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# SIMULATION OF SONAR TRACKING

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**ABSTRACT**

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Equipment has been developed which generates range and bearing data comparable to that obtained from maneuverable own ship and target ship. This continuous information is converted, through circuits simulating the information-handling circuits of the SQS-4 Sonar, to the intermittent data flow which exists between the SQS-4 Sonar and the Mark 5 Attack Director. This equipment has been connected to a Mark 5 Attack Director and has been used to simulate operation of a Mark 105 Fire Control System.

**PROBLEM STATUS**

This is an interim report on one phase of the problem; work on other phases is continuing.

**AUTHORIZATION**

NRL Problem No. S05-13  
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## SIMULATION OF SONAR TRACKING

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### INTRODUCTION

The increased complexity of sonar-fire-control systems has created a need for methods of determining the compatibility of equipment under development. Ultimate shipboard evaluation is required in order to establish the merit of these new systems. Fleet exercises, however, are costly and time consuming; involve extensive preparation and planning; and require the use of scarce submarine time. In addition, difficulty is experienced in obtaining data which is free of such undesired factors as operator error, variability of sonar conditions, uncertainty in target location, and dependency on reconstruction for the evaluation of weapon miss distance. Much information concerning the compatibility of equipments can be obtained prior to shipboard installation from laboratory studies, which use inputs generated from known speeds and courses and are not dependent on a human operator for sonar tracking. A portion of this equipment would be a computer to generate range and bearing of the target from own ship; the remainder would present to the fire-control equipment the target range and bearing modified to include the delays inherent in the sonar equipment. The total equipment would be a simulation of the sonar equipment with maneuverable target and own ship to provide signals to fire-control equipment.

Simulation equipment, shown in Fig. 1, which will achieve the desired performance, has been developed to investigate SQS-4 Sonar and Attack Director, Mark 5, operation. This report describes the Relative Motion Computer and the Sonar Simulator.

### LIST OF SYMBOLS

$S_t$	Target Speed
$S_o$	Own Ship Speed
$C_t$	Target Course
$C_o$	Own Ship Course
$B_q$	True Bearing From Own Ship to Target
$Br_q$	Relative Bearing From Own Ship to Target
$R_q$	Range from Own Ship to Target
$A$	Target Aspect; angle measured clockwise from target course to line of sound
$\Delta CR_q$	Rate Aided Tracking: Range
$\Delta CB_q$	Rate Aided Tracking: True Bearing

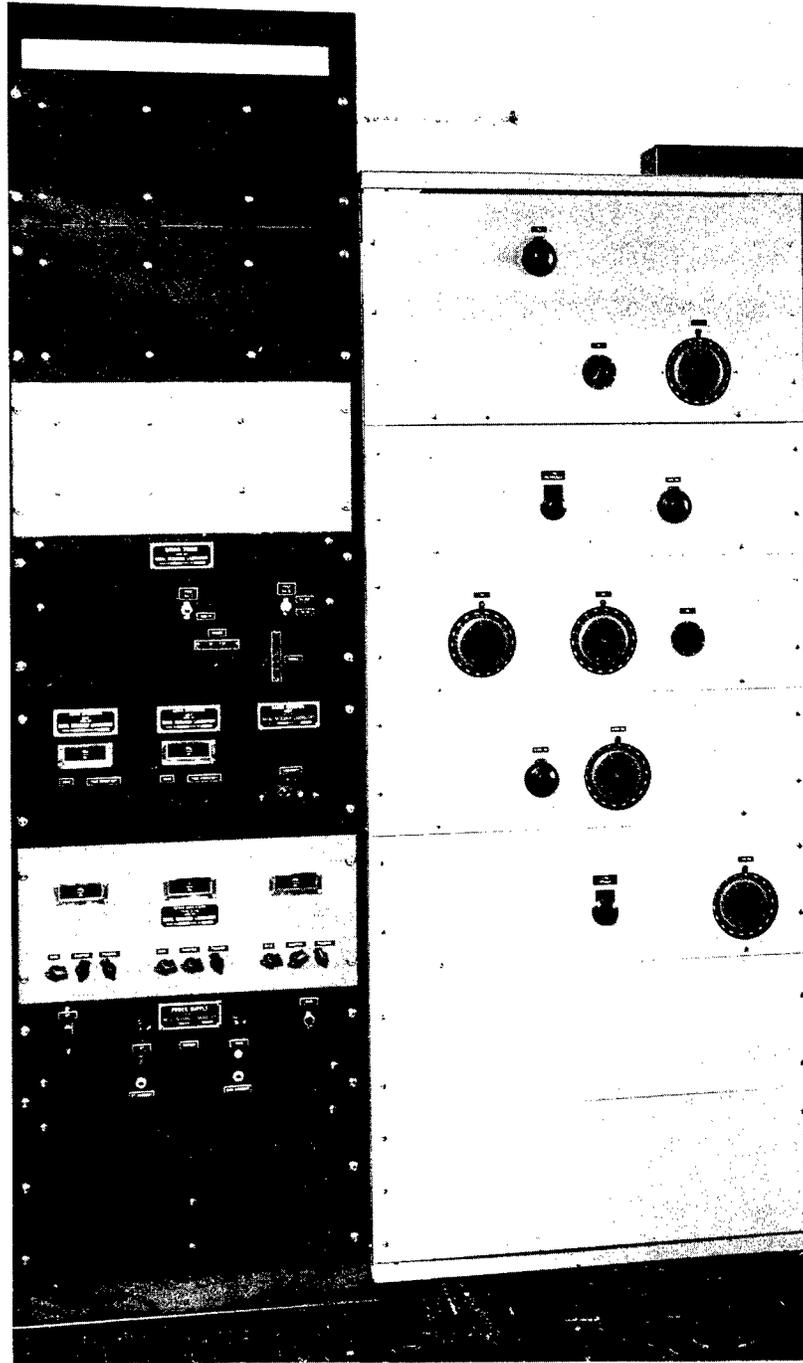


Fig. 1 - Sonar simulation equipment

- jRq    Correction to Range
- jBq    Correction to True Bearing
-     Amplifier
-     Servomotor
-     Tachometer Generator
-     Synchro Generator
-     Synchro Control Transformer
-     Synchro Differential Generator
-     Sine-Cosine Mechanism
-     Ball-Disc Integrator
-     Resolver
-     Mechanical Differential
-     Manual Input Knob
-     Potentiometer
-     Summing Point

**THEORY AND GENERAL DISCUSSION**

**Relative Motion Computer**

The Relative Motion Computer is an analog computer designed to receive inputs of target course and speed together with own ship course and speed, and to compute outputs of range and bearing of target from own ship. All computations are made on the basis of fixed courses and speeds; however, the Relative Motion Computer can, at any time, accept a change in course or speed and compute on the basis of the new information.

Figure 2 is a plot of a typical problem. (A list of terms and symbols is given to aid in interpretation of diagrams and equations.) Inspection of the angular relations at own ship and target on Fig. 2 discloses these equations:

$$B_{r q} = B_q - C_o \tag{1}$$

$$A = -180^\circ + B_q - C_t \tag{2}$$

When the ships are proceeding on constant courses at fixed speeds, differentiating Eq. (1) and (2) with respect to time gives a third equation

$$\frac{d B_q}{dt} = \frac{d A}{dt} = \frac{d B_q}{dt} \tag{3}$$

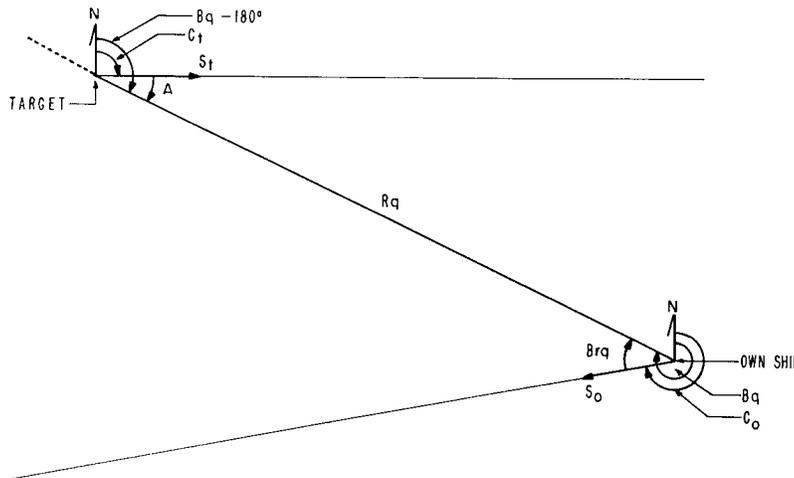


Fig. 2 - Geometry of relative ship motion

Subtracting Eq. (2) from Eq. (1) leads to

$$Brq - A = \text{constant.} \quad (4)$$

The relation for rate of change of range may be developed by consideration of relative ship motion along the line of sound

$$\frac{d Rq}{dt} = S_o \cos Brq + S_t \cos A. \quad (5)$$

Development of the equation for rate of change of bearing is perhaps best undertaken by considering first one and then the other ship to be stationary, and then combining the resulting relations through use of superposition theory. If own ship is stationary, the motion of the target across the line of sound could be expressed by

$$Rq \frac{\Delta Bq}{\Delta t} = -S_t \sin A. \quad (6a)$$

The term  $Rq \frac{\Delta Bq}{\Delta t}$  is the familiar  $R\theta$  relation for an arc of a circle and  $S_t \sin A$  is the chord of that arc; therefore, to preserve accuracy  $\Delta t$  is allowed to approach zero and the equation becomes

$$Rq \frac{d Bq}{dt} = -S_t \sin A. \quad (6b)$$

For a stationary target the relation for motion due to own ship, derived in parallel fashion, becomes

$$Rq \frac{d Bq}{dt} = S_o \sin Brq. \quad (6c)$$

Combining (6b) and (6c) gives the complete relation for rate of change of bearing

$$\frac{d Bq}{dt} = \frac{S_o}{Rq} \sin Brq - \frac{S_t}{Rq} \sin A. \quad (6)$$

A block diagram of a computer which utilizes the relationships defined in Eqs. (1), (2), (5), and (6) to give own ship and target motion is presented in Fig. 3. Description of the relative motion computer can best begin by describing the range-computing section



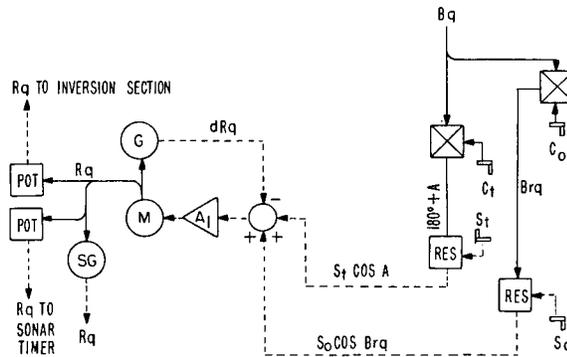


Fig. 4 - Range computer section of relative motion computer

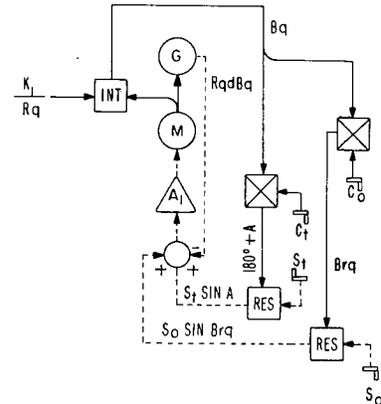


Fig. 5 - Bearing computer section of relative motion computer

to give the desired velocity,  $\frac{dB_q}{dt}$ , and the division is done by use of a ball-disc integrator. A ball-disc integrator is a mechanical device which permits a continuous and precise change of gear ratio. For a given integrator-input-shaft velocity, manipulation of the control shaft will cause the output velocity to decrease from a maximum value to zero and then increase in the reverse direction to the same maximum value. The linear position of the control shaft is accurately proportional to the output speed and is thus inversely proportional to the gear ratio. To divide the velocity,  $R_q \frac{dB_q}{dt}$ , by range,  $R_q$ , the integrator control shaft is moved to a position proportional to  $1/R_q$  and the velocity,  $R_q \frac{dB_q}{dt}$ , is made the input to the integrator. The output speed will be proportional to the position of the control shaft and the input speed; therefore, the output speed will be proportional to the product  $(1/R_q) (R_q \frac{dB_q}{dt})$ , which is rate of change of bearing,  $\frac{dB_q}{dt}$ . The angular position of the output shaft is the time integral of the velocity, and is thus bearing,  $B_q$ .

Figure 6 is a diagram of the range inversion section. This section uses a high-gain amplifier with feedback proportional to range to develop an electrical signal proportional to inverse range. This signal is applied to a servo, which positions a resolver shaft to make the resolver output equal to the inverse range signal. A sine mechanism is used to convert the resolver shaft angle to a linear position proportional to inverse range. This linear motion is applied as the input to the control shaft of the integrator.

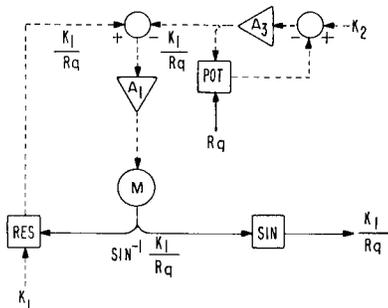


Fig. 6 - Range inversion computer of relative motion computer

The remaining servo in the Relative Motion Computer is used to repeat bearing,  $B_q$ , to facilitate mechanical arrangement of components.

### Sonar Simulator

The Sonar Simulator, Fig. 7, alters the range and bearing signals from the Relative Motion Computer to incorporate the time lags and intermittent data features inherent in any sonar equipment, and in the SQS-4 in particular. The SQS-4 has delays not found in most sonars to aid the operator and in processing the data. The sequence of events in the SQS-4 is as shown in Fig. 8. The transmitter is keyed and the sonic pulse

is radiated omnidirectionally. Immediately following transmission, the equipment is set to receive; and, when the echo is received, it is displayed on a PPI oscilloscope. On the basis of hand-set range, the SQS-4 computes a time of echo and generates a sweep voltage for that time plus a delay time in order to assure that the true echo is shown even with the target fully evasive. At the end of this delay time, a cursor is presented for the operator to match to the echo position. The time of cursor presentation is referred to as dwell time. During dwell time all aided tracking information is interrupted and the sonar is cut off from the Attack Director, to permit easier and more accurate cursor matching. Aided tracking signals are restored at the end of dwell time, and, once the servos have synchronized, the sonar supplies the corrected range and bearing information to the Attack Director.

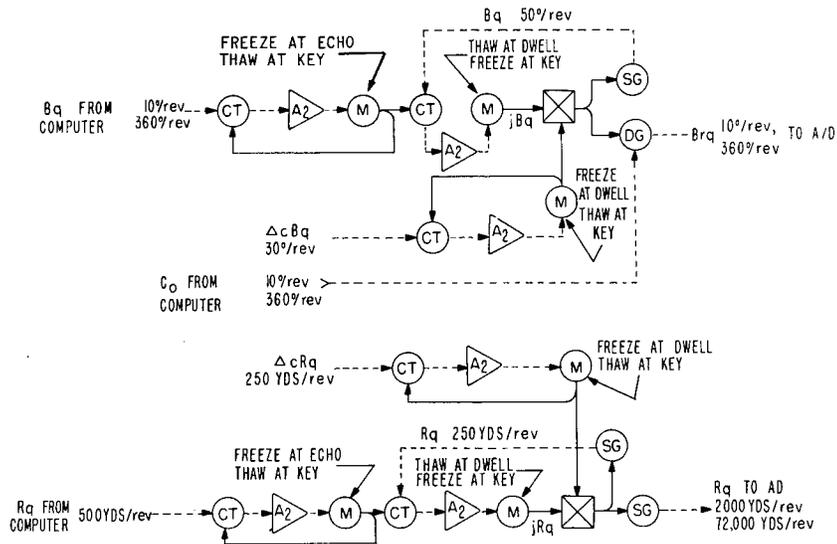


Fig. 7 - Sonar simulator

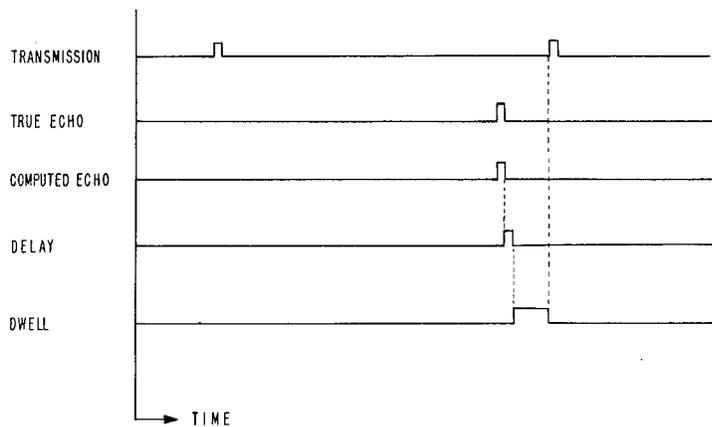


Fig. 8 - Time relationships in the SQS-4 sonar

A sonar timer is used to generate the delay between key and echo of the sonar signal, the constant delay of 400 or 250 milliseconds after echo, the 0.4 to 2.5 seconds dwell time, and the servo synchronizing time. During dwell time, operator corrections are added to the rate aided tracking information; while the Attack Director is held in Position Keeping, and the servos transmitting aided tracking information are frozen. At the end of dwell time, the aided track servos are released, but the Attack Director must be held in Position Keeping until these servos have synchronized to the sum of operator corrections and accumulated aided tracking information in order to avoid giving the Attack Director false rates. The delay to permit the servos to synchronize is referred to as synchronizing or sync time. Controls are provided to set range scale and dwell time; a switch is provided to hold all servos operative and the Attack Director in On Target; and a switch is provided to remove the fixed delay of 400 or 250 milliseconds after echo.

The servos, Fig. 7, receiving range and bearing from the Relative Motion Computer freeze these quantities at the time of echo. A period of 400 or 250 milliseconds later (depending on range), dwell time is initiated; the aided track ( $\Delta$ quantity) servos are frozen, the Attack Director is placed in Position Keeping, and the j-order servos are released to insert corrections. At the end of dwell time, the range and bearing servos and the aided track servos are energized; the j-order servos are frozen and the Attack Director is placed in On Target after the aided track servos are synchronized.

The mechanical differentials add the  $\Delta$  quantities to the j-order corrections to generate the range and bearing signals fed to the Attack Director. The Attack Director must receive relative bearing as an input; therefore, own ship's course,  $C_o$ , is subtracted from generated true bearing in differential synchro generators to provide the Attack Director with relative bearing,  $Brq$ .

#### SAMPLES OF OPERATING PROCEDURE

Place Attack Director in Standby, and turn on Bias Switch on Simulator Power Supply. After blue indicator lights, turn on B+ Power Switch, and place Attack Director in Automatic, On, and Time Motor On. System is now ready for operation.

Normal procedure for selecting input information would be to select a minimum range  $R_{qm}$ , and determine courses, speeds, and initial range on that basis. For parallel courses

$$A = Brq \quad (7)$$

$$R_{qm} = Rq \sin A = Rq \sin Brq. \quad (8)$$

For nonparallel courses:

$$R_{qm} = Rq \cos |Brqm - Brq| \quad (9)$$

$$Brqm = \tan^{-1} \left[ \frac{\frac{S_o}{S_t} + \cos (A - Brq)}{\sin (A - Brq)} \right]. \quad (10)$$

Equations (9) and (10) are solved in graphical form in Fig. 9.

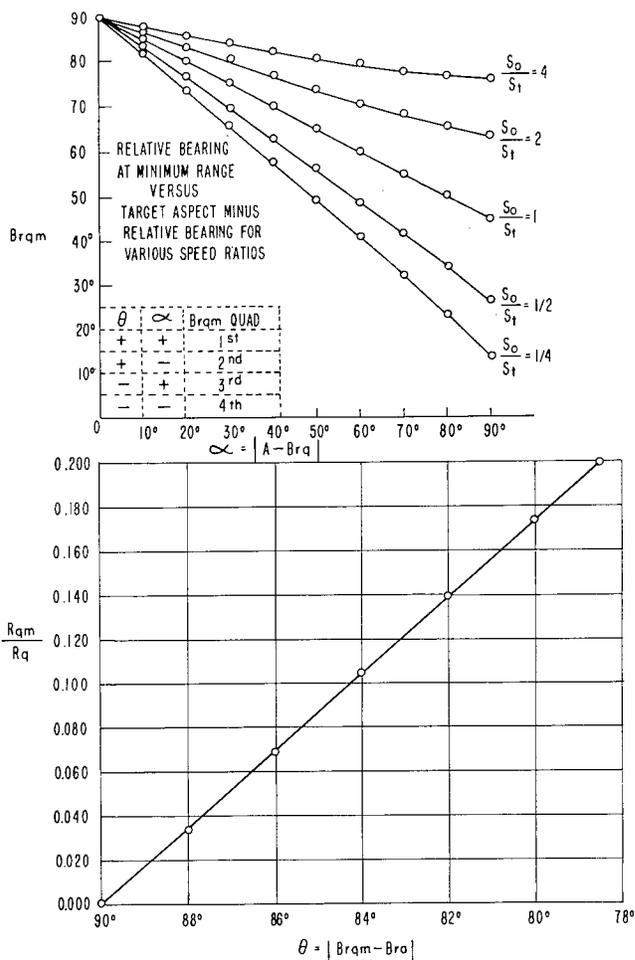


Fig. 9 - Ratio of minimum range to range versus Brqm minus relative bearing

Examples of two problems are given below.

Example 1

Initial settings extant might be

$R_q = 4000$  yards

$B_q = 027^\circ$

$C_t = 030^\circ$

$C_o = 175^\circ$

$S_t = S_o = 0$

Sonar Range Scale = 5000 yards

Sonar Dwell Time = position 2

Test Switch 1: ON (all servos on)

Test Switch 2: OFF (fixed delay in).

Since the Attack Director will accept information from 6000 yards in, computer range should be set to 6000 yards and range and bearing repeating servos should be checked for synchronism. If synchronism does not exist, turn off B+ Power on Simulator Power Supply and adjust the servos to agree. Turn B+ Power on.

Select a minimum range for parallel courses, for example: 200 yards. (Note: Minimum range should be in excess of 100 yards.) Determine initial aspect:

$$A_i = \sin^{-1} \frac{200}{6000} = 1.9^\circ = Brq_i.$$

Determine  $C_t$  and  $C_o$ :

$$\begin{aligned} C_t &= 180 + Bq - A_i \\ &= 180 + 27 - 1.9 = 205.1^\circ; \end{aligned}$$

$$\begin{aligned} C_o &= Bq - Brq_i \\ &= 27 - 1.9 = 025.1^\circ. \end{aligned}$$

Make the initial settings:

$$Rq = 6000 \text{ yards}$$

$$C_t = 205.1^\circ$$

$$C_o = 025.1^\circ$$

Sonar Range Scale: 10K yards

Sonar Dwell Time: Position 2.

Select speeds, for example,  $S_o = S_t = 15$  knots, and set these in; turn sonar test switch 1 to OFF. Problem is now generating. (Note: the j-order range servo may lose synchronism when computer  $S_t$  minus Attack Director  $S_t$  is in excess of 15 knots, Attack Director  $C_t$  is not approximately computer  $C_t$ , range in excess of 4000 yards, and dwell time in excess of 0.4 second (Position 1).)

### Example 2

For the same initial conditions and the same  $Rq$ , select the angle  $(A - Brq)$  and a speed ratio  $S_o/S_t$ . From Fig. 9 determine  $Brqm$ .

Let

$$A - Brq = 30$$

$$\frac{S_o}{S_t} = 2.$$

Therefore,

$$Brqm = 80.0^\circ$$

$$\frac{Rqm}{Rq} = 0.0333.$$

Thus,

$$\text{Brqm} - \text{Brq} = 88.1^\circ$$

$$\text{Brq}_i = -0.1^\circ$$

$$A_i = 21.9^\circ.$$

The initial settings would then be

$$R_q = 6000 \text{ yards}$$

$$B_q = 27^\circ$$

$$C_o = 35.1^\circ$$

$$C_t = 185.1^\circ$$

$$\frac{S_o}{S_t} = 2 \text{ or } S_o = 30 \text{ knots, } S_t = 15 \text{ knots.}$$

The sonar timer range scale should be switched at the appropriate ranges and dwell time should be changed to Position 1 as soon as the Attack Director has a nearly correct solution as indicated by a small j-order correction.

The sonar timer test switch 2 may be turned ON to determine effect of eliminating the constant time delay after echo.

## DESCRIPTION OF COMPONENTS

### Servoamplifier A1

This amplifier, Fig. 10, adds a maximum of four signals in the summing amplifier stage, phases the resultant to be in quadrature relationship with the servomotor fixed field, and then amplifies the signal to a maximum level of approximately 12 watts to be applied to the servomotor control field. Jacks are provided for the inputs, for connection to a lag compensating preamplifier, for output to the servomotor, and for metering.

The summing amplifier<sup>1</sup> is a 6AU6 with 100% feedback to increase the input impedance for the purpose of elimination of input interaction. The output signal should be equal to an input signal applied to any one of the Input jacks or the Damping jack (with Damping control set for full gain), but with 180° phase shift.

The phasing amplifier uses a 6C4 to inject the signal into a phase shift circuit<sup>2</sup> made up of a transformer, a capacitor, and a potentiometer. The circuit will provide about 135° of phase shift with slight voltage gain, and thus permits accurate phasing of the servomotor control field voltage.

The power amplifier is a version of the "General Radio Signal-Ended Push-Pull"<sup>3</sup> amplifier designed to match the impedance of a Diehl FPE 25-11 servomotor. The 6AU6 and first half of the 12AU7 provide voltage gain; the second half of the 12AU7 is the driver and the 6Y6's make up the power stage. The two screwdriver-adjust potentiometers are used to set operating conditions for the 6Y6's. A 100-ma meter is connected to the metering jack on the chassis near the 6Y6's and a voltmeter is connected between chassis ground

<sup>1</sup>Seely, S., "Electron-Tube Circuits," New York:McGraw-Hill, 1950, p. 1948

<sup>2</sup>Chance, B., et al., eds., "Waveforms" (MIT Radiation Lab. Series No. 19), New York: McGraw-Hill, 1949, p. 136

<sup>3</sup>"General Radio Experimenter," October 1951



and the blue pin jack. The two potentiometers are adjusted to give a voltage of 200 volts and a current of 40 milliamperes. If "motorboating" develops, the simplest cure would be to reduce the amount of voltage feedback around the power amplifier by reducing the value of the 8.2K resistor which is in series with a 91K resistor connected to the output.

The gain adjustment is set to that value of gain just below servo oscillation.

Servoamplifier A2

This amplifier, Fig. 11, is designed for use with a two-speed synchro-servo using tachometer-generator damping.

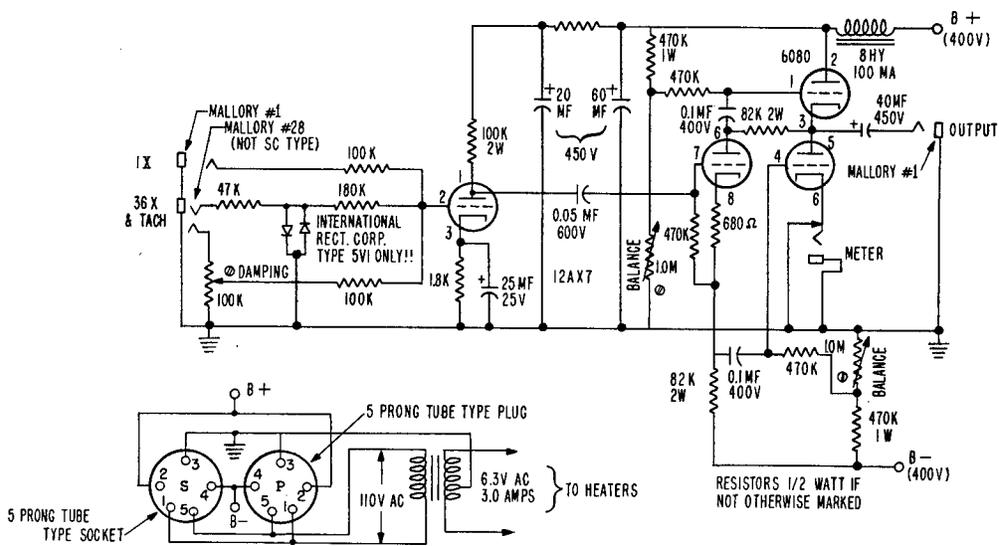


Fig. 11 - Servoamplifier, Type A2

The reason for using a two-speed synchro system is to obtain additional accuracy over a one-speed system. For example, a one-speed (1X) system could be used to repeat bearing with 360° of bearing equal to one revolution of the synchro shaft. The accuracy to be expected in this system using size-1 synchros would be approximately ±30 minutes. If an additional synchro is added, geared 10° of bearing per revolution of the synchro shaft (36X), the accuracy would be approximately ±1 minute. However, some method of selection must be provided to use the 1X synchro for large errors and the 36X for small errors.

The selection, or crossover, network used in this amplifier is made up of the series input resistors and the two selenium diodes. The diodes serve as ac limiters to limit the 36X synchro signal to a value which permits the 1X synchro to assume control for errors larger than 3°.

Tachometer-generator voltage is used for damping and is controlled by the screw-driver adjust potentiometer marked Damping. Damping is adjusted as necessary to keep servo from oscillating.

The 12AX7 and the 6080 tubes operate in the same fashion as the 12AU7 and 6Y6 tubes in amplifier, A1. The operating conditions for the 6080 are set by connecting a 100-ma meter to the metering jack and a voltmeter between ground and pins 3 and 5 of the 6080. The balance potentiometers are used to set current to 40 milliamperes and the voltage to 200 volts.

### Servo Integrator

Figure 12 is a schematic of the active network used to provide lag compensation of the range and bearing servos. The operation of this network is covered fully in Reference 4. Briefly, the network acts as a pseudo integrator to reduce steady-state errors to a fraction of their normal value.

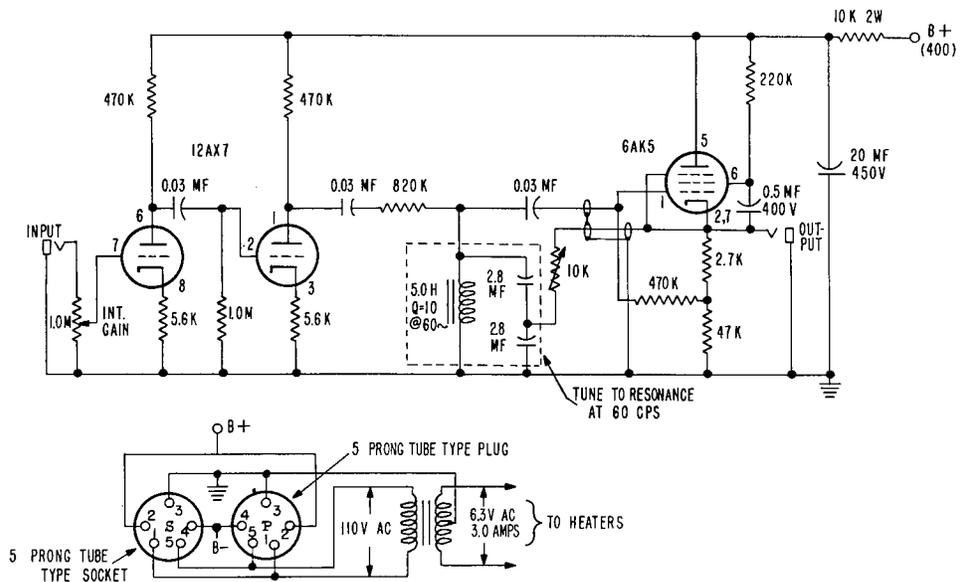


Fig. 12 - Servo integrator

The input of the compensator is connected to the Error jack on A1, and the output is connected to the Integral jack.

The Time Constant control should be set to about one-half and gain then increased to a point just below servo oscillation.

### Range Inversion Amplifier A3

Figure 13 shows the schematic for the inversion amplifier. This amplifier is simply a high-gain dc amplifier which has inverse feedback varied by range. The usual feedback amplifier equation is thus

$$K = \frac{u}{1 - uRq}$$

Consequently, for  $uRq$  large, the amplifier gain is  $1/Rq$ .

<sup>4</sup>Looney, C. H., "An Equalizing Network for Carrier-Type Feedback Control Systems," Proc. IRE. 43 (No. 1):22-22, 1955

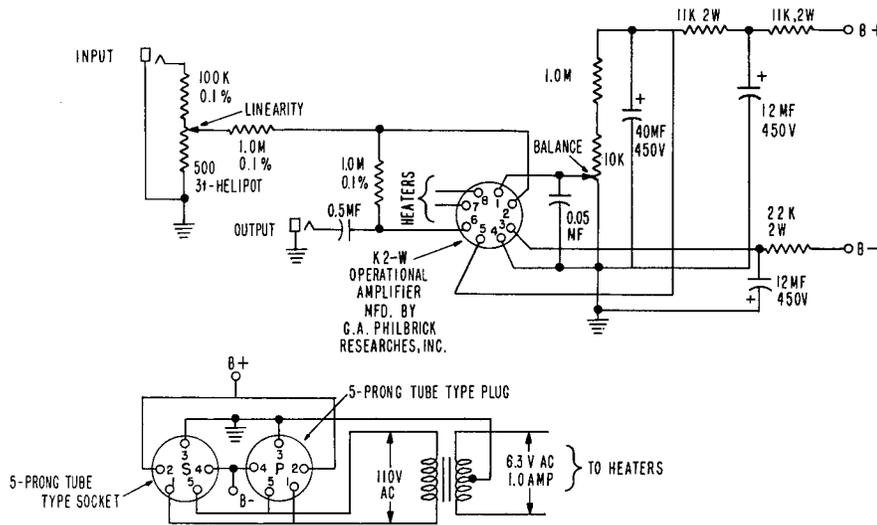


Fig. 13 - Inversion amplifier, Type A3

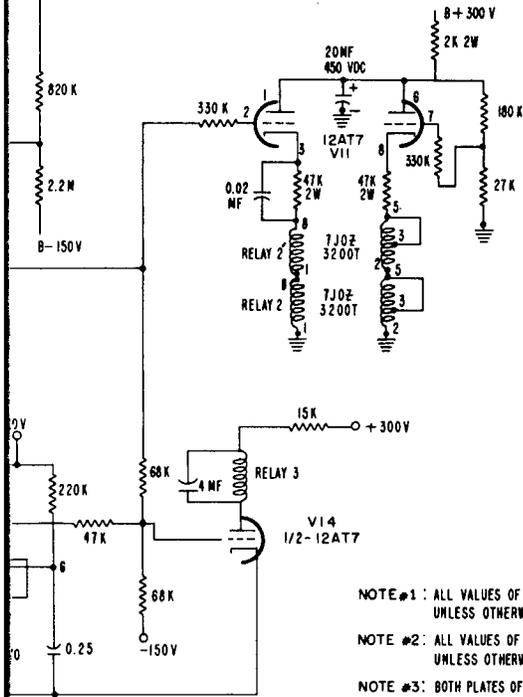
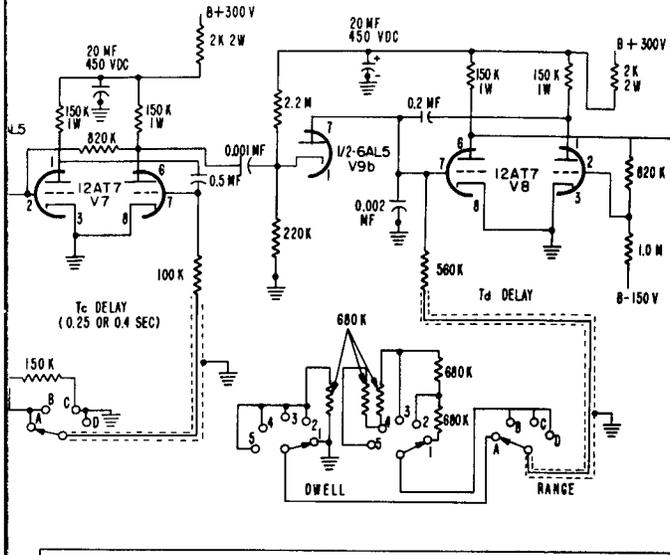
The only controls are balance and input voltage magnitude which determines linearity of the Relative Motion Computer. Balance control is set by reducing computer range to 150 yards and adjusting balance potentiometer for minimum 120-cps component in the error voltage of the main servoamplifier for this servo. Linearity is set to that point giving most accurate computation from 6000 yards in to a minimum range of approximately 200 yards. The best setting will, of course, be a compromise, but linearity should be well within  $\pm 25$  yards of a straight line course.

Sonar Timer

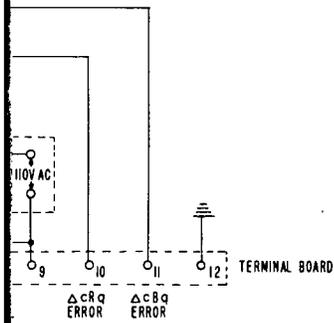
The Sonar Timer, Fig. 14, generates pulses at the time of keying the mock sonar transmitter, at the time the echo would be detected, at the end of the fixed delay  $T_c$ , and at the end of dwell time,  $T_d$ . The timer also provides a delay (during synchronization of the  $\Delta$ -quantity servos) before returning the Attack Director to On Target.

The time base is established by the circuit including V1, V15, and V16. An ac voltage proportional to the reciprocal of the range scale established by the range switch is rectified by V15 and V16 and then charges the 2.0-MF capacitor connected to the grids of V1. The tube V1 is a cathode follower used in a "bootstrap" circuit to linearize the charge curve of the RC network made up of the precision 1.0-M resistor and the 2.0-MF capacitor. The voltage from the cathode follower, V1, is thus a linearly rising voltage having a slope proportional to the range scale selected.

This rising voltage could be termed a sweep voltage, and, in fact, is used as the PPI sweep voltage in the SQS-4. The time of echo is determined by subtracting a dc voltage proportional to range from the sweep voltage and triggering a multivibrator at the time this difference voltage goes through zero. The dc voltage proportional to range is developed from the circuit including tubes V2, V3, and V4, and the pulse at echo is formed by tube V5.



- NOTE #1: ALL VALUES OF RESISTORS ARE 1/2 WATT, UNLESS OTHERWISE SPECIFIED.
- NOTE #2: ALL VALUES OF CONDENSERS ARE 400V DC, UNLESS OTHERWISE SPECIFIED.
- NOTE #3: BOTH PLATES OF EACH 6X4 ARE TIED TOGETHER.



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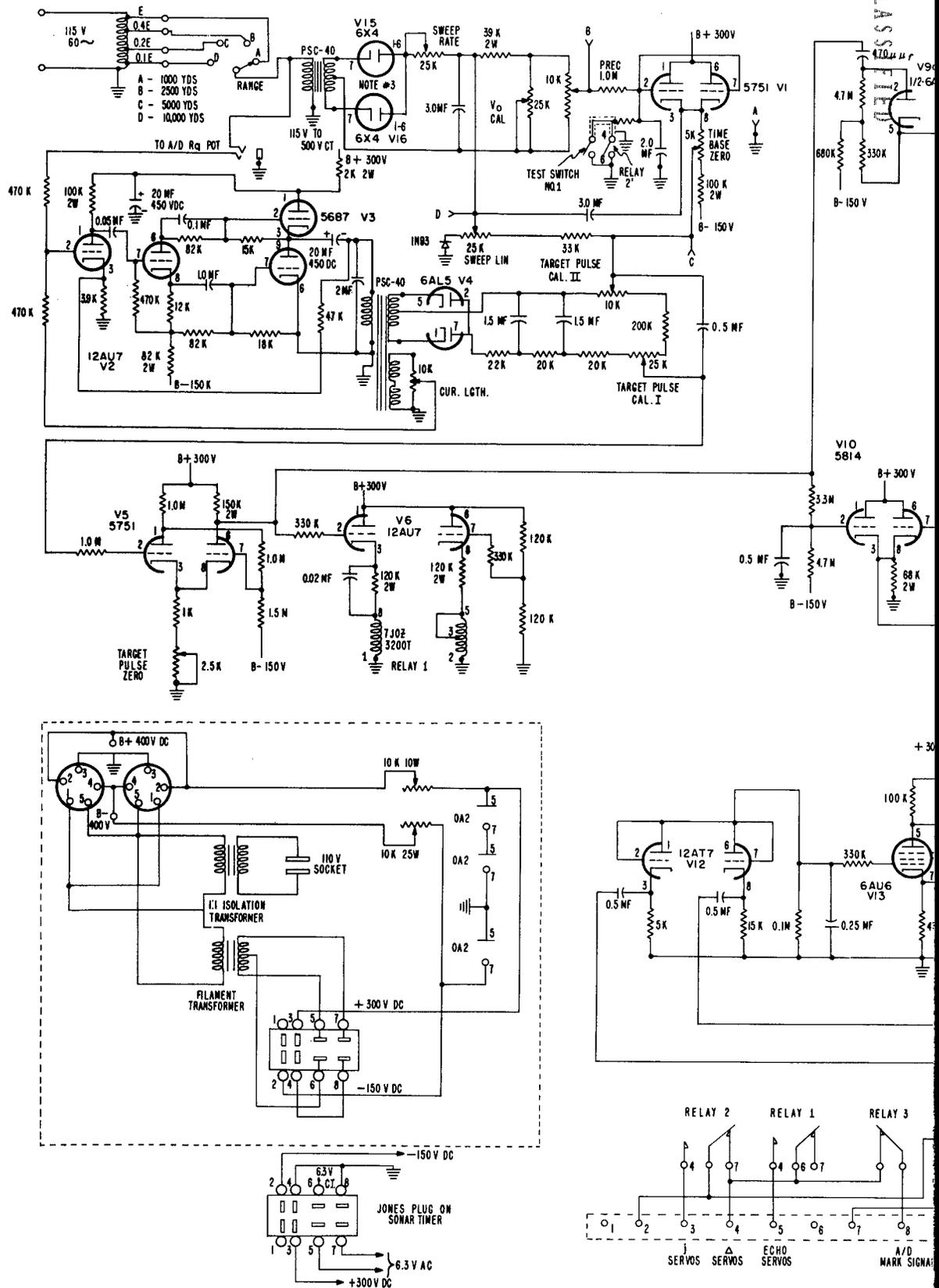


Fig. 14 - Sonar timer

Tube V6 operates Relay 1 at echo time. A time delay of 400 or 250 milliseconds (depending on range) occurs in the SQS-4 after computed echo to avoid the possibility of losing the actual echo. This delay is generated by V7 and V9a. Dwell time is established by the multivibrator utilizing tubes V8 and V9b. The dwell time is varied from 0.4 to 2.5 seconds by the Dwell switch. V11 operates Relays 2 and 2' during dwell time. V10 supplies a pulse to V11 during dwell time, or, if the dwell time multivibrator is not triggered, V10 raises the grid of V11 to operate the relays when the sweep voltage has progressed to a point well beyond full scale. Relay 2' shorts out the sweep capacitor to ready the circuit for the next cycle of operation.

Relay 1 is used to freeze the range and bearing servos to the range and bearing values at the time of echo. Relay 2 is used to freeze the  $\Delta$ -quantity servos and to thaw the j-order servos during dwell time. The dwell time pulse is fed to tube V14 to operate Relay 3 which puts the Attack Director in Position Keeping. Error signals from the  $\Delta$ -quantity servos are rectified by V12, amplified by V13, and applied to V14 to hold Relay 3 open until the servos are synchronized, thus keeping the Attack Director in Position Keeping during dwell time plus synchronizing time.

Circuit adjustments are made primarily to set the slope of the sweep voltage and the magnitude of the range voltage to calibrate key-to-echo times. SQS-4 adjustments are made on the basis of scope presentation, but, since the timer has no associated display, the adjustments are made in a different manner. With test switch 1 turned ON, range scale 1000, and range of 1000 yards, Time Base Zero is adjusted to make the voltage from jack C to jack A equal to zero, and Sweep Linearity is adjusted to make the voltage from jack D to jack A equal to zero.  $V_0$  Cal or  $V_0$  is adjusted to make the voltage from jack B to jack D equal to  $156^\circ$  volts corresponding to a sound velocity of 4800 ft/sec. Connect an oscilloscope Y amplifier between jack C and ground; turn X amplifier OFF; connect the Z input to pin 8 of Relay 1 socket, and connect a 1000-ohm resistor between the Z input and ground. Set range scale to 2500 and simulated range to 2500 yards with test switch 1 OFF. Adjust oscilloscope gain so that the deflection from the position of the C-R beam during dwell to the beam position when brightened is five squares. Set simulated range to 500 yards and adjust T. P. Zero to make the deflection from dwell position to brightened position one square. Return simulated range to 2500 yards and adjust T. P. Cal I or II to make the deflection five squares. Repeat until further adjustments are unnecessary. Check the time from key to echo (brightened C-R beam) for simulated range of 2500 yards and range scale of 2500. Adjust Sweep Rate to make the time equal to 3.06 seconds.

#### Power Supply

Figure 15 is a schematic of the power supply used by all the servoamplifiers and associated electronic instruments in the simulator and computer. Three-phase ac is transformed open delta and applied to a three-phase selenium rectifier which supplies +400 volts at 3.0 amperes maximum. Single-phase ac is used to develop a bias supply of -400 volts at 50 milliamperes. A dc relay is operated by the bias voltage to delay or interrupt application of B+ until bias voltage is present. Current and voltage metering jacks are provided for testing. A blue pilot light indicates presence of bias voltage and a red pilot light indicates B+.



TABLE 1  
Data on Parallel Courses

Time (sec)	C <sub>o</sub> = 000		C <sub>t</sub> = 180		S <sub>o</sub> = 15 knots				S <sub>t</sub> = 15 knots					
	Rq (yd)	Bq (deg)	Brq (deg)	Rq	Sin	Brq	Rqx	Error (yd)	Rq	Cos	Brq	Rqy	ΔRqy (yd)	Error (yd)
0	6000	002.0	002.0	209				0	6000					
15	5720	002.1	002.1	209				0	5720			280		
45	5200	002.2	002.2	200				-9	5200			520		-9
75	4680	002.4	002.4	196				-13	4680			520		-9
105	4160	002.8	002.8	203				-6	4160			520		-9
135	3640	003.1	003.1	197				-12	3640			520		-9
165	3120	003.7	003.7	201				-8	3110			530		+1
195	2580	004.5	004.5	202				-7	2570			540		+11
225	2060	005.7	005.7	205				-4	2050			520		-9
255	1540	007.6	007.6	204				-5	1530			520		-9
285	1030	011.6	011.6	207				-2	1010			520		-9
315	540	023.5	023.5	215				+6	495			515		-14
?	220	090.0	090.0	220				+11	0			495		
375	610	160.0	160.0	209				0	570			570		+3.5
405	1100	169.6	169.6	199				-10	1080			510		-19
435	1610	173.0	173.0	196				-13	1600			520		-9
465	2120	174.7	174.7	196				-13	2110			510		-19
495	2640	175.8	175.8	193				-16	2630			520		-9
525	3160	176.5	176.5	193				-16	3160			530		+1
555	3660	176.9	176.9	198				-11	3660			500		-29
585	4180	177.2	177.2	204				-5	4180			520		-9
615	4700	177.5	177.5	205				-4	4700			520		-9
645	5220	177.7	177.7	209				0	5220			520		-9
675	5740	177.9	177.9	210				+1	5740			520		-9
?	6000	178.0	178.0	209				0	6000			260		

TABLE 2  
Data on Nonparallel Courses

Time (sec)	$C_o = 186.1^\circ$		$C_t = 336.1^\circ$		$S_o = 18$ knots			$S_t = 9$ knots					
	Rq (yd)	Bq (deg)	Brq (deg)	Brqm-Brq (deg)	Rq Cos	Brqm-Brq  (yd)	Rqx (yd)	Error (yd)	Rq Sin	Brqm-Brq  (yd)	Rqy (yd)	$\Delta Rqy$ (yd)	Error (yd)
0	6000	178	-8.1	88.1	199			0	6000				
15	5760	178.1	-8.0	88.0	201			+2	5760		240		
45	5320	178.2	-7.9	87.9	195			-4	5320		440		-5
75	4870	178.4	-7.7	87.7	196			-3	4870		450		+5
105	4420	178.7	-7.4	87.4	200			+1	4420		450		+5
135	3980	179.0	-7.1	87.1	201			+2	3980		440		-5
165	3540	179.3	-6.8	86.8	198			-1	3540		440		-5
195	3090	179.8	-6.3	86.3	200			+1	3090		450		+5
225	2640	180.3	-5.8	85.8	193			-6	2630		460		+15
255	2200	181.2	-4.9	84.9	196			-3	2190		440		-5
285	1750	182.5	-3.6	83.6	195			-4	1740		450		+5
315	1320	184.7	-1.4	81.4	197			-2	1310		430		-15
345	870	189.4	+3.3	76.7	200			+1	850		460		+15
375	450	204.0	17.9	62.1	210			+11	400		450		+5
?	215	266.1	80.0	0	215			+16	0		400		
435	570	335.5	149.4	69.4	205			+6	530		530		+20
465	1000	345.0	158.9	78.9	193			-6	980		450		+5
495	1450	348.6	162.5	82.5	190			-9	1440		460		+15
525	1890	350.3	164.2	84.2	191			-8	1880		440		-5
555	2340	351.5	165.4	85.4	188			-11	2330		450		+5
585	2790	352.2	166.1	86.1	190			-9	2780		450		+5
615	3240	352.7	166.6	86.6	192			-7	3240		460		+15
645	3680	353.0	166.9	86.9	199			0	3680		440		-5
675	4120	353.3	167.2	87.2	201			+2	4120		440		-5
705	4570	353.6	167.5	87.5	199			0	4570		450		+5
735	5010	353.8	167.7	87.7	201			+2	5010		440		-5
765	5460	353.9	167.8	87.8	200			+1	5460		450		+5
?	6000	354.1	168.1	88.1	199			0	6000		540		-5

\* \* \*

**APPENDIX A**  
**Mechanical Components**

Figures A1 through A6 are gear diagrams of the shaft relationships in the mechanical components of the Sonar Tracking Simulator and are included to give a concept of the physical complexity of the equipment.

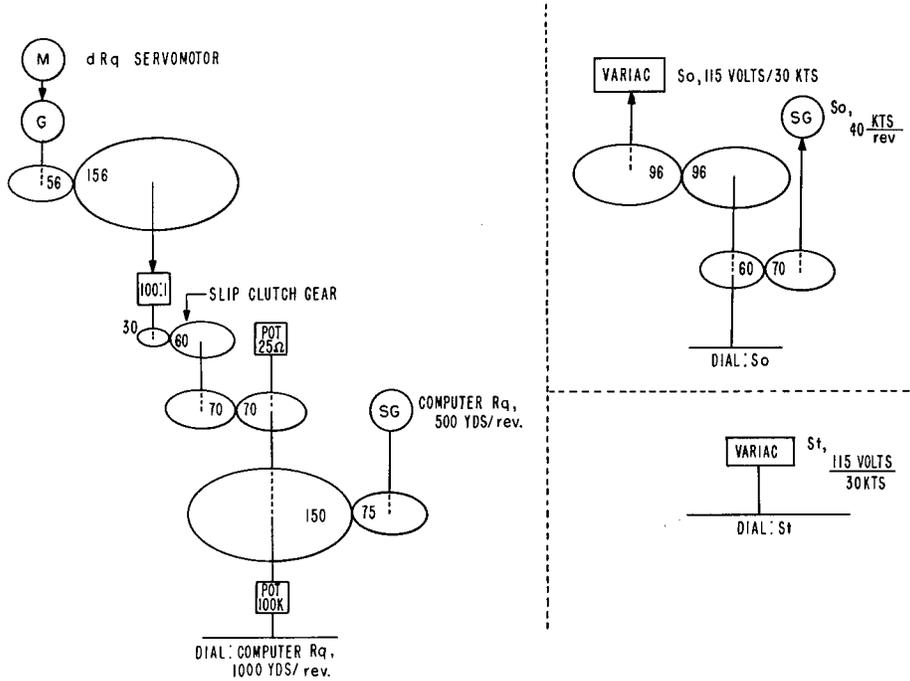


Fig. A1 - Range rate servo; speed sections

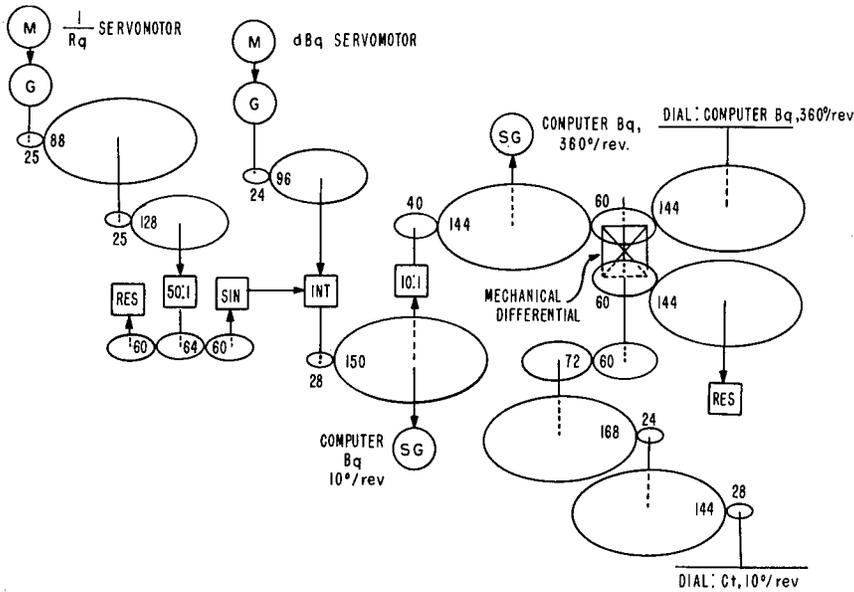


Fig. A2 - Range inversion and bearing-rate servos



