



Automatic control for radio range simulator in instrument flight trainer
by William R Jeffries

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the
degree of Master of Science in Mechanical Engineering

Montana State University

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Abstract:

This report presents a description of the device designed and built by the writer to permit automatic operation of the radio range system of an instrument flight trainer. Many other principles of operation were seriously considered and discarded before the method herein described was finally conceived.

Included are electrical and mechanical drawings which, with the associated text, describe the principle of operation and the physical and electrical details of the model.

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IN INSTRUMENT FLIGHT TRAINER

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WILLIAM R. JEFFRIES

A THESIS

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at

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Approved:

H. Z. Mulliken 8-12-48

In Charge of Major Work

H. L. Hornum 9-2-48
Chairman, Examining Committee

J. A. Nelson
Chairman, Graduate Committee

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97 Graduate Committee

This report presents a description of the device designed and built by the writer to permit automatic operation of the radio range system of an instrument flight trainer. Many other principles of operation were seriously considered and discarded before the method herein described was finally conceived.

Included are electrical and mechanical drawings which, with the associated text, describe the principle of operation and the physical and electrical details of the model.

INTRODUCTION

The following discussion is a complete and detailed description of an automatic simulated radio range control system for instrument flight trainers. While the specifications shown are for one specific model (late type C-3, Link Trainer) the principles of design could readily be applied to an automatic range system for any other instrument flight trainer.

The problem of designing this device was first suggested as a research topic for the writer by Professor T. J. Zilka in 1946. It was felt that a definite need existed for such a device because of the fact that at least two companies were then in the process of attempting its development. Since that time Link Aviation, Inc. has placed on the market a new model trainer which incorporates an automatic range. Only a small amount of information is available concerning the new model but it apparently utilizes ultra-high frequency transmission of range signals from an antenna array mounted directly above the range station to a receiving antenna mounted on the "bug", or recorder. A separate antenna array must be mounted for each different range configuration and, there is apparently no provision for fan-marker signals. Diameter of the "cone of silence" does not change with altitude and there is some static introduced into the signal during transmission.

There is also on the market a completely electronic instrument trainer manufactured by Diehmel which incorporates an

automatic range system. However, no details of any kind are available concerning it.

The design herein described differs very greatly from that used by Link. It is believed to be simpler, more easily maintained, less expensive to manufacture and more readily set up for range problems. Different range configurations are effected by means of adjustments of the main potentiometer, adjustments which can easily be made in a few minutes. Because there is no wireless transmission of the signal there is no distracting static in the tones heard by the student.

Actual research was begun on the project Fall Quarter 1947 and continued through Summer Quarter 1948, the date of completion and submission of this report. Professor Zilka left Montana State College in September 1947 so the research has been largely independent of direct supervision though some valuable advice on technical details has been received from other staff members of the Engineering Division.

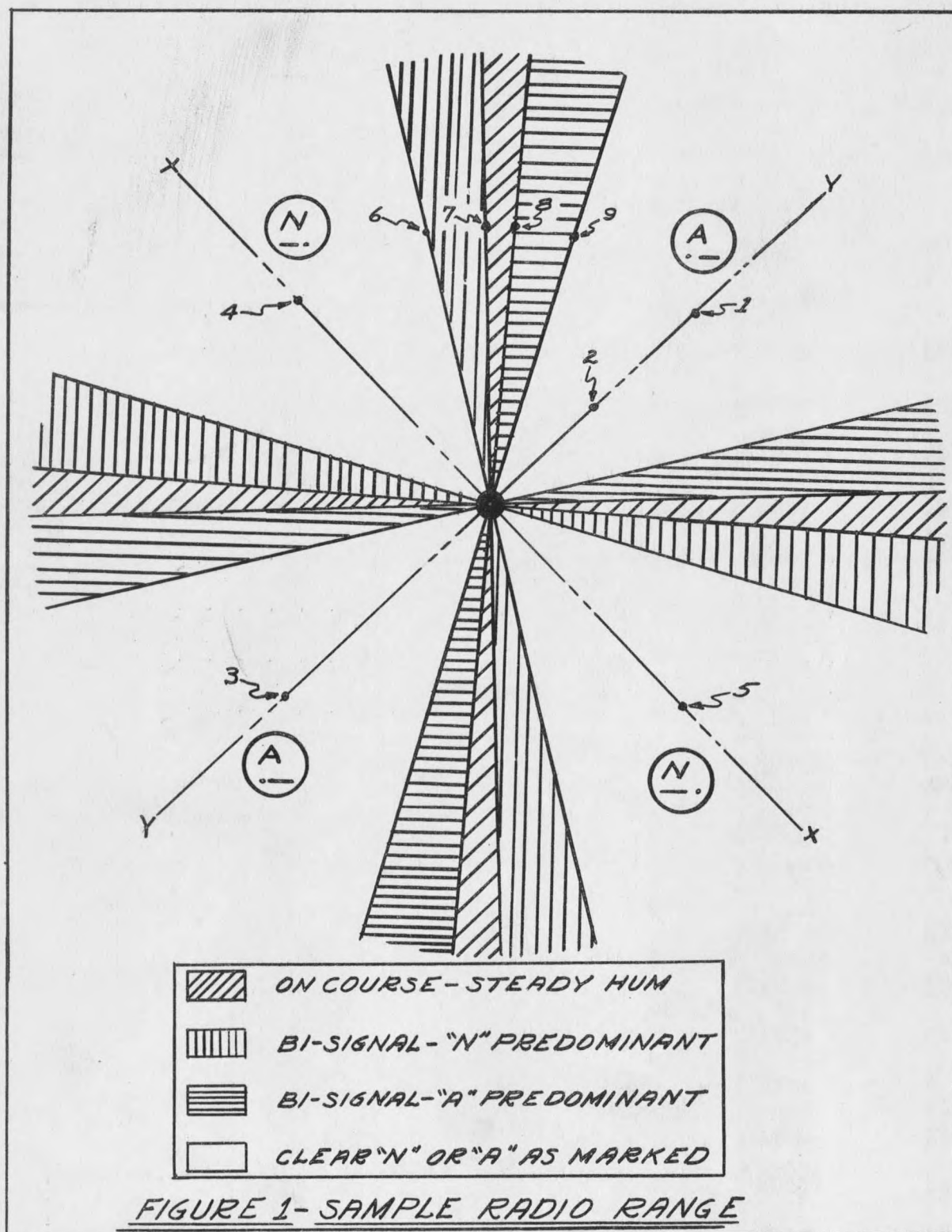
INSTRUMENT FLIGHT TRAINERS

Before attempting to describe the details of design involved, it will be well to treat briefly the background of instrument flight trainers.

When air travel by powered heavier-than-air craft was in its infancy, pilots flew by "contact flight", using visible landmarks to guide them over their routes. During inclement weather, or when fog obscured the ground, it was very difficult to fly cross-country with any reasonable assurance of arriving at the desired destination. A multitude of measuring instruments has now been developed, however, and a well trained pilot can fly several thousand miles without seeing the earth, except, of course, for those times when he lands for refueling, and arrive safely at a predetermined airport. It is not the purpose of this paper to describe in detail those modern flight instruments which make such feats commonplace; however, one of them, the "aircraft radio range receiver" with its associated ground installation, the "radio range system" is important to our discussion and will be explained now.

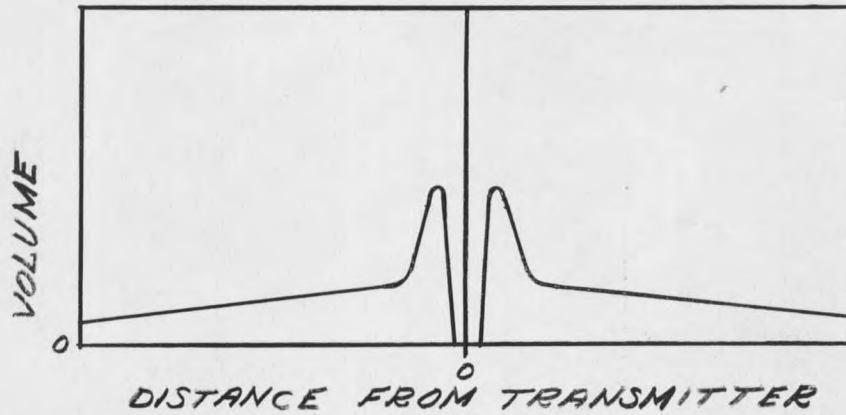
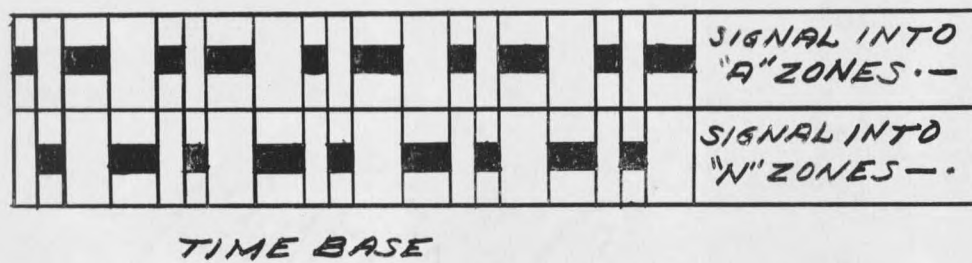
The black dot in the center of Fig. 1 represents a radio transmitter located on the ground. This transmitter broadcasts continuously, sending out the two letters "A" and "N", in code, in different directions. We shall not here be concerned with anything except the effect achieved by this peculiar form of broadcasting. A radio receiver mounted in an airplane at point

1, Fig. 1, would bring to the pilot's ears the code letter "A" repeated over and over. At point 2 the pilot would hear the same signal but it would be louder because of the shorter distance to the transmitter. If the pilot were to fly directly over the transmitter to point 3, from point 1, he would hear first a gradual increase in signal intensity till he came very close to the station, at which time he would hear a sudden increase in volume followed by a complete fadeout as he passed directly over the transmitter; next, in order, would come a loud tone, a rapid decrease in volume, then a more gradual fade as he receded from the station. At point 3, and at all other points on this route, he would hear the same characteristic "A" signal. Figure 2 shows the approximate signal volume plotted against distance from the transmitter. The same volume changes are noted when flying over the station from any angle (e.g. from point 4 to point 5) and the distance of flight with zero signal, directly over the station, increases with altitude so that there is actually a conical shaped zone, having an apex on the ground and a vertical axis, within which no signal is heard. This zone is commonly called the "cone of silence". (Recently, auxiliary transmitters have been installed in many places to send a steady high pitched hum into the cone of silence. This, of course, affords the pilot positive information concerning his location when he is directly above the station in what would otherwise be



a true cone of silence. The transmitter which sends the signal is called a "Z" marker.)

Again referring to Fig. 1, a pilot located at point 4, 5, or any other point in those zones, would hear a steadily repeated "N" signal. If the pilot at point 4 flew in a clockwise direction at a constant distance from the transmitter, the volume of his "N" signal would gradually fade and at point 6 he would begin to hear a very faint "A" signal along with a diminished "N", the "N" being much stronger than the "A". Actually, this will sound like a steady hum with the constantly repeated dash-dot of the N code letter superimposed. The reason for this can be seen by reference to Fig. 3 and Fig. 1. Located in the ground transmitter, Fig. 1, is an oscillator which produces a continuous note. This note is broadcast first into the "N" zones, then into the "A" zones, the timing being such that a dash-dot is heard in the former and a dot-dash in the latter. Lines x-x and y-y are lines of maximum signal intensity for "N" and "A" signals respectively. Fig. 3 shows the timing sequence which produces the N and A. It can now be seen that when the volumes of the two signals become equal the sound heard will be a steady hum. If the pilot continues his clockwise travel from point 6, Fig. 1, he will go through the "bi-signal" (sometimes called "twilight") zone where he hears a predominant "N" with a background "A". As he proceeds the N will become weaker and the

FIGURE 2FIGURE 3 A-N TIMING

A stronger until, between points 7 and 8, the two volumes are equal, and as previously mentioned, the sound is a steady hum. This is the "on-course" zone (two degrees wide) within which a pilot using the range must fly. As can be seen in Fig. 1, there are four of these "on-course" zones or "beams". Between points 8 and 9 is another bi-signal zone; however, in this one, the "A" signal is louder because of the proximity of the clear "A" zone and line of maximum "A" intensity. Further analysis of the sound heard at any point on the range can be easily accomplished by reference to the coded zone markings in Fig. 1.

In actual flight, the pilot attempts to fly within one of the on-course zones, these being laid out along the usual flight paths. They may be spaced 90° apart or at any other angle. It should be here noted that Fig. 1 is an explanatory sketch and not a scaled drawing of any actual radio range.

The "Instrument Flight Trainer" is a classroom device used for training student pilots in the proper use of, among other things, the aircraft radio range system. It consists of a dummy airplane mounted in such a manner that it will respond to movement of its rudder pedals and control stick just as does a regular airplane with one exception: There is no actual forward motion, although the controls may be activated to give effect of forward motion. Its cockpit is fitted with all the regular instruments and controls. In use, the student is completely enclosed inside

the cockpit so that he cannot see outside. When he turns on the ignition switch an electric motor starts, turning a vacuum pump. Through a very complex system of electrical and air-controlled devices all his controls and instruments are made to respond exactly as they would in a real airplane in actual flight; for example, advancing the throttle with controls neutral will cause the airspeed indicator reading to increase. However, advancing the throttle and also pulling back on the control stick will cause the plane to assume a climbing attitude, the airspeed will not increase as much, if at all, and the altimeter will register a steady increase in altitude.

The instructor stands at a table on which is a small three-cornered device mounted on three wheels. These wheels are steered by a servo-mechanism and two of them are powered by small synchronous motors so that the "course recorder", as it is called, will move at all times in the same direction, and at the same "speed" (scaled down to suit a map on the table top) as the "airplane". The third wheel marks the route taken by the course recorder in red ink on the map. This is the theoretical flight path followed by the student in "flying" the dummy airplane. Located in a drawer in the table is a radio control device which produces the "N" and "A" tones which are transmitted through wires to the student's earphones. By proper adjustment of the switches and potentiometers, the instructor can regulate the "N" and "A" volumes to correspond to any

desired location of the trainer relative to the range station. He can also turn on a "Z" marker, indicating a position directly over the station, or a "fan marker". This last is another auxiliary transmitter, in actual radio ranges installed a few miles from the station, one on each of the four courses. It transmits a high pitched note, broken into dashes, the number of dashes corresponding to the on-course zone in which it is located.

When the student is flying a problem, he has a small map of the radio range upon which he supposedly is flying; this is a small scale duplicate of the large map on the table. As the student flies, the course recorder follows his every move, tracing out his flight path on the map. The instructor watches the course recorder and regulates the signal being sent to the student at all times to supply him, in code, with exact information concerning his location. The student thereby learns, in the safety of a classroom, how to interpret the radio range signals and fly according to them.

With the above described arrangement, the instructor must be in constant attendance, which limits the instructor's capacity to one student at a time.

It has been the purpose of the present research to design an automatic device which would control all signals at all times and relieve the instructor of the necessity of constant

attendance, thereby permitting one instructor to handle several students simultaneously. It should also eliminate the possibility of human error. The automatic control device which resulted from the research and development will be described fully, both mechanically and electrically, in the drawings, diagrams and text which follow.

ORIGINAL INSTALLATION - LINK INSTRUMENT TRAINER

We are concerned with the radio control device so a description of the original installation in the late type C-3 Link Trainer follows. Fig. 4 is a complete schematic diagram of the circuits involved. Following this is a description and schematic diagram of the revised radio system. The "A" and "N" notes are produced by a 6C5 vacuum tube (V_1) and its associated circuit acting as an oscillator and putting out a continuous, audio-frequency note. The output of V_1 goes to the center post of a single pole, double throw, cam-operated switch. This is the A-N cam and is so noted on the diagram. From each of the outside contacts of the switch is a wire, one carrying the A and the other the N signal. The oscillator output is thus connected alternately to the A and N channels by the A-N cam in the proper timing sequence (see Fig. 3) to produce a series of dot dashes in the former and dash dots in the latter. The two wires, one carrying N and the other A signals then go to the switching cam contacts marked "SW" on the diagram. Here two cams keep the center contacts of their respective switches connected to the A and N channels respectively except for a short interval occurring every thirty seconds. During these intervals the contact of the A switch is returned to a neutral position while the contact of the N switch is transferred to the output of the station identification switches, which are also cam operated, (these will be described later) so that a series of code

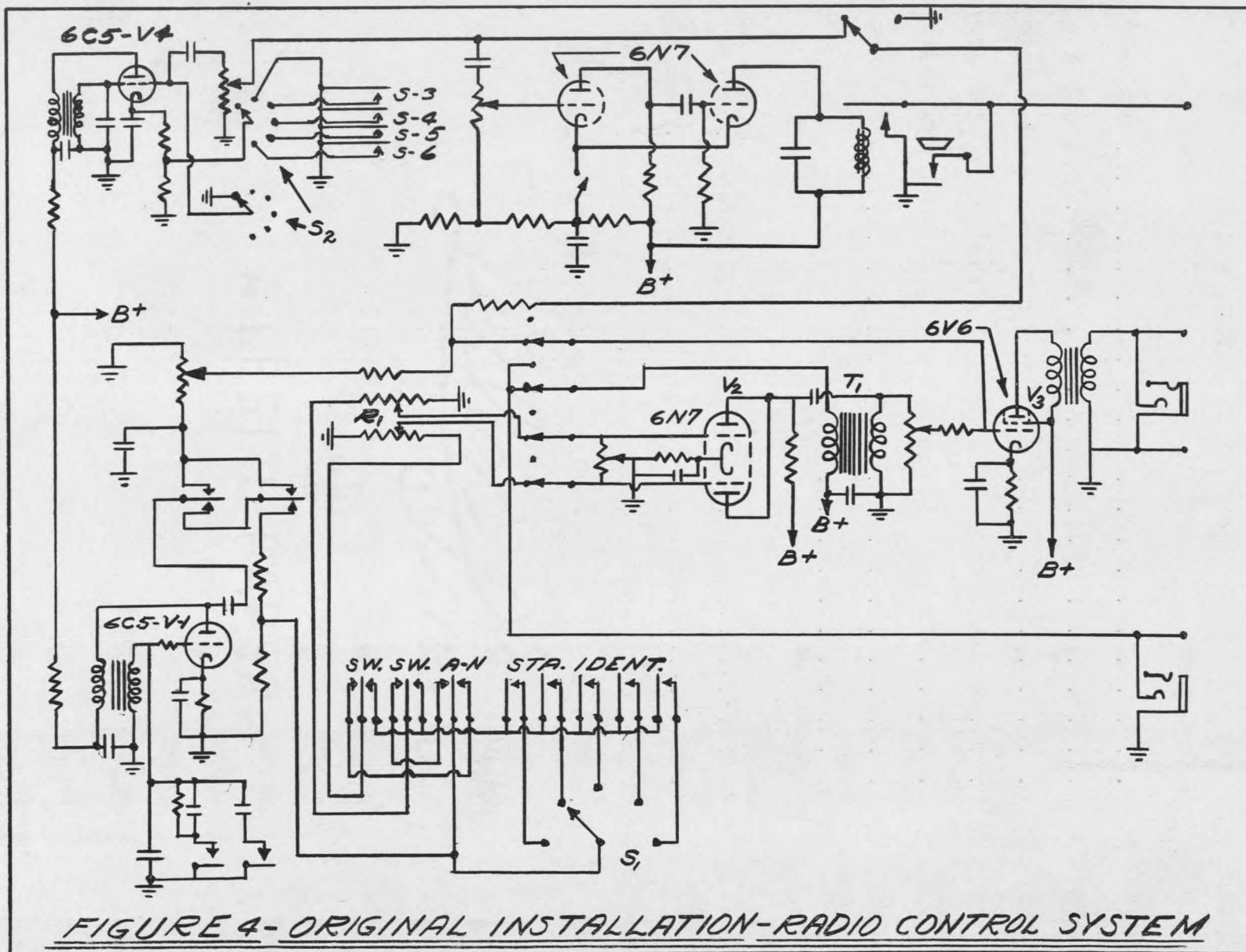
letters is sent into the N channel; then, the N contact is returned to neutral while the A channel is connected to the station identification cam output. If it were possible to tap into both channels here and listen to the signals there would be a steady hum (A and N signals of equal strength) for thirty seconds; then a series of code letters would come through the N channel while the A channel remained silent; then a series of the same code letters would come through the A channel with the N channel silent; then the cycle would begin again. The code letters are produced by the station identification cams and their switches receiving the output of the oscillator V_1 and breaking it into dots and dashes. Each radio range station has its own set of identification letters so that in actual flight, the pilot hears the letters which tell him what range he is flying on. In the Link Trainer the instructor has a choice of five different sets of letters which he can select by turning the station identification selector switch, S_1 . If some other set of letters is desired it can be arranged by installing a properly designed cam in place of one of the five supplied with the trainer.

From the switching cam contacts two wires go to the ends of two potentiometers, R_1 , the other ends of which are grounded. The two potentiometer arms are ganged in such a manner that increasing the potential of one decreases that of the other so

that by turning the one knob the instructor can increase the N and decrease the A output level (or vice versa) simultaneously and in the proper relative amounts. The two potentiometer arms, kept electrically insulated, are then connected, each to one control grid of a 6N7 vacuum tube, V_2 . This tube serves the dual purpose of amplifying and combining the A and N signals into one channel. The 6N7 output is resistance-capacitance coupled to the grid of a cathode-biased 6V6 beam power output tube, V_3 . The 6V6 output goes through an output transformer to a jack on the radio chassis and also through a wire to the headphones in the cockpit of the dummy airplane. Volume control, which is regulated to give distance effect, is achieved at the input side of the 6V6 by a potentiometer R_2 . Transformer T_1 couples voice input into the same channel.

In addition to the A-N and station identification signals, the radio control has provision for Z-marker and fan markers. The tone used for these purposes is higher pitched and is obtained from another 6C5 (V_4) used in an oscillator circuit. The oscillator output is coupled, through a potentiometer volume control, to the grid of the same 6V6 output tube used in the previously described circuit. This oscillator, unlike the other one, does not operate continuously. In the "off" position of the Z-Fan Marker Selector switch S_2 the oscillator output (taken off the control grid) is grounded and the tube is

biased to cutoff. When the switch is turned to any other position the ground is removed from the output; in the Z-marker position a portion of the resistance in the cathode circuit is removed lowering the cathode bias and permitting continuous oscillation. This produces a steady, high-pitched hum in the earphones, corresponding to the sound heard by a pilot flying in the cone-of-silence. When the switch is turned to Fan Marker One (FM1) position, the extra resistance is alternately removed and inserted in the cathode circuit through a cam actuated switch S₃, producing a series of single dashes. This corresponds to the signal heard by the pilot flying over a fan marker on a true north beam, or, if there is no beam located exactly on a true north line, the first beam encountered in a clockwise direction from true north. FM2, the fan marker located on the next beam in a clockwise direction from FM1, is simulated in the Link Trainer by turning the selector switch to position FM2. This produces a series of two-dash signals in the same manner as the one-dash signals are produced in position FM1. FM3 and FM4 operate in a similar manner.



INSTALLATION REVISED FOR AUTOMATIC OPERATION

The device, designed and built by the writer, which permits automatic operation of the radio range system in the Trainer is wired into the same radio chassis as the original installation and a selector switch permits conventional (manual) or automatic operation. With an eye toward savings in space and equipment, advantage has been taken of some previously unused contacts on existing switches so that, for automatic operation, the "Voice-Range---Voice" switch must be placed in "Voice" position and the Z-Fan Marker Selector switch must be in the "Off" position. The automatic feature has been incorporated as an integral part of the original installation and, as such, applies only to the particular model trainer for which it has been designed. However, the general principle could be readily applied to any trainer. Figure 5 shows the revised circuit diagram and Figure 6 shows the general physical appearance of the device.

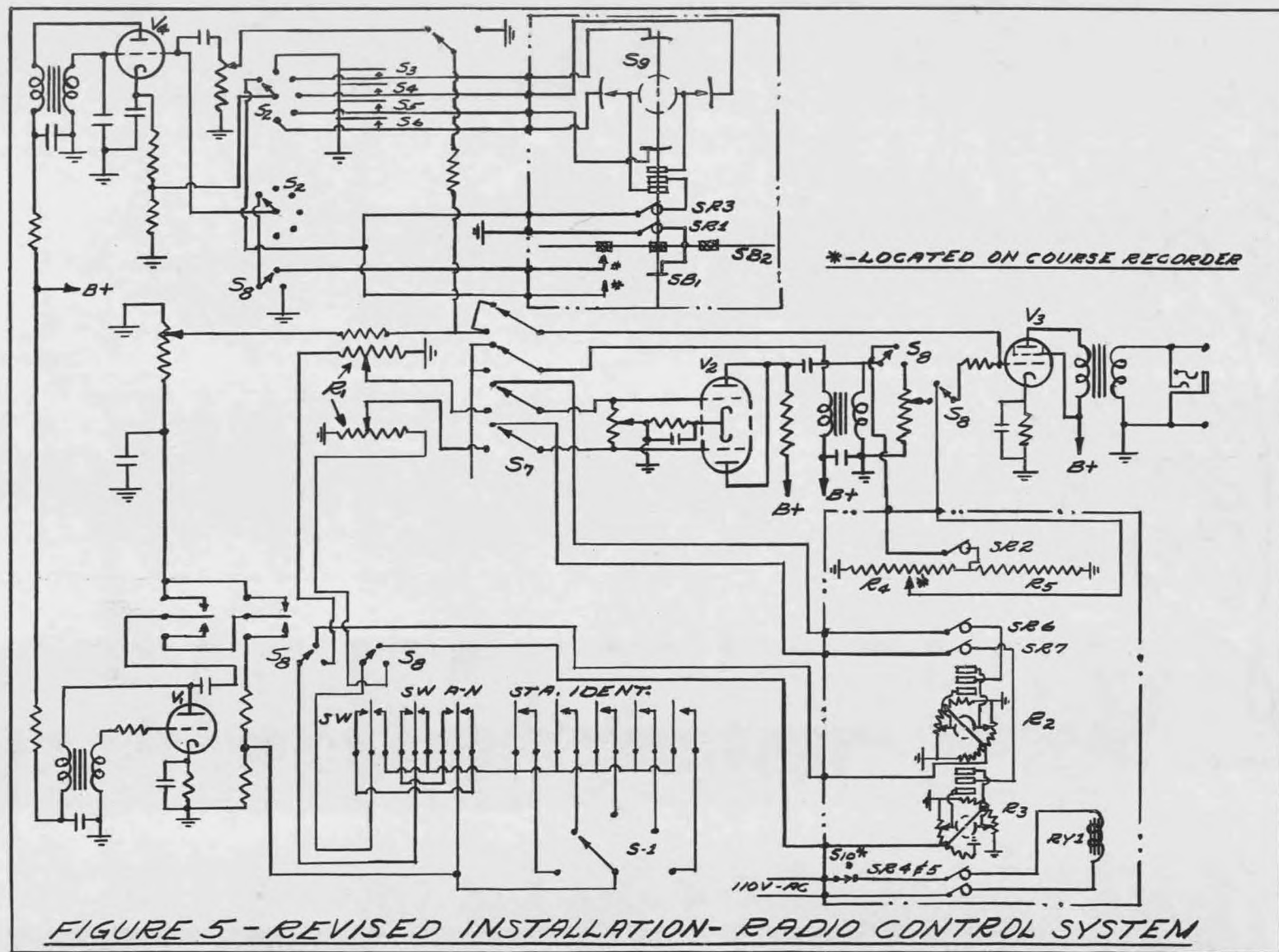
Generally speaking, the A-N potentiometer, R-1, has been replaced by specially built potentiometers, the arms of which are actuated by the course recorder and caused to turn about a center directly above the radio range station. If the course recorder undergoes any angular movement about the station it turns the potentiometer arms and changes the A and N outputs. The mechanical connection between potentiometer arms and course recorder is a horizontal bar pivoted at the potentiometer center and engaging a fork on the top of the course recorder which

slides on the bar. R-2 of the original circuit has been replaced by potentiometers R-4 and R-5 wound on this bar to give distance effect.

Refer to Figure 6. The device consists basically of:

1. A vertical, hollow shaft, 1-3/8 inches in diameter and 9-1/4 inches long at the lower end of which is a horizontal, rectangular bar approximately 1-1/2" x 3" x 32". The arms of R-2, R-3 and S-9, as well as Relay 1 and seven slip rings, are attached to the vertical shaft. R-4, R-5, SB-1 and SB-2 are laid out along the underneath surface of the horizontal bar. There are also two cam followers which can be caused to slide along the bar and move strips of insulation along SB-2. The followers are held against their cam by a coil spring, one end of which is fastened to each follower.
2. A housing which contains two ball bearings to support the shaft assembly, resistors R-2 and R-3, fixed contacts of switch S-9 and brushes (not shown) which contact the seven slip rings on the vertical shaft.
3. A framework which permits the entire working mechanism to be mounted at any desired location above the table top.
4. A pickup assembly mounted on the course recorder. This assembly contains the movable contacts of SB-1, SB-2, R-4 and R-5 as well as microswitch S-10; it also acts as a physical connection between the course recorder and the horizontal bar.

Returning to Figure 5, it may be seen that under automatic, operation, the A-N signal path is from V-1 through the cam-



SCALE ~ APPROX. $\frac{1}{8}$

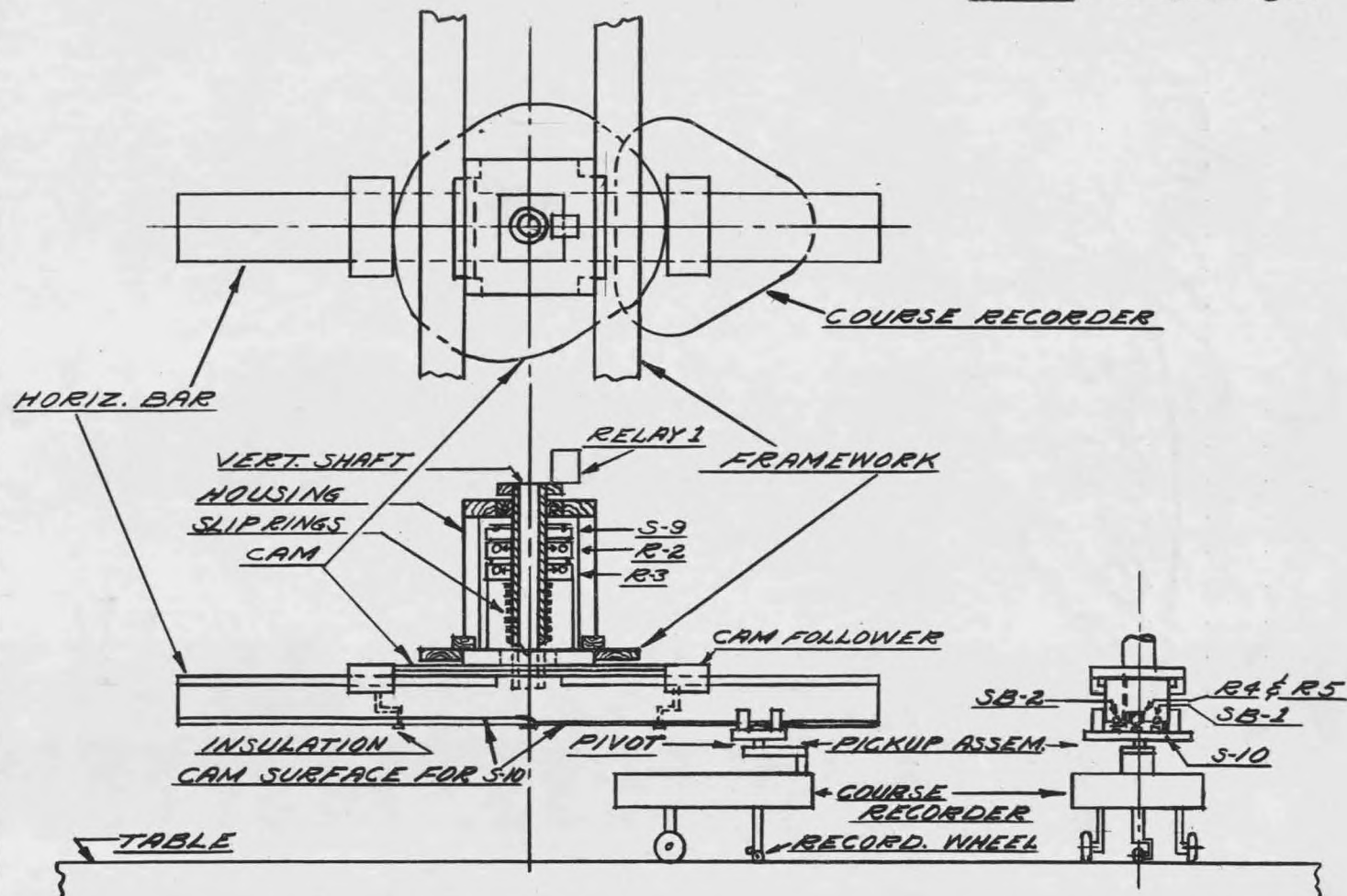


FIGURE 6 - PHYSICAL LAYOUT

actuated switches, just as in manual operation, up to the "Manual-Automatic" selector switch, S-8, which is shown in Figure 5 set for automatic operation. The N signal goes to the centers of the two wound resistors which comprise R_2 while the A signal goes to corresponding points on R_3 . These coils are fixed and are so positioned physically above the range station that the points of highest potential (where the N and A signals are tied in) are on lines X-X and Y-Y, respectively, of Figure 1, or wherever those lines are located for any particular radio range. The ends of the coils terminate in ground connections at the boundaries of their respective bi-signal zones. Figure 7 shows the setup for R_2 and R_3 superimposed on a typical radio range map.

Each potentiometer has two arms, 180° apart, mechanically ganged but electrically insulated from each other. The reason for having two arms will be explained later; assume now that relay 1 is not energized so that the center contacts are connected to the upper contacts, placing the right-hand arms of R_2 and R_3 in direct connection with slip rings 6 and 7. From the slip rings the signal is carried through shielded wires to the upper terminals of two poles of S7, the "Voice-Range---Voice" switch, shown here in "Voice" position. The circuit described thus far has obviously replaced R_1 with R_2 and R_3 , the arms of which fixed to the vertical shaft, are moved when the course recorder undergoes any angular movement about the

center of the assembly. Since the center of the assembly is directly above the radio range station on the map, R_2 and R_3 are at all times correctly adjusted to produce the proper A and N outputs.

From S_7 the signal goes through the original circuit till it comes to two more poles of S_8 which switch the output of V_2 from the manually operated distance potentiometer through slip ring 2 to R_4 and R_5 , the other ends of which are grounded. R_4 and R_5 are resistance coils wound on the horizontal bar. The pickup, shown engaging R_4 in Figure 5, is located on the course recorder and connected through S_8 back to the grid to V_3 . The pickup may engage either R_4 or R_5 depending on which side of the range station the course recorder is operating. The combined resistance of R_4 and R_5 in parallel is the same as that of the potentiometer which they replace. Their effect is to automatically adjust the signal input to V_3 according to the distance of the course recorder from the center or station. The resistors are so designed that they will produce the volume changes in the manner shown in Figure 2.

The necessity of having two arms on each of the potentiometers R_2 and R_3 may be examined now. In the actual mechanism R_2 is located directly above R_3 and their centers are on a vertical line, the line which, if extended downward, would pass through the center of the range station. When the course

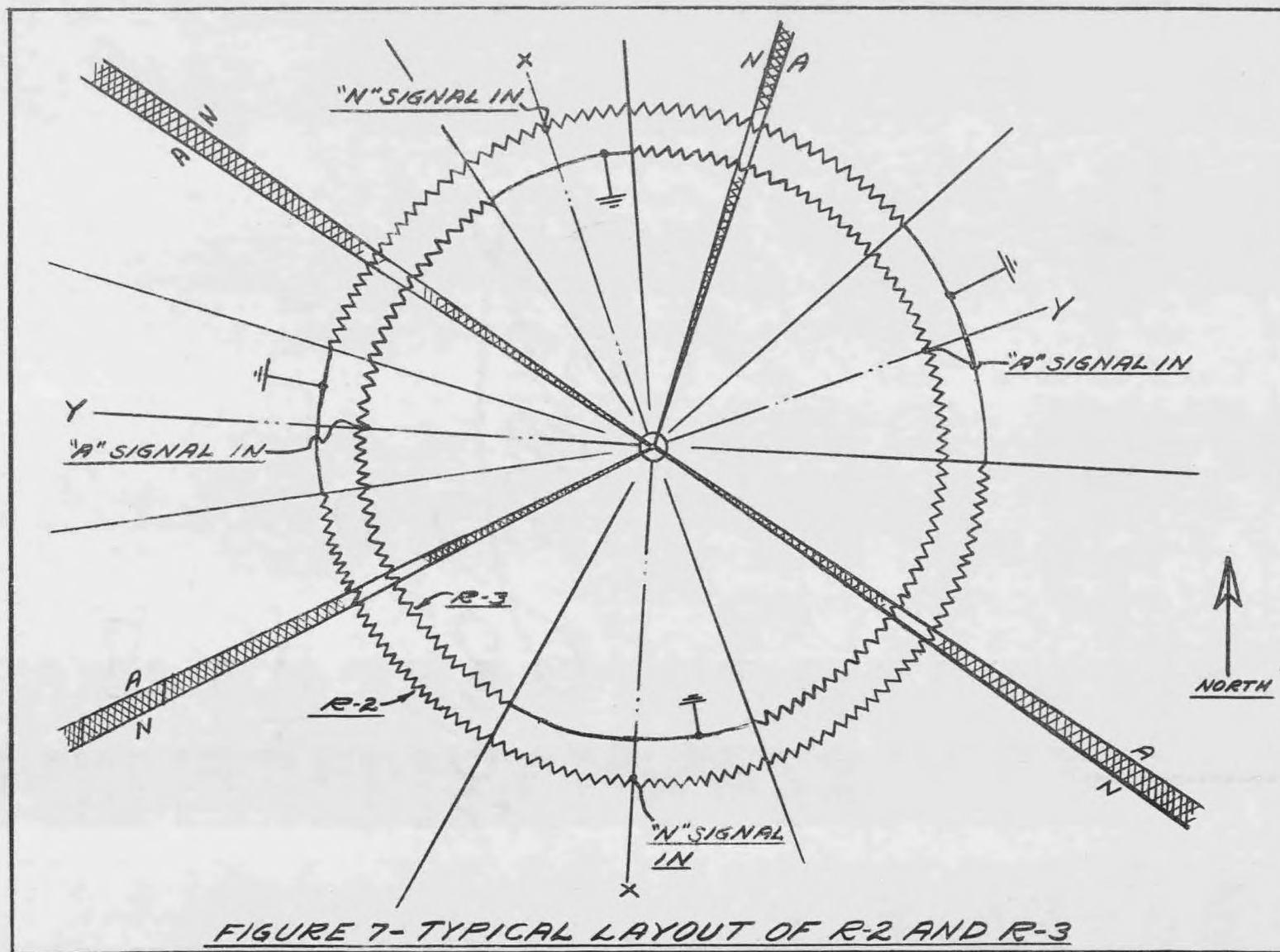


FIGURE 7- TYPICAL LAYOUT OF R-2 AND R-3

recorder is to the right of the station for example, relay 1 is not energized and the right hand arms of R2 and R3 are connected through the relay contacts to the slip rings. The potentiometer coils which these arms engage are wound correctly for that portion of the radio range. Now, if the course recorder were to describe a circular path about the station to the left-hand side, the arms would be carried around to the other coils on the potentiometers, these coils being properly made for the left-hand portion of the range, and the correct signal would be sent out. However, if the course recorder were to travel from its original right-hand position directly through the range station to the left-hand side, it would be operating 180° physically from the potentiometer arm. To correct this difficulty a second arm has been incorporated on each of the potentiometers. When the recorder passes directly through the station a micro-switch, S-10, located on the recorder, is closed by a cam surface on the horizontal bar and relay 1 becomes energized, switching the circuits in such a manner that the left hand arms are connected to the slip rings.

The remaining requirement for fully automatic operation is that the Z marker and Fan Markers be made to function in that manner. The mechanism which accomplishes these effects is shown enclosed in phantom lines in the upper center of Figure 5. S-9, which produces Fan Marker effects, is located actually directly above R2 and R3 and the two arms, with the contacts

of relay 1, function exactly as do the arms of the potentiometers. The arms engage strips of copper, each strip placed on a radial line corresponding to a radio beam of the range; the arrangement shown in Figure 5 is for four beams spaced 90° apart. Each strip is connected to one contact of switches 3 through 6. SB2 (shorting bar 2) is a piece of heavy copper wire mounted parallel to R4 and R5 on the horizontal bar and connected through slip ring 1 to a ground on the radio chassis. It is covered in three places by strips of insulation, the outer two of which are movable along the wire and positioned by a cam. SB1 is a very short copper wire connected to and mounted parallel to SB2.

Let us now re-examine Figure 4 to recall the method of operation of the Z and Fan Markers. V4 and its associated circuit will produce an audio frequency output when a portion of the resistance is removed from the cathode circuit and a ground connection is removed from the control grid. Under manual operation the Z-Marker effect is achieved by placing S2 in the "Z-Marker" position (second position counting clockwise), and a continuous note is produced. Looking now at Figure 5 it can be seen that this effect is achieved automatically when the two pickups on the course recorder approach a central position. The upper pickup is removed from ground when it strikes the central strip of insulation on SB2, thereby removing the ground connection from the grid of V4. The lower

pickup shorts out the extra cathode resistance when it strikes SB1. In this manner the oscillator is made to produce a continuous note while the course recorder passes through the cone of silence. Any desired altitude may be simulated by choosing the proper length for SB1 and the insulation on SB2.

In Figure 4, Fan Markers are achieved by connecting the top of the extra cathode resistance through S2 to one of the cam operated switches S3, 4, 5, or 6. In Figure 5 it may be noted that when the proper arm of S9 is aligned with one of its contacts, (This will occur when the course recorder is located on a beam.) the cathode resistance is connected to one of the cam operated switches. However, the grid of V4 is grounded by SB2 except when the pickup is removed from it by striking a strip of insulation. The two outer strips are positioned by a cam so that they are at the same distance from the station as is each Fan Marker. Therefore, a Fan Marker signal will be heard when the course recorder is on a beam and is the proper distance from the station. The four connections from S9 to the cam-operated switches are so made that the correct number of dashes will be produced for each marker.

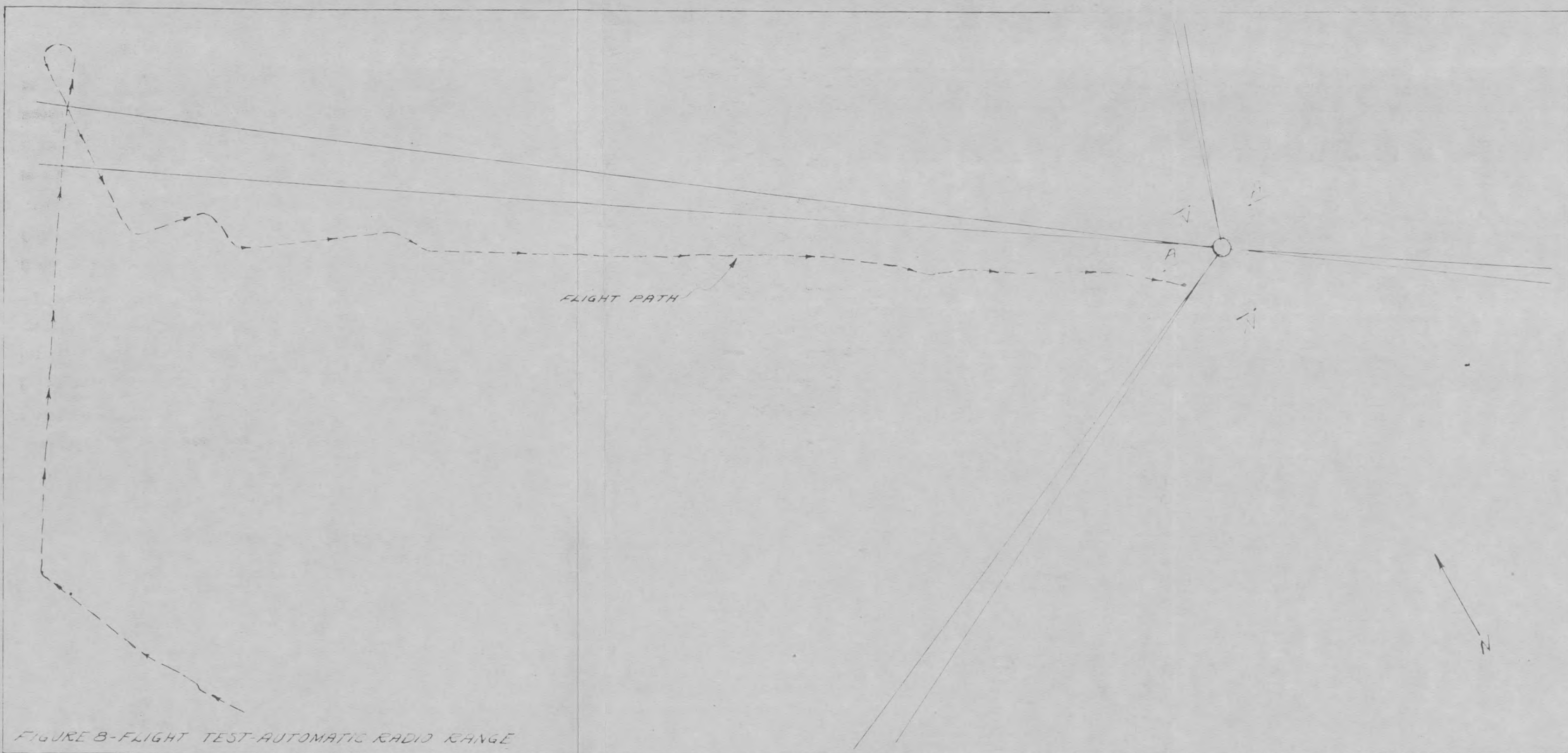


FIGURE B-FLIGHT TEST-AUTOMATIC RADIO RANGE

CONCLUSIONS

The purpose of this project was "--to conduct research into the possibilities of designing an automatic radio range for instrument flight trainers". There was some doubt at the outset as to the possibility of working out any practical solution to the problem. However, the writer believes that he has answered the question with a definitely affirmative reply. The model built in the Montana State College laboratory is, naturally, a "laboratory model", as is the first of any new machine or device, and some additional refinements would undoubtedly be found desirable during the course of placing it in production. However, the basic ideas, both electrical and mechanical, embodied in the model are believed to be entirely sound and practical so that any changes would be minor ones. Figure 8 shows the results of an actual test made on this device.

LITERATURE CITED AND CONSULTED

Army Air Forces Manual--"Instrument Flying-Basic"

Army Air Forces Manual--"Instrument Flying-Advanced"

Army Air Forces Manual--"Instrument Flying-Instrument Trainer"

Army Air Forces Manual--"Instrument Flying Trainers"



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