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DOPPLER CONTROL OF EJECTION-TYPE EMERGENCY BARRIER

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DOPPLER CONTROL OF EJECTION-TYPE EMERGENCY BARRIER

CONTENTS

ABSTRACT

A control system utilizing doppler radar and analog computing techniques has been developed which will actuate an accelerator used to raise a cross-deck cable at such time that this emergency barrier will miss the nosewheel of tricycle landing-gear aircraft and engage the main landing gear of any landing aircraft. A doppler radar antenna located on the aft end of the flight deck and oriented forward is used to measure the velocity of the landing aircraft. A zero-position doppler radar antenna located on the side of the flight deck and oriented perpendicular to the velocity doppler radar is used to determine the instant at which a given point on the aircraft is at a specified distance from the barrier. When the reference point of an aircraft traveling with a speed greater than 35 knots passes the zero-position, an analog computer unit is initiated which determines by means of appropriate circuits and parameters the proper instant for actuating the barrier accelerator. These parameters include (a) the voltage corresponding to the instantaneous velocity of the aircraft, (b) the distance from the reference point to the main landing gear, (c) the distance from the zero-position to the barrier, and (d) the time delay between actuating and final positioning of the barrier. Evaluation of a single-barrier model has shown that the barrier can be actuated with ± one foot of the required position relative to the aircraft. By using one velocity radar, three zero-position radars, and three computer units each with two null detectors, six barriers 25 feet apart may be controlled. The control system described is believed sufficiently flexible in design to be applicable to the most general specifications for the barrier and adaptable to most types of carrier-based aircraft.

PROBLEM STATUS

This is a final report on the problem; unless otherwise notified by BuAer, the Laboratory will consider the problem closed one month from the mailing date of this report.

AUTHORIZATION

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DOPPLER CONTROL OF EJECTION-TYPE EMERGENCY BARRIER

INTRODUCTION

A series of emergency barriers are located aboard aircraft carriers immediately following the normal arresting gear system. The primary purpose of this barrier system is to prevent collision of a landing aircraft with other aircraft that may be parked on the foredeck or to prevent the landing aircraft from going overboard. A secondary requirement of the barrier is to accomplish this emergency arresting with minimum damage to the aircraft.

The fixed-position emergency barrier (a cable suspended cross-deck) used with aircraft having conventional-type landing gear is inadequate for use with aircraft having tricycle-type landing gear. A fixed-position cable either fractures the nose gear causing the aircraft to somersault forward or passes over the fuselage with likely hazard to the pilot.

Therefore, to provide positive emergency-barrier engagement of various types of carrier-based aircraft, particularly those having tricycle landing gear, it is necessary to construct an ejection-type barrier which will eject an arresting cable from deck level with appropriate synchronization to cause the cable to rise aft of the nosewheel and engage the aircraft's main landing gear. The purpose of this project is to develop a suitable control system for actuating such a series of ejection-type barriers with the required fractional-second timing for engagement. The accelerator for such ejection-type barriers is being designed and constructed at the Naval Air Material Center (1). This report presents the results of the developmental work on the application of doppler radar as a means of velocity measurement and position determination for control of ejection-type barriers.

SPECIFICATION ANALYSIS FOR BARRIER CONTROL

The limits placed on the trajectory of the landing aircraft for successful emergency arresting are (2):

(a) Aircraft landing speeds between 35 and 105 knots.

(b) Aircraft touching the deck and in various angles of yaw and pitch within 15 degrees of the horizontal and vertical axes.

(c) The same as (b) except main wheels above deck 18 inches as measured from the bottom of tires.

A full-scale model of the cable accelerator is yet to be completed by NAMC. Because specifications for the barrier operating characteristics are not available, only the most general specifications for the control system can be developed at this time. Any barrier accelerator devised must transmit sufficient momentum to give the arresting cable an average velocity $\overline{V}_c$ about equal to the maximum approach velocity of the aircraft at the barrier position. That is,

$$\overline{V}_c > V_m H/M \tag{1}$$

where V_m is the maximum approach velocity, H is the minimum vertical distance traversed by the cable to assure positive engagement, and M is the distance between the nosewheel and the main landing gear.

If it is assumed that $\overline{V}_c$ is a constant within limits of H variation for all types of aircraft, then the time required for the cable transport is

$$T_c = H/\overline{V}_c . \tag{2}$$

Furthermore, because of inertia, the barrier system will possess an additional time delay T_i between the reception of the triggering signal and the beginning of cable motion. Thus barrier ejection should be initiated at the instant when a point on the aircraft a distance,

$$D = V\,(T_c + T_i) \tag{3}$$

forward of the main landing gear passes the barrier, where V is the instantaneous velocity of the aircraft. It is assumed that acceleration of the aircraft during the interval $(T_c + T_i)$ is negligible.

In addition to the barrier, another deck reference position, a zero-position, will be needed from which the timing of the operation can begin for a given reference point K on the aircraft (Figure 1). If the distance from the barrier to the zero-position is L, and the distance from K to the main landing gear is N, then the distance of the main landing gear from the barrier at any time, t, after K passes the zero-position is

$$L + N - \int_0^t V\,dt.$$

The barrier should be actuated when

$$L + N - \int_0^t V\,dt = D = V\,(T_c + T_i) \tag{4}$$

with a maximum error of about plus or minus one foot.

Such precision triggering could be obtained using analog computers provided suitably accurate means could be developed for measuring the aircraft's instantaneous forward component of velocity and determining the instant at which point K departs from the zero position. One analog computer component would be required to furnish a continuous and instantaneous output equivalent to the left member of Equation (4) and a second component would be required to do the same for the right member. When the outputs from the two components are equal, as measured by a null detector, the barrier would be actuated.

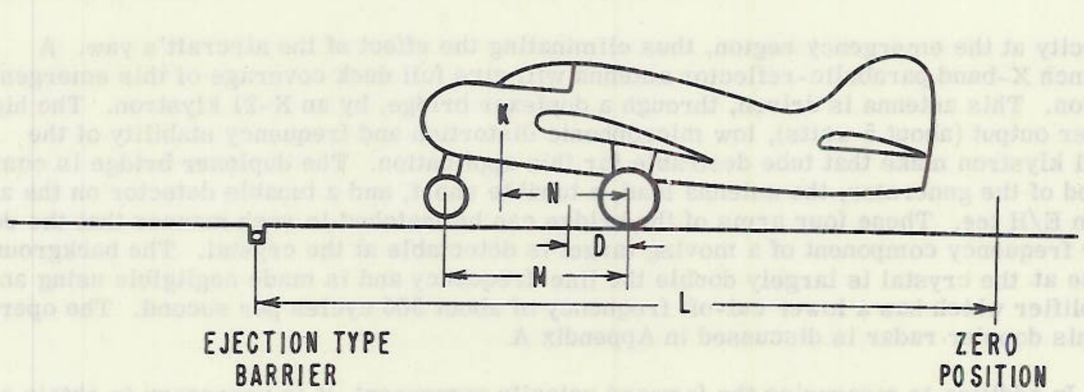

Figure 1 - Carrier flight deck

The magnitudes of parameters N and T_c will be a function of the aircraft type. For tricycle landing-gear aircraft, K would probably be the nosewheel and thus N would be equal to M; for conventional landing-gear aircraft, K would be the main landing gear and N would equal zero. If $\bar{V}_c$ were sufficiently large, T_c could become negligible which would necessitate allowing for the diameter of the landing-gear wheel in the calculations; otherwise, the cable might strike the wheel and be deflected toward the deck. If the barrier design incorporated a hold mechanism to fix the cable at the required height until engagement, T_c could be a constant parameter. Since such a mechanism may or may not be feasible, it is likely that remote control will be required to insert proper parameters for each type of aircraft to be landed.

It is to be noted that as the barrier specifications are supplied in greater detail the control system may simplify. However, the control system described is believed sufficiently flexible in design to be applicable to the most general specifications for the barrier and adaptable to most types of carrier-based aircraft.

APPLICATION OF DOPPLER RADAR TO BARRIER CONTROL

Doppler radar is a velocity measuring technique. It can be shown that to a very good approximation the frequency of the beats between a transmitted continuous-wave sinusoidal oscillation and the echo signal reflected from a moving object is

$$F = 2V/\lambda \qquad (5)$$

where V is the component of velocity of the object in the direction of propagation and λ is the wavelength of the transmitted radiation. Recent developments in klystron oscillators make such velocity measurements very practical. For example, F 35 cycles/sec/knot with an X-band klystron ($\lambda = 3$ cm) which produces a convenient frequency for amplification. Since it is required to measure only the forward component of velocity when the aircraft is in the emergency region, a stationary antenna oriented forward located at approximately the center of the aft end of the flight deck can be utilized. The emergency region is defined as the area extending from the final normal arresting cable to the final emergency barrier. For carriers of the CV-9 class and CVB-41 class the forward velocity component of the aircraft as measured from a stationary antenna is within ± 1 percent of the measured relative velocity at the emergency region, thus eliminating the effect of the aircraft's yaw. A 12-inch X-band parabolic-reflector antenna will give full deck coverage of this emergency region. This antenna is driven, through a duplexer bridge, by an X-21 klystron. The high power output (about 5 watts), low microphonic distortion and frequency stability of the X-21 klystron make that tube desirable for this application. The duplexer bridge is composed of the generator, the antenna load, a tunable short, and a tunable detector on the arm of an E/H tee. These four arms of the bridge can be matched in such manner that the doppler frequency component of a moving target is detectable at the crystal. The background noise at the crystal is largely double the line frequency and is made negligible using an amplifier which has a lower cut-off frequency of about 500 cycles per second. The operation of this doppler radar is discussed in Appendix A.

In addition to measuring the forward velocity component, it is necessary to obtain a synchronizing signal at the instant the reference point K on the aircraft passes the zero-position. Such a signal also can be obtained using doppler radar. This second doppler radar consists of a 36-inch X-band parabolic-reflector antenna located at a given deck position aft of the emergency barrier. This antenna is mounted off the side of the flight deck and oriented perpendicular to the velocity radar antenna. Such an antenna produces a cross-deck cylindrical field having a diameter of about 3 feet in the Fresnel region which extends about 85 feet from the antenna. Experiments show that it is possible to obtain intelligence from the landing gear of an aircraft as it intercepts this beam using a relatively low power klystron (723 A/B) to drive the same type duplexer bridge previously discussed. In this case it is necessary to measure the very small tangential component of velocity which requires amplification of frequency signals in the five cps to 200 cps range. The bridge and oscillator can be tuned to obtain a 20-1 signal-to-noise ratio for this range.

The gradient of this cross-deck field tangential to the antenna is very large near the boundary. Thus any moving object can be located within ± 9 inches of the zero-position (determined by aft extremity of beam) depending on its altitude. Therefore, if this beam extends from deck level, the first component on the aircraft within 3 feet of the deck is detectable. Although that component would likely be one of the landing gears, the fuselage of some types of aircraft are lower than 3 feet. Therefore, it is necessary to lower the antenna a little below deck level using a radiation absorber in front of the below deck portion of the beam. About a 1 foot section of the beam can be absorbed without excessive field distortion or loss of gain. This final field configuration extends cross-deck and has dimensions approximately 2 feet high and about 2 feet wide as measured from the aft boundary of the field. This reference region will detect the nose gear of tricycle types of aircraft or the main gear of conventional type.

Because the emergency barrier engages the main landing gear it is convenient to use the main landing gear as the zero-position reference on the aircraft. For tricycle landing-gear aircraft a manual operation is required to insert the range correction, N = M, in the analog computer. The cross-section dimension of the landing gear is of the same order of magnitude as the beam width and hence serves as a suitable target. The advantage of doppler measurement of the zero-position is that it detects only moving objects and requires no auxiliary components on the aircraft. However, it does require the main landing gear to be functional; if an aircraft with an inoperative or damaged nose landing gear is brought aboard, the landing officer would have to select an approximate value of N depending on the estimated angle of pitch as it approaches the zero-position.

In order to prevent accidental actuation of the integration process by activity of the deck a coupling unit or interlock is required between the two doppler radar systems. To meet this requirement the zero-position indication is not completed until the velocity radar detects an object traveling faster than 35 knots. This minimum speed is greater than any type of normal deck activity.

DESIGN OF ANALOG COMPUTER AND TRIGGER CIRCUITS

The output of the zero-position doppler radar is rectified as shown in Figure 2. The thyratron T_3 is maintained below triggering grid voltage by E in series with the negative bias supplied by rectification of the doppler noise level. The RC time constant is made large preventing triggering of the thyratron by drift in noise level. A transient doppler signal caused by an aircraft crossing the zero-position is rectified by T_2 to add a positive signal to the grid and drive the thyratron to conduction and actuate the relay.

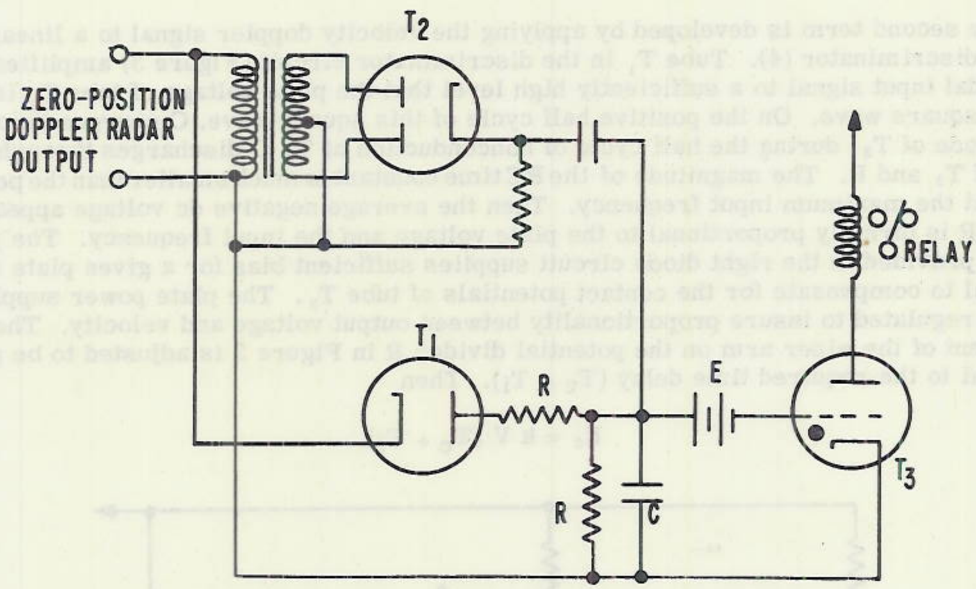

Figure 2 Initiating circuit

The analog computer must be designed to solve the following equation, which is a transposition of Equation (4),

$$\int_0^t V\,dt + V\,(T_C + T_I) = L + N . \qquad (6)$$

It is desired to obtain a computer accuracy of ± 6 inches. The right member of this equation is a constant for any particular aircraft. An analog is established making distances proportional to voltages. The integrating component furnishes a dc voltage proportional to the first term. Converting the velocity doppler signal to a voltage and multiplying this voltage by the factor $(T_C + T_I)$ develops a dc voltage equivalent to the second term. Adding these two voltages in series yields an output voltage proportional to the left member. This voltage is supplied to an output trigger circuit which is adjusted to trigger at the equivalent (L + N) voltage.

 [redacted]

The integration required is done by a digital type integrator (3). This integrator was adopted since the integrand is proportional to the doppler frequency and the integral of frequency is proportional to phase. If a sufficiently high frequency be chosen, the integration of velocity with respect to time becomes proportional to the summation of complete cycles. Then one uniformly shaped pulse may be formed for each cycle and these pulses may be applied to a gated condenser. Each pulse supplies a unit of charge equal to q to the condenser, and therefore the voltage developed across the condenser is

$$E_1 = C \sum_{0}^{n} q = k \int_{0}^{t} V\,dt \qquad (7)$$

where a practical value of k makes one volt equivalent to five feet.

The second term is developed by applying the velocity doppler signal to a linear frequency discriminator (4). Tube T_1 in the discriminator circuit (Figure 3) amplifies the sinusoidal input signal to a sufficiently high level that the plate voltage of tube T_2 is approximately square wave. On the positive half cycle of this square wave, C charges through the right diode of T_3; during the half cycle of nonconduction of T_2 C discharges through the left diode of T_3 and R. The magnitude of the RC time constant is much smaller than the period of the signal at the maximum input frequency. Then the average negative dc voltage appearing across R is directly proportional to the plate voltage and the input frequency. The potential divider provided in the right diode circuit supplies sufficient bias for a given plate supply potential to compensate for the contact potentials of tube T_3. The plate power supply must be well regulated to insure proportionality between output voltage and velocity. The displacement of the wiper arm on the potential divider R in Figure 3 is adjusted to be proportional to the required time delay $(T_c + T_i)$. Then

$$E_2 = k\,V\,(T_c + T_i). \qquad (8)$$

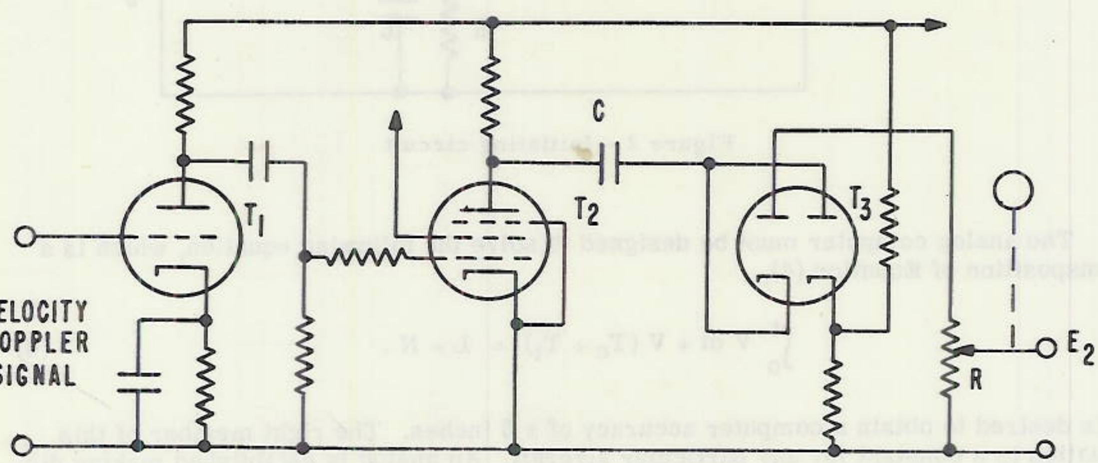

Figure 3 - Discriminator circuit

The remaining component of the analog computer is an output triggering circuit. A Schmidt-type trigger circuit (Figure 4) is used, because it provides very sensitive control and good stability. Tube T_1 is nonconducting. T_2 is conducting since the grid voltage is

[redacted]

positive as determined by R. As $E_1 + E_2$ increases positively the initial conditions hold due to the large common cathode bias until the grid of T_1 is driven positive. At this instant there is rapid transfer of conduction from T_2 to T_1. The voltage magnitude at which this transfer occurs is determined by the cathode resistance and R. It is convenient to fix the cathode resistance and adjust R to such magnitude that this transfer occurs when

$$E_1 + E_2 = k(L + N). \tag{9}$$

The current through T_1 is suitable to drive a relay actuating the emergency barrier.

The coupling unit between the doppler radar systems is also a Schmidt-type trigger circuit. The velocities of all moving objects on the flight deck are measured and indicated by a dc voltage at the output of the discriminator. This discriminator signal is amplified and applied to a Schmidt-type circuit (Figure 4) whose parameters are adjusted to prevent triggering until a voltage equivalent to the minimum aircraft velocity or greater is indicated. A relay in the triggered plate circuit then completes the thyratron circuit in the zero-position initiator enabling the latter circuit to be actuated by the moving target at its zero-position.

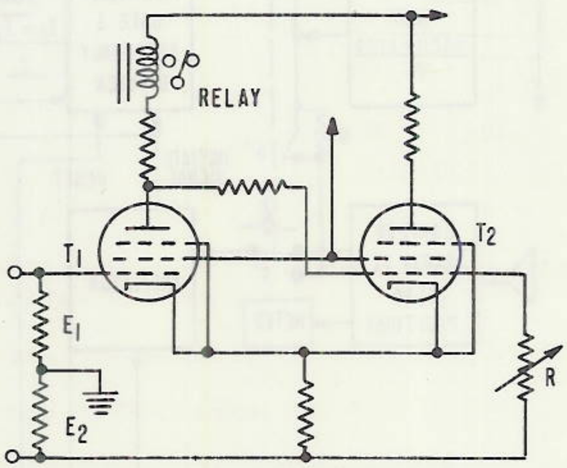

Figure 4 - Schmidt-type trigger circuit

THE DOPPLER CONTROL SYSTEM

A block diagram of the doppler control system is shown in Figure 5. Aircraft move in a direction indicated by the arrow. That is, the targets recede from Radar I and pass Radar II. Radar I measures the velocity of every landing aircraft. The magnitude of the signal received from the aircraft is indicated on the amplifier output meter. The meter serves to indicate the operation of this radar gear and also is used in tuning the duplexer bridge to a minimum noise level. The sinusoidal output of Radar I is applied to the discriminator. The indication of discriminator output meter is proportional to the velocity of each aircraft during its landing operation. The doppler frequency is also applied to the counter gate. The counter gate is a pulse forming circuit for driving a decascale frequency divider and includes a gate circuit which prohibits transfer of pulses until an initiation signal is applied. This gating action is obtained by applying a large dc bias to an output diode. This dc bias is the plate voltage of the initiator thyratron.

One output of the discriminator is applied to the minimum velocity detector. As long as the aircraft maintains a velocity greater than 35 knots the relay in this detector remains closed which completes the thyratron circuit in the initiator. Thus, an aircraft reaching the zero-position with a velocity greater than 35 knots triggers the initiation thyratron. The plate voltage of the thyratron drops practically to zero and opens the counter gate. Simultaneously a relay which is normally closed across the integrating condenser is opened. The input frequency F_1 is then divided by a factor of 10 by a plug-in decascale binary counter having feedback to enable a count of 10. Scaling the input frequency before performing integration (3), permits design of the integrator to minimum specifications.

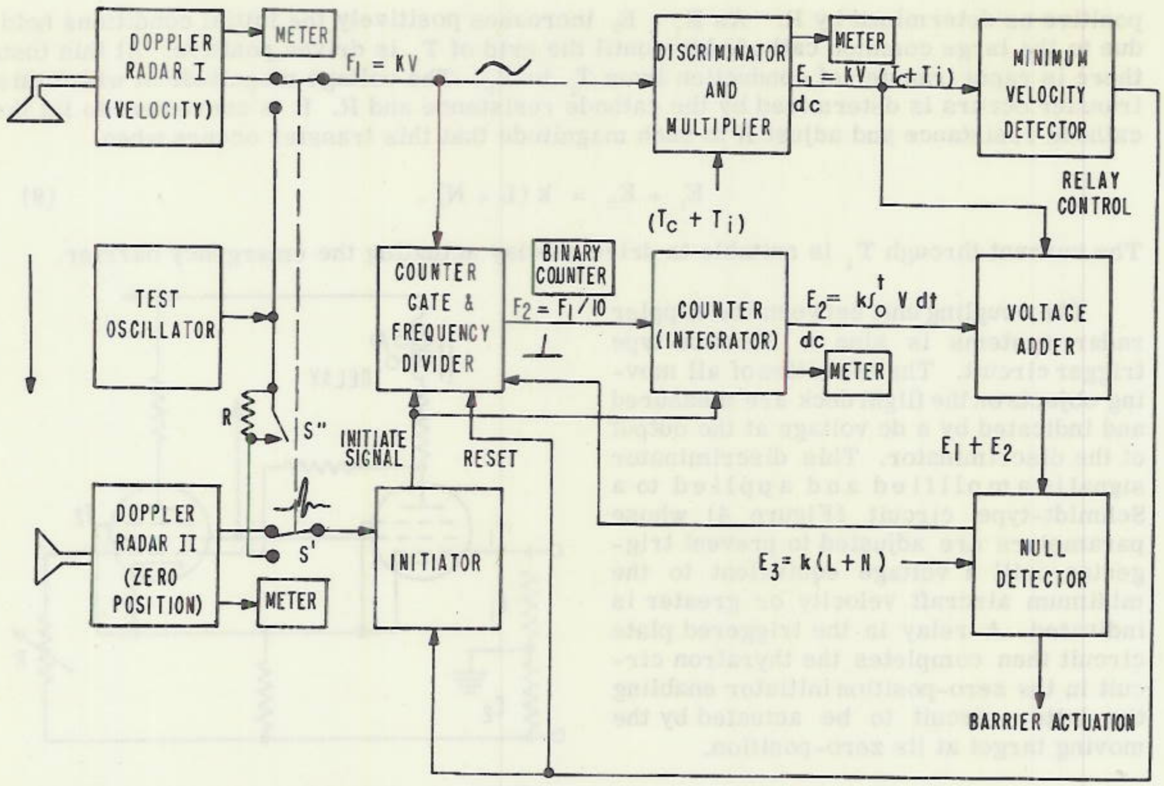

Figure 5 - Block diagram of doppler triggering system

The integrator is designed to count a maximum of about 100 pulses. Two additional decascale units are included to furnish a visible indication of the counting process by neon lamp indicators. The dc meter on the output of the integrator indicates the voltage proportional to the integrated frequency. This meter can be checked against the neon lamp indication to inspect the integrator operation. E_2 is added in series with E_1 and applied to the input grid of the null indicator.

A portion of the resistance R in the null detector (Figure 4) is fixed and represents the parameter L; additional resistance is added or not according to the magnitude of N (zero or M) for each approaching aircraft. Then the triggering potential is $E_3 = k(L + N)$. E_1 and E_2 are functions of time. E_1 varies with velocity while E_2 continually increases at a rate dependent on velocity. When $E_1 + E_2 = E_3$ the null detector actuates a relay energizing the emergency barrier. The energizing relay remains actuated until the velocity of the aircraft decreases to less than 35 knots. At this time the velocity sensitive relay opens which extinguishes the thyratron discharge and resets the binary counters and integrator.

A test oscillator is provided in the system for use in calibrating the computers and in testing the computer and trigger components. When the selector switch (S') is thrown from the "operate" position to the "test" position a secondary standard frequency oscillator having a frequency about equal to the doppler frequency equivalent of the minimum velocity is applied to the computing circuits. The discriminator output should indicate a voltage calibrated for a given ($T_C + T_i$) parameter. A push button switch (S′) is then actuated manually which shorts out the resistor R providing an initiating signal. The operations now proceed identically to a doppler input frequency except that when the null detector triggers, the "test hold" circuit stores the integration information so that it can be read visually. The binary counter indication can be compared with the indicated value of E_2. Total count on the binary counter should equal within one count

$$k'\int_0^t V\,dt,$$

where

$$\int_0^t V\,dt = L + N - V(T_C + T_i) \tag{10}$$

and k′ is the constant relating pulses to distance. All of the parameters in the right member of this equation are known constants. The accuracy of the computing system is ± 1 count since only whole periods of the doppler frequency are integrated.

MULTIPLE-BARRIER CONTROL

For shipboard installation of the doppler control device it is necessary to consider a doppler system capable of actuating a series of barriers (six barriers maximum). The velocity doppler radar unit discussed for the single-barrier system applies without alteration to the multiple-barrier case. The remaining components must be duplicated. Several types of doppler systems could be designed to operate a series of barriers. The optimum system must be determined by weighing the duplication of equipment against dependability of the entire system. To a first approximation dependability increases with the quantity of control equipment employed. However, this approximation may not be valid with respect to the number of zero-position initiators used. The most dependable system from purely equipment considerations would be a system using a separate zero-position unit and computing unit to control each barrier. For such a system a failure occurring in any one unit will cause but one barrier engagement failure. But this system seems impractical from consideration of the number of zero-position indicators required. The amount of deck area used for zero-position triggering is even more critical than the size of these antennae, because a zero-position indicator can be triggered erroneously by any moving target which intercepts the radiation during the interval when the velocity radar is measuring the approach speed of a landing aircraft. Therefore, increasing the number of zero-positions increases proportionally the deck regions which must be cleared of personnel during landing operations.

On the other hand, it is not feasible to control a barrier which is at a range of more than 50 feet from the zero-position. The computer has been designed to provide triggering action with an accuracy of ± 6 inches. Then the desired accuracy of the computer becomes 99 percent for a computing range of 50 feet. This is a maximum accuracy which can be expected of such equipment. Thus, if the distance between barriers is of the order of 25 feet, one zero-position detector will be required for every two barriers.

The practical duplication of computing equipment is also a function of dependability requirements. Maximum dependability would be obtained using a computer to actuate each barrier. Computing equipment could be reduced to a minimum by providing each computer unit with two null detectors and two output relays. The triggering potential for each null detector would be adjusted for the range of its barrier from the zero-position. A doppler control system utilizing least equipment to control six barriers 25 feet apart would consist of (a) one velocity doppler radar, (b) three zero-position radars, and (c) three computer units.

EVALUATION OF PROTOTYPE MODEL I

The Prototype Model I doppler radar control was designed for actuating a single emergency barrier. The integrating component contained sufficient storage for a maximum computing range of 25 feet. Two types of integrators were evaluated in this model. The first consisted of a scale of 64 electronic binary counters. The plate voltage of each binary stage controlled the conduction of an auxiliary triode. The plate resistance for each of these triodes was chosen so that each tube had a conduction current proportional to the binary indication. That is, the conduction current for the first stage was one unit of current, the second two units of current, the third four units of current, etc. The cathodes of these auxiliary triodes had a common cathode resistance across which the output voltage was obtained. The grid of each triode was switched from cut-off to zero-bias by grid limiting. This integrator did not function accurately for counts exceeding 50, because the relationship between grid bias and cathode bias was not independent for the larger values of cathode bias.

The second integrator evaluated was the accumulated charge integrator using a gated pentode (3) which has been discussed earlier in this report. This integrator performed satisfactorily during the test program for the limited range of L.

The doppler radar system of Protype Model I was identical to that previously discussed. The Prototype Model I barrier control was evaluated at NAMC by using an H-4 catapult installation to accelerate dead loads for triggering targets and employing a photographic scheme to simulate the barrier action (Figure 6).

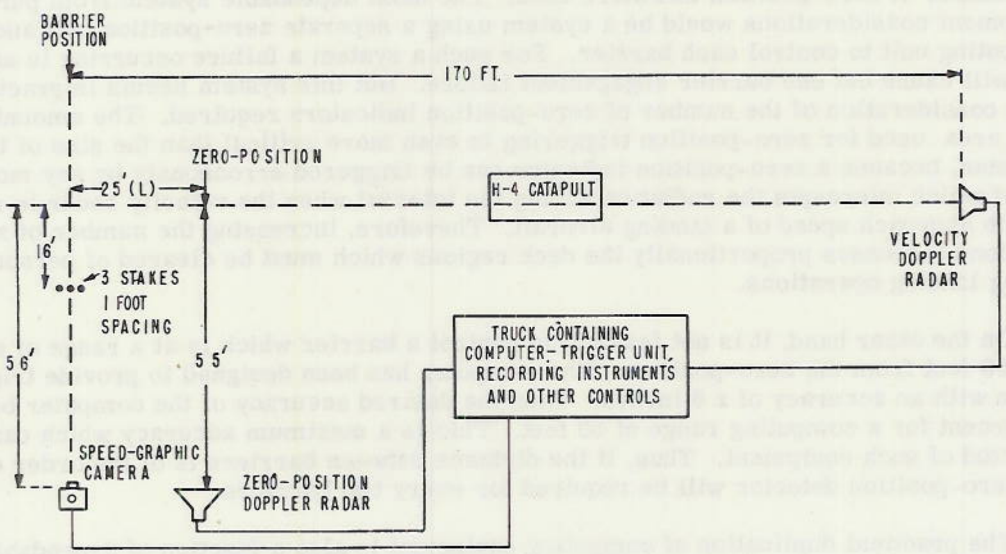

Figure 6 - Sketch showing locations of experimental equipment used in evaluation tests at NAMC

The between-the-lens shutter on the Speed Graphic camera was controlled by a time-delay relay on the output of the computer-trigger unit. The time-delay relay was adjusted for a delay of 0.10 second which simulated a barrier delay time ($T_C + T_i$) of that magnitude. Also, L = 25 feet, and for simplicity N = 0. With these parameters the camera exposure should occur at the instant that the leading edge of the front wheel of any dead load is at the barrier position independently of its speed.

From the configuration of the calibration stakes at the barrier position it was possible to determine the position of the dead loads with respect to the barrier from the film exposures. The operation of the Doppler Triggering Device was recorded as a function of time using a dual-beam oscilloscope and camera. Such an oscillogram furnished data on the velocity of the dead load as measured by the doppler radar and trigger range. From these oscillograms the accuracy of the computer could be determined independently of the time-delay camera which occasionally failed to operate.

A total of 39 catapult operations were performed during the test program. These operations involved two types of vehicular dead loads and a F6U aircraft. Of this total, nine operations were used to determine the accuracy of the zero-position doppler radar. All three types of dead loads initiated the integrator within ± 2 inches of the aft edge of the beam.

The remaining operations were used to evaluate the complete triggering system. The free-run velocities for these operations varied from 40 to 70 knots for each type target. The oscillograms indicated an accuracy of better than ± 6 inches for 21 operations. Measurements on the Speed Graphic exposures showed the leading edge of the front wheel to vary from six inches aft to ten inches forward of the barrier position. The computer is designed to give an accuracy of ± 6 inches, and this accuracy was obtained in these tests. The additional error shown by the picture is due to the zero-position error. The Speed Graphic camera was operated erroneously on six operations. The over-all accuracy obtained with the Model I control was ± 9 inches.

The only deficiency of the Model I Doppler Triggering Device which became apparent in these tests was decreased reliability due to a low line voltage. Upon completion of the test program the effect of line voltage on the computer was studied, and this effect has been minimized. The computer now functions reliably on line voltages varying from 100 to 125 volts. The only maintenance required on the Doppler Triggering Device during the test program was a daily check on the visual indicators to make certain that all components were working properly.

It is believed that these tests give a reasonable evaluation of the Model I Doppler Triggering Device. The only other variable which will influence the accuracy of this system in a shipboard installation is the effect of the aircraft's altitude. An additional zero-position displacement error of ± 2 inches could be introduced by a conventional landing-gear aircraft with the wheels 18 inches above deck. This error could be increased to ± 4 inches for tricycle landing-gear aircraft. Therefore, it is expected that the Doppler Triggering Device will be capable of releasing the barrier at such an instant that the cable should rise to within ± 1 foot of a chosen point referenced to the landing gear of the aircraft.

MODEL II DOPPLER TRIGGERING DEVICE FOR MULTIPLE-BARRIER SYSTEM

A second prototype model doppler triggering device was designed following the evaluation of prototype Model I. The binary counter type integrator was discarded in favor of the accumulated charge type integrator which permits Model II to compute over a range of 50 feet. The null detector was then redesigned making this model suitable for multiple barrier operation. The remaining circuits in the computer unit were redesigned to permit fabrication of a computer approaching minimum physical size. Specifications for the Model II Doppler Triggering Device are given in Appendix B.

The laboratory tests of the prototype Model II indicate that this equipment will give improved operation over Model I. A precision regulated power supply has been obtained to operate the X-21 klystron. With this equipment every component of the system operates reliably for line voltages between 100 - 130 volts.

There are two time delays in the Model II Computer Trigger Unit which must be considered in calibrating that instrument. These time delays are introduced by two relays. One is the initiating relay which requires 4 milliseconds to open its contacts across the integrating condenser. The output relay operation requires 6 milliseconds. Therefore, the discriminator output should be adjusted for a total time delay of $(T_c + T_i + 0.01)$ second. If the magnitude $(T_c + T_i)$ is less than 0.10 second it may be desirable to install faster operating relays.

The accuracy of the null detector is dependent on temperature. Therefore, to obtain maximum precision the computer equipment should reach temperature equilibrium before calibration. Also, the computer should not be triggered more frequently than once every two minutes. The triggering operation changes the temperature of the output trigger circuit, and it is necessary to maintain an operating accuracy of 99 percent in order to limit the null detector error to ± 6 inches for a computing range of 50 feet. For shorter ranges the precision required of the null detector is decreased making the circuit less critical with respect to temperature. The prototype Model II equipment is available for installation with the emergency cable ejector at NAMC to determine the reliability of engagement on dead loads.

* * *

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(2) Project Directive AER-Sl-23, S83-3, Ser. 01404, 13 February 1950.

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(4) Seeley, S. W., Kimball, C. N., and Barco, A. A., "A Linear Frequency Demodulator," RCA Review 6:269-286, 1941-42.

For additional related material see:
Montgomery, C. G., "Technique of Microwave Measurements," Radiation Lab Series, Vol. II, McGraw Hill, N. Y., 1947.

* * *

APPENDIX A

Operating Instructions for Model II Doppler Triggering Device

Experience indicates that the balance adjustments on the microwave bridges for the velocity radar and the zero-position radar are very stable and reliable when done properly. Prototype models of these units have been operated satisfactorily for six months and longer without requiring further adjustment.

VELOCITY DOPPLER RADAR

Read instruction book for Browning amplifier before operating radar.

Normal Operation

1. Assembly equipment as shown in Figure A1. Connect power* to the power supply and amplifier.

2. Turn FILAMENTS switch on power supply and POWER switch on amplifier to ON. Allow at least 30 seconds for warm up. See that the blower on the klystron is operating.

3. Turn the INPUT switch on the amplifier to the input channel being used; turn the corresponding input gain control to about maximum. See that the crystal-bolometer switch is in the XTAL position.

4. Turn course GAIN selector to FULL and adjust fine GAIN control knob to about position 5.

5. Turn HIGH VOLTAGE switch on power supply to ON.

6. Adjust the voltage output with the COARSE VOLTAGE CONTROL. As the correct power voltage is approached the amplifier standing-wave meter will give prominent deflection. <u>CAUTION</u>: Do not permit BEAM CURRENT to exceed 100 milliamperes.

7. Adjust the FINE VOLTAGE CONTROL to obtain minimum noise level on standing-wave meter. Be sure there are no moving targets in the beam during this operation. Changing the power supply voltage slightly in either direction from the optimum voltage should produce an increase in the noise level. If a minimum noise level is not detectable or irregular deflection is noted on the meter, the bridge is not balanced or the system may be unstable. If such is the case, carry out steps 10 to 21 for balancing the bridge.

* For the laboratory model, 115 v, 60 cycle, single-phase power was used. However, it is recommended that the circuits be redesigned so that the normal 440 v, 60 cps, 3-phase power obtained aboard ship may be used.

8. When a minimum noise level has been obtained on the standing-wave meter, rotate the fine GAIN control on the amplifier to give a noise level of about 2 on the lower scale of the standing-wave meter at the FULL gain selection. The output noise level should not be greater than 1 volt (an external meter is needed for this measurement as the meter on the amplifier does not indicate the output terminal voltage).

9. Finally, turn the coarse GAIN selector to 1/10. The velocity radar is now in operation. If the equipment is adjusted properly targets moving with velocities above 10 knots will give a large deflection on the standing-wave meter. If the noise level increases as the klystron warms up, repeat steps 7 through 9.

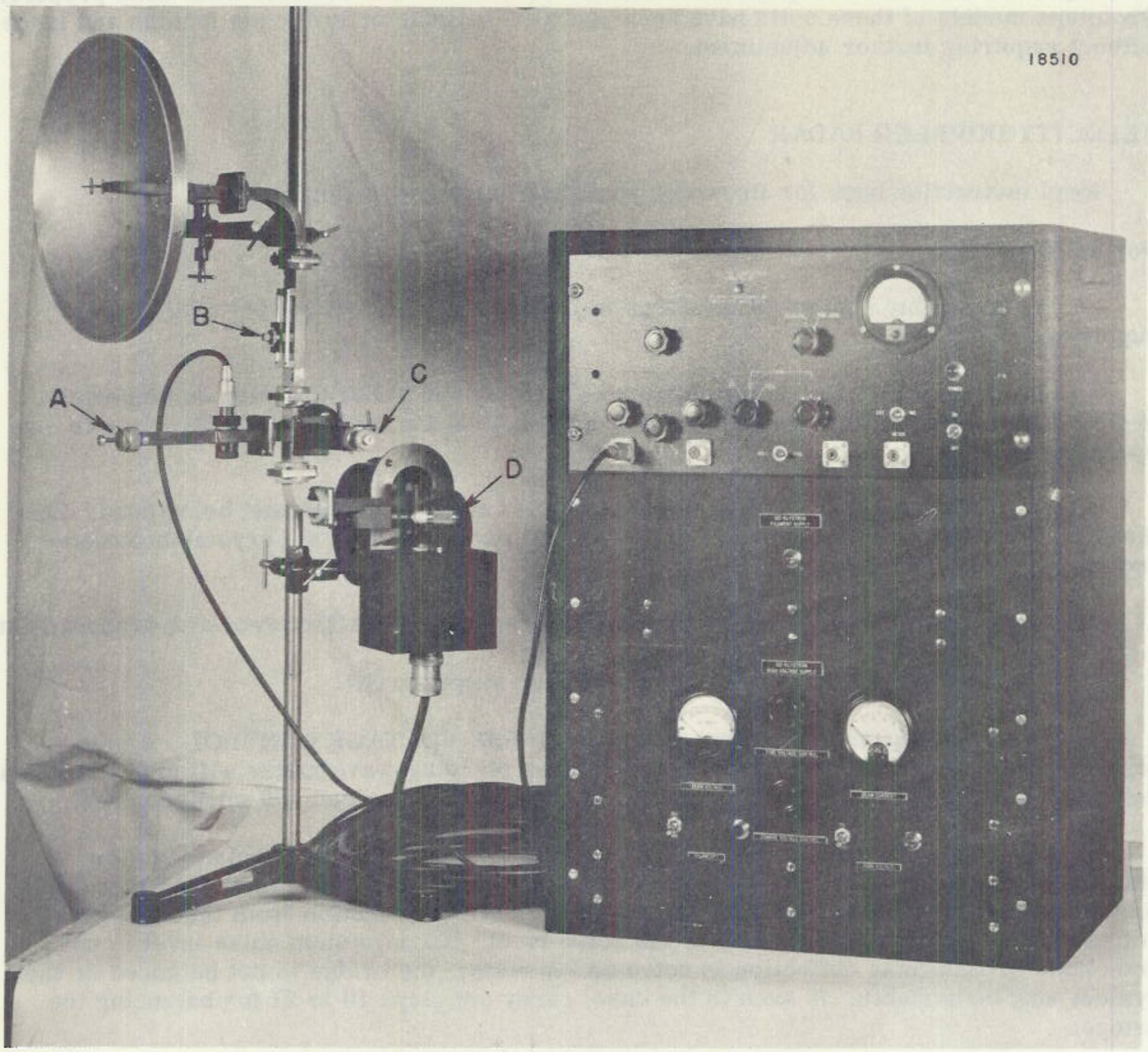

Figure A-1 - Velocity doppler radar: (A) tunable detector, (B) slide screw tuner, (C) tunable short, and (D) frequency meter

Balancing the Bridge

10. Connect an oscilloscope to the amplifier output and use this instrument for the tuning indicator. Adjust COARSE VOLTAGE CONTROL until a steady 60 cps or 120 cps fundamental wave form appears on scope. Some type of moving target is required to balance the duplexer bridge. A rotary fan is convenient for this purpose. Locate the fan about 10 feet from the antenna and near the center of the beam. Turn the fan on. Make certain that the tuning probe on the slide screw tuner is out of the waveguide (Figure A2).

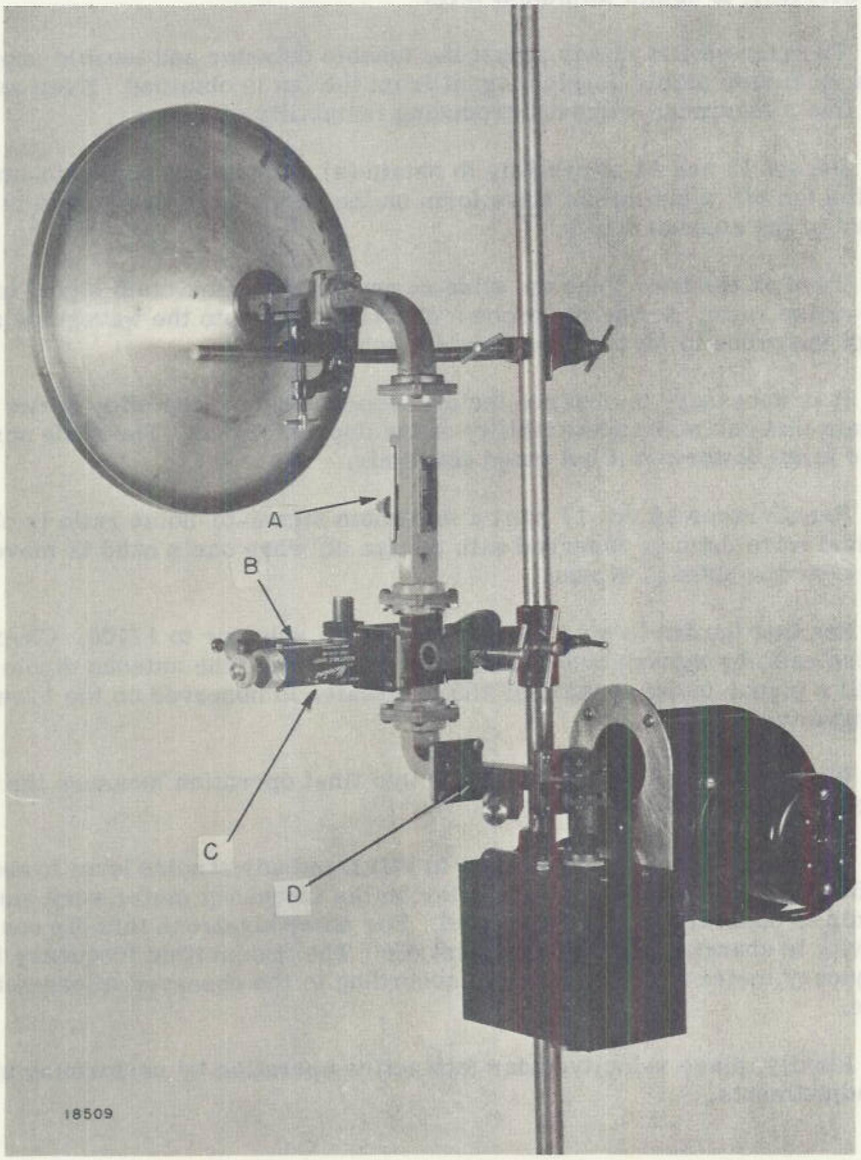

Figure A-2 - Duplexer bridge components for velocity doppler radar: (A) tunable detector, (B) slide screw tuner, (C) tunable short, and (D) frequency meter

11. Slowly adjust the tunable detector until a signal from the fan is obtained. Sometimes it is necessary to turn the fan on and off to distinguish the low-level signal from the noise.

12. If no signal is obtained, adjust the tunable short a few turns and repeat 11. Repeat 11 and 12 until a signal is observed.

13. Turn off the fan. Adjust the COARSE VOLTAGE CONTROL slightly to locate the minimum noise level at FULL gain. Continue minimum noise adjustments with FINE VOLTAGE CONTROL to obtain minimum level.

14. Turn fan on and slowly adjust the tunable detector and tunable short alternately until a maximum stable doppler signal from the fan is obtained. Keep wave meter on scale and find a maximum without introducing instability of signal.

15. Repeat 13 and 14 alternately to obtain (a) a maximum signal-to-noise ratio and (b) with the fan off, a sinusoidal wave form on the scope when one's hand is moved slowly in front of the antenna dipole.

16. Turn on the fan. Tune the slide screw tuner to maximum signal to increase the signal-to-noise ratio. Screw the probe a short distance into the waveguide and vary the position of the probe to locate a maximum signal position.

17. It is necessary to observe the oscilloscope during the slide screw adjustments to make certain that one maintains stability of the doppler signal. The slide screw tuner will introduce large distortion if not tuned correctly.

18. Repeat steps 14 to 17 until a maximum signal-to-noise ratio is obtained and a sinusoidal wave form is observed with the fan off when one's hand is moved at a uniform rate near the antenna dipole.

19. See that the fan is off. Turn coarse GAIN selector to 1/100. Check the signal-to-noise ratio by moving one's hand very rapidly near the antenna dipole. Repeat 14 to 18 until a signal-to-noise ratio of 200 or greater is observed on the lower scale of the standing-wave meter.

20. Before placing the velocity radar into final operation measure the transmitted frequency as follows:

Turn the coarse GAIN selector to FULL and adjust noise level to about midscale with fine GAIN control. Adjust the micrometer on the frequency meter very slowly. At resonance, a dip is observed in the noise level. For some klystrons this dip can be observed only when cavity is changing giving a transient dip. The transmitted frequency is then read from the frequency meter calibration curve according to the observed micrometer setting for resonance.

21. Finally, place velocity radar into active operation by performing steps 8 and 9 and lock all adjustments.

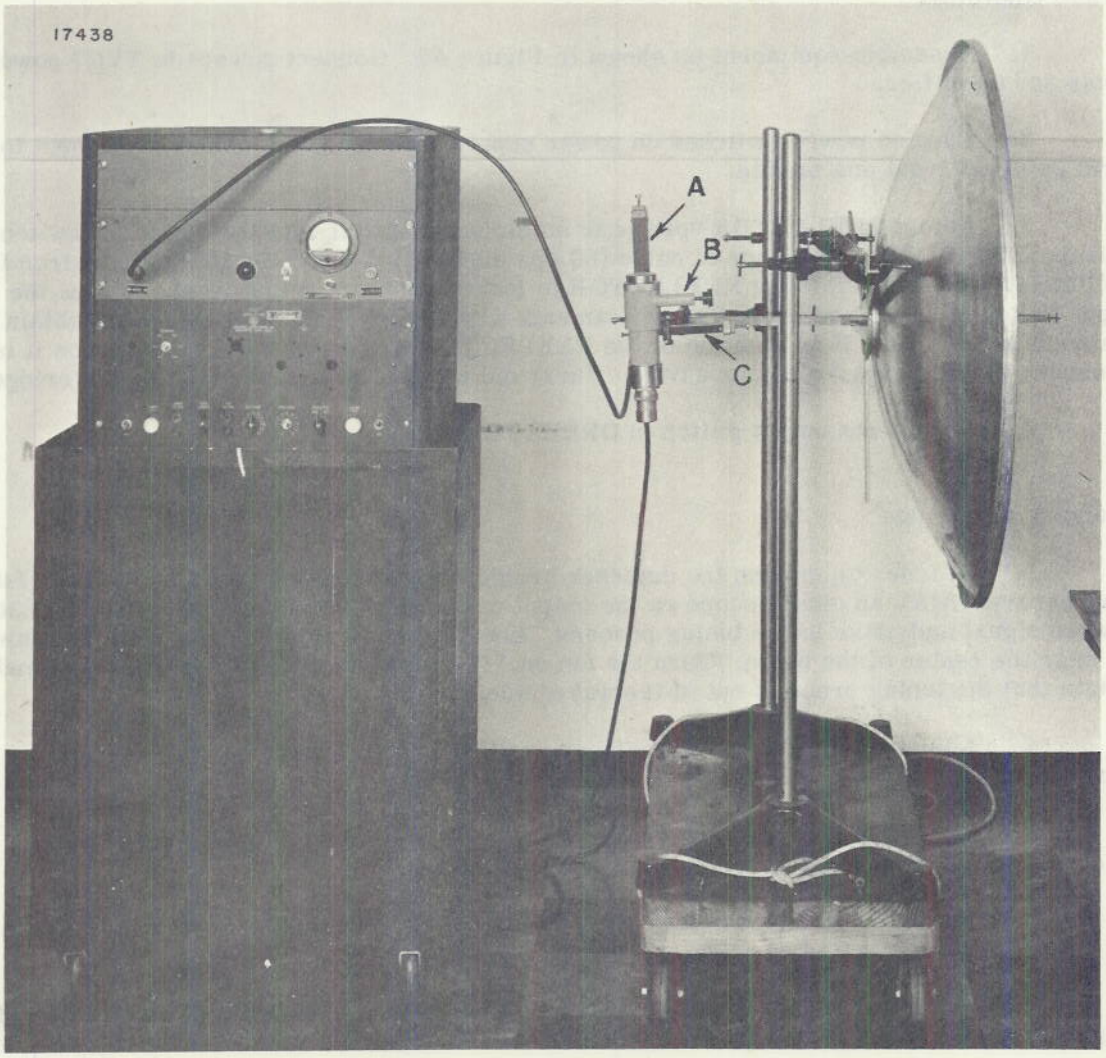

Figure A-3 - Zero-position doppler radar: (A) tunable detector, (B) cavity adjustment, (C) tunable short, and (D) absorbing material

ZERO-POSITION DOPPLER RADAR

The operation of the zero-position equipment is very similar to the operation of the velocity doppler radar. If the doppler bridge is known to be tuned from previous operation only steps 1 through 5 are necessary to put this equipment into active operation. Read instruction books for Browning TVN7 power supply and Hewlett-Packard amplifiers.

Normal Operation

1. Assemble equipment as shown in Figure A3. Connect power* to TVN7 power supply and amplifier.

2. Turn on power switches on power supply and amplifier. Allow equipment to warm up for at least one minute.

3. Adjust REFLECTOR voltage to obtain noise signal with the amplifier switch position to OPERATE. Evidence of noise (60 cps or 120 cps) indicates that the klystron is oscillating. Continue adjusting REFLECTOR to locate minimum noise level. Throw the output switch to TEST and make fine adjustments with the REFLECTOR control to obtain minimum noise level. If no position of the REFLECTOR control produces oscillation it is necessary to adjust the oscillator cavity. Carry out steps 5 to 12 for balancing the bridge.

4. Finally put output switch in OPERATE position.

Balancing the Bridge

5. In order to balance the duplexer bridge, a moving target (such as a rotary fan) is necessary. Also, an oscilloscope on the output of the amplifier is useful to differentiate between signal and noise in the tuning process. Locate the fan about 10 feet from the antenna and near the center of the beam. Turn the fan on. If a slide screw tuner is required, make certain that the tuning probe is out of the waveguide.

6. Adjust the tunable detector (Figure A4) to obtain maximum doppler signal from the fan on the scope.

7. Next, adjust the tunable short to amplify the signal to a maximum. Throw the output switch to OPERATE when meter goes off scale.

8. Turn fan off. Repeat step 3 and check the cavity adjustment to make certain that it is at minimum noise position.

9. Repeat steps 6, 7, and 8 until optimum adjustments are found and, with the fan off, a signal-to-noise ratio of at least 40 is obtained on moving one's hand near the dipole.

10. If a matching section (slide screw tuner) is required on the output of the bridge, tune it to maximum doppler signal by turning on the fan and following the instructions given in steps 16 and 17 for the velocity doppler radar.

11. Repeat steps 8, 9, and 10 until optimum adjustments are found.

12. To put zero position system into final operation, make certain that the output switch is in the OPERATE position and lock all adjustments.

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* See footnote on page 13.

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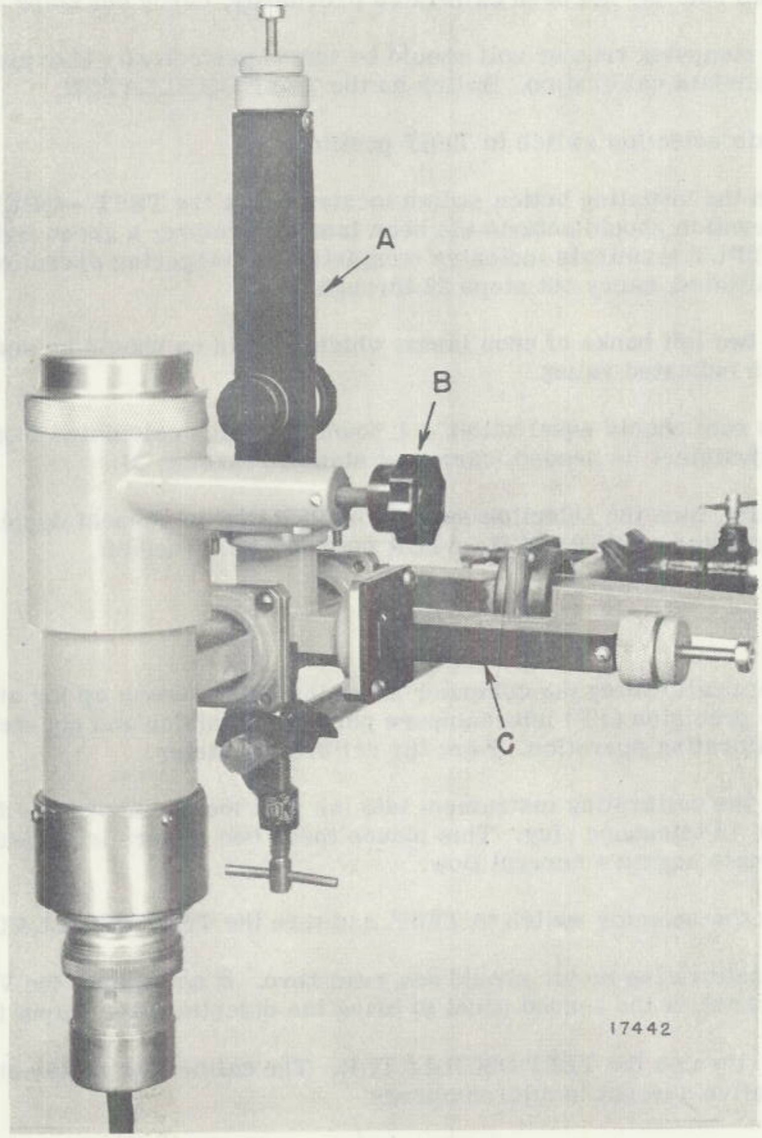

Figure A-4 - Duplexer bridge components for zero-position doppler radar (A) tunable detector, (B) cavity adjustment, and (C) tunable short

COMPUTER AND TRIGGER UNIT

Normal Operation

1. Connect the computer and trigger unit (Figure A5) to 115 v, 60 cps line.*

2. Turn on power switch and allow unit to warm up for at least 10 minutes.

* See footnote on page 13

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DECLASSIFIED

3. If this unit has not been calibrated previously, carry out steps 10 to 21.

4. The computer trigger unit should be tested periodically (for example, once a day) to maintain calibration. Switch on the TEST OSCILLATOR.

5. Rotate selection switch to TEST position.

6. Push the initiating button switch located below the TEST - OPERATE switch. This operation should actuate the neon lamp indicators; a green light above the COMPUTER OUTPUT terminals indicates completion of triggering operation. If counting process is not initiated, carry out steps 22 through 26.

7. The two left banks of neon lamps which remain on should be summed according to each indicated value.

8. This sum should equal within ± 1 count the value calculated from Equation (A3) If calibration adjustment is needed, carry out steps 10 through 21.

9. Finally, turn the selection switch to OPERATE to connect doppler radar system to the computer. TEST OSCILLATOR may now be turned off.

Calibration

10. Before calibrating the computer allow the unit to warm up for at least one-half hour. Use a precision (1%) microampere portable ammeter and not the panel instruments for the calibrating operation. Zero the calibrating meter.

11. Plug the calibrating instrument into the jack located above the discriminator meter with a type 75 telephone plug. This places these two meters in series. Connect the meter to indicate negative current flow.

12. Turn the selector switch to TEST and turn the TEST OSCILLATOR off.

13. The calibrating meter should now read zero. If not, adjust the VOLTAGE CONTROL at the back of the second panel to bring the discriminator output to zero.

14. Next, turn on the TEST OSCILLATOR. The calibration meter should indicate the following negative current in microamperes:

$$I_1 = \left(10\, K_1 F_t\right)\left(T_c + T_i + 0.01\right) \qquad \text{(A1)}$$

where F_t = 1,000 cps for General Radio type 723-C test oscillator* and

$$K_1 = \frac{0.2\left(9.84 \times 10^8\right)}{2F_k} = \frac{9.84 \times 10^7}{F_k} \text{ volts/cycle,} \qquad \text{(A2)}$$

in which F_k is the klystron frequency.

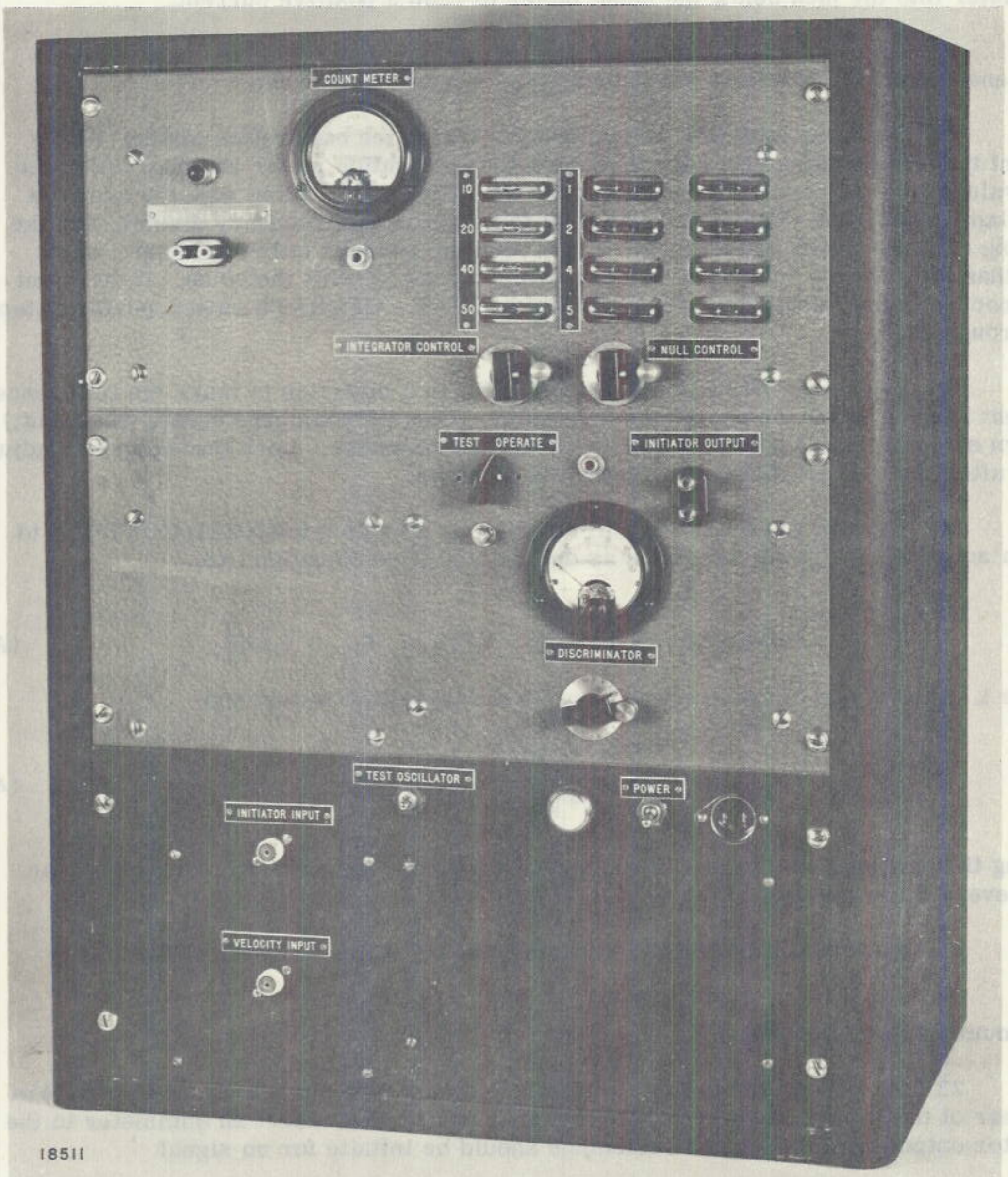

Figure A-5 - Computer and trigger unit

15. Adjust the discriminator control to give the correct value of current obtained from Equation (A1) for the test frequency. Tighten the lock screw after adjustment.

16. Now calibrate the integrator using the same calibration meter. Plug the meter into the jack below the count meter to read a positive current.

17. Adjust the zero setting on the calibration meter to give a convenient reference position. The zero count indication is not zero current.

18. Push the initiating button switch. Watch the calibration meter. At the instant that the counting process stops, note the calibration meter reading. Subtract this value form the zero value and compare the difference reading with the summed neon lamp indication. The third counter at the right is the frequency divider, and the reading of these lamps is neglected. If the counting process fails to stop at a count less than 99, turn the "null control" counterclockwise to limit the count. If the counting process is not initiated by the button below TEST - OPERATE switch, perform steps 22 through 26.

19. Adjust the INTEGRATOR CONTROL in a direction to make the difference current reading equal the neon lamp indication. (One microampere equals one count.) Return selector switch to OPERATE to re-set the computer. Lock the integrator adjustment after the correct difference current is obtained.

20. Finally, calibrate the null detector by adjusting the NULL CONTROL to give a summed neon lamp indication as determined from Equation (A3).

$$\text{Total count} = 2\left[(L + N) - V(T_c + T_i + 0.01)\right] \tag{A3}$$

where L is the range of the barrier from the zero-position in feet and

$$V = \frac{9.84 \times 10^8 F_t}{2 F_k} \text{ ft/sec} \cdot \tag{A4}$$

During this calibration process the computer should not be initiated more often than once every three minutes.

21. Lock NULL CONTROL and set selector switch to OPERATE.

Minimum Velocity Detector

22. To adjust the minimum velocity detector turn the potentiometer (R16) at the rear of the middle chassis to full clockwise position. Connect an ohmmeter to the initiator output terminals. The resistance should be infinite for no signal.

23. Turn on the TEST OSCILLATOR. Turn the selector switch to TEST. Push the initiating button.

24. The ohmmeter indication should remain infinite. If not, a small adjustment of R14 which is located inside the middle chassis is necessary.

25. Now rotate the potentiometer at the rear of the chassis (R16) a small amount counterclockwise.

26. Repeat steps 23 and 25 until the initiating operation causes the internal relay contacts across the INITIATOR OUTPUT to close. It has been useful to connect a signal generator (20 cps to 20,000 cps) to the input terminals to adjust the minimum velocity detector. Place the selection switch to OPERATE and use an external initiating switch. Then optimum adjustments of R14 and R16 can be obtained giving desired hysteresis differential between "make" frequency and "break" frequency. The Schmidt trigger circuit is unstable if the hysteresis differential is made too small.

CHECKING THE ZERO-POSITION

Field Configuration

The field configuration of the zero-position radar should be measured whenever an antenna or absorbing material is installed or adjusted. A 10-inch corner reflector made of good conducting material is useful for this measurement. The doppler signal from a moving corner reflector in the region of the antenna radius at any range to 80 feet should be decreased to about 1/10 of the signal at slightly smaller radius. This technique can be used to locate the deck zero-position by making the initiating edge of the field parallel to the barrier.

Zero-Position of the Aircraft

The INITIATOR OUTPUT terminals can be used to check the zero-position of the aircraft. A remotely controllable camera such as a Speed Graphic is required. Place calibration stakes in the region of the aft edge of the zero-position beam. Connect the shutter solenoid and battery in series with the INITIATOR OUTPUT terminals. Use fastest shutter speeds. The minimum velocity detector adjustment can be decreased for this operation to allow initiation at smaller velocities if necessary.

* * *

APPENDIX B
Equipment Specifications for the Model II Doppler Triggering Device

These equipment specifications are for the laboratory prototype model and some of the components used in this system could be improved (particularly in weight and size) for shipboard installation.

For shipboard installation, some alterations are necessary to meet specifications and others are recommended because of better suitability. The prototype Model II electronic gear is mounted in standard relay cabinets. For shipboard installation the packaging of these components must meet the "drip proof" requirements of Navy Specification "Mill E2036." Although the power voltage specification (115 v) is convenient for laboratory and test operations, the basic power aboard ship is 3 phase, 440 v, 60 cps. Therefore it is recommended that the power supplies and associated electrical equipment be designed for 440 volts to eliminate the added weight and space which would be required for step-down transformers.

The components involving changes in specifications to meet shipboard requirements are indicated by an asterisk. A dagger indicates that for shipboard installation, the connector must be altered to meet Navy Department Specification 17C13. A block diagram of the triggering device showing the components is given in Figure B1.

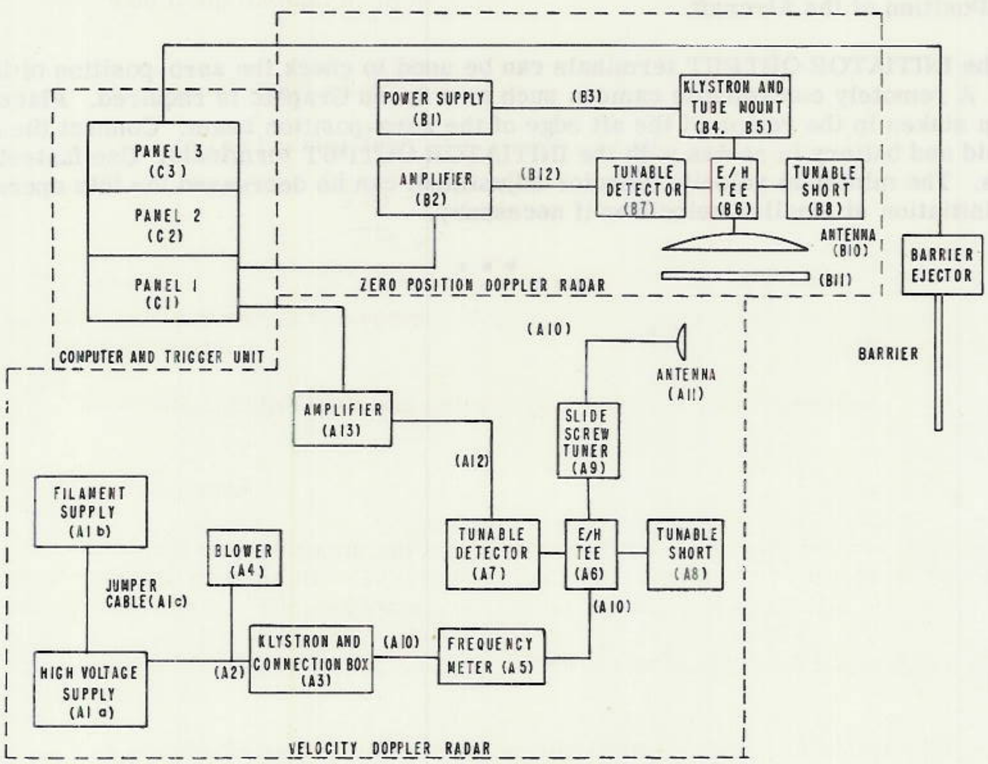

Figure B-1 - Block diagram of doppler triggering device. Numbers in parentheses refer to paragraphs in the text.

A. VELOCITY DOPPLER RADAR

Items A1 through A9 must be accessible for maintenance.

A1.* Power Supply - The power supply for the X-21 klystron was designed and built at NRL. It was found advisable to provide the X-21 klystron filament with dc in order to reduce 60-cycle modulation of the beam current. It was necessary to insulate the entire filament supply from gound since one side of the filament is at the high negative potiential.

A1a. High Voltage Supply. The specifications for the circuit given in Figure B2 are:

Input voltage:	Normally 115 v, 60 cps, single phase.
Output voltage:	Variable, 900 to 1,500 volts dc.
Output current:	0 to 100 milliamperes dc.
Regulation:	1 percent or better over rated current and/or voltage range and line voltage variation of 105 to 125 volts.
Ripple:	0.10 volt maximum.
Grounding:	Positive side of output grounded.

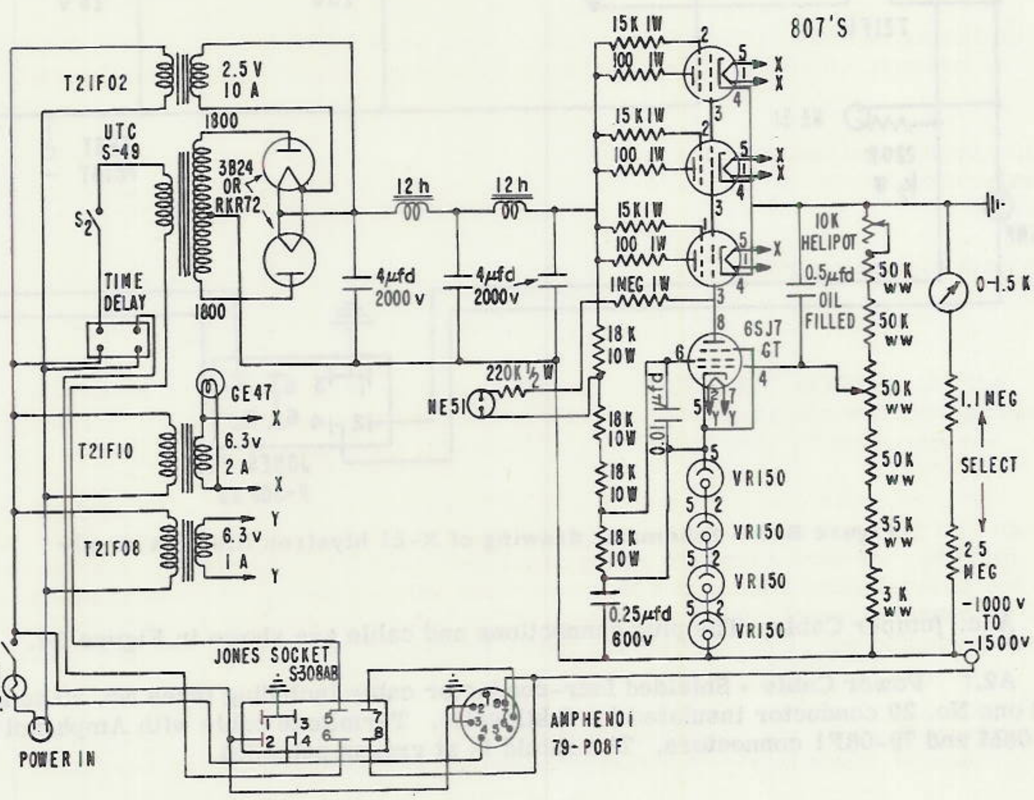

Figure B-2 - Schematic drawing of X-21 klystron high voltage supply

A1b. Filament Supply. The circuit shown in Figure B3 was designed to meet the following specifications:

Input voltage:	Normally 115 v, 60 cps, single phase.
Output voltage:	Variable, 6 to 7 volts dc.
Output current:	1.5 amperes dc.
Ripple:	0.10 volt maximum.
	Positive side attached to high negative potential.

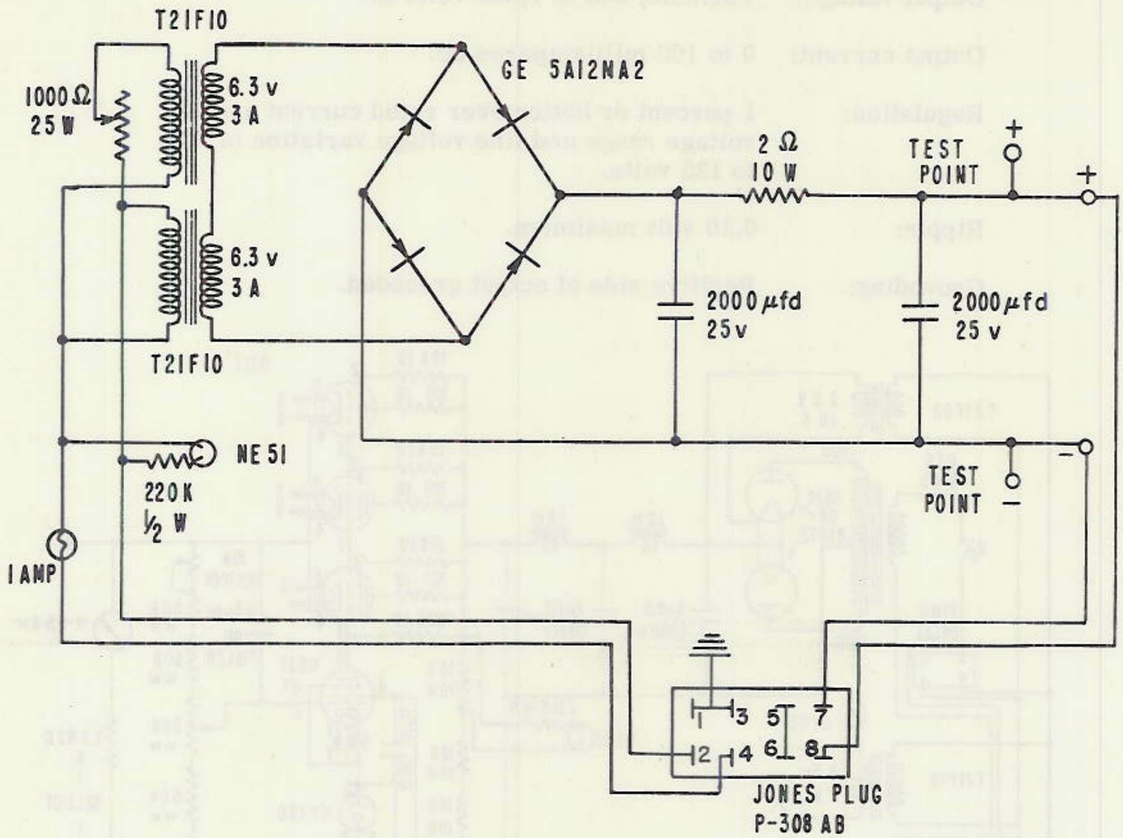

Figure B-3 - Schematic drawing of X-21 klystron filament supply

A1c. Jumper Cable. The plug connections and cable are shown in Figure B4.

A2.† Power Cable - Shielded four-conductor cable including three No. 20 conductors and one No. 20 conductor insulated for 2 kilovolts. Terminate cable with Amphenol types 79-08M and 79-08F1 connectors. The shield is at ground potential.

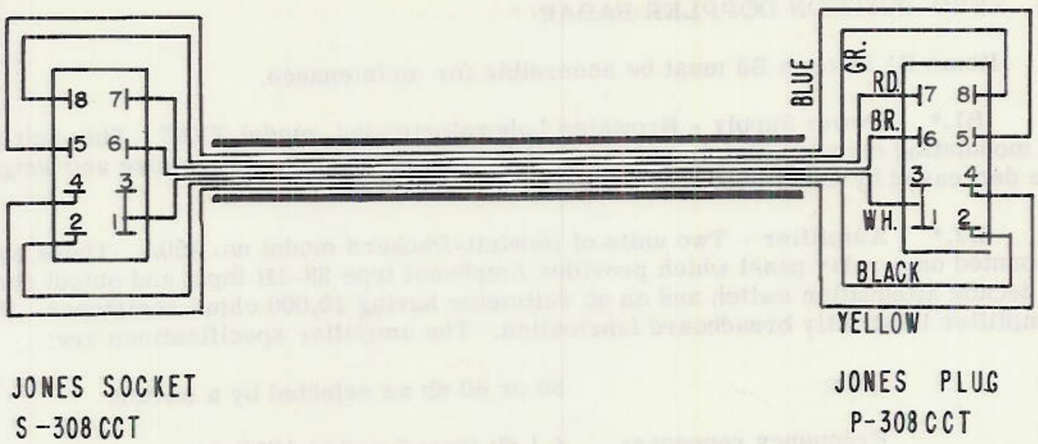

Figure B-4 - Schematic drawing of power supply jumper cable

A3.† Klystron, Connection Box - The X-21 klystron requires Amphenol type 91PC3F receptacle. The power receptacle is Amphenol type 79-P08M.

A4. Blower - Fasco Industries, Inc. type 50747-30G.

A5. Frequency Meter - Sperry Gyroscope Co. (SGC) model 126.

A6. E/H Tee - Polytech Research and Development Co. (PRD) model 481.

A7. Tunable Detector Section - (SGC) model 360.

A8. Adjustable Short Section - (SGC) model 377.

A9. Slide Screw Tuner - (PRD) model 303.

A10.* Waveguide - type RG 52/U with type UG 39/U flanges. The amount of waveguide required will depend on installation. Waveguide installation must be waterproof.

A11. Antenna - 12-inch parabolic reflector type, X-band. Note: In shipboard installation the only components located on the flight deck are the required antennae. It is recommended that these antennae be rigidly mounted to the ship's structure with no mechanical connection across the waveguide flanges at the antenna other than a jig to keep the flanges aligned. Such fabrication should prevent damage to other components of the microwave system if the antenna were damaged by aircraft, debris, shell fire, etc.

A12. Coaxial Cable with Amphenol type 83-1SP connectors.

A13. Amplifier - Browning Laboratories, Inc. type TAA-16. An output connector, Amphenol type 83-1R, is required on the front panel. The output connection is made to the grid of the 6V6 tube which permits using the standing-wave meter in this instrument. The capacity in the standing-wave circuit must be reduced from 100 to about 8 microfarads to make the time constant sufficiently short for use with the frequency meter.

B. ZERO-POSITION DOPPLER RADAR

Items B1 through B8 must be accessible for maintenance.

B1.* Power Supply - Browning Laboratories Inc. model TVN7. This unit includes a modulating circuit which is not used. For a shipboard installation size and weight could be decreased by using equipment of the power supply section only.

B2.* Amplifier - Two units of Hewlett-Packard model no. 450A. These units are mounted on a relay panel which provides Amphenol type 83-1R input and output connectors, a decade attenuation switch and an ac voltmeter having 10,000 ohms resistance. This amplifier is strictly breadboard fabrication. The amplifier specifications are:

Gain:	80 or 60 db as selected by a switch.
Frequency response:	± 1 db from 5 cps to 1000 cps.
Stability:	Line voltage variation of 105 to 125 volts.
Output:	10 v to 5000 ohms or more load.
Zero noise level:	1 millivolt or less.
Power requirement:	115 v, 60 cps, single phase.

B3.† Power Cable - 4 conductors no. 20 insulated and a shield over-all. Amphenol type 79-08M and 79-08F1 connectors.

B4. Oscillator - 723 A/B or 2K25 klystron.

B5. Klystron Tube Mount - (PRD) type 703.

B6. E/H Tee - (PRD) model 481.

B7. Tunable Detector Section - (SGC) model 360.

B8. Adjustable Short Section - (SGC) model 377.

B9.* Waveguide - Type RG 52/U with type UG 39/U flanges. The amount of waveguide required will depend on installation. Waveguide installation must be waterproof.

B10. Antenna - 36-inch parabolic reflector type, X-band, 12-inch focal distance.

Note: In shipboard installation the only components located on the flight deck are the required antennae. It is recommended that these antennae be rigidly mounted to the ship's structure with no mechanical connection across the waveguide flanges at the antenna other than a jig to keep the flanges aligned. Such fabrication should prevent damage to other components of the microwave system if the antenna were damaged by aircraft, debris, shell fire, etc.

B11. Radiation Absorber - Type MX410 or equivalent.

B12. Coaxial Cable with Amphenol type 83-1SP connectors.

C. COMPUTER AND TRIGGER UNIT

The components of the computer and trigger circuits are assembled on three standard relay panels 19 x 8-3/4 inches. The circuit diagrams associated with each relay panel are shown in Figures B5 to B7. The component specifications which follow are located according to panel location.

C1. Panel 1 - The lower panel (Figure 5B) contains the master dc power supply, test oscillator, and input terminals.

C01*†	GE 2291 Motor Base Receptacle.
C02, C03, and C04*†	Amphenol 61MIP-61F.
C05*†	Amphenol Plug 61M10.
C06 and C07	Coaxial Receptacle 83-1R.
C08*†	Amphenol Receptacle 91PC3F.
C09*†	Amphenol Receptacle AN3102-14S-2S.
C010*†	Amphenol Receptacle AN3102-14S-5S.
R1	1000 ohms, 20 watts.
R2	3000 ohms, 15 watts.
R3	100K ohms, 1 watt.
R4	100K ohms, 1 watt.
R5	2,250 ohms, 10 watts.
C1	0.01 microfarad, 50 volts.
C2	20 microfarads, 600 volts.
C3	20 microfarads, 600 volts.
C4	20 microfarads, 350 volts.
C5	20 microfarads, 350 volts.
L1	Thordarson T20C56 choke.
L2	Thordarson T20C53 choke.
T1	UTC type R5 transformer.
T2	Thordarson T22R02 transformer.
V1	5Z3 tube.
V2	6X5 tube.

V3	VR75 tube.
V4	VR150 tube.
V5	VR150 tube.
V6	VR150 tube.
F1	2 ampere fuse.
F2	1 ampere fuse.
S1	SPST switch.
S2	SPST switch.
LA1	115 volt lamp and panel type socket.
Test Oscillator*	General Radio type 723-C, Vacuum tube fork. (It is recommended that the 723-C be altered to obtain a test frequency of 1200 cps.)

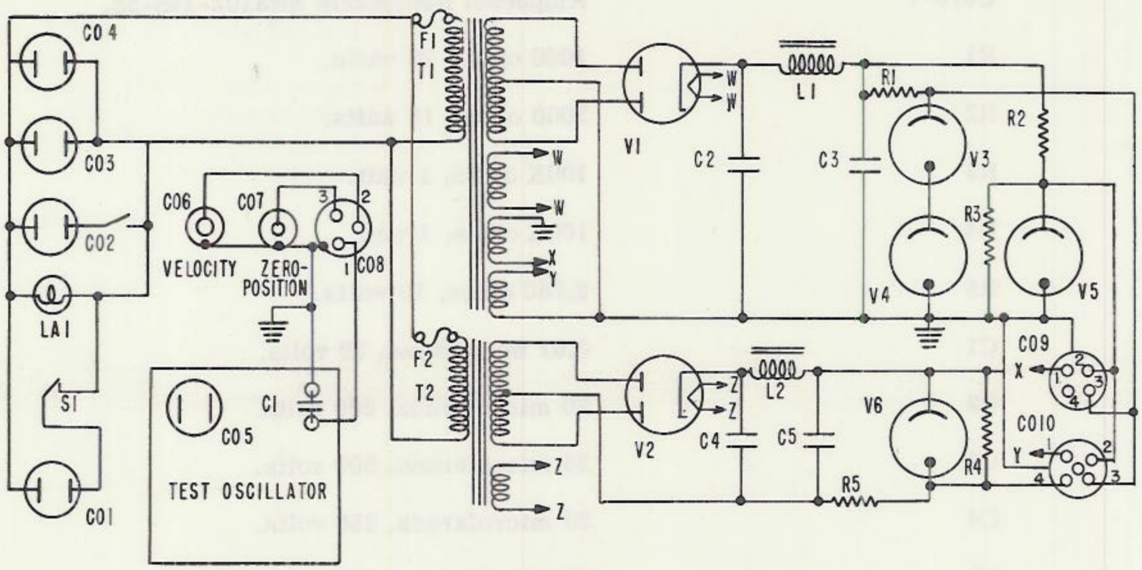

Figure B-5 - Computer circuit diagram, panel 1

C2. Panel 2 - The second panel (Figure B6) consists of the discriminator, minimum velocity detector, the zero-position initiating circuit, a pulse forming section and counter gate.

C011*†	Amphenol Plug 61M10.
C012*†	Amphenol Receptacle 91PC3F.
C013*†	Amphenol Receptacle AN3102-14S-2P.
C014*†	Amphenol Receptacle AN3102-18-12S.
C015*†	National Components Co. type FWA Binding Posts.
C021	Mallory type 702A Telephone Jack.
R6	500K ohms, 1/4 watt.
R7	100K ohms, 1/4 watt.
R8	5M ohms, 1/4 watt.
R9	5M ohms, 1/4 watt.
R10	8000 ohms, 1 watt.
R11	39K ohms, 1/2 watt.
R12	48 ohms, 1 watt.
R13	100K ohms, 1/4 watt.
R14	2,500 ohms, 1 watt potentiometer.
R15	15K ohms, 4 watts, wire wound.
R16	10K ohms, 10 turn Helipot.
R17	5000 ohms, 1 watt, wire wound.
R18	120K ohms, 1/2 watt.
R19	20K ohms, 4 watts, wire wound.
R20	1000 ohms, 4 watts, wire wound.
R21	20K ohms, 1/4 watt.
R22	68K ohms, 1/2 watt.
R23	220K ohms, 1/4 watt.
R24	100K ohms, 1/4 watt.
R25	220K ohms, 1/2 watt.
R26	12K ohms, 1/2 watt.

R27	3,900 ohms, 1/4 watt.
R28	22K ohms, 1/4 watt.
R29	100K ohms, 1 watt, 1% precision wire wound.
R30	1000 ohms, 10 turn Helipot. (Use remote controlled potential divider for shipboard installation.)
R31	1,500 ohms, 4 watts, wire wound.
R32	220 ohms, 1 watt.
R33	25K ohms, 10 watts.
R34	7000 ohms, 10 watts.
R35	470K ohms, 1/4 watt.
R36	470K ohms, 1/4 watt.
R37	1000 ohms, 1/2 watt.
R38	270K ohms, 1/4 watt.
R39	220 K ohms, 1/2 watt.
C6	0.5 microfarad, 50 volts.
C7	0.2 microfarad, 50 volts.
C8	10 microfarads, 50 volts.
C9	1.0 microfarad, 50 volts.
C10	10 microfarads, 50 volts.
C11	0.1 microfarad, 450 volts.
C12	.007 microfarad, 450 volts.
C13	.002 microfarad, 450 volts.
C14	0.2 microfarad, 50 volts.
C15	.01 microfarad, 450 volts.
C16	10 microfarads, 50 volts.
C17	0.1 microfarad, 450 volts.
L3	Western Electric type 276-J Relay.
L4	Western Electric type 276-J Relay.

T3	Thordarson type T72S58 transformer.
V7	6AL5 tube.
V8	6AL5 tube.
V9	2D21 tube.
V10	6AU6 tube.
V11	6AU6 tube.
V12	6AC7 tube.
V13	6AC7 tube.
V14	6AU6 tube.
V15	6AU6 tube.
V16	6AL5 tube.
V17	6AQ5 tube.
V18	6AU6 tube.
S3	3 pole 2 position rotary switch.
S4	Normally open push button switch or microswitch.
B1	4-1/2 volts bias cell.
M1	50 microampere panel type ammeter.
Power Supply	Electronic regulated, Hewlett-Packard type 710A.
D1	Tracerlab type SC12 Gate Circuit.

C3. Panel 3 - The upper panel (Figure B7) is composed of the integrator and null detector with their separate power supplies. These separate power supplies are required due to the necessary shift in the ground level in these circuits.

C016* †	Amphenol Plug 61M10.
C017* †	Amphenol Receptacle AN3102-18-12S.
C018* †	Amphenol Receptacle AN3102-14S-5P.
C019* †	National Components Co. type FWA Binding Post.
C022	Mallory type 702A Telephone Jack.

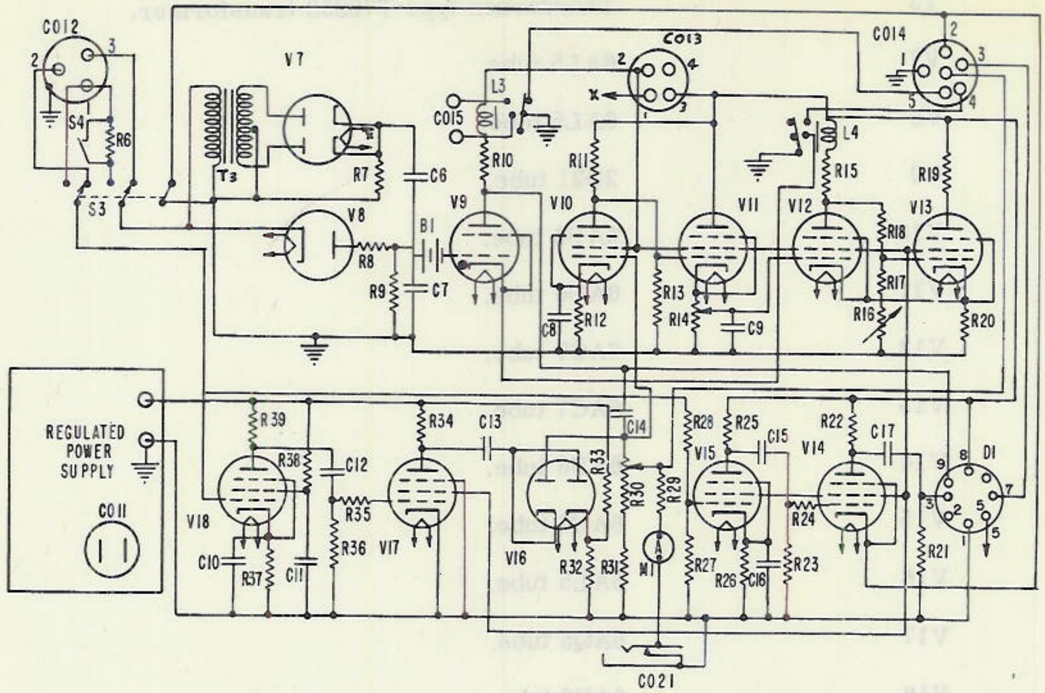

Figure B-6 - Computer circuit diagram, panel 2

R40	1000 ohms, 10 watts.
R41	280K ohms, 1/4 watt.
R42	30K ohms, 10 turn Helipot.
R43	100K ohms, 1% precision, wire wound.
R44	550 ohms, 10 watt, wire wound.
R45	120K ohms, 1/2 watt.
R46	15K ohms, 4 watts, wire wound.
R47	20K ohms, 4 watts, wire wound.
R48*	10K ohms, 3 turn Helipot. (Use remote controlled rheostat for shipboard installation.)
R49	4000 ohms, 4 watts, wire wound.
R50	3000 ohms, 10 watts.
R51	3.3M ohms, 1/4 watt.

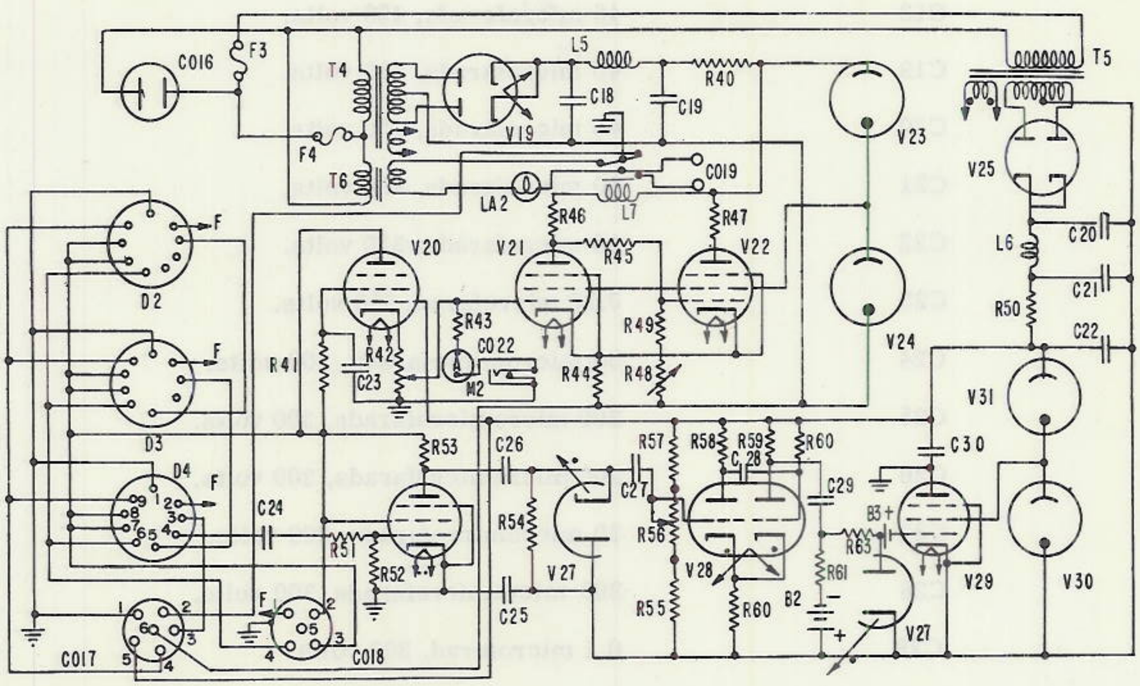

Figure B-7 - Computer circuit diagram, panel 3

R52	1.0M ohm, 1/4 watt.
R53	200K ohms, 1/2 watt.
R54	120K ohms, 1/4 watt.
R55	120K ohms, 1/4 watt.
R56	100K ohms potentiometer.
R57	120K ohms, 1/4 watt.
R58	20K ohms, 1/2 watt.
R59	10K ohms, 1/2 watt.
R60	10K ohms, 1/2 watt.
R61	1M ohm, 1/4 watt.
R62	2.2M ohms, 1/4 watt.
R63	1.5M ohms, 1/4 watt.

C18	40 microfarads, 450 volts.
C19	40 microfarads, 450 volts.
C20	40 microfarads, 450 volts.
C21	40 microfarads, 450 volts.
C22	16 microfarads, 350 volts.
C23	0.25 microfarad, 350 volts.
C24	50 micromicrofarads, 300 volts.
C25	200 micromicrofarads, 300 volts.
C26	200 micromicrofarads, 300 volts.
C27	30 micromicrofarads, 300 volts.
C28	200 micromicrofarads, 300 volts.
C29	0.1 microfarad, 300 volts.
C30	2.0 microfarads, Condenser Products Co. type LAC 205.
L5	Thordarson type T20C53 choke.
L6	Thordarson type T20C53 choke.
L7	Western Electric type 276-J Relay.
T4	Thordarson type T22R02 Transformer.
T5	Thordarson type T22R02 Transformer.
T6	Thordarson type T21F08 Transformer.
V19	6X4 tube.
V20	5693 tube preferred, 6SJ7 satisfactory.
V21	6AC7 tube.
V22	6AC7 tube.
V23	OB2 tube.
V24	OA2 tube.
V25	6X4 tube.

V26	6AU6 tube.
V27	6AL5 tube.
V28	5692 tube preferred, 6SN7 usable.
V29	5693 tube preferred, 6SJ7 satisfactory.
V30	OB2 tube.
V31	OA2 tube.
F3	1 ampere fuse.
F4	1 ampere fuse.
LA2	6-volt GE47 bulb and panel type socket.
D2	Tracerlab SC11 Scaler.
D3	Tracerlab SC11 Scaler
D4	Tracerlab SC11 Scaler
B2	30 volts bias battery.
B3	3 volts bias battery.
M2	100 microamperes panel type ammeter.

C4. Connecting Cables - In addition to the following cables which connect the panels, two coaxial cables with 83-1SP connectors are required to connect the computer trigger unit to the doppler radar amplifiers.

C02 to C05	lamp cord.
C03 to C011	lamp cord.
C04 to C016	lamp cord.
C08 to C012	3 no. 20 conductors insulated and group shielded terminated by 91MC3M plugs.
C09 to C013	3 no. 18 conductors insulated and group shielded terminated by AN3106-14S-2P and AN3106-14S-2S plugs.
C010 to C018	4 no. 18 conductors insulated and group shielded terminated by AN3106-14S-5P and AN3106-14S-5S plugs.
C014 to C017	6 no. 22 conductors insulated and terminated by AN3106-18-12P plugs.

* * *

NAVY-DPPO PRNC, WASH., D.C.