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AN AUTOMATIC LIGHTWEIGHT HOMING SYSTEM

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NAVAL RESEARCH LABORATORY

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AN AUTOMATIC LIGHTWEIGHT HOMING SYSTEM

G. P. Ohman

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March 30, 1948

Approved by:

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CONTENTS

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ABSTRACT

This report covers the development, construction, and test of an experimental model of an automatic lightweight homing system. This system should operate over line-of-sight ranges giving continuous meter indications of range and left-right homing course. A description is given of the antenna switch, the transmitter-receiver unit, and the ground beacon used with the system. Recommendations are given for the correction of azimuth ambiguity, the reduction of loss of the beacon signal, and the improvement of antenna designs. Overall weights should be approximately 40 pounds and power consumption, approximately 200 watts. Methods for reducing the present weight include reduction of the size and number of power supply components, use of a smaller r-f head, combination of the two indicators in the pilot's indicator unit, and unification of the antenna and antenna switch.

PROBLEM STATUS

This report concludes the work on this problem. Unless otherwise advised by the Bureau of Aeronautics, the problem will be closed one month from the mailing date of this report.

AUTHORIZATION

NRL Problem No. R04-01

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AN AUTOMATIC LIGHTWEIGHT HOMING SYSTEM

INTRODUCTION

The major emphasis of the work of this problem has been placed on the development and design of circuits for a homing system for aircraft which will be reliable, accurate, completely automatic, and which will supply the necessary homing data to the pilot in a simple, readily usable form.

Although it was recognized that it would be desirable to make the airborne part of this system as small in size and weight as possible, the experimental equipment was not built to conform to this ideal because of difficulty in obtaining the required components in small sizes and weights. In many cases components much larger and heavier than would normally be required were used simply because they were available while others more suitable were not. Later in this report specific recommendations are made of means to reduce materially both the size and weight of the present equipment.

The requirements of the radar-type beacon, which is the non-airborne part of this system, have not been fixed. Consequently, this problem has not concerned itself with beacon design over and above the design of the temporary beacon which is used in the present experimental system.

DESCRIPTION OF THE AIRPLANE EQUIPMENT

This aircraft homing system is basically an interrogator-respondor system (Figure1) which continuously furnishes range and azimuth information to the pilot. Range information is obtained with respect to a beacon by measuring the time elapsed between the sending of an interrogation pulse from the airborne equipment and the reception of a respondor pulse from the beacon. Azimuth information is obtained by comparing the relative strength of signals obtained by each of two antennas, one which has its maximum sensitivity to beacon signals arriving on the right side of the plane and the other which has a symmetrical sensitivity to signals arriving on the left side of the plane. The information thus obtained is presented to the pilot by two pointer-type indicators. (See Figure 27.) One gives the distance of the plane from the beacon, and the other tells the pilot in what direction he must turn his plane in order to "home" on the beacon.

The system consists of components and circuits located in the plane and a respondor beacon located on the ground. The plane equipment consists of an antenna switch, a transmitter-receiver unit, a strobe searching and locking unit, directional antennas with right-left symmetry, a pilot's indicator unit, and various power supplies for the units.

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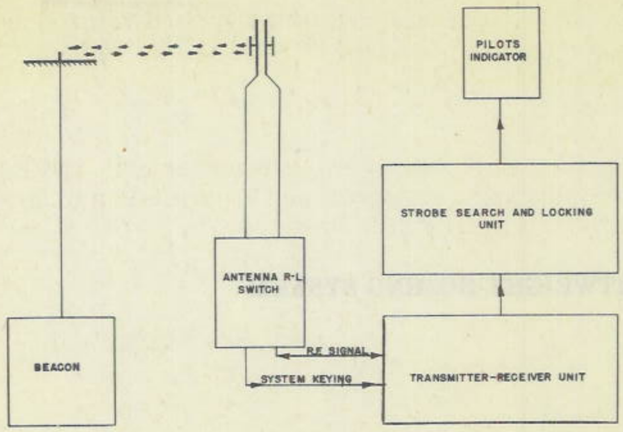

Fig. 1 - Homing System

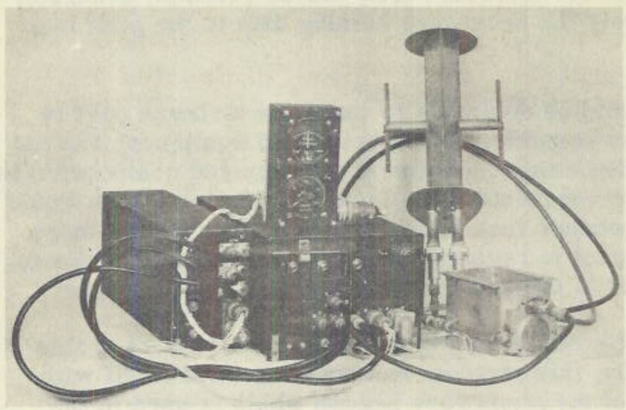

Fig. 2 - Airborne Components of Homing System

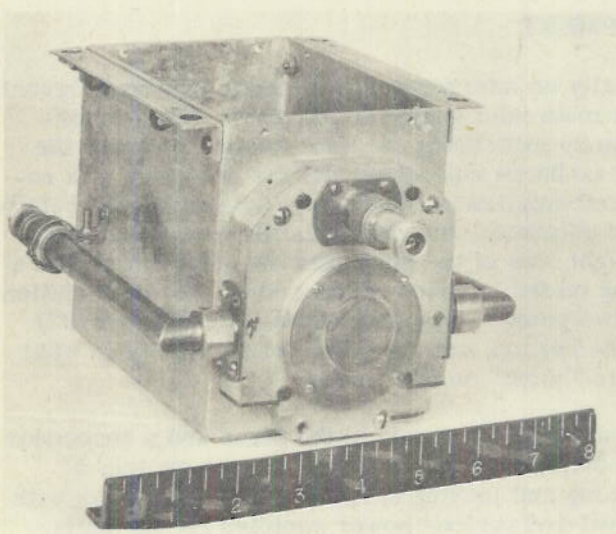

Fig. 3 - Antenna Switch

In the plane equipment are included a full ATR rack, a half ATR rack, and three smaller units. (See Figure 2.) The full ATR rack houses the transmitter and receiver, including an i-f strip and the necessary power supplies for these equipments. It has a gross weight of 37 pounds. In the half ATR rack are housed the strobe searching and locking circuits, the right-left indicating circuits and the necessary power supplies. This unit weighs 16 pounds including cables. The three smaller units are the pilot's indicator unit weighing 7 pounds, an antenna switch weighing 6 pounds, and an antenna weighing 8 pounds. The plane equipment requires a 24-volt d-c power source to drive the antenna switch and several relays, and a 110-volt 800-cps power source to supply the remaining power requirements. The power consumption is 11 watts dc and 300 watts 800 cps at a power factor of 94 percent.

Antenna Switch

Since the antenna switch (Figure 3) determines the PRF of the system as well as acts as an antenna switch, it will be found convenient to begin the description of the system with this unit.

Schematically this unit is shown on the transmitter print (Figure 8), which also shows the r-f portion of the receiver. It consists of a motor driven capacity type r-f switch plus two sets of eccentrically operated switch contacts. One set of switch contacts directly keys the transmitter and consequently sets the PRF of the system. The second set of switch contacts operates a relay in the strobe unit used in the right-left indicating circuits. Correct operating sequence requires that both the r-f switch and the relay operating contacts be closed before the keying contacts close.

The drive motor which operates from a 24-volt d-c source turns at a rate of approximately 30 rps giving a PRF of approximately 60, i. e., two pulses per revolution, one for each antenna. The speed of the drive motor is roughly proportional to the applied voltage so that the PRF of the system will vary somewhat with normal variations in line voltage.

The Transmitter-Receiver Unit

Figures 4 and 5 show top and bottom views of the transmitter-receiver unit, and Figures 6 and 7 show the physical location of the component parts, and Figure 8 is a diagram of the entire unit. A description of the circuits of the unit follows.

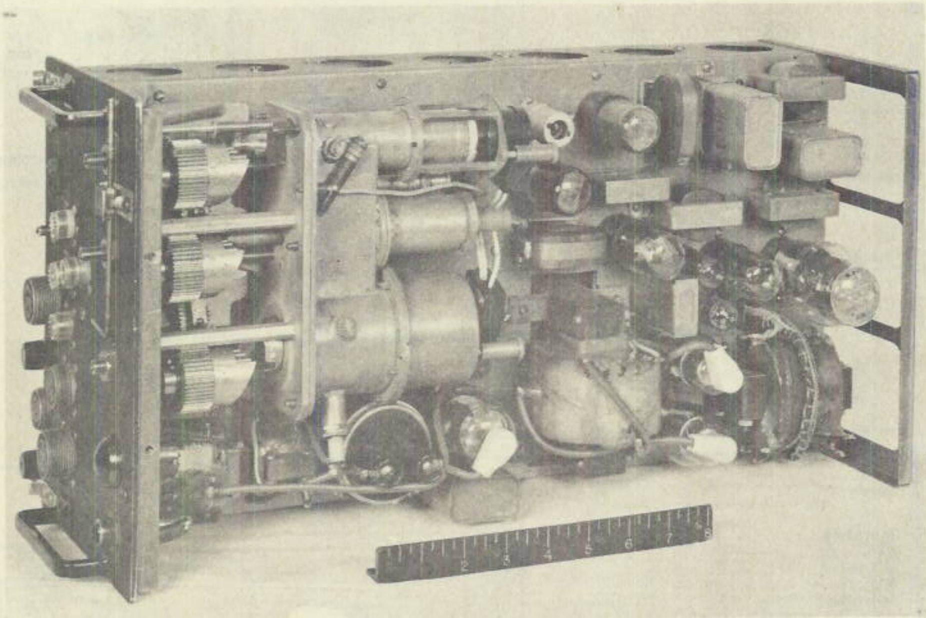

Fig. 4 - Transmitter-Receiver Unit, Top View (Cover Removed)

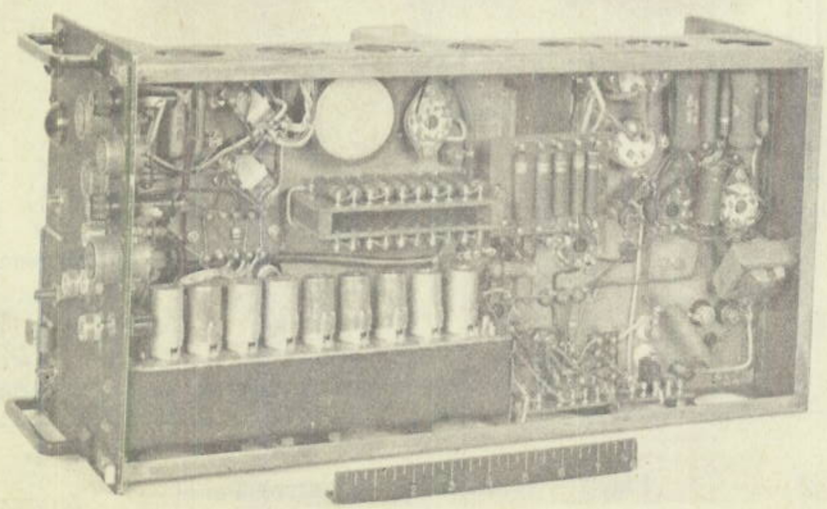

Fig. 5 - Transmitter-Receiver Unit, Bottom View (Cover Removed)

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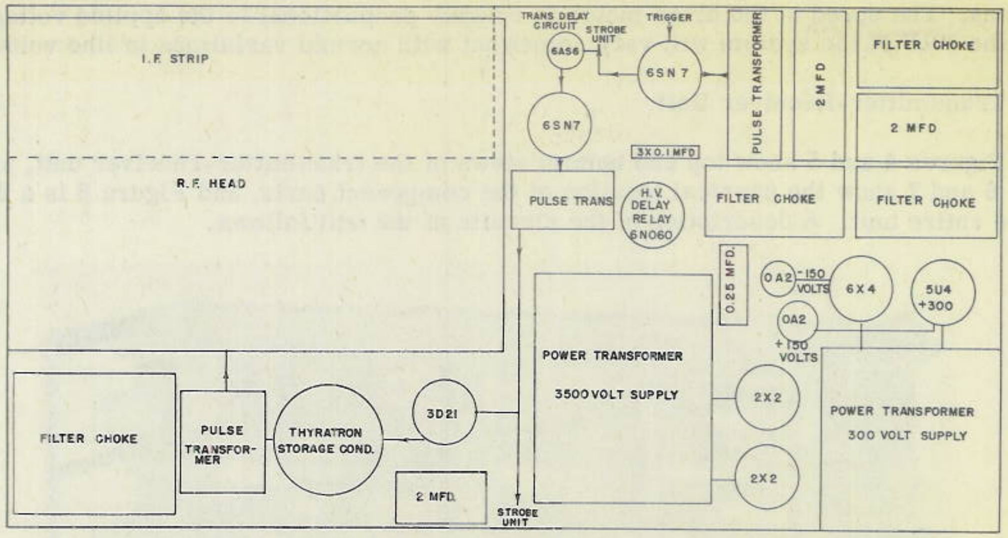

Fig. 6 - Component Location in Transmitter-Receiver Unit

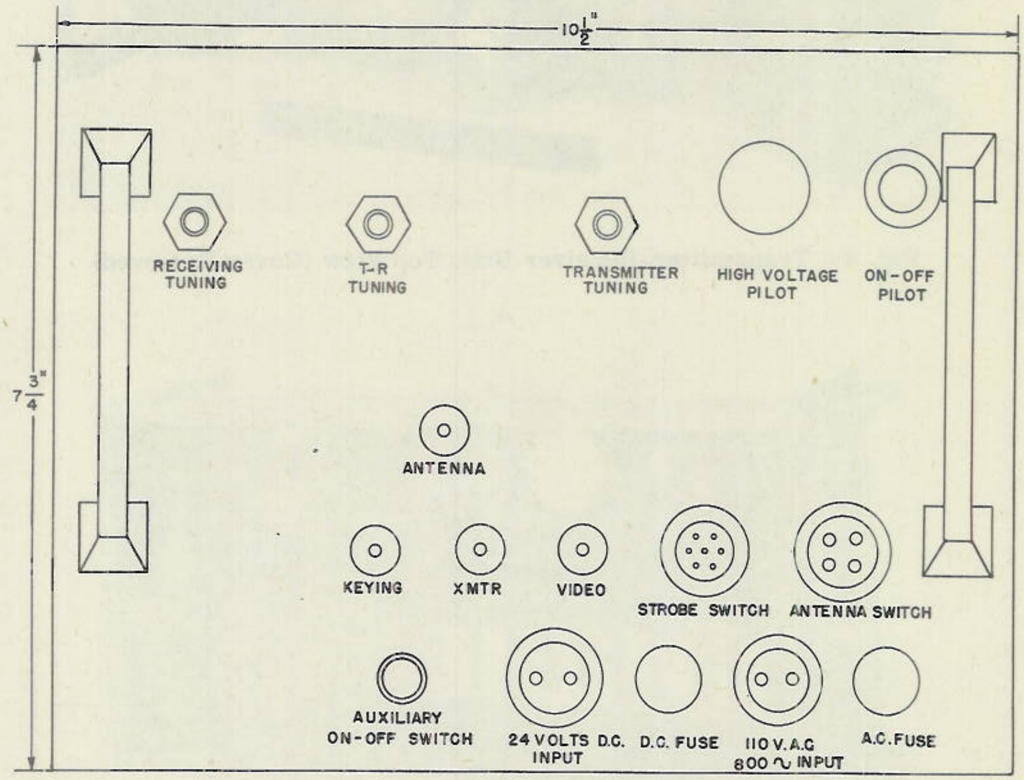

Fig. 7 - Transmitter-Receiver Panel

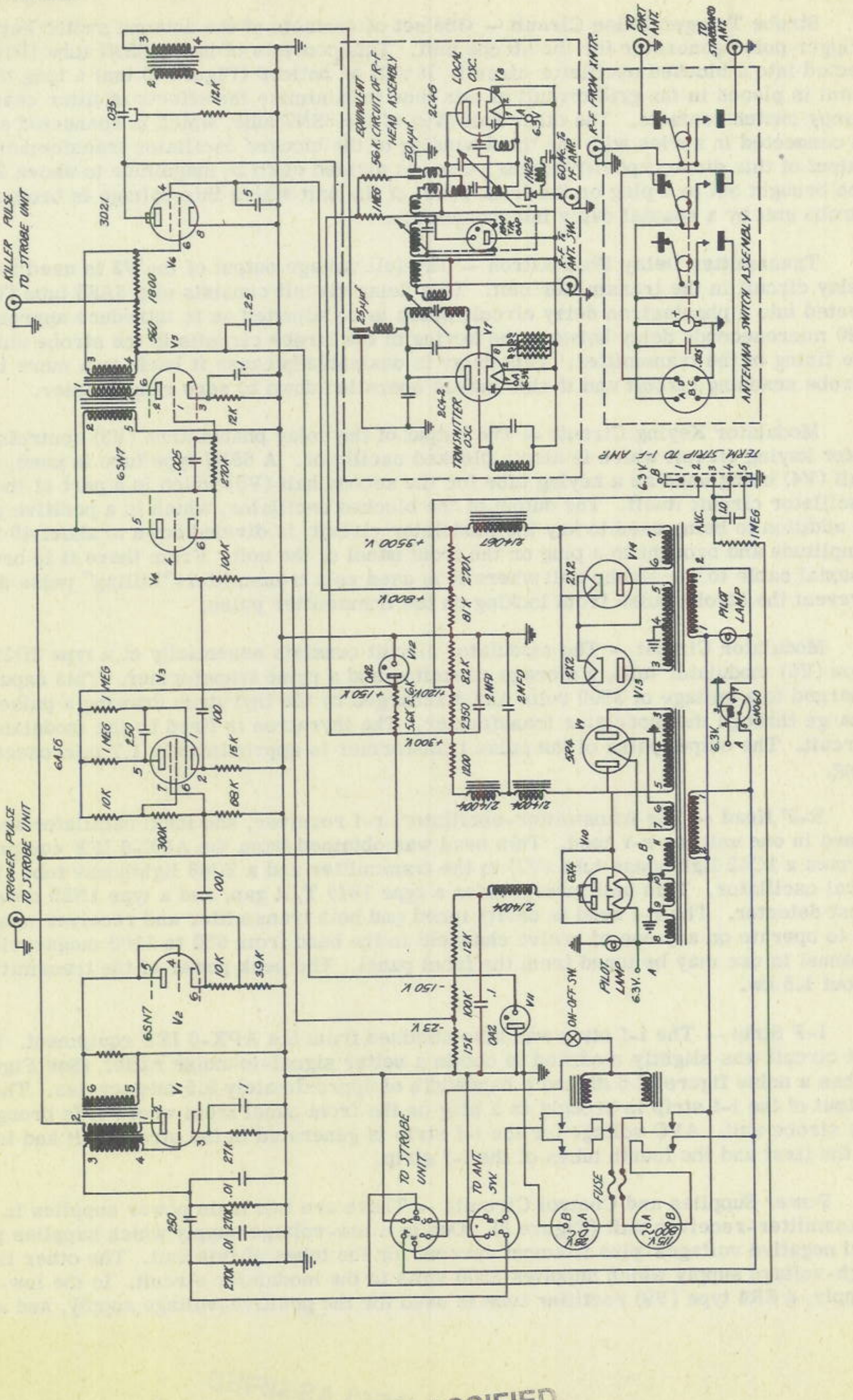

Fig. 8 - Transmitter-Receiver Unit for Homing System

Strobe Trigger Pulse Circuit — One set of contacts of the antenna switch keys a trigger pulse generator for the strobe unit. This consists of half a 6SN7 tube (V1) connected into a blocked oscillator circuit. It will be noticed (Figure 8) that a long time constant is placed in the grid circuit of this tube to minimize the effects of jitter caused by jumpy switch contacts. The other half (V2) of the 6SN7 tube, which is connected as a diode, is connected in series with the third winding of the blocked oscillator transformer. The output of this diode, a positive going pulse, is divided down in magnitude to above 20 volts and brought out to a plug on the front panel of the unit where this voltage is brought to the strobe unit by a coaxial cable interconnection.

Transmitter Delay Phantastron — The full voltage output of the V2 is used to key a delay circuit in the transmitter unit. This delay circuit consists of a 6AS6 tube (V3) connected into a phantastron delay circuit which is so adjusted as to introduce approximately 120 microseconds delay between the keying of the strobe circuits in the strobe unit and the firing of the transmitter. This delay is desirable because it leads to a more linear strobe scanning circuit and it also makes operation down to zero range easier.

Modulator Keying Circuit — The output of the delay phantastron (V3) controls a modulator keying circuit which is also a blocked oscillator. A 6SN7 type tube is used, the first half (V4) being used as a keying tube for the second half (V5) which is a part of the blocked oscillator circuit itself. The output of the blocked oscillator, which is a positive pulse, in addition to being used to key the modulator circuit, is divided down to about 40 volts in amplitude and brought to a plug on the front panel of the unit. From there it is brought by coaxial cable to the strobe unit where it is used as a transmitter-"killing" pulse and to prevent the strobe pulse from locking on the transmitter pulse.

Modulator Circuit — The modulator circuit consists essentially of a type 3D21 thyratron (V6) modulator tube, a storage capacitor and a pulse transformer. This capacitor is charged to a voltage of 3500 volts and discharged by the thyratron drawing a pulse of charge through the modulator transformer. The thyratron is fired by the modulator keying circuit. The output pulse of the pulse transformer is approximately 1.7 microseconds long.

R-F Head — The transmitter-oscillator, r-f receiver, and local oscillator are combined in one unit, or r-f head. This head was obtained from the APX-6 IFF equipment. It uses a 2C42 lighthouse tube (V7) in the transmitter and a 2C46 lighthouse tube (V8) as local oscillator. This unit incorporates a type 1840 T/R gap, and a type 1N25 crystal as first detector. The r-f head is cavity tuned and both transmitter and receiver may be set up to operate on any one of twelve channels in the band from 950 to 1100 megacycles. The channel in use may be tuned from the front panel. The peak power of the transmitter is about 1.5 kw.

I-F Strip — The i-f strip was also obtained from the APX-6 IFF equipment. Its input circuit was slightly modified to obtain a better signal-to-noise ratio. (See Figure 9.) It has a noise figure of 6 db and a bandwidth of approximately 9.5 megacycles. The video output of the i-f strip is brought to a plug on the front panel from where it is brought to the strobe unit. AVC voltage for the i-f strip is generated in the strobe unit and is applied to the first and the fourth tubes of the i-f strip.

Power Supplies and Control Circuits — There are two main power supplies in the transmitter-receiver unit (Figure 8). One is a low-voltage supply which supplies positive and negative voltages plus filament current for the tubes of this unit. The other is a high-voltage supply which supplies 3500 volts to the modulator circuit. In the low-voltage supply, a 5R4 type (V9) rectifier tube is used for the positive-voltage supply, and a 6X4

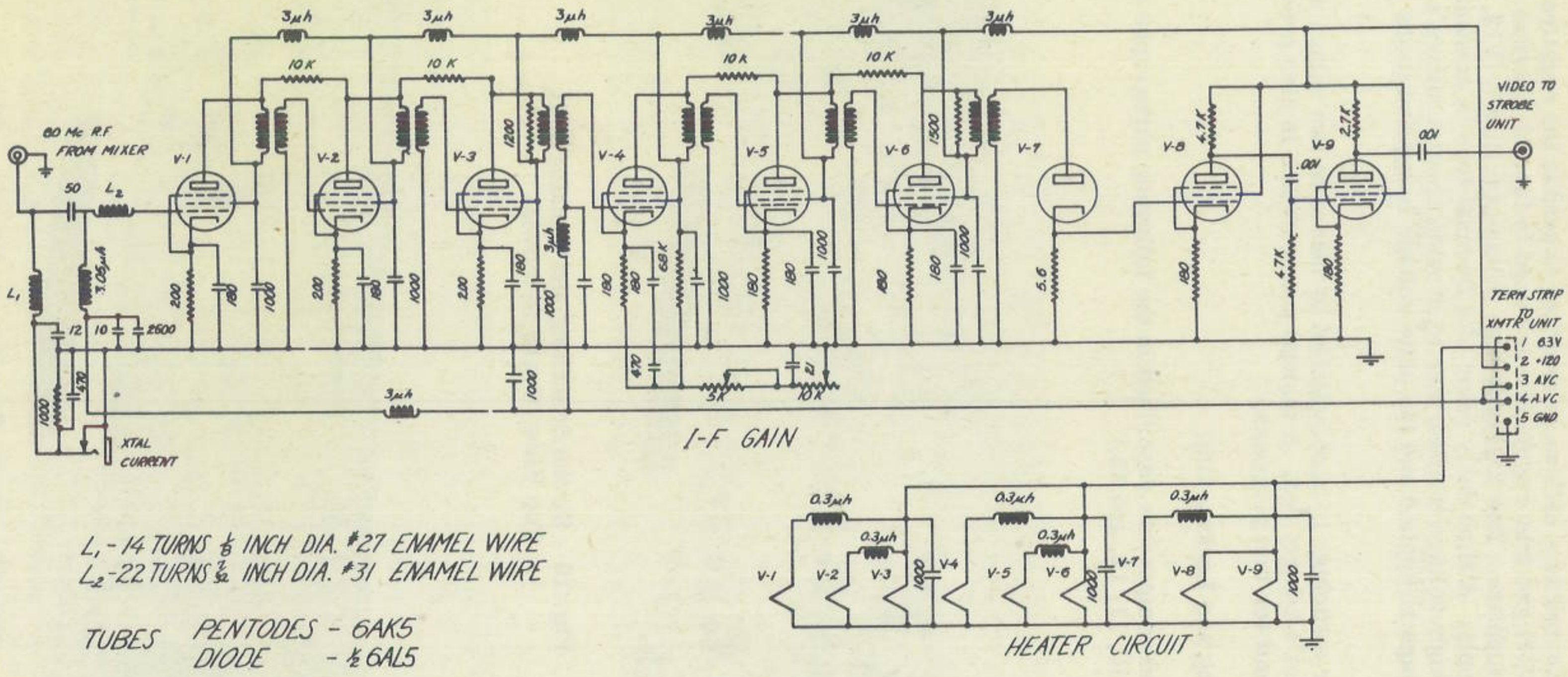

Fig. 9 - I-F Amplifier for Homing Equipment

type tube (V10) connected as a half-wave rectifier is used in the negative supply. Two type 0A2-VR 150 (V11, V12) gas tube regulators are used to furnish positive and negative regulated 150-volt supplies. Two 2X2 type high voltage rectifiers (V13, V14) are used in the high-voltage supply. A time delay relay of a thermal type is connected in series with the primary of the high-voltage transformer to provide about a minute's delay between the time the heater voltage is applied and the plate voltage is applied to the transmitter and modulator tubes.

Primary power switching is accomplished by means of two relays which are controlled from the pilot's control box. A manual power switch is also provided on the panel of the transmitter unit for test purposes.

The Strobe Searching and Locking Unit

The circuits and components described in the following paragraphs are found in this unit. (See Figures 10, 11, 12, and 13.)

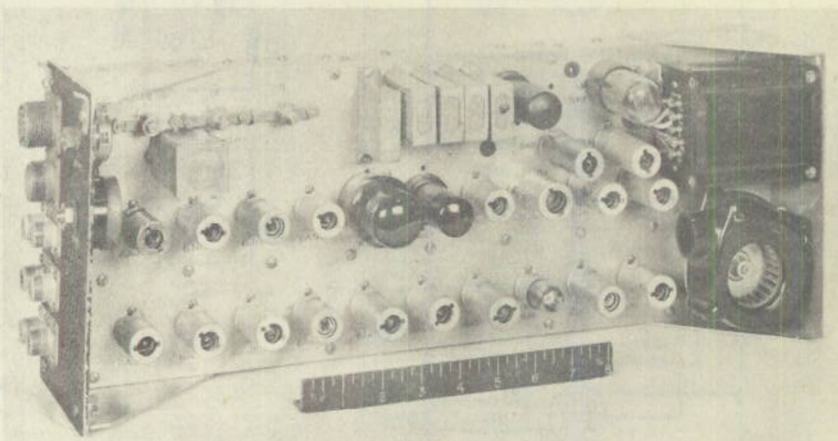

Fig. 10 - Strobe Searching and Locking Unit
Top View (Cover Removed)

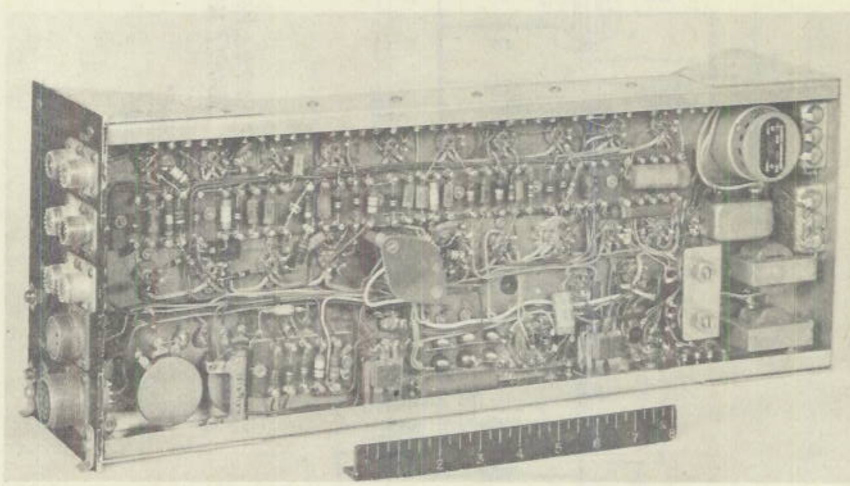

Fig. 11 - Strobe Searching and Locking Unit
Bottom View (Cover Removed)

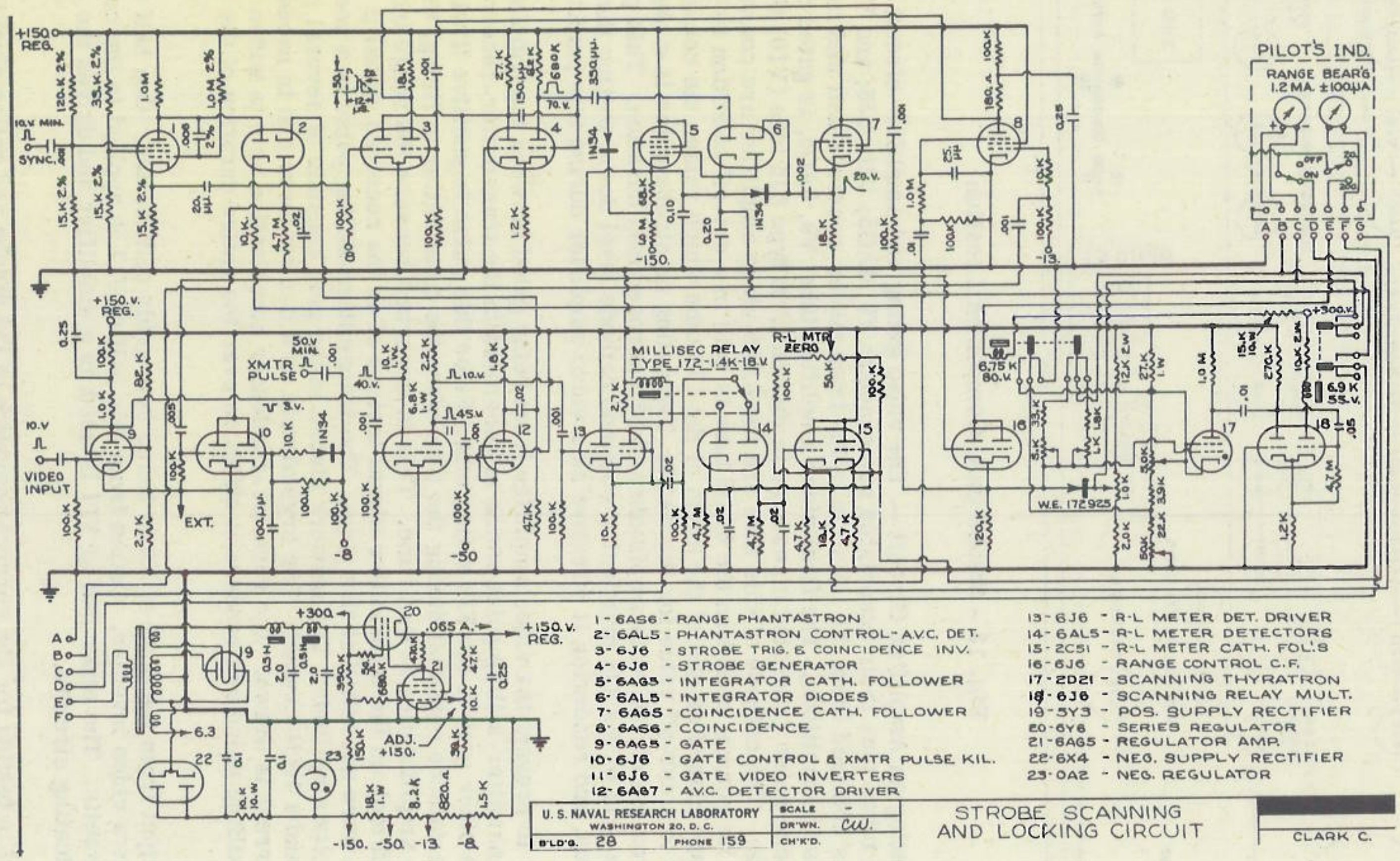

Fig. 12 - Strobe Scanning and Locking Circuit

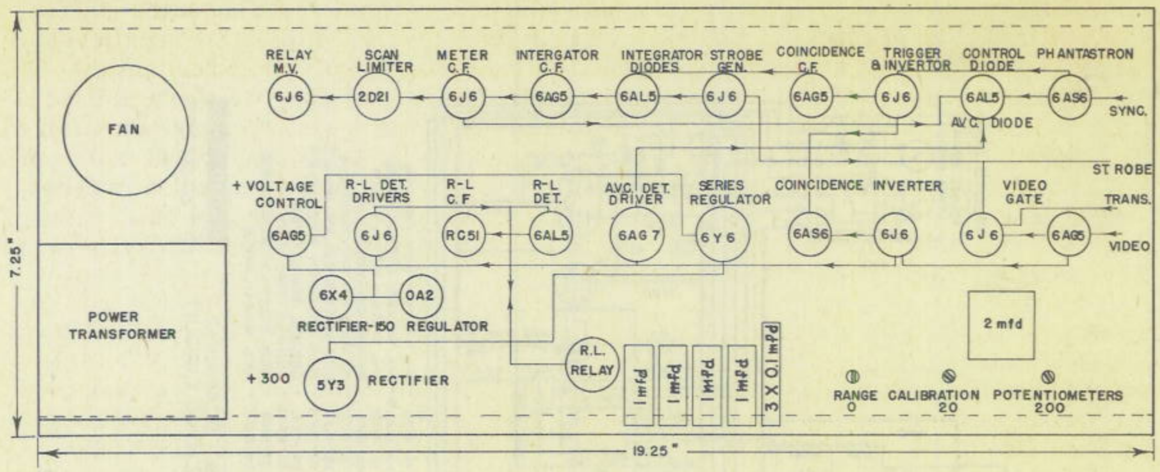

Fig. 13 - Strobe Unit, Component Location

Video Gating an Amplifier Circuit — The video gating and amplifier circuit consist of the following tubes plus their associated components: V9, 6AG5; V10, 6J6; and V11, 6J6. Video input is obtained from the i-f strip in the transmitter-receiver unit and is normally about 10 volts in amplitude. The first video amplifier tube, V9, 6AG5, is gated on by a gating or strobe pulse generated elsewhere in this unit. A type 6J6 tube (V10) is used as the gating tube. The cathode of this tube and the 6AG5 video amplifier are connected together. In its normal condition the 6AG5 tube is held in a cut-off condition by the high positive voltage placed on one of the grids of the 6J6 tube which raises the common cathode voltage level to a cut-off value for the 6AG5. The gating or strobe pulse is a negative pulse of approximately 40 volts amplitude and 12 microseconds duration. This pulse is applied to the grid of the 6J6 driving the common cathode level down, putting the 6AG5 into conduction, and rendering it effective as a video amplifier during this period of time.

In order to prevent the video amplifier from being gated on when the transmitter fires, the transmitter-killing pulse which is generated in the transmitter-receiver unit is applied to the other grid of the 6J6 gating tube. Since this pulse is positive it will prevent the fall of the cathode potential during the time when the transmitter is firing, thus preventing video amplification at that time. This is important because the range indicating circuits would lock on the transmitter signal instead of on the received signal if video amplification were not killed at that time. The transmitter-killing pulse is a positive pulse of 40 volts amplitude. The network placed in the grid consists of several resistors, a condenser and a 1N34 crystal. The crystal acts as a d-c restorer and is needed because some grid current is drawn. The resistor-condenser combination acts to widen the transmitter-killing pulse and renders it effective over the entire duration of the transmitted pulse.

Video output from the plate of V9 is fed to both grids of V11, 6J6. One half of this tube serves as a video inverter. Output from this half of V11 is applied to the coincidence measuring circuits. The other half of V11 is used as a amplifier and drives the AVC and right-left indicating circuits.

As an aid in testing for the correct operation of the strobe and gating circuits the cathode of the gating tube V10, 6J6 is connected to a test plug, marked "Strobe", on the front panel of the unit.

AVC Circuit — The AVC circuit is a high gain delayed type which holds the video output of the i-f strip essentially constant over a very wide range of signal input level. A constant video level is required by the right-left indicating circuits in order that the right-left characteristics be independent of range. The part of V11, 6J6 which is used as a video amplifier drives V12, 6AG7, which is biased 50 volts negative, to give the desired AVC delay. One half of V2, 6AL5 double diode is used as an AVC detector and is driven by V12 which has a very low impedance output so that only a single short pulse is necessary to generate nearly the full AVC voltage. Because of the relatively low PRF of the system, a very long time constant is placed in the AVC circuit to prevent the AVC voltage from decaying materially between pulses.

Right-Left Indicating Circuits — The right-left indicating circuits are fed from V11, 6J6. V13, 6J6, a high-speed single-pole double-throw relay; V14, 6AL5; and V15, 2C51 are the principal components of these circuits. Essentially these circuits are composed of two peak reading voltmeter circuits which compare the amplitude of signal arriving on the right side of the plane with that arriving on the left. The difference in amplitude is translated into a voltage which is applied to a right-left meter in the pilot's indicator unit. This meter is essentially a galvanometer which is so connected as to point to the right if the right-side signal is larger and to the left if the converse is true. The input to these circuits is obtained from V11 and is so controlled by the action of the AVC circuit that the greater of the two signals is held in the neighborhood of 10 volts.

In order to obtain a low impedance signal source the signal from V11 is fed to V13, 6J6 connected as a cathode follower. Only one half of this 6J6 is used. The output of the cathode follower is fed through the high-speed relay to voltage measuring circuits. This relay is controlled by the antenna switch and connects the output of the cathode follower to one peak voltage measuring circuit when the system is transmitting and receiving on the right-side antenna and to the other when the left is in use. Thus the voltage measured by these two circuits will be proportional to the relative signal strengths. V14, 6AL5, which is a double diode, is the principal component of the peak voltage reading circuits. Long time constants are placed in the cathode of this tube in order to prevent rapid changes in output voltage of these circuits which would result in jitter in the right-left indication. Two cathode followers V15, 2C51 drive the right-left indicating meter in the pilot's indicator unit. These cathode followers are driven by the two diode circuits.

The actual characteristics of the right-left indicating system are dependent on a number of things. Of course the actual meter sensitivity may be controlled by varying the size of the resistor in series with this meter. Also small errors in zero set caused either by nonsymmetrical circuitry or antenna pattern may be compensated for by a potentiometer connected between the cathodes of the meter cathode followers and ground.

Probably the greatest factor in the right-left indicator characteristics is the antenna pattern. The effect of the antenna pattern will be taken up in the section devoted to the antenna. The present system is adjusted to give full-scale deflection of the right-left meter for 15 degrees of course.

Automatic Strobe Search and Locking Circuit — The automatic strobe searching and locking circuits consist of a number of circuits which cause the strobe pulse to move out progressively in range or scan until it occurs simultaneously with the reception of a beacon response. Once having found the range of the beacon responses, these circuits will cause the strobe pulse to lock on the responses and automatically indicate to the pilot via the range meter on the pilot's indicator unit, the range of the airplane with respect to the beacon.

Since there are so many individual circuits involved in this chain of circuits they will be taken up individually for the sake of clarity.

Phantastron Delay Circuit — The position or time occurrence of the strobe pulse relative to the transmitter or interrogatory pulse, is controlled by a phantastron delay circuit. This is a conventional phantastron circuit utilizing a 6AS6 type tube which is a sharp suppressor cut-off pentode. The 6AS6, V1 is triggered by the strobe triggering pulse obtained from the transmitter-receiver unit. It is a positive going pulse of about 20 volts amplitude and 2 microseconds length. It is applied to the suppressor grid. The output of the phantastron circuit is a negative going square pulse at the cathode of the 6AS6 of about 10 volts amplitude. The length of this pulse, i. e., the delay introduced by the phantastron, is controlled by the d-c level at which the plate is held. This delay is very nearly linear with plate voltage over a wide range. In order to eliminate some non-linearity at short delays the phantastron delay circuit is triggered 120 microseconds before the transmitter so that the minimum utilized delay need never be below this figure. The B+ voltage is regulated for greater stability.

Delay Control Diode — The time delay, i. e., the length of the pulse at the cathode of V1, 6AS6, is controlled by one half of the V2, 6AL5 diode which clamps the plate of the 6HS6 phantastron at a certain positive level and prevents it from going higher. The cathode of this diode is connected through a small isolating resistor to the cathode of the range meter cathode follower V16, 6J6. Thus the voltage of the cathode relates the phantastron delay to the range so indicated on the range meter which is driven by the meter cathode follower. As was previously mentioned, the other half of V2, 6AL5 is used as an AVC detector.

Strobe Generator Keying Circuit — The strobe generator keying circuit consists principally of one half of V3, 6J6. The end or rise of the delay pulse from the cathode of the phantastron tube is differentiated and applied to the grid of this tube which is biased just beyond cut-off. The plate is tied directly to one of the plates of the strobe generator tube V4, 6J6. The other half of V3, 6J6 is used in the coincidence circuits.

Strobe Generator — The strobe generator is simply a "one-kick" multivibrator circuit utilizing a 6J6 (V4) double triode. Two outputs are taken from this generator, one at each plate. One output is a negative square pulse of 40 volts amplitude, the other a positive square pulse of about 70 volts amplitude. Both pulses are 12 microseconds long. The negative pulse serves as a gating or unblanking pulse for the video amplifier, and the positive pulse is applied to the "bootstrap" integrating circuit.

Bootstrap Integrating Circuit — Two tubes are used in this circuit: V5, 6AG5 bootstrap cathode follower, and V6, 6AL5 integrating double diode. In addition, two 1N34 crystals are used as d-c restorers. One of the 6AL5 diodes is used to place positive charge on a 0.2 microfarad condenser, the other diode is used to remove it. Charge is put in by the positive strobe pulse and is removed only when a video signal is received during the strobe pulse, i. e., when the video amplifier is gated on. More will be said about this when the coincidence circuits are discussed. At present the charging circuit will be considered.

The positive strobe pulse is applied through a small condenser, 350 micromicrofarads, to the plate of one of the diodes of V6, 6AL5. In the cathode is placed the 0.2 microfarad condenser which receives a certain additional charge upon each application of the positive strobe pulse. In order that each successive pulse place the same amount of positive charge on this condenser, i. e., so that the condenser voltage may rise linearly, a bootstrapping circuit is incorporated. The voltage or the 0.2-microfarad condenser is applied to the grid of V5, 6AG6 which is connected as a cathode follower. Thus the cathode voltage of the cathode follower rises with the condenser voltage. Between a tap on the cathode resistor and the plate of the diode is placed one of the 1N34 crystal diodes which maintains the potential of this plate relatively constant with respect to the cathode. It is necessary to tap down on the cathode resistor slightly because the d-c cathode voltage is slightly higher than that of the grid. If this were not done the cathode follower itself would change the condenser. The cathode resistor of the follower is returned to -150 volts in order to make the gain of the cathode follower more nearly constant, and the cathode is bypassed by a 0.1-microfarad condenser to prevent jitter or other short time variations in cathode voltage.

Meter Cathode Follower — The integration condenser drives another cathode follower designated as the meter cathode follower. This circuit employes V16, 6J6, the two halves being connected in parallel. This cathode follower serves two functions: one to drive the range meter, the other to control the delay of the phantastron delay circuit. This control is effected through the delay control diode V2. The chain of circuits beginning with the delay phantastron and returning to the delay phantastron via the delay control diode causes the strobe pulse to step itself out in time or range with each successive transmitter pulse.

Assuming that there is no response received through the r-f - i-f - video channel, the sequence of events which causes the strobe pulse to be progressively stepped out in range may be summarized as follows: the cathode potential of the meter cathode follower fixes the the delay of phantastron delay circuit. At the end of this delay period a strobe pulse is generated by the strobe pulse generator which places additional positive charge on the integrating condenser. The additional charge causes the condenser voltage to rise. This in turn raises the control voltage on the phantastron delay circuit increasing its delay slightly so that the next strobe pulse will occur a little later relative to the transmitter pulse than the previous one. Obviously each successive strobe pulse will be delayed a little more relative to the transmitter pulse so that the strobe pulse may be said to "walk out" in range. Each strobe pulse causes itself to walk out approximately a quarter of a mile. Since the voltage of the cathode of the meter cathode follower determines the position of the strobe pulse in time, or range, by measuring this voltage and using a meter with suitable calibration, this voltage can be and was translated directly into range. As a consequence of the linearity of the phantastron delay circuit, the cathode voltage of the meter cathode follower is very nearly proportional to range.

Scan Limiting Circuits — Obviously the cathode voltage of the meter cathode follower can not be permitted to increase indefinitely. To prevent this condition a scan limiting circuit is employed which restrains the strobe pulse from walking out beyond either 20 or 200 nautical miles depending on the position of the range switch. This circuit causes the strobe pulse to return to zero range after it has scanned the desired range.

The scan limiting circuits employ as their principal elements: a V17, 2D21 thyratron, a V18, 6J6 connected into a one-kick multivibrator circuit, and two double-pole double-throw relays. Bias is placed on the 2D21 thryatron by placing its cathode at a positive potential, the amount being controlled by the position of the range switch on the pilot's indicator unit which controls a relay in the strobe unit. The grid of the 2D21 is connected to the cathode of the meter cathode follower. As the potential of this element rises, a point is reached where the thyratron fires, triggering the 6J6 one-kick multivibrator circuit. In series, with one of the plates of this tube, is placed the other dpdt relay which is normally held in an energized state. However, when this circuit is triggered, conduction switches to the plate causing the relay to open for about a tenth of a second. In the open state one set of relay contacts shorts the integrating condenser to ground, discharging it and causing the cathode follower voltage to fall and the range meter to return to zero. In order to clamp the fall of the range meter the other set of relay contacts short the meter during this period. The very high resistance, one megohm, in the plate of 2D21 thyratron causes it to extinguish very shortly after it has fired making it ready for the next cycle.

Coincidence and Strobe Locking Circuits — The foregoing discussion has been based on the assumption that no video signal is received during the time of the strobe pulse, or video gate. If signal is received during this time the strobe will be restrained from walking out farther in range and may be said to lock on the signal. The following discussion will explain the mechanics of this process.

If a signal is received during the period of the strobe pulse it will be amplified by the then operative video amplifier. The amplified video signal, a positive pulse of 40 volts amplitude, is applied to the grid of V8, 6AS6 which is biased beyond cut-off. In addition a negative square pulse obtained from the gating tube V10, 6J6 is applied through an integrating circuit to the suppressor grid of the 6AS6, which acts to vary the gain of this tube as a function of time during the period of the strobe pulse. More will be said about this shortly. The output at the plate of the 6AS6 is fed to one half of V3, 6J6 which acts as a combination amplifier-inverter. The inverted voltage which is now a positive going voltage is applied to the grid of V7, 6AG5 connected as a cathode follower. The output of this cathode follower is applied to the other half of V6, 6AL5 integrating diode. This half is connected so as to remove positive charge from the integrating condenser. A 1N34 crystal diode is used as a d-c resistor as in the case of the other half of the integrating circuit. Thus this coincidence circuit acts to remove positive charge from the integrating condenser whenever a signal, i. e., a beacon response, is received during the period of the strobe pulse.

The removal of charge from the integrating condenser causes its voltage to fall. In fact, if the circuit is so adjusted as to make the removal of charge by the coincidence circuits equal to the charge put in by the strobe pulse, the condenser voltage will remain constant and the strobe pulse will remain stationary in range. The range meter will now read the range of the beacon and will continue to do so, so long as beacon responses are received.

The balance between charge put into the integrating condenser and that removed is automatically maintained by V8, 6AS6, the coincidence tube. In fact, as the plane approaches the beacon the strobe pulse will actually be made to walk backward in range. This is accomplished in the manner described below.

As previously stated a negative square pulse is applied to the suppressor grid network of the 6AS6 coincidence tube. The shape of this pulse will approximate that shown in Figure 14. Due to the integrating network in the suppressor grid circuit the voltage at the suppressor grid will have the wave form shown in Figure 15. Since the gain of the 6AS6 tube varies greatly with suppressor voltage due to its sharp suppressor cut-off characteristics, the gain of the coincidence tube will vary with time approximately as shown in Figure 16. However, since the gain of the coincidence tube is important only during the time of the strobe pulse, because no signal reaches the tube except during this time, the effective gain will be as shown in Figure 17.

The beacon response pulse is an approximately square pulse of 5 microseconds length such as shown in Figure 18.

From the preceding discussion it is apparent that the amplification the beacon response experiences in the coincidence tube will depend upon the time during which the strobe pulse is received. It follows, therefore, that the amount of charge the response pulse causes to be removed from the integrating condenser is also dependent upon the time during the strobe pulse in which the response is received. The charge removal

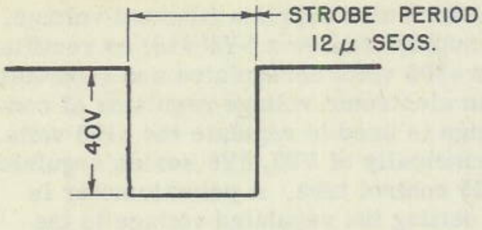

Fig. 14 - Pulse Applied to Coincidence Circuit

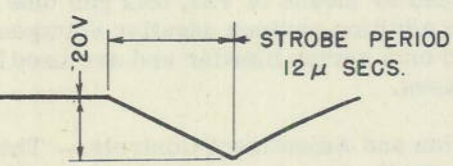

Fig. 15 - Suppressor Grid Voltage

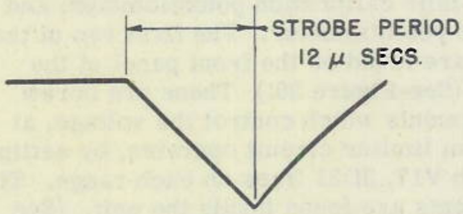

Fig. 16 - Coincidence Circuit Gain

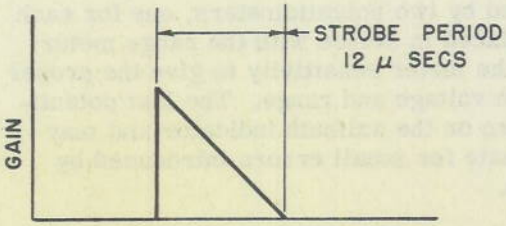

Fig. 17 - Effective Coincidence Circuit Gain

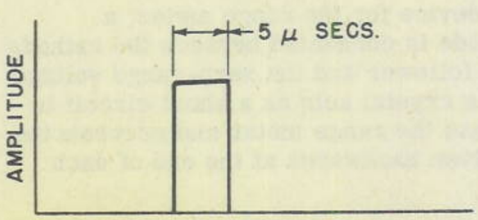

Fig. 18 - Beacon Response Pulse

characteristic approximates that shown in Figure 19. Some charge is shown removed outside the strobe period because the beacon response has width which makes it possible for part of the response to lie within and part without the strobe pulse period.

In operation, the strobe pulse will move out into the beacon response pulse until the amount of charge which is taken out of the integrating condenser is equal to the amount which is normally put into each cycle. If the plane is moving toward the beacon, the response pulse will come back progressively sooner so that it will begin to creep farther and farther into the strobe pulse causing a greater amount of charge to be removed from the integrating condenser. This, of course, causes the condenser voltage to fall and the strobe pulse to occur a little sooner relative to the transmitter pulse thus maintaining synchronism with the reception of the response pulse. The range meter will therefore continuously show the distance of the plane from the beacon.

It is possible to miss several responses in succession and yet not lose synchronism due to the fact that it takes about four or five cycles to move the entire strobe pulse past a given point. This system is designed to maintain synchronism even if three responses in a row are lost so long as the average number of receptions is about 40 percent of the normal 60 pps. If synchronism is lost the strobe pulse will scan the entire range, return to zero and proceed to scan again until it again "picks up" the beacon responses and reestablishes synchronism.

Power Supplies - There are two d-c voltage power supplies in this unit, one positive and one negative. They are both powered by a single

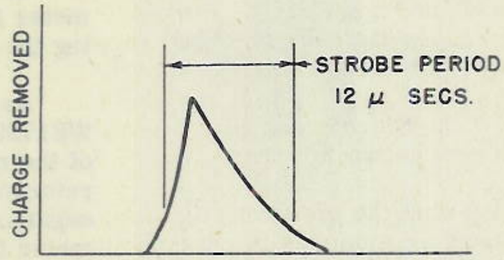

Fig. 19 - Beacon Response Position vs Charge Removed

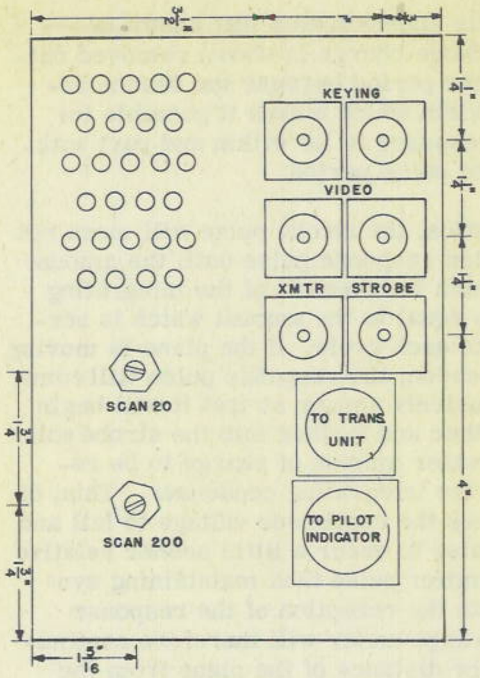

Fig. 20 - Strobe Unit Panel

transformer which also supplies filament voltage. The positive supply utilizes a 5Y3(V19) as rectifier and furnishes +300 volts unregulated and +150 volts regulated. An electronic voltage regulator of conventional design is used to regulate the +150 volts. It consists principally of V20, 6Y6 series regulator and V21, 6AG5 control tube. A potentiometer is provided for setting the regulated voltage to the desired value. The negative voltage supply uses a 6X4 (V22) connected as a half-wave rectifier and supplies a regulated -150 volts. Voltage regulation is accomplished by means of V23, 0A2 gas tube regulator. In addition various negative voltages are furnished on a series bleeder and are used for biasing purposes.

Calibration and Adjustment Controls — The calibration and adjustment controls for the system are found on the strobe searching and locking unit. They are six in number: 20- and 200-mile limit potentiometers; zero-range adjustment potentiometer; 200-mile calibration potentiometer; and azimuth-zero potentiometer. The first two of these adjustments are found on the front panel of the strobe unit. (See Figure 20.) These are screw driven adjustments which control the voltage, at which the scan limiter circuit operates, by setting the voltage at which V17, 2D21 fires on each range. The other four adjustments are found inside the unit. (See Figures 10 and 13.) The zero adjustment is a potentiometer which sets the reference voltage for the range meter, i. e., the negative side of the meter is returned to a voltage which corresponds to zero range. Range calibration is controlled by two potentiometers, one for each range, which are placed in series with the range meter in order to adjust the meter sensitivity to give the proper correlation between voltage and range. The last potentiometer sets the zero on the azimuth indicator and may be used to compensate for small errors introduced by the antenna pattern.

The sensitivity of the azimuth or bearing indicating meter is fixed, but it can be changed if desired by changing the value of the series resistor.

As a protective device for the range meter, a WE172925 crystal diode is connected between the cathode of the meter cathode follower and the zero-range voltage reference point. This crystal acts as a short circuit to negative voltage across the range meter and prevents the meter from being driven backwards at the end of each scan.

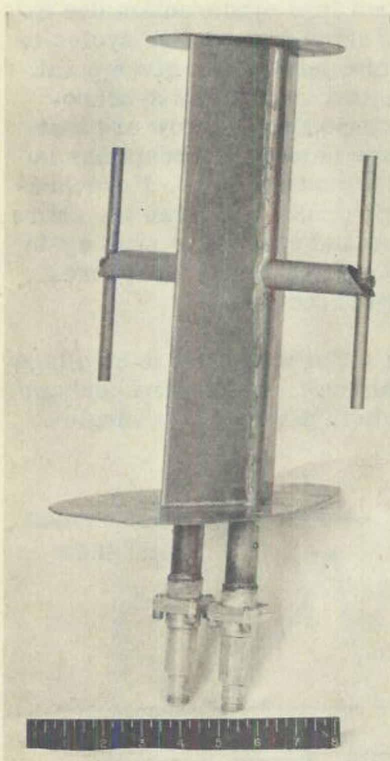

Fig. 21 - Antenna Unit

For test purposes three test points are placed on the front panel of the strobe unit. (See Figure 20.) These

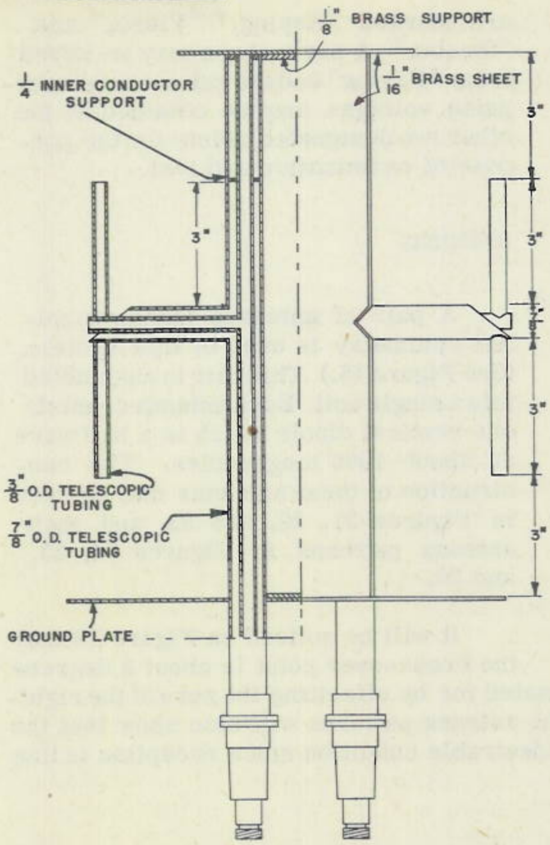

Fig. 22 - Antenna Construction

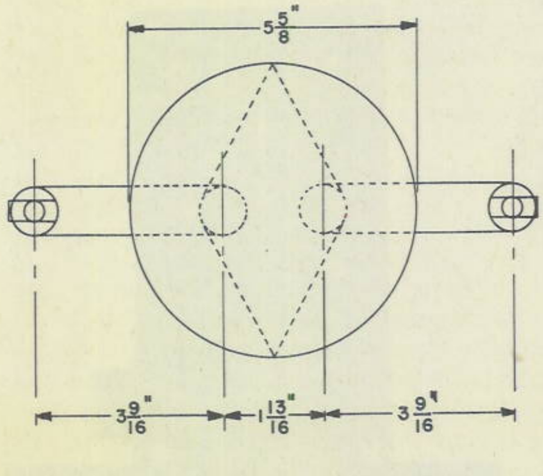

Fig. 23 - Antenna Construction Top View

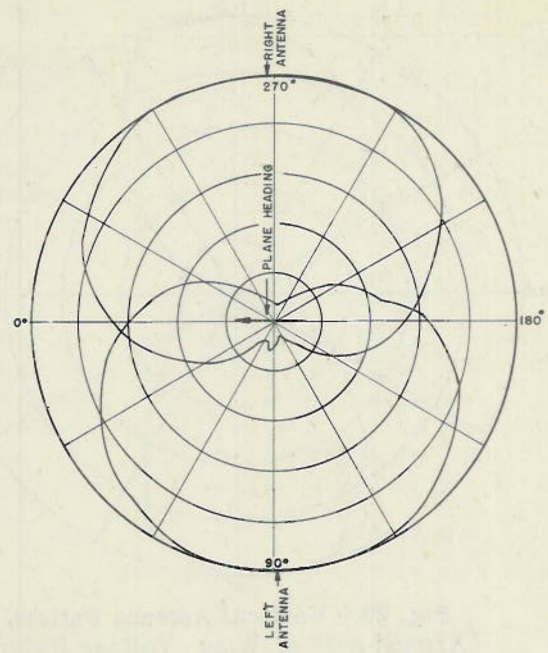

Fig. 24 - Horizontal Antenna Pattern (Voltage Ratio)

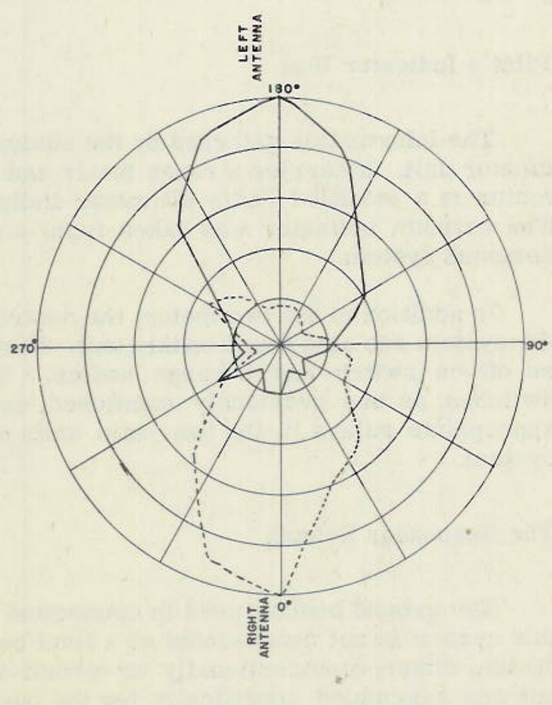

Fig. 25 - Vertical Antenna Pattern Around Axis of Plane (Voltage Ratio)

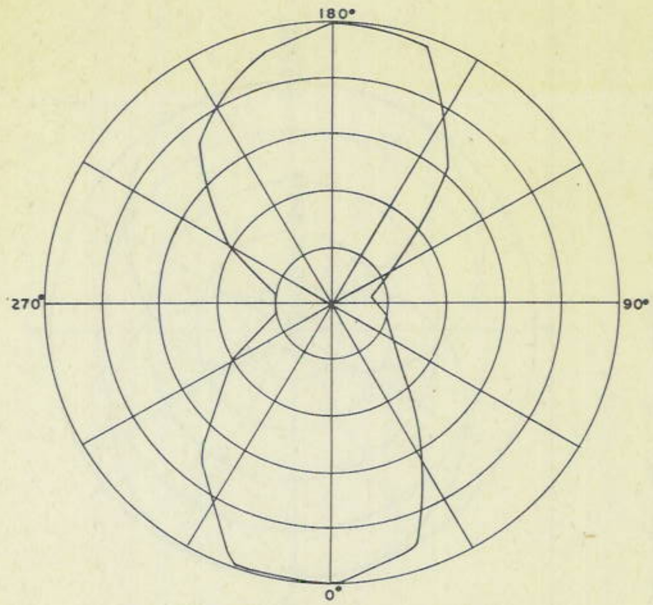

Fig. 26 - Vertical Antenna Pattern (Around Axis of Wing Voltage Ratio)

are marked "Keying," "Video," and "Strobe." A servoscope may be keyed from "Keying" and the video- and strobe-pulse voltages may be obtained at the other two designated points for the purpose of examination and test.

Antennas

A pair of antennas having right-left symmetry is used in this system. (See Figure 15.) This pair is assembled into a single unit. Each antenna consists of a vertical dipole which is a half wave at about 1000 megacycles. The construction of these antennas may be seen in Figures 21, 22, and 23, and their antenna patterns in Figures 24, 25, and 26.

It will be noticed on Figure 18 that the cross-over point is about 3 degrees to the left. This amount may be closely compensated for by offsetting the zero of the right-left meter by a small amount. Examination of the antenna patterns will also show that the greatest sensitivity is in the horizontal plane, a desirable condition since reception is line of sight.

Pilot's Indicator Unit

The information gathered by the equipment is presented to the pilot via the pilot's indicator unit. It carries a range meter and an azimuth meter. (See Figure 27.) The range meter is a modified radio altimeter indicator. The azimuth indicator was taken from a radio compass system.

In addition to the two meter, the controls of the system are also found on this unit. They are an off-on switch and a range switch. These switches, as was previously mentioned, control appropriate relays in the two main units of the system.

The Respondor Beacon

The ground beacon used in connection with this system is not represented as a final beacon design, either constructionally or circuit-wise, but was assembled specifically for the purpose of testing the other components and circuits of the system. Figure 28 gives a circuit diagram of the beacon.

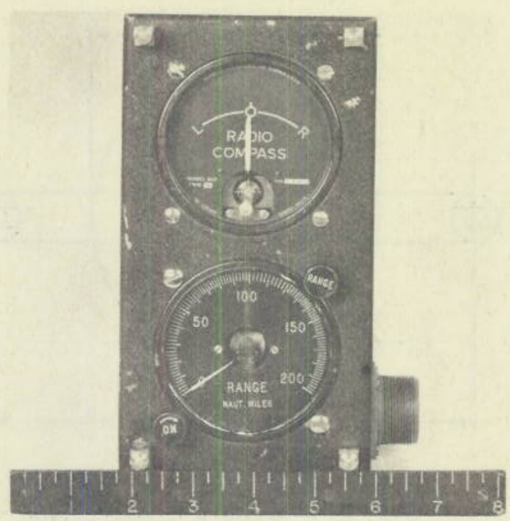

Fig. 27 - Pilot's Indicator

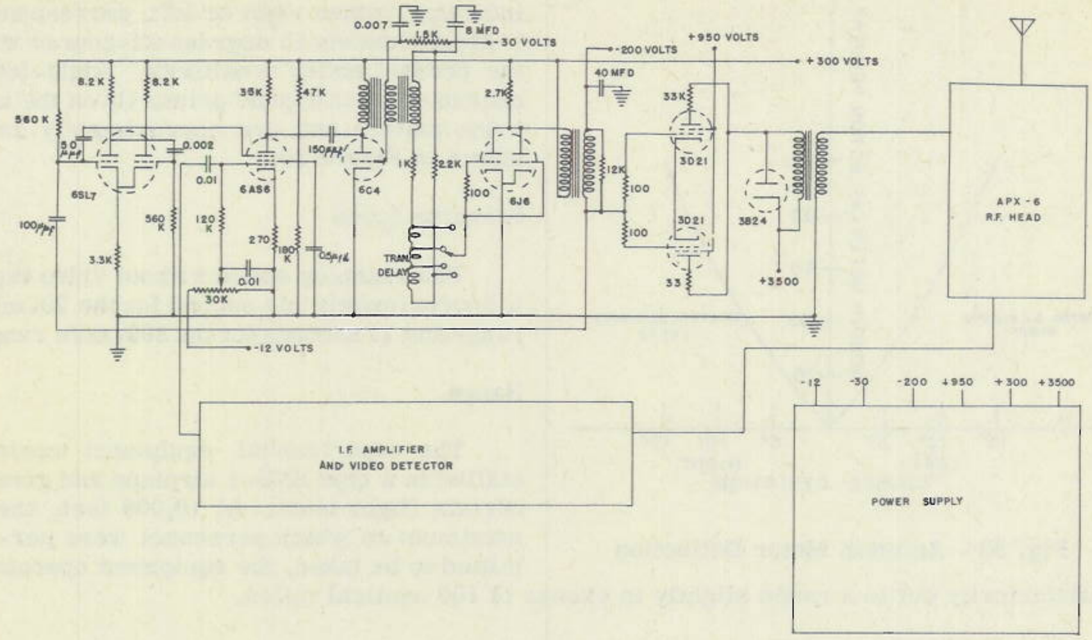

Fig. 28 - Homing System Beacon

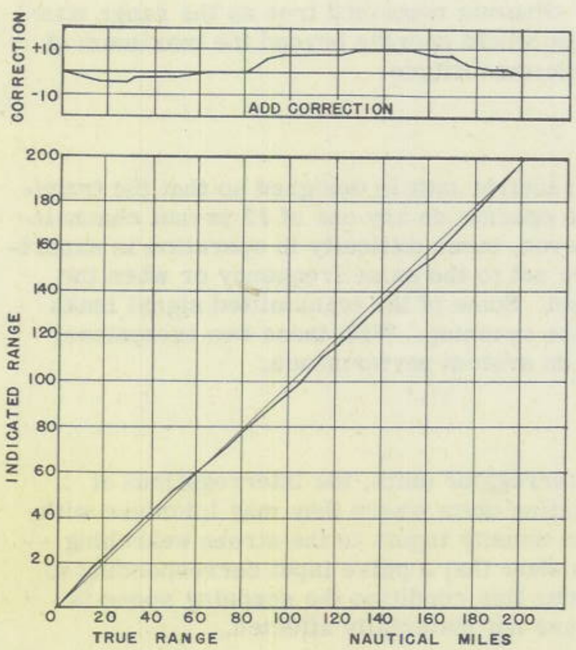

Fig. 29 - Typical Calibration Curve of Range Meter

TECHNICAL CONSIDERATIONS

Sensitivity

With i-f strip gain adjusted to a point where the receiver noise would not interfere with strobe scanning, approximately 30 microvolts input is required to lock the strobe if the input is placed on both the right side and left side of the antenna switch. About 40 microvolts is required if the input is on one side only.

Accuracy

Range error on either range is generally less than 5 percent. Almost all of the range error is attributable to error in the range meter movement rather than to the circuitry of the system. A typical calibration curve for the range meter for the 0- to 200-mile range is given in Figure 29. It is difficult to evaluate the azimuth accuracy accurately because measurements had to be made in a moving plane which does not generally maintain a true heading for any length of time. The influence of air currents also did not permit accurate evaluation. However, flight tests seem to indicate that the azimuth zero indications were not in error by more than 3 degrees. Full-scale deflection of the azimuth

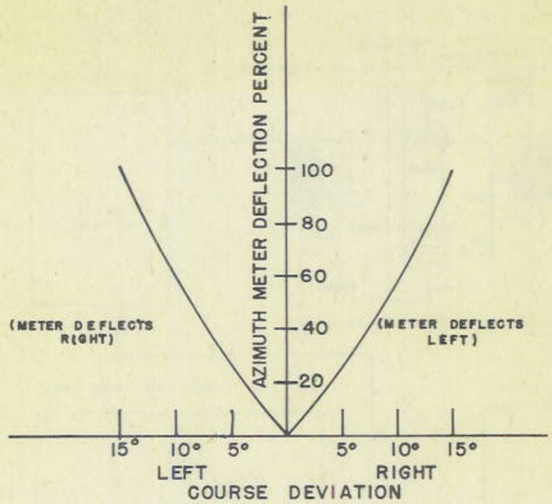

Fig. 30 - Azimuth Meter Deflection

indicator, either right or left, corresponds to approximately 15 degrees off-course with the present meter sensitivity. Right-left characteristics depend primarily on the antenna pattern and are approximately as shown in Figure 30.

Scanning Speed

The scanning speed without video input is approximately one second for the 20-mile range and 11 seconds for the 200-mile range.

Range

The experimental equipment was installed in a type SNB-1 airplane and given certain flight tests. At 10,000 feet, the maximum to which personnel were permitted to be taken, the equipment operated satisfactorily out to a range slightly in excess of 100 nautical miles.

The absolute maximum operable range was not determined owing to altitude limitations. At 6000 or 7000 feet the system would generally cease to function properly for a range of 50 or 60 nautical miles. However, after gaining another 1500 or 2000 feet of altitude, operation again became normal. This situation remained true as the range was increased; consequently, it is felt that the system would operate beyond the maximum of 100 nautical miles obtained if the plane had sufficient altitude.

Effect of Operating Frequency

The r-f head contained in the transmitter-receiver unit is designed so that the transmitter and receiver may independently be set to operate on any one of 12 preset channels in the band from 950 to 1100 megacycles. However, some difficulty in operation is experienced when the transmitter and the receiver are set to the same frequency or when the transmitter is set at the very low end of the band. Some of the transmitted signal leaks into the strobe unit and interferes with the strobe scanning. With these two exceptions, operating frequency seems to have little effect on system performance.

Traffic Handling Capacity

In a system involving a large number of interrogator units, the interrogations of some units might be received by other interrogating units where they may interfere with their normal operation. The effect of high pulse density inputs to the strobe searching and locking unit has been investigated. Results show that a pulse input corresponding to 300 other interrogators could be tolerated. Under this condition the scanning speed is reduced to half but the locking characteristics are not materially affected.

The effect of such a high interrogation rate on the beacon has not been investigated. However, at the present time some theoretical investigations are being made to determine the requirements of a beacon capable of handling such a high traffic condition.

Error in Zero Set

After the strobe scans the entire 200-mile range and then locks on a very short range beacon response, there will be a temporary error in range indication of approximately

1 1/2 miles. This is a characteristic of the 6AS6 tube in phantastron delay circuit in the strobe unit. This 6AS6 tube requires time to receive after long delays. The recovery time is about a minute long after which the meter indication will be correct. No measurable error of the same kind occurs after the strobe has scanned the complete 20-mile range. This error is transitory and increases with scanning range.

COMMENTS AND RECOMMENDATIONS

Azimuth Ambiguity

It is true that the azimuth indicator will show "on course" if the plane is flying directly away from the beacon as well as directly toward it as reference to the horizontal antenna pattern will show. (See Figure 24.) However, this should pose no serious problem because either a simple maneuver or the inherent instability of 180 degrees azimuth zero, will tell the pilot he is flying away from the beacon rather than toward it. Moreover, he would quickly observe that his range is increasing rather than decreasing as it should be. In any case, all the pilot need do is turn his plane, 10 degrees to the right, for example; and, if the azimuth indicator then points to right instead of to the left as it should, the pilot knows that he is flying away from the beacon. In most cases the pilot would not need to do this since air currents will generally cause the plane to change its heading several degrees. In trying to correct for these, the pilot will automatically turn his plane around 180 degrees.

Loss of Beacon Signal

When the plane equipment fails to receive four of five beacon responses in succession, the strobe pulse will fail to remain locked and the strobe pulse will begin to scan the remaining portion of the range and then begin to scan the entire range again. On this latter scan the plane equipment will, in general, pick up and lock on the beacon response again. It is almost inevitable that this loss of signal will take place occasionally and will not be objectionable if not too frequent. The loss is mostly attributable to the beacon which may become swamped with other signals, very often resulting from a burst of noise, so that it will be incapable of responding to plane interrogating. Improvement of beacon design will tend to minimize this effect. A possibility in this direction is to make the beacon sensitive only to pulses of a prescribed width. Occasionally, too, the loss of signal will be due to the attitude of the plane which may be such as to effectively hide the plane antennas from the beacon. This will not often occur in normal flight.

It is, of course, possible to modify the circuits so that the loss of a greater number of responses is required before the strobe becomes unlocked, but this carries the disadvantage of slowing down the scanning speed and rendering the equipment more susceptible to the adverse effects of noise.

Even though the strobe may become occasionally unlocked, it will in most cases remain locked for sufficient periods of time to give the pilot the needed range and azimuth information to enable him to home on the beacon. The results of the flight tests indicated that one can expect the strobe to be locked at least 80 percent of the time even though no special efforts were made to improve the characteristics of the beacon.

Considerations for Antenna Design

The physical design of the antenna to be used with this system will hinge to a considerable extent on the type of plane on which installation is contemplated since the shape of the plane and the location of the antennas on the plane may significantly affect the shape of the antenna pattern. The present antenna was designed to be used on a type SNB plane and was mounted on top of the fuselage near the front in the plane formerly occupied by a direction-finder loop. The SNB is a relatively slow plane and consequently the problem of antenna size and streamlining was not very critical. However, in the case of high-speed planes the present antenna structure would be too large and aerodynamically unsuitable even if it would give a suitable antenna pattern. The antenna problem may therefore be unique with each type of plane and in some cases could cause considerable difficulty.

Ideally one would desire the antennas to exhibit their maximum gain in a horizontal direction but have considerable width vertically, say 60 or 70 degrees, to permit a considerable amount of manuevering. Perhaps one of the most important features of the antenna pattern is the cross-over characteristics of the right and left antenna patterns. The cross-over points should obviously be located fore and aft. If a linear azimuth deflection vs angle-of-course characteristic is desired, the ratio of right-to-left sensitivity on the right side should increase linearity with angle deviation from cross-over point, and similarly for the left side. This feature was not exactly obtained in the present equipment as Figure 30 shows. The ratio increases not linearly but at some higher power of angle off course. To obtain close linearity may be very difficult and in most cases some compromises will have to be made.

Antenna Switch "Ghosts"

An objectionable characteristic of the present antenna switch is its generation of spurious or ghost signals. These signals consist of two short pulses, one for each antenna, which are generated by the antenna switch. The ghost signals have an indicated range of about 140 nautical miles and display considerable jitter. The exact cause of these spurious signals has not been determined although quite a number of antenna experts have been consulted. Tests seem to indicate that they are not caused by the keying or relay switching contacts which are a part of the antenna switch but are somehow caused by the capacity switch itself. These spurious signals are somewhat affected by the transmitter frequency. No great effort was expended in attempting to eliminate them since their effect is slight. Their net effect is to slow down the scanning speed at this 140-mile range. The strobe pulse would not lock on them because of the considerable jitter associated with them.

Size and Weight Reduction

It is felt that both the size and the weight of the existing equipment may be reduced materially without affecting the system performance adversely. In fact, some improvements would probably result.

In the plane equipment there are three separate power transformers, two of which are in the transmitter-receiver unit. Both of these are considerably larger than required. Not only are there separate power transformers but also separate rectifiers and filter circuits. It is felt that these power transformers could be reduced to two in number, one to supply the filament current and low voltage positive and negative supplies, and the other to supply the high voltage required by the transmitter. The saving in weight by means of reduction in size resistors should amount to at least 10 pounds; and there should be accompanying saving of power consumption of about 50 or 60 watts.

The r-f head used in this system was taken from the APX-6 IFF equipment and is quite large and bulky. It seems very probable that a much smaller and lighter unit could be designed which would serve equally well. Probably 5 pounds could be saved here.

With smaller power supplies and r-f head, it should be possible to house the transmitter-receiver unit in a half ATR rack instead of a full one. This would save both size and weight.

Fig. 31 - Indicator Meter

Originally it was attempted to house the transmitter-receiver circuits and the strobing and locking curcuits in a single unit. Some difficulty arose, however, in that the transmitter pulse would leak into the strobe circuits causing premature firing of strobe generator and discharging of the integrating condenser. As a consequence of these and other resulting troubles, no recommendation is given that these two units be combined into one. Also, two separate units generally make the problem of servicing easier.

The present pilot's indicator unit weighs 7 pounds. If the two indicators were combined into one in the form shown in Figure 31, they could be mounted on the dashboard and the weight reduced to 2 pounds.

The antenna switch and the antenna together weigh 14 pounds. These could probably be combined into a single unit. In any case the individual weights could be pared down to a total of 8 pounds without too much trouble.

If these recommended major weight reductions were made, as well as some minor ones which are generally possible, the estimated weights of the component parts would be as follows:

Transmitter-Receiver Unit	15 pounds
Strobe Searching and Locking Unit	15 pounds
Pilot's Indicator Unit	2 pounds
Antennas and Antenna Switch	8 pounds
Total Weight	40 pounds

It is felt that the estimated weight of 40 pounds is conservative. A power consumption of 200 watts is estimated.

The present system requires both a 24-volt d-c source and an 110-volt 800-cycle source. The 24-volt d-c source which is used principally to power the antenna switch motor could be eliminated by using an 800-cycle motor to drive the antenna switch.

* * *

PREVIOUS REPORTS AND CORRESPONDENCE

(1) Proposed Aircraft Homing System, NRL Letter Report S-F42-1/69H(313), S-310-106/45, Serial No. 4925, dated 18 July 1945.

(2) Addendum to Proposed Homing System, NRL letter to BuAer S-F42-1/69H(313), S-310-184/45(emh), Serial No. 5466, dated 22 October 1945.

(3) Proposed New Type of Ranging and Homing System, NRL Report R-2623 (Secret), by R. C. Miedke.

(4) Request for Assignment of Problem, BuAer letter to NRL Aer-E-3114-JRE, F42-9/69, dated 9 November 1945.

PRNC-6394-7-12-48-100