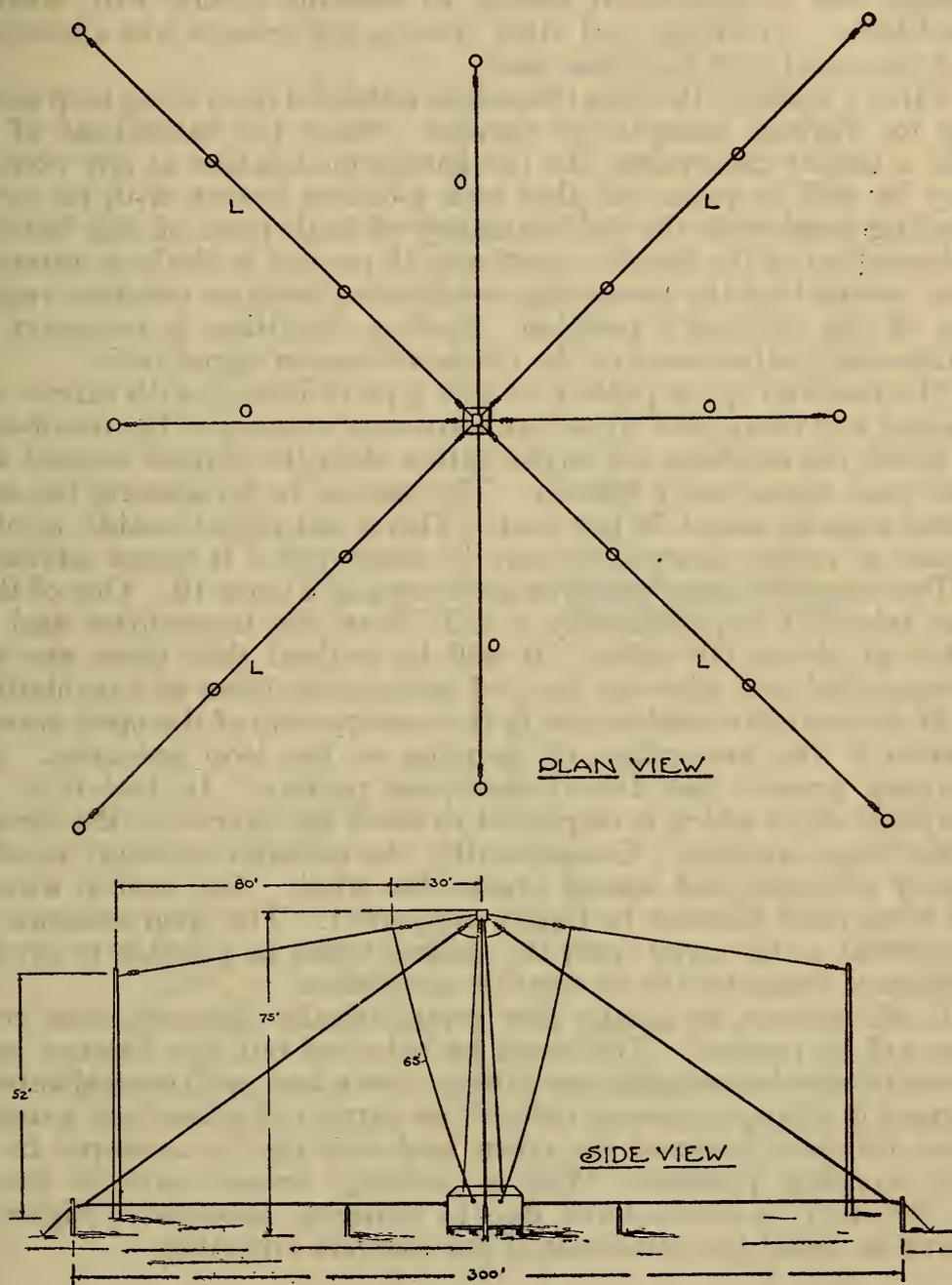


FIGURE 18.—Antenna system

several serious difficulties were encountered, and in consequence thereof it was not tested. The first of these was the necessity for very accurate control of frequency. A change of more than 100 cycles in 290 kc. would seriously affect their operation. While such

⁵ R. L. Smith-Rose and R. H. Barfield, The Cause and Elimination of Night Errors in Radio Direction finding, *J. Inst. Elect. Engrs. (London)*, 64 pp. 831-843; Aug. 26, 1926.

⁶ H. Pratt, Apparent Night Variations With Crossed Coil Radio Beacons, *Proc. Inst. Radio Engrs.*, 16, p. 653; May, 1928.

control can be obtained, the necessity for close tuning of the antenna system introduces disadvantages in operation. A second objection was the high voltage gradient near the ground. The physical size of the antennas being limited, a great deal of loading would be necessary in the base of the down lead. This creates high potentials near the ground and a consequent change of antenna tuning with weather conditions. For these and other reasons the scheme was abandoned and the usual loop antennas used.

Table 1 includes the field intensities obtained from these loop antennas for various amounts of current. Since the magnitude of the field intensity determines the percentage modulation at any point, it may be well to point out that in a 4-course beacon with no course bending employed, the field intensity of both pairs of side bands is independent of the angular relation with respect to the loop antennas. This means that the percentage modulation remains constant regardless of the airplane's position. Such a condition is necessary for satisfactory adjustment of the phone-to-beacon signal ratio.

The received space pattern of this type of beacon with carrier suppressed and resupplied by an open antenna consists of figures-of-eight of which the elements are circles rather than the ellipses secured with the usual visual range beacon. This results in broadening the equisignal zone by about 50 per cent. This is not objectionable, as other means of course sharpening may be employed if it seems advisable.

Two received space patterns are shown in Figure 19. One of these was taken at approximately 1 mile from the transmitter and the other at about 110 miles. It will be noticed that these are very symmetrical and show no trace of undesirable lobes or irregularities.

An important consideration in the construction of the open antenna system is the prevention of coupling to the loop antennas. Any coupling present will distort the space pattern. In fact it is this coupling effect which is employed to bend the courses of the airways radio range stations. Consequently, the antenna structure must be rigidly anchored and braced against the wind. Any lead-in wires or tie wires must likewise be rigidly supported. The open antenna was supported as far away from the central tower as possible to prevent change of capacity due to weather conditions.

In all systems, no matter how symmetrically disposed, some coupling will be present. This must be balanced out, the balance being accomplished by swinging one antenna down lead until normal antenna current in the open system induced no current in either loop antenna. Once this was attained the down lead was rigidly anchored in the zero coupling position. With a properly braced antenna system no difficulty is encountered due to swinging antennas. Figure 18 shows in detail the essentials of the antenna structure.

IV. THE RECEPTION PROBLEM

The problem of receiving the combined signals in the airplane and properly separating them required a different method of attack than that employed in the design of the transmitter. As previously mentioned, receiving set equipment on airplanes has become standardized to a certain degree and every effort was made to provide a transmission system which would require a minimum amount of change in the aircraft equipment. In addition to this, the limitations on receiv-

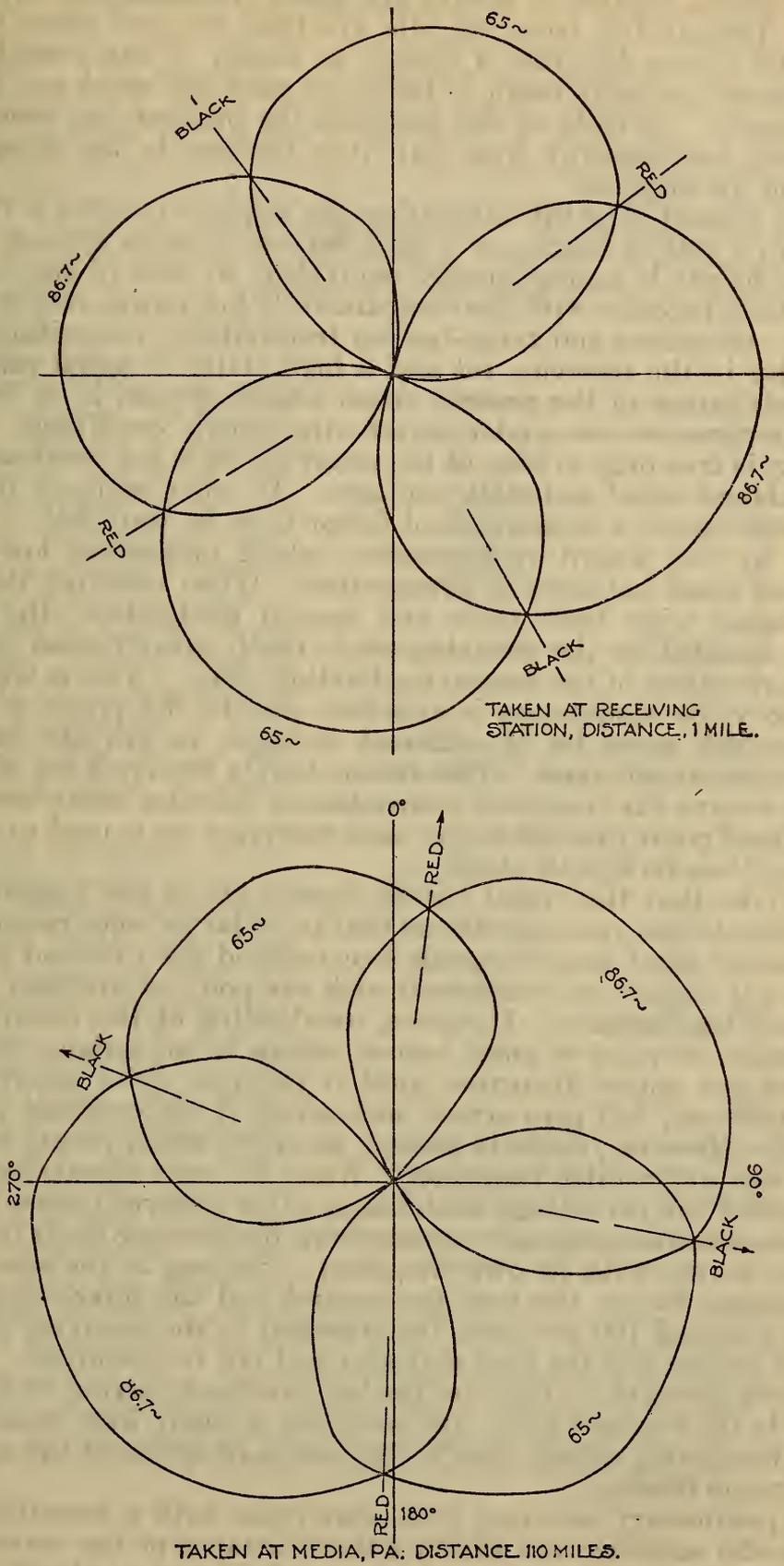


FIGURE 19.—Polar patterns for combined transmitting set

ing set design, because of weight and space considerations are quite severe. Present-day receiving sets are built to meet these limitations, and it was felt that a change in design of any considerable extent would probably result in failure to meet the space and weight requirements. In spite of this handicap the problem has been dealt with quite satisfactorily with but little increase in the equipment carried in the airplane.

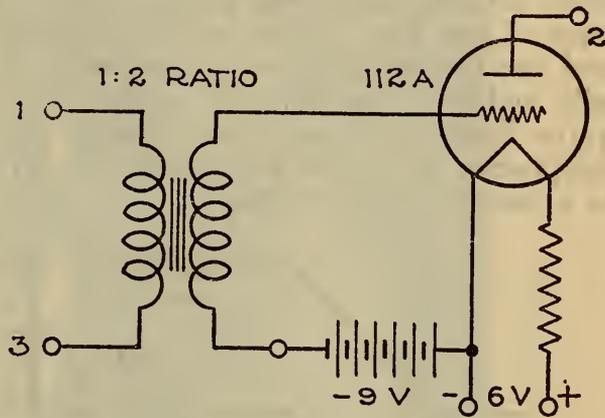
At the present time the antenna on the airplane is either a vertical pole, 5 to 6 feet in length, or a rigid flat-top antenna system whose effective height is approximately equivalent to that of the vertical pole. This, together with the comparatively low power output of the airways radiophone and range-beacon transmitters, necessitates high sensitivity in the receiving set and a high static to signal ratio. A major advantage of the present visual beacon system is its freedom from interference even under severe atmospheric conditions. This, however, is true only so long as the receiving set is not overloaded by the combined signal and static voltages. In order to insure freedom from interference, a high overload factor must be provided. This is limited by the weight requirements, which necessitate low-power tubes and small batteries or dynamotors. When receiving the combined signal with both voice and beacon modulation, the signal voltage handled by the receiving set is much greater than encountered in reception of the beacon modulation alone. This is true even when no voice modulation is supplied, due to the presence of the carrier which must be of sufficient strength to provide for both modulations at all times. This means that a receiving set which is used to receive the combined transmissions operates much nearer to its overload point than when the same receiving set is used to receive the visual beacon signals alone.

It is true that the visual beacon signals are of low magnitude in proportion to the voice signals, so that in so far as voice reception or reception of aural beacon signals is concerned the overload point is altered but slightly in comparison with the point of overload for the combined transmission. However, overloading of the receiving set in reception of voice or aural beacon signals is not serious, since the ear does not notice distortion until it becomes quite severe. The reeds, however, will give erratic indications if the overload point is reached. However, there is present an effect which offsets to some extent this undesirable condition. When no voice signals are being transmitted the percentage modulation of the received carrier is quite low. An interfering signal or atmospheric disturbance tends to modulate this carrier with its own frequency. So long as the sum of the modulations due to the reed frequencies and the interfering signal does not exceed 100 per cent, the transient in the receiving set is of a minor nature and the reed indicator will not be disturbed. Flight tests have shown that in spite of the fact that the receiving set operates nearer to its overload point, the reeds are actually freer from flutter due to interfering signals than is the case in reception of the ordinary visual range beacon.

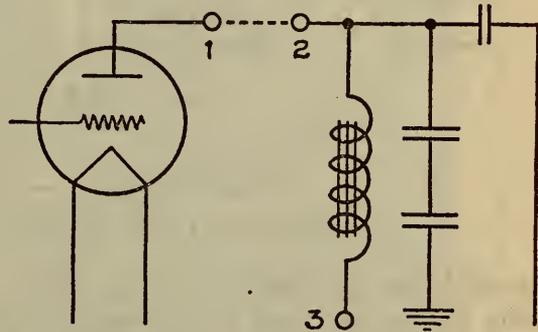
The preliminary receiving tests were made with a detector and 2-stage audio amplifier and within a short distance of the transmitter. This gave very good results and, since weight was no object, the set was designed for high overload; consequently, no difficulty was encountered.

When tests were made at a distance from the transmitter a conventional aircraft receiving set was employed with a separate audio amplifier. This amplifier had a higher amplification than that normally employed, hence the detector signal voltage was lower than would otherwise be necessary. Results of these tests were so free from overloading effects that it was felt that the conventional receiver could be employed for this work if the audio amplification was increased by the addition of a single amplifier stage. Accordingly, an amplifier was built and connected to the receiver. Figure 20 shows the circuit arrangement and the method of connecting it to the receiving set employed. This amplifier required only a small "C" battery in addition to those already carried for the receiver, and the percentage increase in load on the batteries was small in comparison with the increased overload capacity now available. No loss in stability was encountered in the use of this amplifier. The receiver operated in the normal manner with the exception of a decided increase in the permissible static to signal ratio.

During conditions of low static disturbance, even this amplifier is unnecessary, and numerous flights have been made employing only the conventional radio receiver. However, it is felt that in order to retain the desirable freedom from interference which the visual range beacon provides, it is well worth while to include the extra amplifier as part of the receiving equipment. Tests on this system were all made with an aircraft receiving set which was available at the time the research was begun. Since that time several new receiving sets have been developed with higher overload points and improved audio-frequency characteristics. When such receiving sets are used to receive the combined service the amplifier should not be necessary and the speech quality and general intelligibility should be greatly improved.



AMPLIFIER UNIT, FOR USE WITH STANDARD RADIO RECEIVER.



OUTPUT CIRCUIT OF AIRCRAFT RADIO RECEIVER SHOWING MEANS OF CONNECTING AMPLIFIER.

FIGURE 20.—Electrical circuit arrangement of amplifier for receiving set

1. FILTER UNITS

The output of the receiving set may be directly connected to a reed course indicator and head telephones with no additional apparatus. This will cause a low-frequency hum in the telephones and cer-

tain voice frequencies which are harmonics of the reed frequencies will cause a slight flutter in the indicator. Neither of these effects are serious and they can be neglected. They may be entirely eliminated by the use of a suitable filter circuit which provides the reeds with reed frequencies only and the head telephones with frequencies over 250 cycles only. A filter suitable for use with the receiving set employed is shown in Figure 21. This has a cut-off at 300 cycles and a characteristic impedance of 5,000 ohms. Its use insures steady operation of the reed indicator and silence in the head phones during the period when no voice broadcast is made. Oscillographic studies show an additional advantage. By properly matching the impedance of the three components—the receiving set, the head phones, and the reed indicator—the distortion of the received signal is markedly reduced, resulting in better intelligibility. This advantage is quite important and recommends its employment whenever head telephones and reed indicators are to be connected simultaneously to a receiving set output.

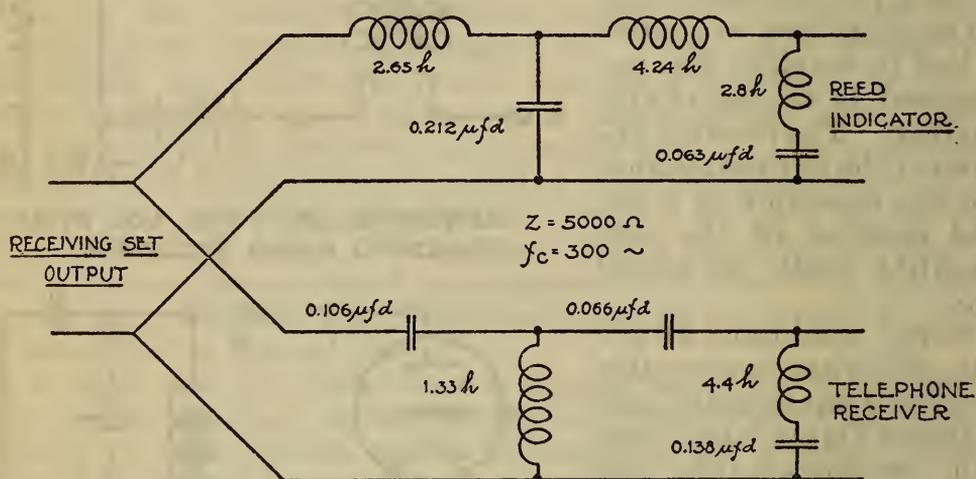


FIGURE 21.—Filter unit for use on airplane

In addition to this particular filter, several others were tried. The results indicated that wide latitude in design is permissible.

The use of a filter of this type is also advantageous in that it permits employment of automatic volume control, details of which have recently been published.⁷ This type of volume control has a decided advantage over other systems, since it is applicable regardless of whether signals are being received from the visual range beacons or the combined visual beacon and phone transmitter.

The equipment used at the receiving station during these tests is shown in Figure 22. From right to left it shows the aircraft radio receiver, the 1-stage amplifier and the receiving set control box, the output filter unit, the reed indicator, an impedance matching transformer, and the oscillograph used to check the operation of the system. The filter unit and the 1-stage amplifier are shown to better advantage in Figure 23.

While it is assumed that the reed course indicator⁸ will be used with this system, any other type of course indicator utilizing low fre-

⁷ W. S. Hinman, Automatic Volume Control for Aircraft Receivers, B. S. Jour. Research, **7** (RP330); July, 1931.

⁸ F. W. Dunmore, A Tuned Reed Course Indicator for the 4 and 12 Course Radio Range; B. S. Jour. Research, **4** (RP160); April, 1930; also Proc. Inst. Radio Engrs., **18**, pp. 963-982.

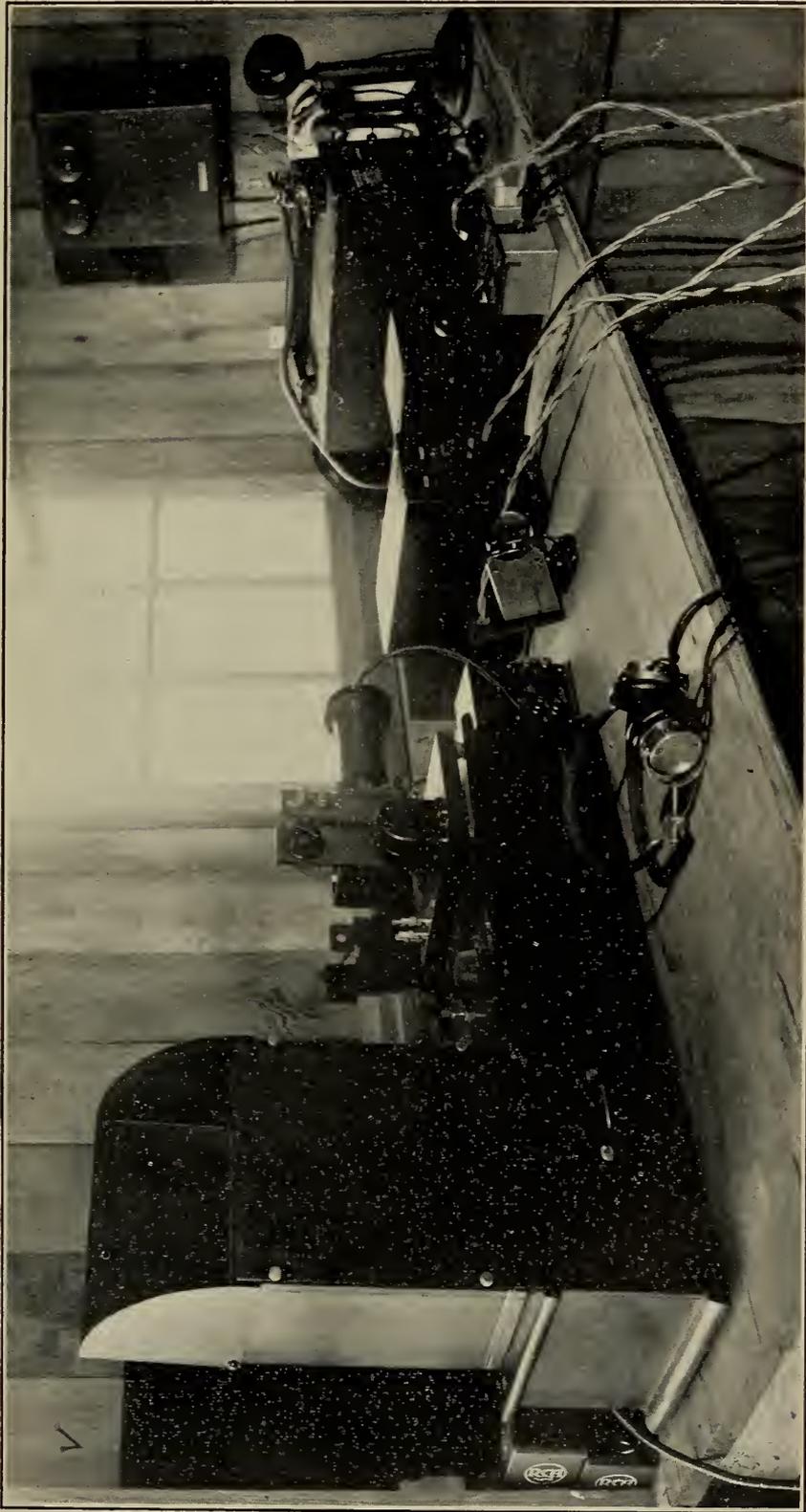


FIGURE 22.—Receiving station equipment

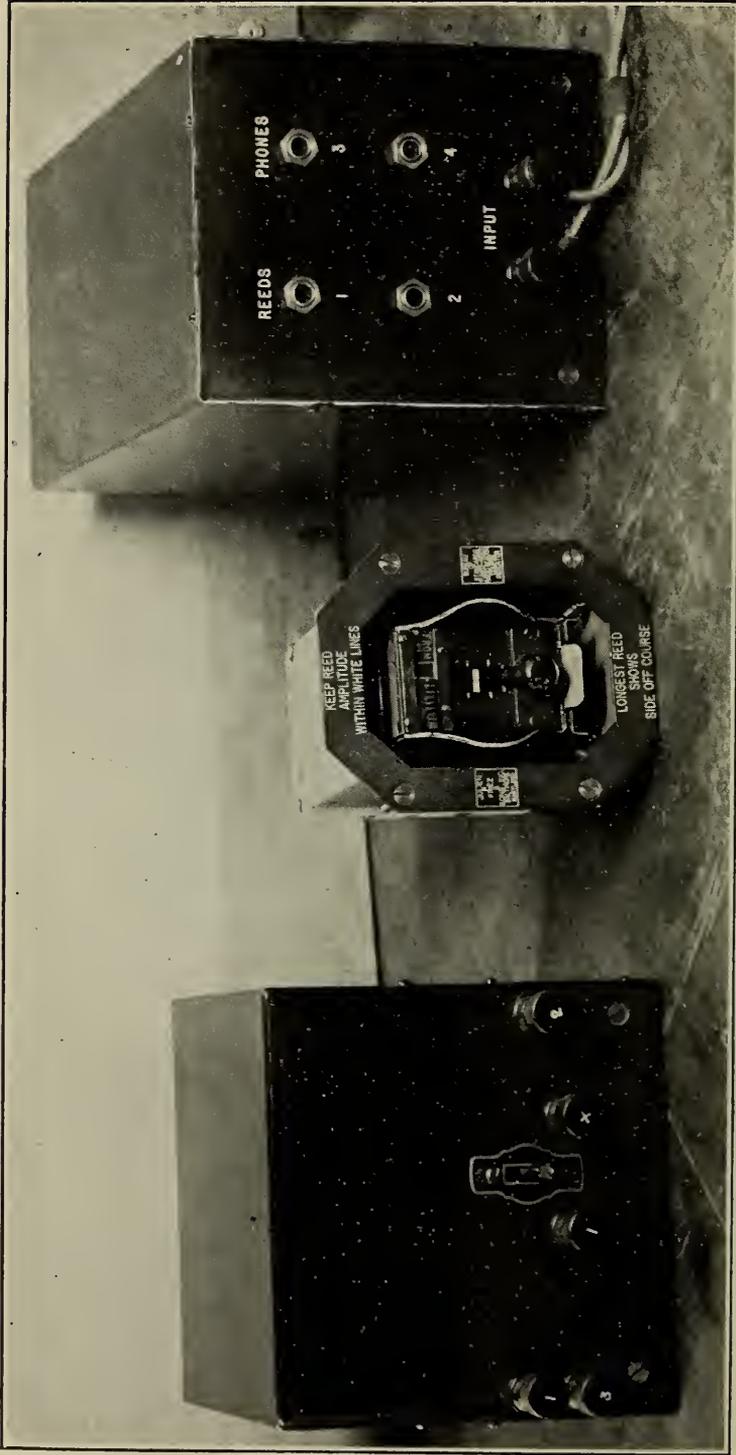


FIGURE 23.—Filter unit and amplifier

frequency alternating voltage for indication will serve equally well. For example, the reed converter, together with a zero center pointer type instrument,⁹ has been successfully employed in various tests with no change in either the transmitting or receiving equipment.

V. FURTHER WORK

1. COURSE BENDING

The courses of the combined system may be adjusted to fit the airways in the same manner employed on the present beacon system.¹⁰

The open-antenna system necessary for shifting the 90° courses is already in place. It is only necessary to apply a modulation of the proper reed frequency to the carrier supplied to this antenna. Since the phase of the radio-frequency voltages is already the optimum relation for shifting the course, no change is required other than proper control of the percentage modulation. However, the phase of the applied reed frequency voltage must be such that it will add in the correct phase in the radio receiver. This can best be determined by the use of an oscillograph at the receiving point. By observation of the phase of the detected signal with and without modulation of the carrier it is possible to make this adjustment quite accurately. The amount of modulation required on the carrier will be quite low, necessitating the use of small audio-frequency currents. The phase can, therefore, be controlled by chokes and condensers when necessary in the same manner as the radio-frequency phases are adjusted. The low percentage modulation required also insures that the voice frequencies will not be affected by its presence in the speech circuits.

2. APPLICATION OF SIMULTANEOUS TRANSMISSION TO THE 12-COURSE RADIO RANGE BEACON

While all of the recent work on simultaneous transmission has been performed on the 4-course beacon, the same principle may be applied to the 12-course beacon.

It has already been demonstrated that this may be accomplished by supplying the three amplifier branches in time phase, thereby suppressing the carrier. The carrier and voice would then be supplied over an open antenna system. This would probably be unsatisfactory due to goniometer coupling and general unavoidable dissymmetry. The preferred plan would be to utilize three amplifier branches modulated to the reed frequencies and suppressing the carrier within themselves. The three sets of side bands would then be supplied to the loop antennas through a 3-stator goniometer. This method permits of a better check on carrier suppression and also permits course alignment without a reintroduction of carrier due to dissymmetry.

With such a system it probably would be necessary to employ link circuits in the goniometer stators to prevent intercoupling. The action of these circuits has been described in detail in a previous paper.¹¹ With the exception of the use of these link circuits, it is apparent that no change in design is necessary to employ the 12-course beacon.

⁹ F. W. Dunmore, A Course Indicator of Pointer Type for the Visual Radio Range Beacon System, B. S. Jour. Research, 7 (RP 336); July, 1931.

¹⁰ See footnote 2, p. 271.

¹¹ See footnote 1, p. 263.

The overloading of the receiving set would be increased due to the presence of a third unused frequency, but the percentage of this is so small compared with the amount of carrier present that the effect should be negligible.

3. POSSIBLE MODIFICATIONS OF DESIGN

(a) CARRIER SUPPRESSION

Several modified designs can be employed which would give substantially the same results. For example, it is unnecessary to use a complete balanced amplifier system. This was merely a matter of convenience in the installation at College Park. If the more usual single-sided amplifier is used, the carrier may be suppressed in the goniometer or in a tuned circuit within the amplifier. This is accomplished by supplying the grids of the modulated amplifiers in parallel and the alternating plate voltage in push-pull. The radio-frequency output is supplied to the extremities of a tuned circuit (or the goniometer) in push-pull. This method is probably somewhat simpler than that previously described. Either method will produce the same results.

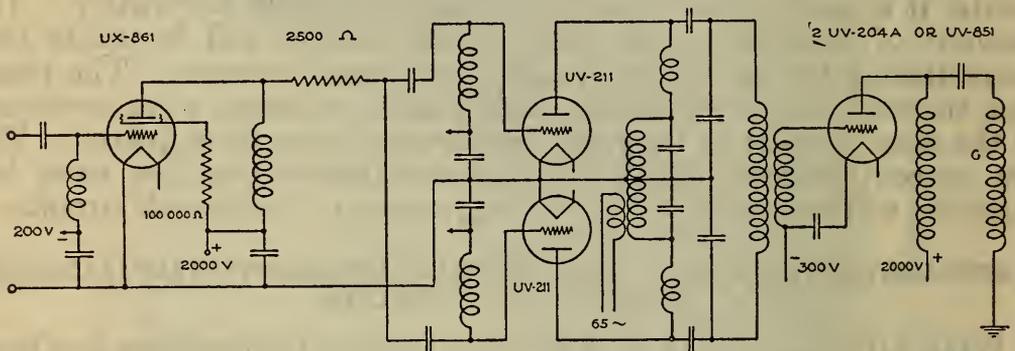


FIGURE 24.—Modified range-beacon amplifier circuit showing (1) carrier suppression in tuned circuit; (2) elimination of balanced amplifiers; and (3) class C power amplifier for stability

(b) COURSE STABILITY

The present method of modulation on the last tubes of the beacon amplifiers might profitably be changed in a final design. With this method of modulating, any change in plate voltage will produce a change in the course. In an experimental transmitter this made no difference as the voltage could be kept constant. In a remote-controlled installation, this would probably not be satisfactory unless voltage regulators were provided for the modulation frequency alternators. However, if the modulation and carrier suppression is accomplished in an intermediate stage and the last stage is a class C amplifier, then the courses will be independent of the alternator voltages. Furthermore, the plate voltage on the class C amplifiers being from the same source will vary the same amount on each amplifier branch. A change in this voltage will change the transmitted power but not the course. This is the method employed in the present range beacons to reduce the possibility of a course change.

Figure 24 shows the modified beacon amplifier with modulation on an intermediate stage. It also illustrates the second means of carrier suppression without the use of balanced amplifiers.

The use of class C amplifiers after a modulating stage introduces harmonics which are undesirable. The increased stability of service offered by their use, however, may be sufficiently great to outweigh the effects of harmonic distortion.

VI. FLIGHT TESTS

The proof of a satisfactory design for an airways transmitting system lies in the results of exhaustive flight tests. Such flight tests on the College Park installation have shown the service rendered to be consistently good. The quality of speech is superior to that usually encountered in aircraft reception and the freedom from interference in the reception of the beacon signals is very marked. On several flights over Aberdeen, Md., interfering code signals made the use of head telephones unbearable. At the same time the reeds were entirely free from flutter.

All test flights were made with an early model of commercial aircraft radio receiver. A filter unit was used, but not the extra stage of amplification. This, together with the fact that flights were made along the Atlantic seaboard with excessive marine radio interference, meant that the ratio of signal to noise was very unfavorable. In spite of this, the beacon service was remarkably free from interruption, although frequently the interference completely blanketed the voice signals.

Since these tests proved so satisfactory, it is reasonable to assume that an airplane equipped with an amplifier in addition to the standard receiving set, or with a later type of aircraft radio receiver designed with a higher overload point, can expect to receive a thoroughly satisfactory radio telephone and range beacon service with the type of transmitting set herein described.

VII. ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance rendered by the other members of the research division of the Aeronautics Branch during the progress of this research.

Particular acknowledgement is made to H. Diamond's suggestions in initiating the work on the combined phone and beacon system, and for many subsequent suggestions in regard to circuit arrangements.

The assistance of the engineering staff of the Bell Telephone Laboratories in collaborating in the design of a circuit arrangement which formed the basis of the research is also acknowledged.

The speech input equipment used in the transmitter was furnished by the Chesapeake & Potomac Telephone Co. It was formerly part of the equipment of station WCAP, at one time operated by them in Washington, D. C.

Credit is also due to Justus U. Steele for assistance in field measurement work and flight tests, and to H. M. Horsman for mechanical work in the construction of the various units.

WASHINGTON, May 23, 1931.