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EXPERIMENTAL RECEIVER-INDICATOR  
FOR COMMON-FREQUENCY RADUX

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**ABSTRACT**

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Radux is a long-range radio-navigation system in which position is determined by the intersection of loci of constant phase between synchronized low-frequency modulation signals transmitted from distant stations, utilizing sky-wave propagation. The system, as proposed by J. A. Pierce, consists of several synchronized low-frequency transmitters operating in a single radio-frequency channel on a time-sharing basis. During 1951 and 1952 an experimental Radux system was put into operation. The Naval Research Laboratory developed techniques for the common-frequency receiver-indicators and supplied six experimental monitors which were constructed at this Laboratory. The receiver-indicator consists of a single radio-frequency channel receiver, a synchronous switch for separating the demodulated signals, and a mechanical servo-driven differential phase-shifting means for measuring and indicating the phase difference. The present report describes the basic principles and techniques of the equipment, which has been used to show that the system operation is in agreement with the predictions of J. A. Pierce's proposal. It is recommended that navigator's equipment be developed for operational use in accordance with plans and decisions as formulated by the Radux Steering Committee.

**PROBLEM STATUS**

This is a final report on one phase of the problem; work on the problem is continuing.

**AUTHORIZATION**

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BuShips Problem S-1558

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EXPERIMENTAL RECEIVER-INDICATOR FOR  
COMMON-FREQUENCY RADUX

INTRODUCTION

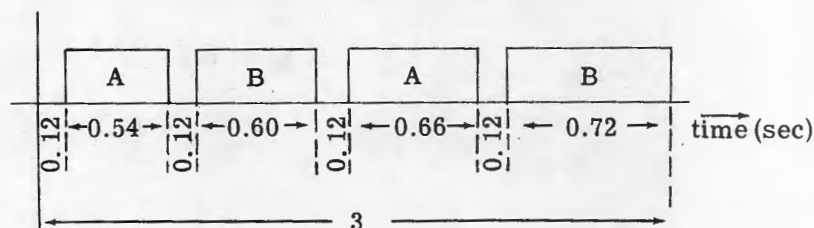
Radux is a long-range, radio-navigation system in which position is determined by the intersection of two or more hyperbolic lines-of-position. Each line represents a locus of constant phase obtained by measuring the phase difference between synchronized audio-frequency modulation on master and slave low-frequency carriers from distant stations. As originally proposed (1), several distant stations would transmit alternately on the same frequency. Later a method was proposed (2) in which the transmissions would be continuous but on different radio frequencies which might allow existing low-frequency stations to be used. These two similar systems are known as Common-Frequency and Multi-Frequency Radux.

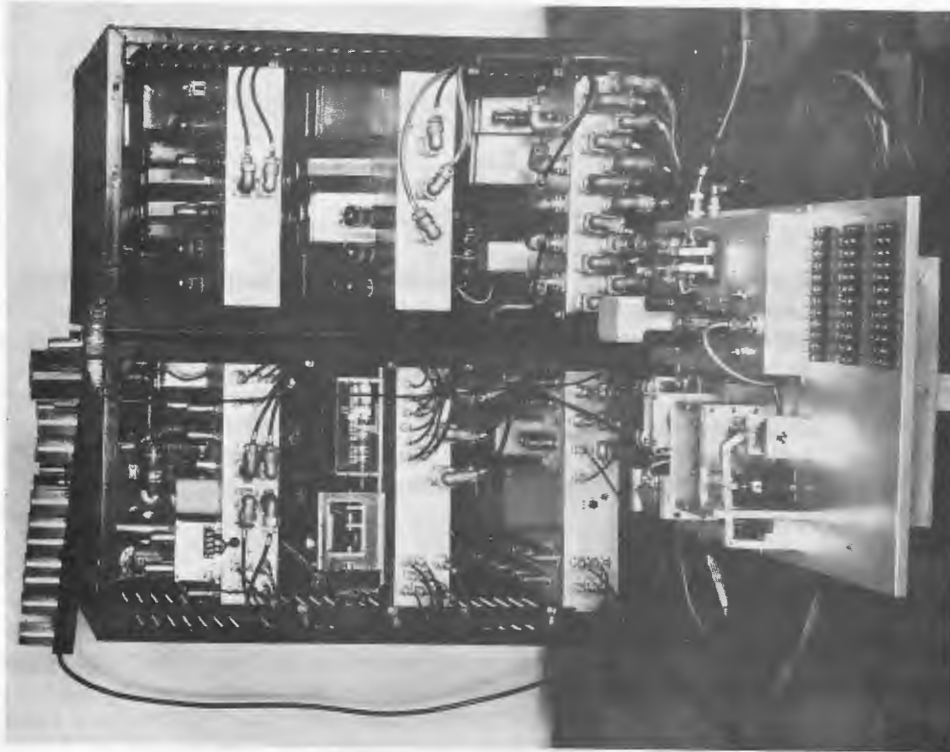
To obtain information for the development of operational equipment, a partial Radux system was assembled during 1951-1952 and put into operation. Transmitters were installed by the Navy Electronics Laboratory at Chollas Heights, Calif., and Haiku, T. H., the station at Chollas Heights being equipped with a synchronizer and operated as a slave to the Haiku transmitter. Monitor equipment was obtained for both Common-Frequency and Multi-Frequency Radux and a means of recording the time (or phase) difference readings from both monitors was provided. From recordings made over long periods of time, both day and night, the phase stability of the Radux signals could be determined using statistical methods.

The receiver-indicator (Fig. 1) for monitoring the Common-Frequency Radux signals was developed at the Naval Research Laboratory following a basic design formulated by J. A. Pierce, and six equipments were built by the Engineering Services Division. Detailed circuitry, operation, and alignment of the equipment have been published previously (3).

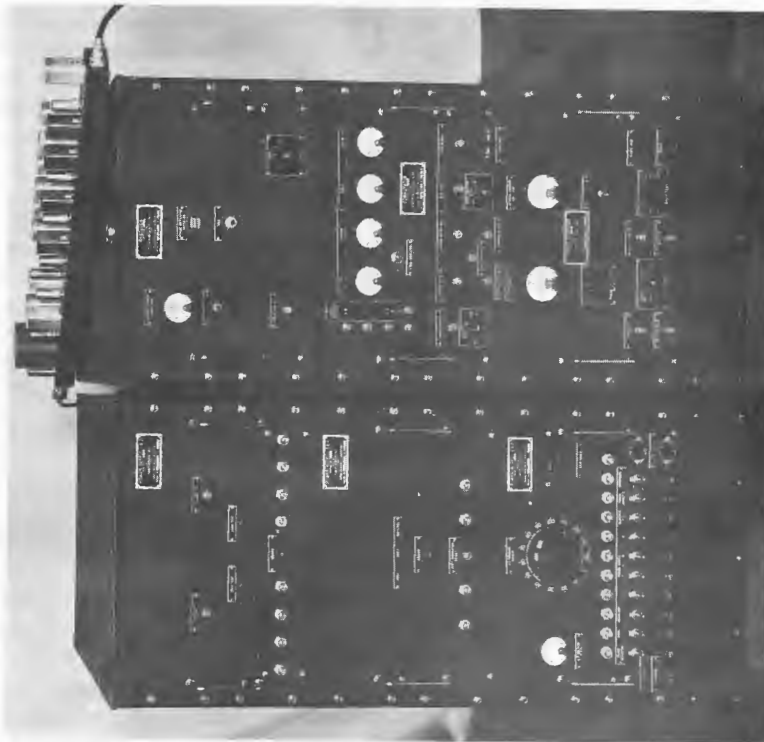
THEORY OF OPERATION

Each of the experimental stations for Common-Frequency Radux transmits on a common-frequency channel of 40 kc using narrow-band 200-cps sine-wave frequency (or phase) modulation. The transmissions are sequential on a time-sharing basis as follows:





(b) Rear view



(a) Front view

Fig. 1 - Experimental Common-Frequency Radux Receiver-Indicator

in which the A signals are transmitted from the master station at Haiku and the B signals from the slave station at Chollas Heights. The phase difference  $\theta$  between the phases  $\phi_A$  and  $\phi_B$  of the 200-cps modulations of the A and B signals form one set of hyperbolic lines-of-position, each line corresponding to a particular phase difference. In the receiver-indicator, the A and B signals are demodulated in the receiver, the phase of each being stopped here shifted by an amount  $\alpha_A$  and  $\alpha_B$ , respectively. Since the signals do not appear simultaneously at the antenna, the phase of each of the demodulated signals is compared with the phase of a corresponding local 200-cps reference signal in a phase detector by switching between the A and B reference inputs in synchronism with the received signals. The dc outputs of the phase detector, which vary in proportion to the phase difference between each signal and its reference, are separated into the A and B components by means of synchronized switching to RC integrators. The integrator outputs are used to drive resolvers which shift the phase of the respective reference, phase-locking each signal and its reference. If the equipment is properly synchronized, the phase of the reference signals will be shifted until the following relations are set up:

$$\beta_A = (\phi_A - \alpha_A) - \mu \quad (1)$$

$$\beta_B = (\phi_B - \alpha_B) - \mu \quad (2)$$

where  $\beta_A$  and  $\beta_B$  are the phase shifts of the A and B reference signals, respectively, and  $\mu$  is the initial reference phase and is identical for both reference signals. A differential gear mechanism controlled by the A and B reference phase shifters gives the phase difference between the reference signals,

$$\beta_A - \beta_B = (\phi_A - \alpha_A) - (\phi_B - \alpha_B) = (\phi_A - \phi_B) - (\alpha_A - \alpha_B). \quad (3)$$

Thus, by the use of this switching technique, it is possible to measure the difference in phase between two signals even though they do not exist simultaneously at the antenna. However it does impose special requirements on the receiver, for as indicated in Eq. (3), the true phase difference,  $\theta = \phi_A - \phi_B = \beta_A - \beta_B$ , is obtained only if the shift in phase experienced by both the A and the B signals in passing through the receiver is identical.

#### DETAILED CIRCUIT ANALYSIS

As shown in Fig. 2, the two signals are received at an antenna and are demodulated in a receiver. The 200-cps demodulated receiver output is passed to commutator segments 1-4 which sample the A and B signals and the noise. The outputs of these segments are added on RC integrators. When the commutator is properly synchronized, the dc output of each integrator will be a function of the A signal-to-noise voltage ratio and the B signal-to-noise voltage ratio.

To synchronize the commutator which is driven through a differential by a 50-cps synchronous motor, the demodulated receiver output is also fed to a narrow-bandpass filter and rectifier. The plus and minus dc signals thus obtained are sampled by commutator segments 5-10, and the outputs are added on RC integrators. Initially, if the commutator is not in synchronism with the incoming Radux signals, the output from the search integrator will be below a preset threshold. Under this condition, a synchronizing circuit allows a constant dc signal to be applied to a converter, the ac output being amplified by the servo power amplifier to drive the servomotor. This servomotor advances the phase of the commutator shaft slowly through the differential until the commutator is in

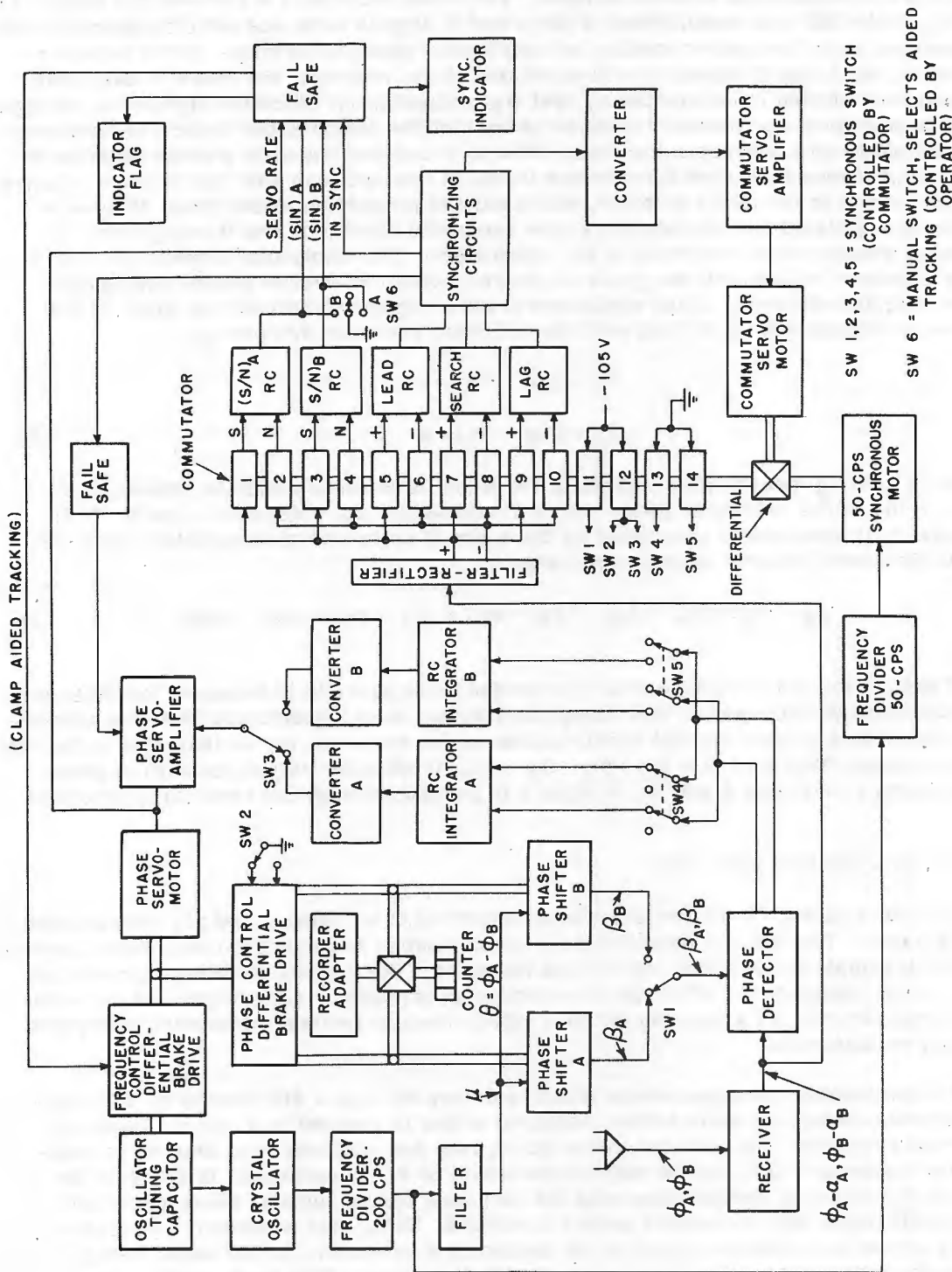


Fig. 2 - Functional diagram of Receiver-Indicator

synchronism with the incoming plus and minus dc signals. When this condition is reached, the output of the search integrator increases sharply, actuating three relays in the synchronizing circuit; one operates the indicator and the "in sync" signal, and the other two connect the converter to the lead and lag integrators through a differential dc amplifier. The difference in dc outputs from these integrators is zero at exact synchronism, positive if the phase of the commutator leads that of the signals, and negative if the phase lags. Thus the commutator is maintained in exact synchronism by these circuits which form a closed-loop servo system. When the "in sync" condition is reached, a fail-safe circuit removes a -105 v bias from the phase servoamplifier.

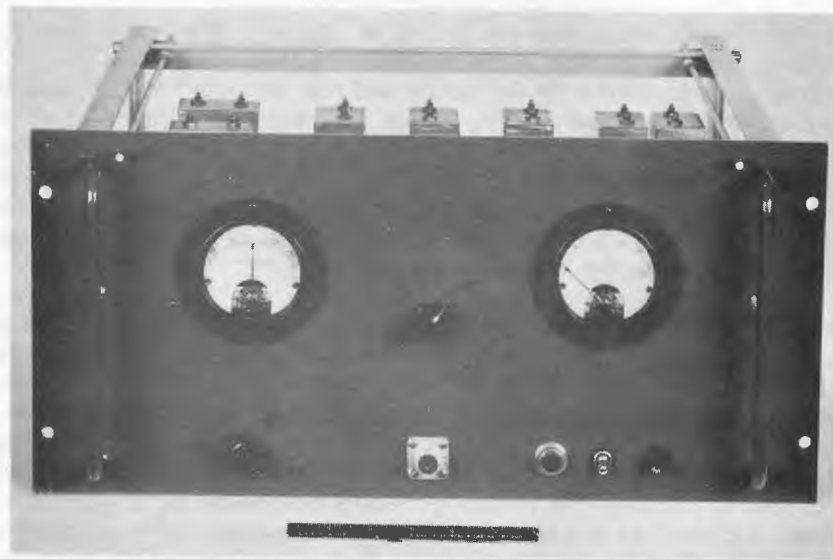
In determining the phase difference, the 200-cps demodulated receiver output is fed to the phase detector where it is compared with the 200-cps references derived from the crystal oscillator, divider, and low-pass filter. The A and B reference signals are passed through phase shifters A and B, and the outputs are switched alternately into the phase detector in synchronism with the incoming signals by a relay controlled by segment 11 of the commutator. The dc outputs of the phase detector are separated by synchronized switching to the RC integrators by means of relays controlled by segments 13 and 14 of the commutator. Converters change the integrator dc outputs to ac signals which are then switched into the phase servoamplifier by a relay controlled by segment 12 of the commutator. The phase servomotor then drives phase shifters A and B alternately by means of the differential brake drive which operates in synchronism with the inputs to the phase servoamplifier. The phase shifters shift the phase of the local 200-cps reference signals, phase-locking the A reference to the incoming A Radux signal and the B reference to the B Radux signal. As the phase shifters turn toward the phase-locked condition in which the reference and signal at the phase detector are 90 degrees out-of-phase, the output of the phase servoamplifier tends toward zero. This causes a relay in the fail-safe circuits to operate provided the commutator is properly synchronized and the signal-to-noise ratios are usable. This relay releases the frequency-control brake. The phase servomotor then drives the oscillator tuning capacitor so as to reduce the frequency difference between the Radux signals and the crystal oscillator. The difference in phase is taken by a differential and indicated on a Veeder counter. The phase difference is also automatically transferred to a recorder by means of the recorder adapter.

#### Receiver Unit

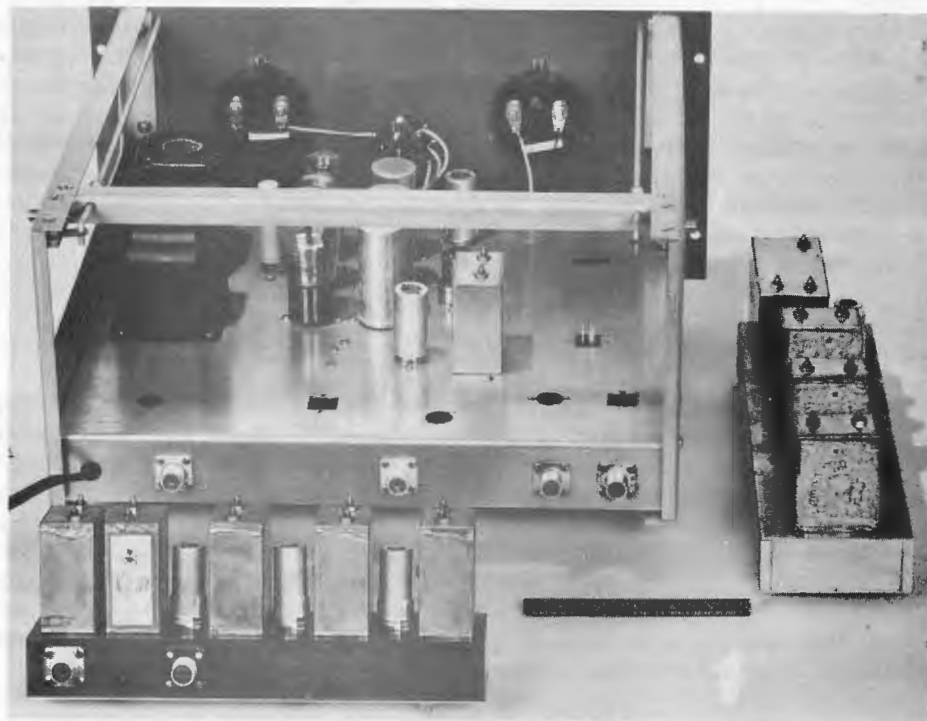
The receiver unit shown on top of the rack in Fig. 1 consists of three rf stages, two limiter stages, and a discriminator. The double-tuned rf stages have a bandwidth of about 600 cps. The over-all gain is approximately 130 decibels. This receiver, however, has excessive phase shift with change in input level; as the input is varied from 10 to 10,000 microvolts, the phase of the modulation is shifted by about 70 microseconds. Therefore, a receiver (Fig. 3) developed by the Navy Electronics Laboratory was used which showed a shift of only about 10 microseconds over this range. This receiver is essentially the same except that no tuned circuits are used in the plate circuits of the amplifier stages. Also the input and output are isolated physically to prevent coupling between them since this was found to be a major cause of phase shift with amplitude.

The NEL receiver consists of a preamplifier, limiter, and discriminator output stage. The preamplifier is composed of three stages of rf amplification with only single-tuned grid circuits. Series resistors are provided in the grid circuits to allow limiting at high levels. The preamplifier bandwidth is 800-cps and is followed by a three-stage limiter which feeds into the discriminator. An amplifier and cathode follower provide the audio output. Meters are provided to observe the limiter current and to tune the discriminator.

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(a) Front view



(b) Rear view

Fig. 3 - NEL Receiver

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### Resolver Unit

In the resolver (Figs. 4 and 5), a crystal oscillator provides a 1.2-kc output at J1001, which is fed to a 200-cps frequency divider and filter in the phase detector unit. The 200-cps filtered sine wave at J1002 is then applied to resolvers A and B in parallel. The outputs of these resolvers are obtained at J1003 and J1004, through isolating cathode followers.

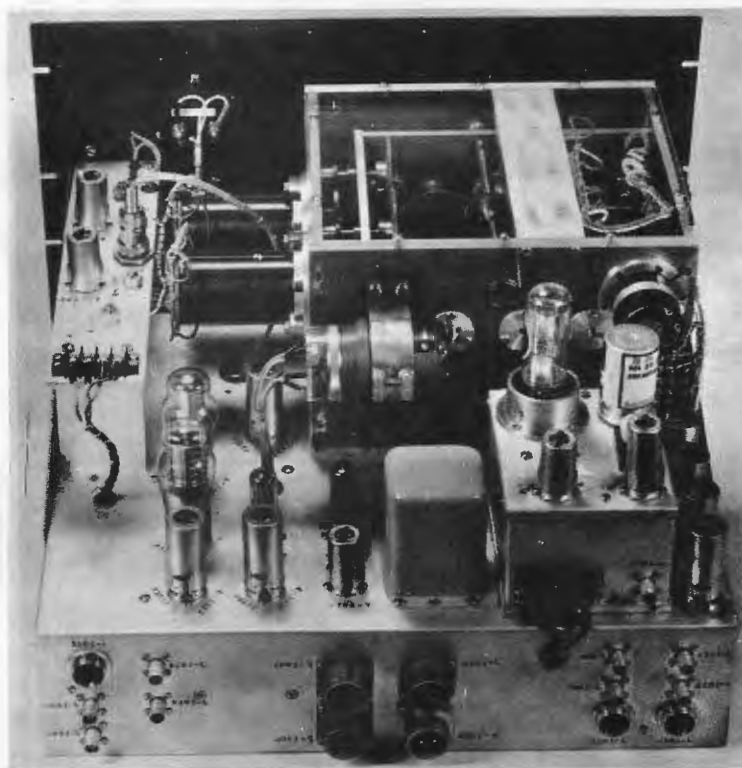


Fig. 4 - Resolver Unit

When synchronization of the commutator is attained, a minus 105-volt dc signal is removed from the grids of the phase servoamplifier at J1014. The servoamplifier then amplifies ac phase-error signals at J1010 from the converters on the commutator unit and causes the phase servomotor to drive the resolvers through differentials. At J1011, a ground appears alternately at the inputs to the A brake circuit and the B brake circuit. The switching of the ground is done in synchronism with the inputs to the phase servoamplifier and is controlled by the commutator unit. When the ground is applied to the A brake circuit, the A brake operates, the B brake releases, and the servomotor drive is transferred to the B resolver through differentials. The resolvers will be driven until the ac phase-error input to the servoamplifier is zero. As the servoamplifier output approaches zero, the fail-safe circuit releases the frequency-control brake by transferring a ground from the input of the idler brake circuit to the input of the frequency-control brake circuit at J1012. These circuits then operate the idler brake and release the

Key to Gears in Gear Box

Key No.	Type	Mat'l	No. of Teeth	Pitch	Press. Angle (deg)	Pitch Diam. (in.)
1	spur	brass	240	96	20	2.500
2	spur	brass	48	96	20	0.500
3	L.H. worm gear	brass	100	48	14.5	2.083
4	R.H. worm gear	steel	--	48	14.5	0.333
5	worm	steel	100	48	14.5	2.083
6	spur	brass	140	64	20	2.1875
7	spur	brass	35	64	20	0.5468
8	spur	brass	160	64	20	2.500
9	spur	brass	128	64	20	2.000
10	bevel	brass	18	48	--	0.375
11	bevel	brass	36	48	--	0.750
12	spur	brass	96	64	20	1.500
13	spur	alum.	80	64	20	1.250
14	spur	alum.	64	64	20	1.000
15	spur	nylon	84	48	20	1.750
16	spur	nylon	36	48	20	0.750
17	spur	nylon	80	48	20	1.6667
18	spur	nylon	20	48	20	0.4166
19	R.H. worm gear	steel	--	20	--	---
20	worm	brass	100	20	--	---
21	L.H. worm gear	steel	--	20	--	---
22	worm	brass	100	48	--	0.333
23	worm	brass	100	48	--	2.083

The three differentials are Ford type 29-599

$$\frac{\text{Motor rpm}}{\text{Resolver rpm}} = \frac{18,667}{1}$$

$$\frac{\text{Motor rpm}}{\text{Osc. capacitor rpm}} = \frac{46,667}{1}$$

Requires 11.7 minutes for resolver to make one turn with motor at full speed 1600 rpm

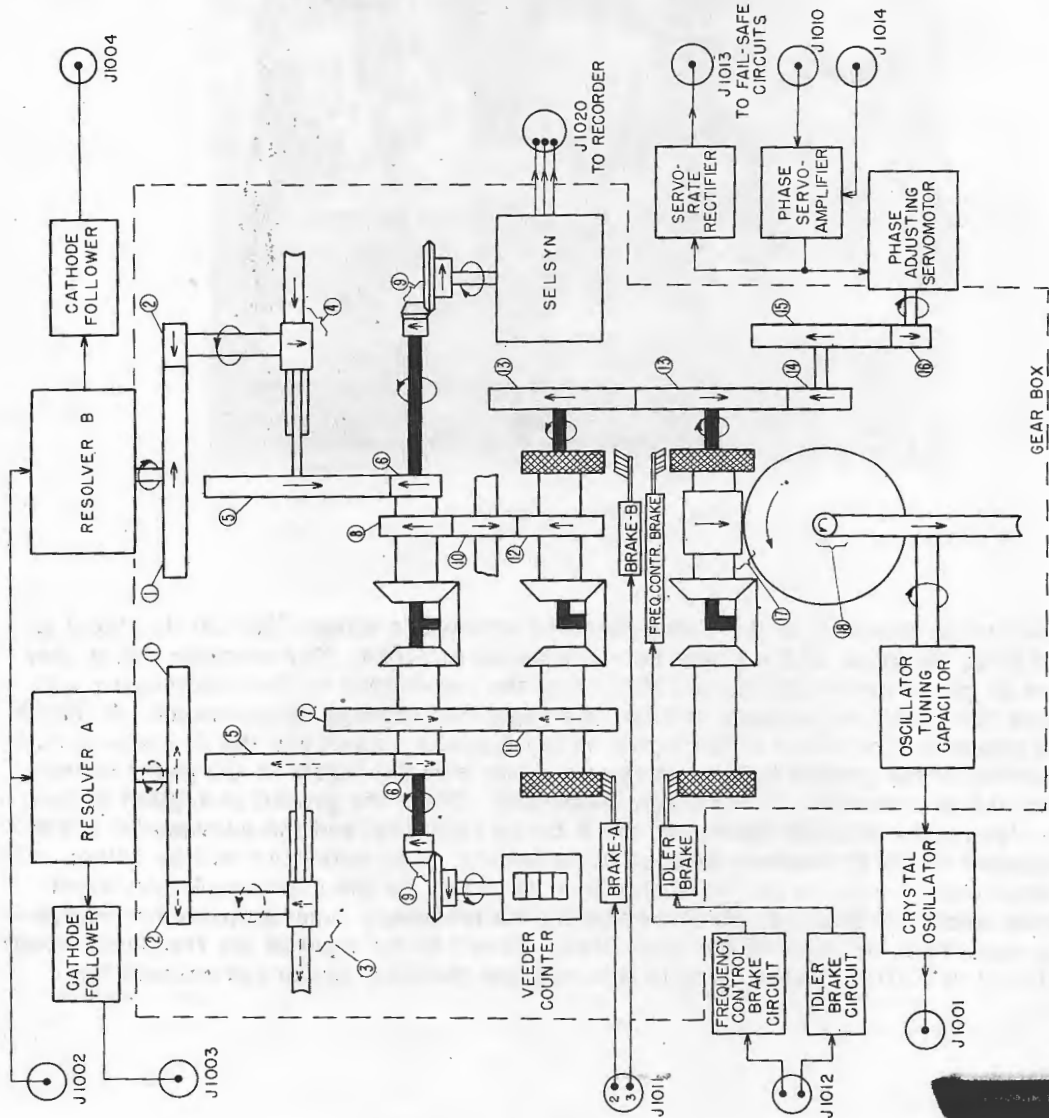


Fig. 5 - Block diagram of resolver unit showing detailed operation of gear box with idler brake clamped and either A brake clamped (solid arrow) or B brake clamped (broken arrow)

frequency-control brake. This allows the crystal oscillator tuning capacitor to be driven by the servomotor through the differential, thereby adjusting the oscillator frequency to the system modulation frequency, thus reducing the phase error because of this frequency difference. The counter then indicates the signal phase difference, and the selsyn generator in the resolver unit provides an electrical ac error signal to the selsyn receiver in the recorder adapter unit.

A fail-safe flag-indicator circuit is provided. When the equipment is operating properly, a relay in the fail-safe circuit pulls a metal flag up which uncovers the phase difference counter. If the equipment is not operating properly, because of a low signal-to-noise ratio for example, the flag will cover the counter. A test switch is provided in the grid circuit so that the flag can be raised at times for tests. After the servo error has been reduced to zero, if any sudden phase changes occur due to improper operation of the equipment or excessive movement of the receiver-indicator, the servoamplifier output is rectified by the servo-rate rectifier. This dc servo-rate error appears at J1013 which is then fed to the fail-safe circuit in the commutator unit which clamps the aided tracking.

A simplified diagram of the resolver and compensating network is shown in Fig. 6. The networks in the resolver secondaries are necessary to eliminate secondary voltage amplitude changes and resulting phase errors when the resolver is rotated. The type R-600 resolver consists of two fixed primary windings, only one of which is used, and two rotatable secondary windings in space quadrature. The magnitude of the voltage induced in each of the rotor windings varies as the sine or cosine of the angle between the axes of the rotor and stator windings. The secondary rotor voltages are

$$E_{R1} = E_{S1m} \sin \theta \sin \omega t$$

$$E_{R2} = E_{S1m} \cos \theta \sin \omega t$$

where  $E_{S1m}$  is the maximum value of the primary voltage,  $\omega$  is the primary exciting angular frequency,  $\theta$  is the space angle between the axes of the rotor and stator windings,  $E_{R1}$  is the instantaneous secondary rotor voltage, and  $E_{R2}$  is the instantaneous voltage of the second rotor winding. The vector diagram of the resolver voltages and currents is shown for  $X_c = R$ , so that the secondary current lags the secondary voltage by 45 degrees. The progressive figures are shown for the same instant of time ( $\omega t = 90^\circ$ ), and for progressively increasing space angle  $\theta$ . It can be seen that as  $\theta$  increases, the electrical phase angle of the output voltage  $E_o$  at point 2 measured relative to point 1 also increases proportionally, and that the magnitude of  $E_o$  remains constant.

#### Commutator Unit

The commutator, synchronizer, signal-to-noise ratio indicating circuits, fail-safe circuits, and phase-detector-integrator circuits are located on the commutator unit chassis (Figs. 7 and 8). The commutator with its synchronous driving motor, differential, and phase-correcting servomotor can be seen on the back of the chassis.

**Commutator** - The commutator, which consists of Bakelite cams and silver inlays and brushes, is driven at 20 revolutions per minute by a synchronous motor, the motor speed being controlled by the reference oscillator. A servomotor, which is controlled by the synchronizer, keeps the commutator in phase with the incoming signal. This is done by means of a differential drive between the servomotor and the synchronous motor.

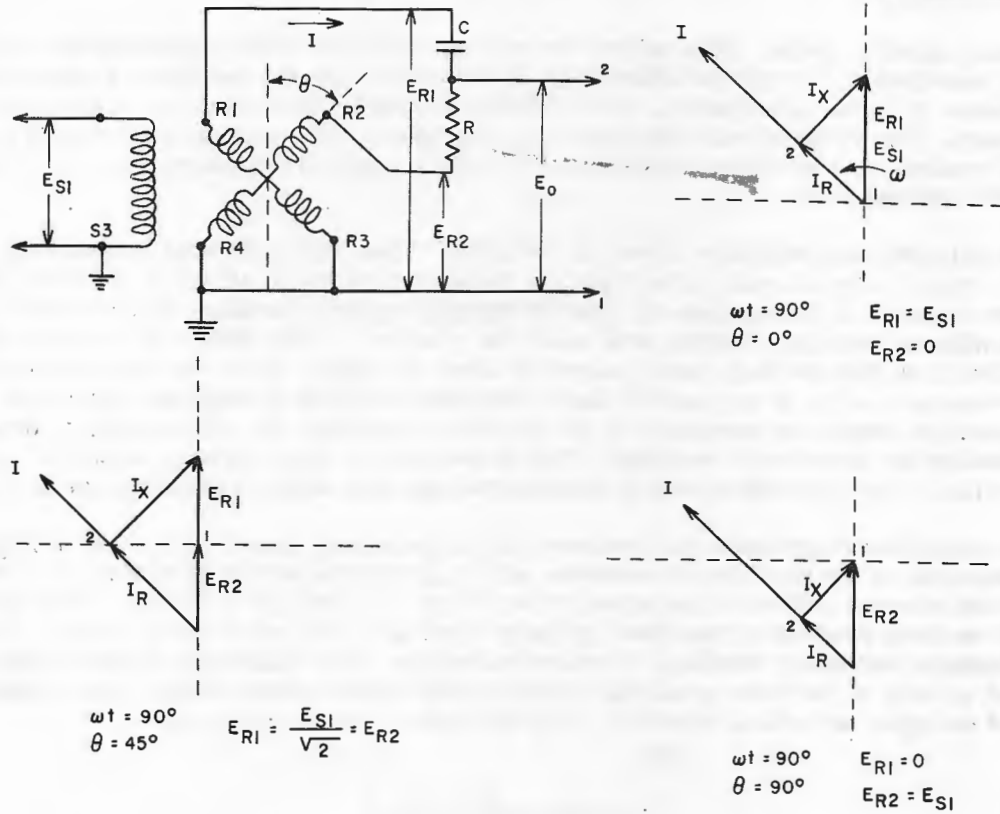


Fig. 6 - Electrical and vector diagrams of resolver used as phase shifter



Fig. 7 - Commutator unit

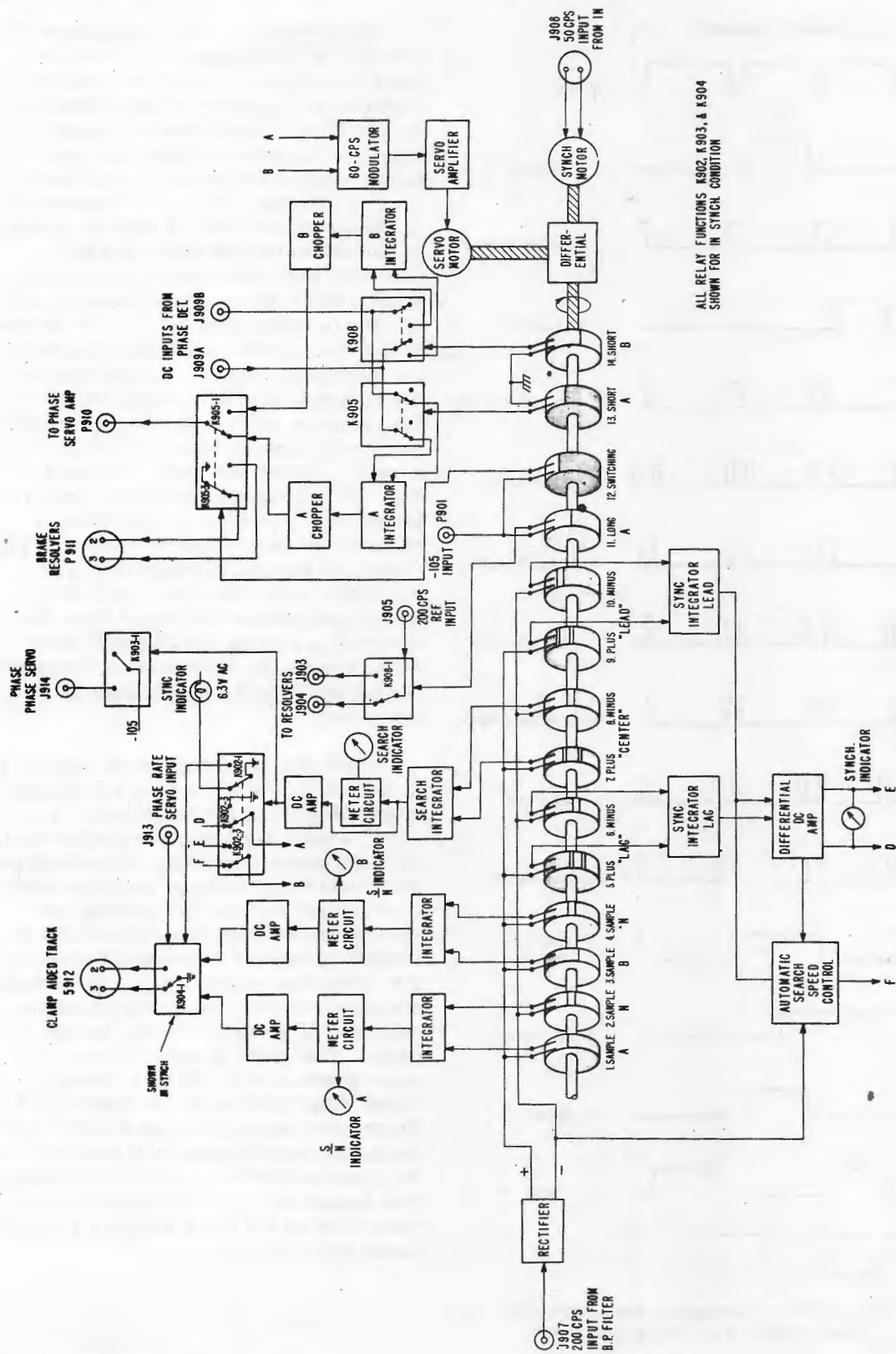


Fig. 8 - Block diagram of commutator unit

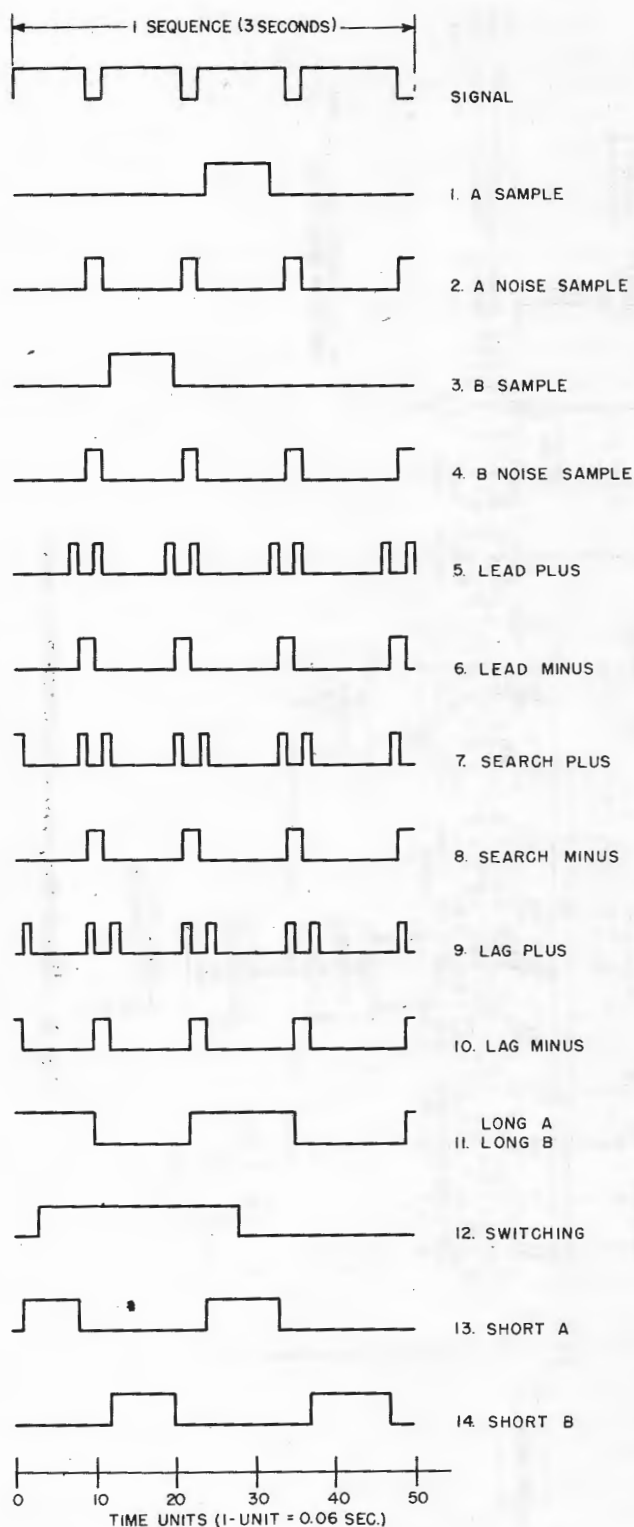


Fig. 9 - Transmission sequence and commutator switching functions

**Synchronizer** - The signal from the receiver is rectified by full-wave rectifiers. From this circuit are obtained positive and negative voltages which go on and off with the incoming signal (Fig. 9). Samples of these plus and minus signals are used to synchronize the commutator. When the commutator is not in synchronism, a search voltage is applied to the servomotor which advances the phase of the commutator shaft. When this is done, voltages are applied to integrating circuits by means of the search plus and minus commutator segments (Fig. 9). As the phase of the commutator varies with respect to the incoming signals the voltage on the integrator circuit, which is indicated on a search meter, will vary as shown in Fig. 10. As can be seen from the curve the voltage increases greatly when a condition of zero phase is reached. This voltage is applied to the grid of a dc amplifier, such that when the grid is driven positive by the signal from the integrating circuit, a relay will open. This changes the synchronizer from the search mode to the servo mode of operation.

When the synchronizer is operating in the servo mode, the lead and lag segments (Fig. 9) of the commutator are used. These segments are similar to the plus and minus segments but are shifted ahead and back in phase one time unit. The outputs of these integrators are applied to the grids of a differential dc amplifier, and the difference between the integrator outputs (Fig. 11) is used to maintain commutator synchronism, as indicated by a "Sync" meter, on the front panel. The speed at which the search takes place may be set by a "Search Speed Max." control on the front panel. To prevent passing the point of synchronism, the search speed will decrease as the commutator comes into synchronism. The amount which it will slow down is controlled on the front panel by a "Search Speed Min." adjustment.

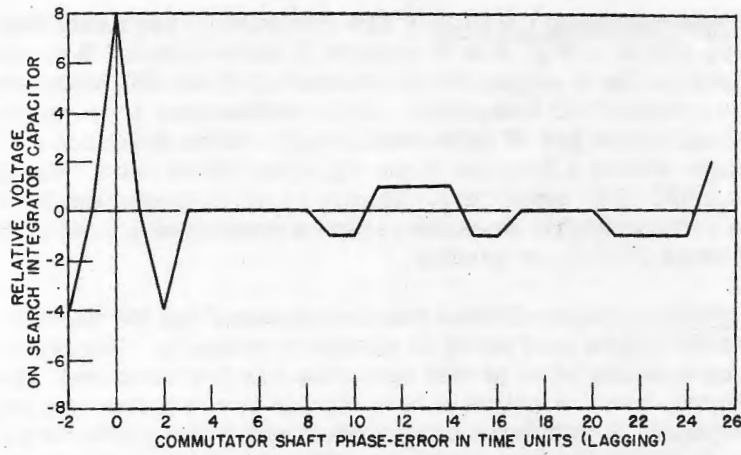


Fig. 10 - Commutator synchronizer search integrator output as a function of commutator synchronizing error; shown for positive (lagging) synchronization only, but function is symmetrical about zero phase

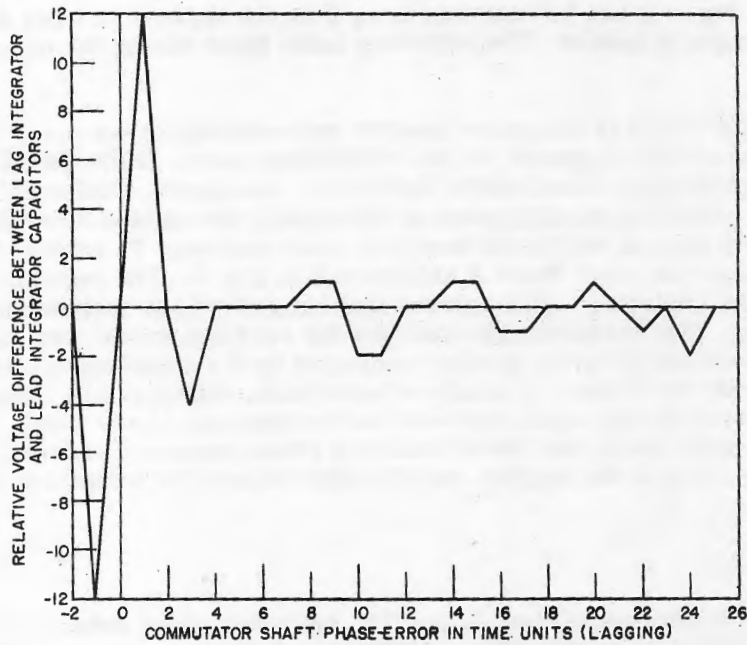


Fig. 11 - Difference between the lead and lag integrator outputs as a function of commutator synchronizing error

Signal-To-Noise Indicating Circuits - The commutator segments that give the signal-to-noise ratios are shown in Fig. 9 as A sample, A noise sample, B sample, and B noise sample. The outputs of the A segments are connected to one RC integrator and those of the B segments to a second RC integrator. If the commutator is in synchronism, the voltage samples of signal and noise are of equal total length. When these are fed into the integrator the resultant voltage will be a function of the signal-to-noise ratio. The integrator outputs are placed on the grids of dc amplifiers. Meters in the cathode circuits of these amplifiers will then indicate relative signal-to-noise ratios, a reading of 1.0 ma indicating a signal-to-noise ratio of about 10 to 1, or greater.

Fail-Safe Circuits - These circuits receive signals from the various functions of the equipment and indicate when everything is operating properly. The fail-safe also unclamps the frequency-control brake when proper operation has been obtained. The fail-safe circuit checks the signal-to-noise ratios of both signals to see if they are sufficient for proper operation and checks for commutator synchronism and phase-servo rate. A switch permits the operator to select the best signal for aided tracking. It disables one of the fail-safe functions which sample the signal-to-noise ratios. This switch labeled "Aided Tracking" has three positions. The center position is used for normal operation. If it is desired to have fail-safe information from one station either position "A" or "B" is used.

Integrating, Chopping, and Switching Circuits - The commutator segment designated as Long A (Fig. 9) is used to switch the outputs from the A and B resolvers into the phase detector. From Fig. 9 it can be seen that Long B is the negative of Long A so only one commutator segment is needed. The switching takes place during the interval between the signals.

Originally, the output of the phase detector was switched to the A and B integrators directly by means of four segments on the commutator shaft. It was found, however, during field evaluation at the Navy Electronics Laboratory, San Diego, California, that slight errors in timing caused by misalignment of the brushes would lead to unbalance of the integrator circuits causing errors in the phase measurement. To correct this, only one set of two segments was used, Short A and Short B in Fig. 9. The segments control relays which do the actual switching. This insures that balance will be maintained by the signals to the integrators. Two choppers are used, one for each integrator, and the outputs are switched to the servoamplifier by a relay controlled by the switching commutator segment (Fig. 9). The switching is done on a half-and-half basis, which can be done because the information is stored on the integrators and can be taken out at any time. Originally, only one chopper was used, but it was found that more stable operation resulted using two choppers and switching at the chopper output rather than at the integrator output.

#### Phase Detector Unit

In the phase detector unit (Figs. 12 and 13), besides a phase detector, there is a divider chain, a 200-cps low-pass filter, a resolver-driving amplifier, a synchronous motor power amplifier, a 200-cps bandpass filter, a scope inspection circuit, and a metering circuit.

The resolver-driving amplifier circuit receives a 200-cps square-wave signal from the frequency divider. The 200-cps signal is passed through a cathode follower and a 200-cps low-pass filter which makes the signal sinusoidal. The 200-cps sinusoidal signal is amplified and split into two signals 180 degrees out-of-phase. The two 200-cps signals drive a push-pull amplifier which works into a transformer. Feedback from the secondary

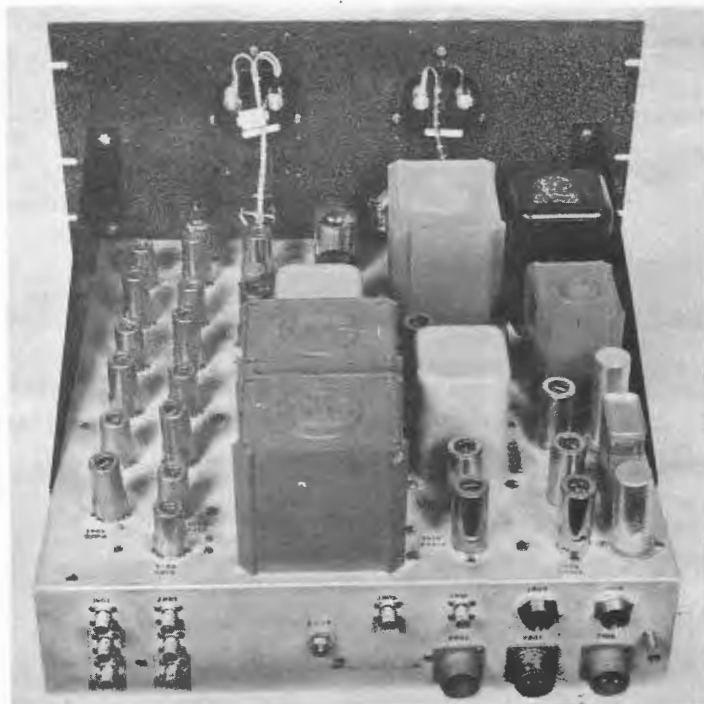


Fig. 12 - Phase detector unit

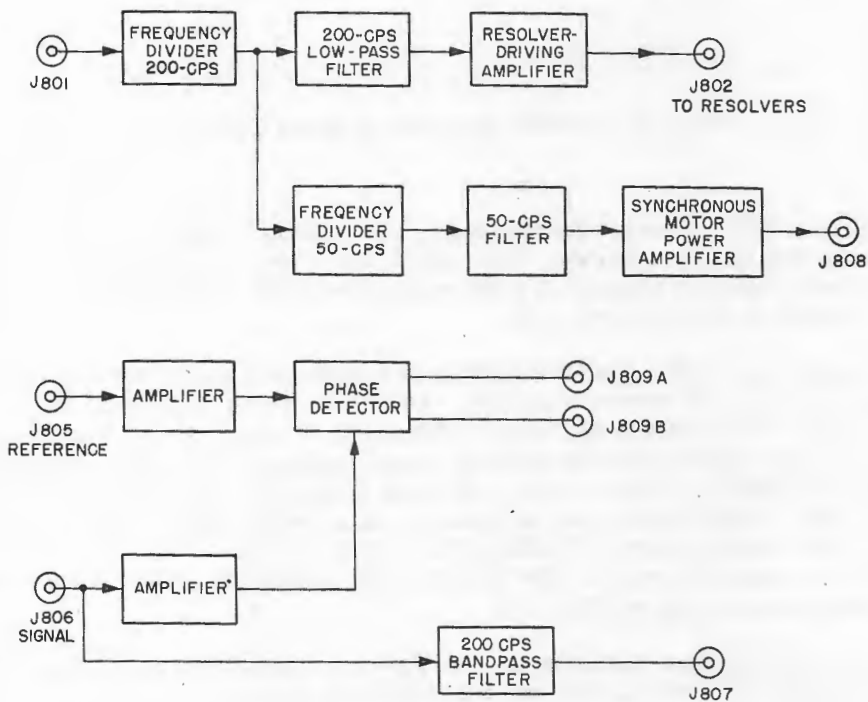


Fig. 13 - Block diagram of phase detector unit



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both sections connected in parallel and two matched 130,000-ohm resistors R885 and R886 rectify the ac signals on T801 and T802 and put a dc voltage on J809A and J809B which goes to the integrators on the commutator unit. Resistors R8125, R8123, and R8124 are used to make voltages  $E_3$  and  $E_4$  equal in amplitude. Resistors R8120, R8121, and R8122 are used to balance  $E_1$  and  $E_2$ . Potentiometer R898 and resistors R897 and R899 provide an adjustment for balancing out the contact potentials of the phase-detector diodes V820 and V821.

A vector diagram (Fig. 15) shows the phase detector in three different phase conditions between the signal voltage and the reference signal voltage. In all three conditions the signal voltage and reference signal voltage are equal in amplitude. In the first condition the signal and reference signal are 90 degrees out-of-phase. The dc voltages  $E'_A$  and  $E'_B$  developed across resistors R886 and R885 are equal in amplitude and opposite in polarity, thus canceling out. In the second condition the signal and reference signal are in phase and the dc voltages  $E'_A$  minus  $E'_B$  equals a positive voltage. In the third condition the signal and reference signal are 180 degrees out-of-phase and the dc voltages  $E'_A$  minus  $E'_B$  equals a negative voltage.

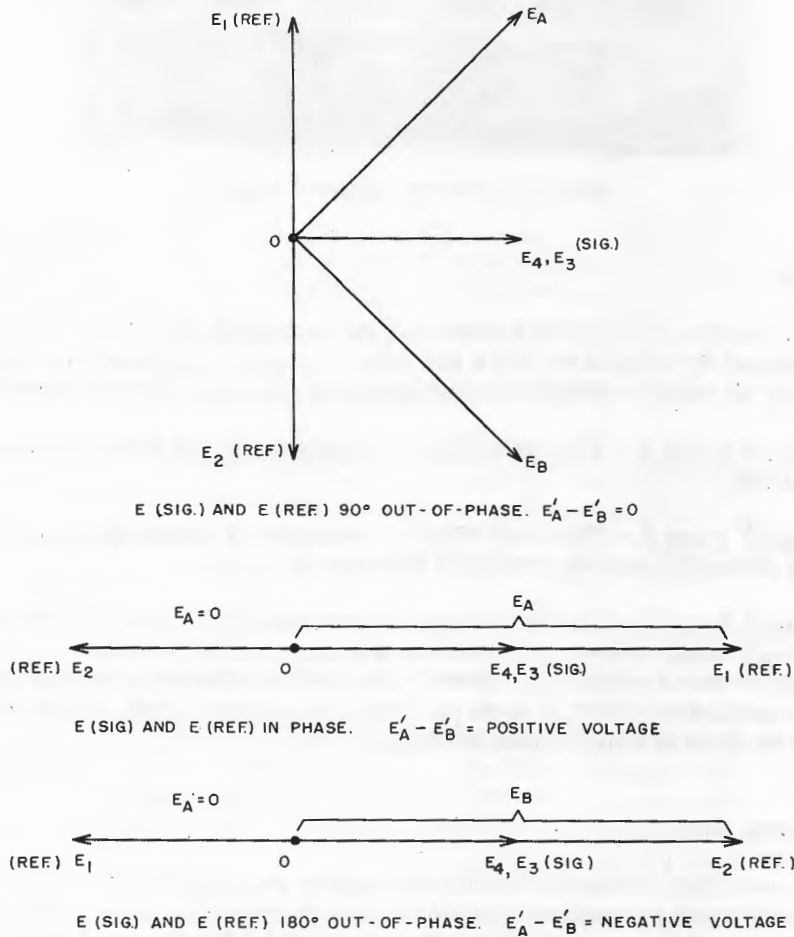


Fig. 15 - Vector diagram of phase detector operation



Fig. 16 - Power supply 1 and 2

#### Power Supplies

The power supply units provide regulated dc outputs of 250 v, 300 v, and -105 v, as well as unregulated dc outputs of 300 v and 400 v. A high-impedance vacuum-tube voltmeter is used to check all output voltages since protective resistors are provided at the test points.

Power Supply 1 and 2 - This unit (Fig. 16) consists of two 250-volt dc electronically regulated supplies.

Power Supply 3 and 4 - This unit (Fig. 17) consists of an unregulated 300- and 400-volt dc supply, and an electronically regulated 300-volt dc supply.

Power Supply 5 and 6 - This unit (Fig. 18) consists of a full-wave gas-tube regulated minus 105-volt dc supply, power distribution switches, main line switch and circuit breaker, and line voltage variac control. The power distribution system is located on this chassis, and a variable autotransformer is used to obtain the correct input voltage from the power source. A meter is provided for this setting.

#### Recorder Adapter Unit

The data recording adapter unit (Fig. 19) adapts the receiver-indicator to the Sperry teletype automatic data processing equipment now in use at the monitoring sites. This equipment is designed to process information derived by the Sperry Radux Test Equipment (4) and to record it automatically on teletype tape. Such information may then be used to operate a teletypewriter or an IBM tape-controlled card-punching machine.



Fig. 17 - Power supply 3 and 4



Fig. 18 - Power supply 5 and 6

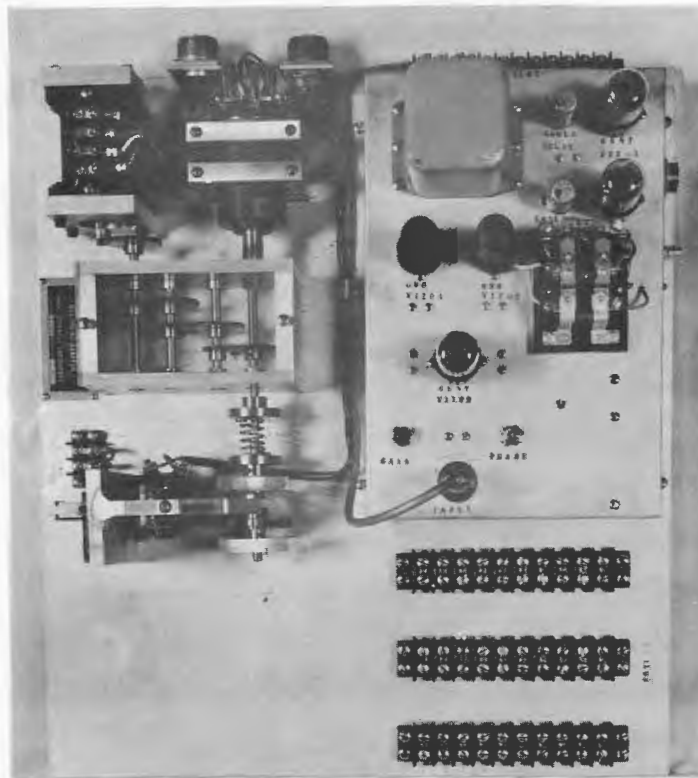


Fig. 19 - Recorder adapter unit

Referring to the block diagram of the recorder adapter (Fig. 20), 60-cps signals are applied to J1120. These signals are obtained from a selsyn transmitter which is geared to the phase difference indicator on the resolver unit. The selsyn receiver is an error detector which provides a 60-cps error signal proportional to the difference in the angular positions of the indicator phase difference shaft and the servo output shaft which drives the Sperry slave delay coder unit. The error signal is applied to the amplifier and servomotor which drives the output shaft through a gear box to reduce the error to zero. Thus, the output shaft follows the phase difference indicator shaft. The delay coder unit converts the output shaft rotation to coded digital teletype signals by means of photocells. At preset intervals, a sequence timer in the Sperry teletype rack applies a grounding signal to terminal 8 on TS1101. This completes the 48-volt circuit to relay RY1103. One pair of contacts on RY1103 applies a grounding signal to J1118 which grounds the grid of the phase servo-amplifier in the indicator. The other contacts complete the 110-volt circuit to the solenoid which pulls the alignment clamp down onto a ten-pointed star-wheel. The output shaft is thus positioned to the nearest  $1/10$  revolution. At the same time a microswitch provides a grounding signal to the alignment switch in the Sperry Teletype Equipment which is necessary before the teletype will operate. The spring coupling is necessary to take up the backlash when the alignment clamp positions the star-wheel shaft. The dc inputs obtained from the S/N circuits at J917 on the commutator unit chassis are measures of the signal-to-noise ratio of each signal and are applied to J1117. The (S/N)<sub>A</sub> dc signal causes tube V1101 to conduct, and the (S/N)<sub>B</sub> dc signal causes tube V1102 to conduct, energizing relays RY1101 and RY1102. The relay contacts provide 48-volt dc signals to the teletype printer, which prints either a zero or a one, indicating usable or not usable S/N ratio.

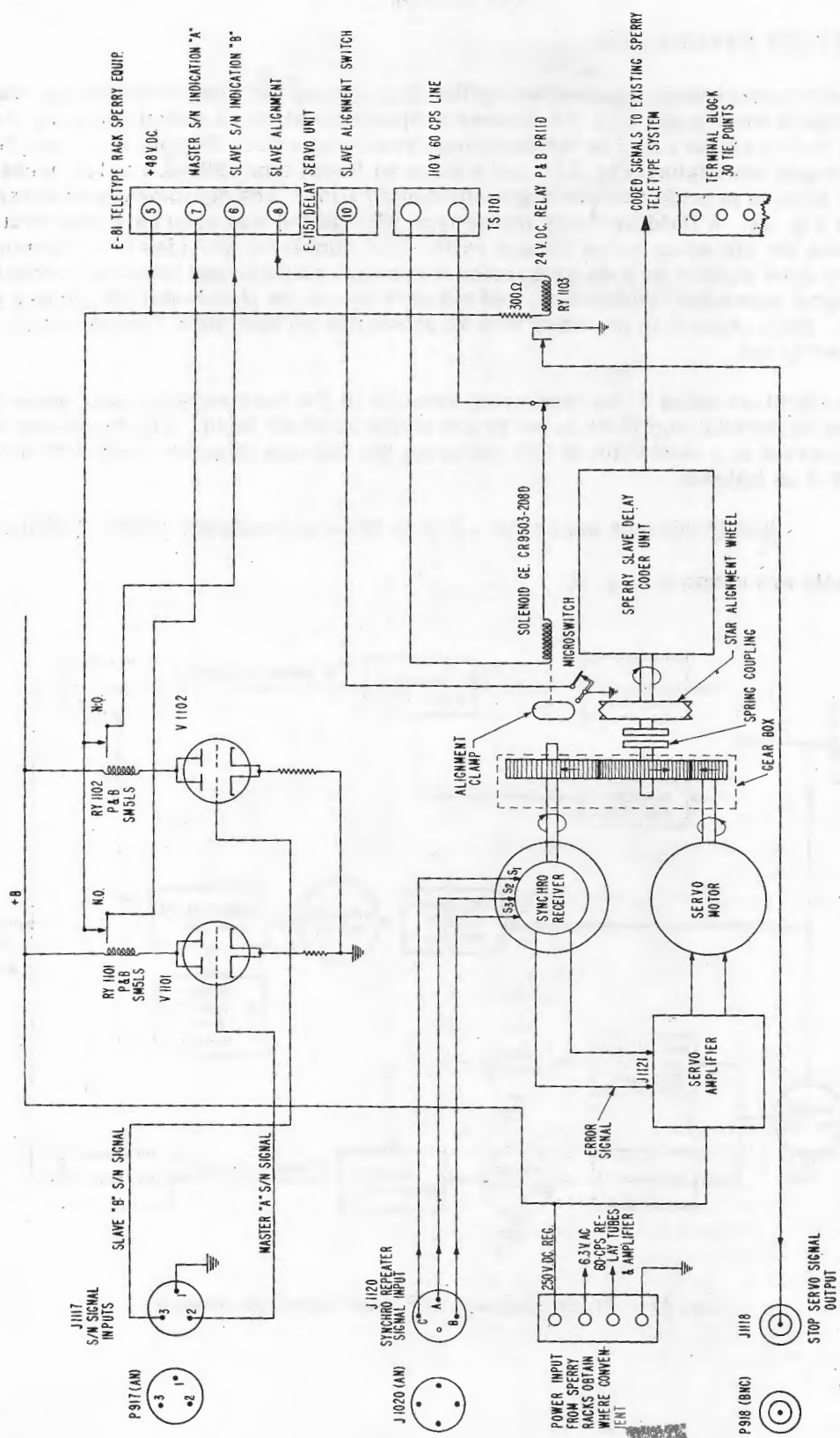


Fig. 20 - Block diagram for adapting NRL Receiver-Indicator to Sperry data recording system

## LABORATORY EVALUATION

Six equipments were constructed by the Engineering Services Division and laboratory investigations were made with the number 6 equipment at this Laboratory using the NRL receiver to determine some of the equipment characteristics. Signals were supplied by a Radux signal simulator (Fig. 21), and a General Radio type 1390-A random noise generator was used to provide various signal-to-noise ratios. The equipment was arranged as shown in Fig. 22. A field intensity meter type AN/URM-6 was used as a microvoltmeter to measure the signal-to-noise voltage ratio. The simulator provides two common-frequency-type signals on a 40-kc carrier frequency with 200-cps frequency modulation. The B signal spectrum, modulation, and r-f carrier can be phase-shifted relative to the A signal. Each channel is provided with an attenuator so that the r-f signal levels can be accurately set.

The signal-to-noise-ratio measuring circuits in the receiver-indicator were checked by setting up various signal-to-noise ratios at the receiver input. The measured ratios were converted to a bandwidth of 600 cps using the 250-cps effective bandwidth of the AN/URM-6 as follows:

$$S/N \text{ in } 600\text{-cps bandwidth} = S/N \text{ in } 250\text{-cps bandwidth} (\sqrt{250}/\sqrt{600}).$$

The results are shown in Fig. 23.

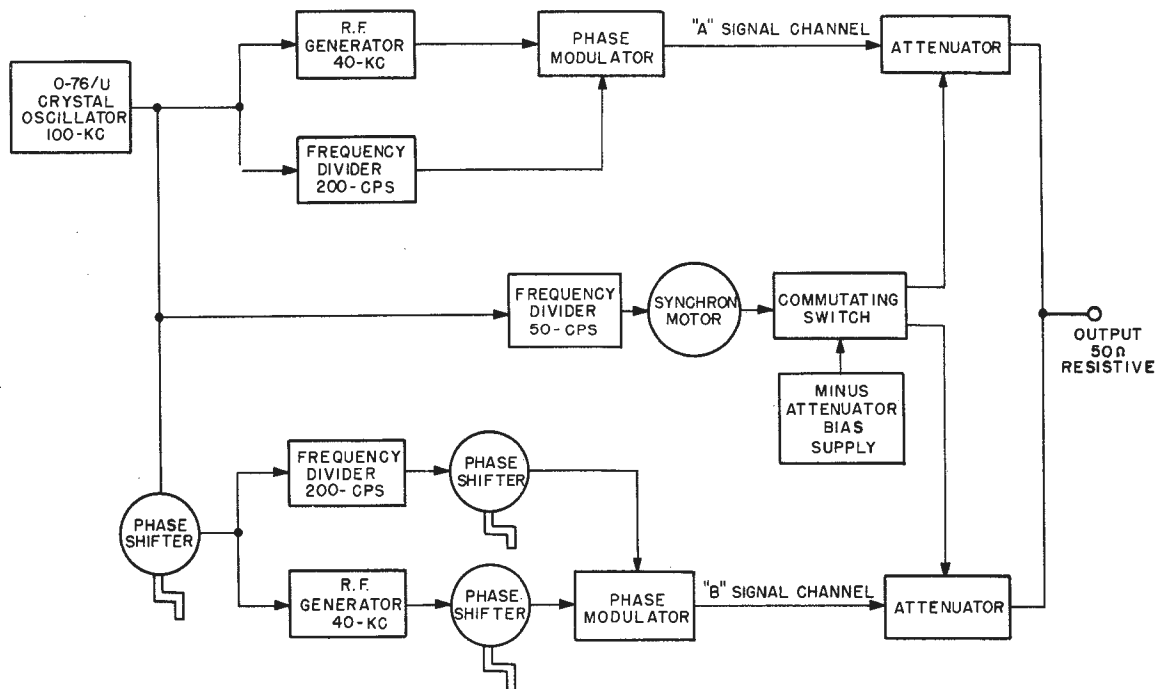


Fig. 21 - Block diagram of Radux Signal Simulator

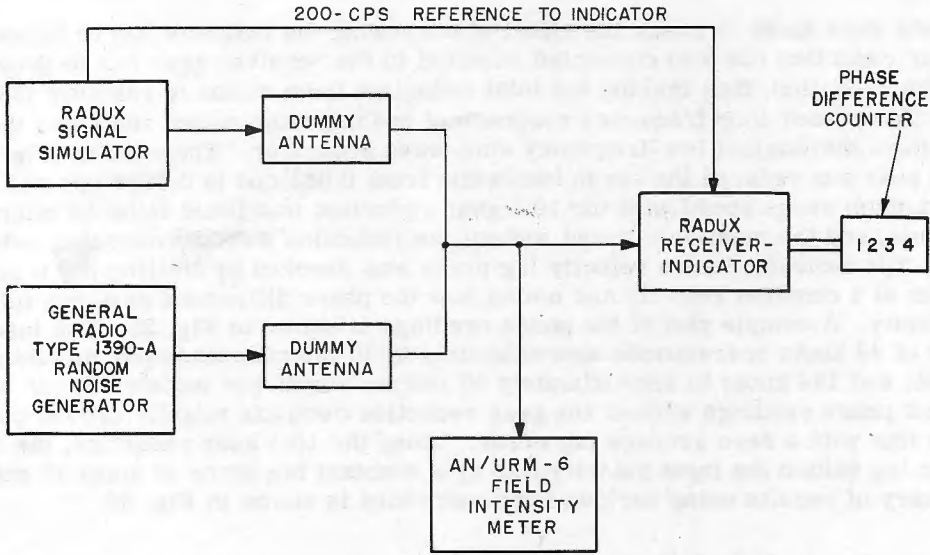


Fig. 22 - Block diagram of equipment used in laboratory evaluation

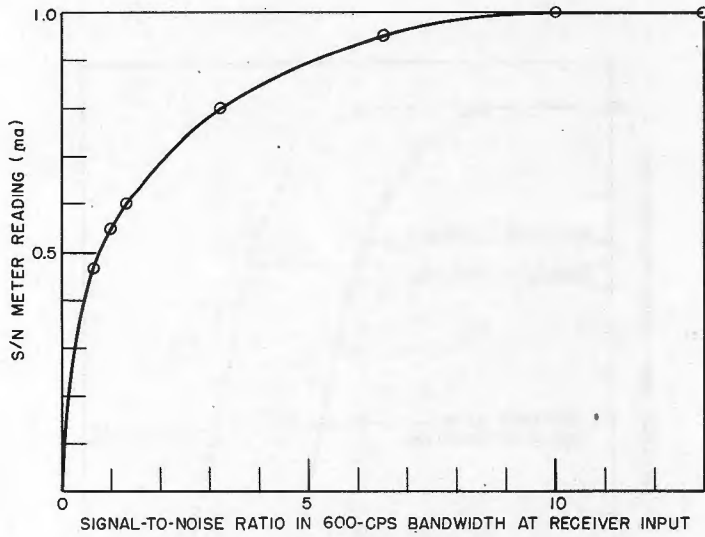


Fig. 23 - S/N indicator reading as a function of rms signal-to-noise voltage ratio at receiver input

Tests were made to check the effect of narrowing the indicator servo bandwidth. A 10:1 gear reduction box was connected external to the resolver gear box to provide the bandwidth reduction, thus making the total reduction from motor to resolver (3/56,000) (1/10). The closed-loop frequency response of the indicator output shaft was then measured using a mechanical low-frequency sine-wave generator. The results (Fig. 24) show that the gear box reduced the servo bandwidth from 0.023 cps to 0.0086 cps at 3 db down. The maximum servo speed with the 10:1 gear reduction was found to be 18 microseconds per minute, and the maximum speed without the reduction was 200 microseconds per minute. The indicator servo velocity lag error was checked by shifting the B signal spectrum at a constant velocity and noting how the phase difference readings followed this velocity. A sample plot of the phase readings is shown in Fig. 25. The input phase velocity of 49 knots corresponds approximately to 10 microseconds per minute along the base line, and 194 knots to approximately 40 microseconds per minute. It can be seen that the output phase readings without the gear reduction oscillate slightly around the input phase velocity line with a zero average lag error. Using the 10:1 gear reduction, the output phase readings lag behind the input velocity line by a constant lag error of about 10 microseconds. A summary of results using various input velocities is shown in Fig. 26.

Tests were made to determine how much time is required for the commutator to be synchronized under various noise conditions. The results (Fig. 27) show that if the signal-to-noise ratio of both signals is less than 0.6, the commutator cannot be synchronized.

The effect of noise on the system was determined for both gear ratios. Six hour runs were made for each signal-to-noise ratio used and the readings taken every six minutes by means of an automatic data-recording camera. From these data standard deviations were computed. The results of these tests are shown in Fig. 28. These tests also showed that there was little or no shift of the average reading for various signal-to-noise ratios.

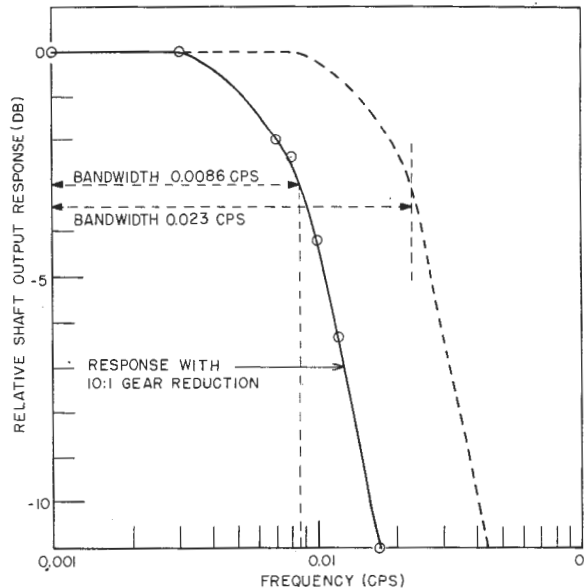


Fig. 24 - Indicator servo frequency response

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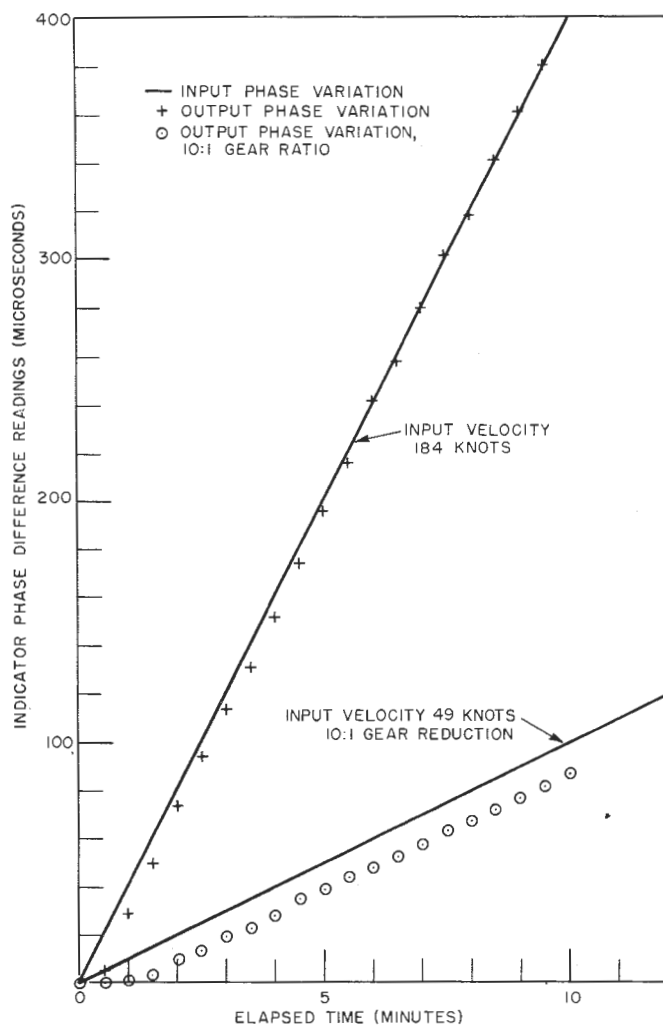


Fig. 25 - Receiver-Indicator velocity tracking

**FIELD CHANGES**

After preliminary adjustments, five of the equipments were sent to the Navy Electronics Laboratory where they were prepared for use in the field. It was found, after a short period of operation with Radux signals, that improved results could be obtained if some modifications were made.

The 1.2-kc crystal in the reference oscillator was not satisfactory under field conditions where a large variation of temperature occurred. It was decided to substitute a 100-kc crystal oscillator and a frequency divider to obtain more stable operation.

The gear ratio in the resolver drive system was increased by a factor of ten to get improved operation at low signal-to-noise ratios.

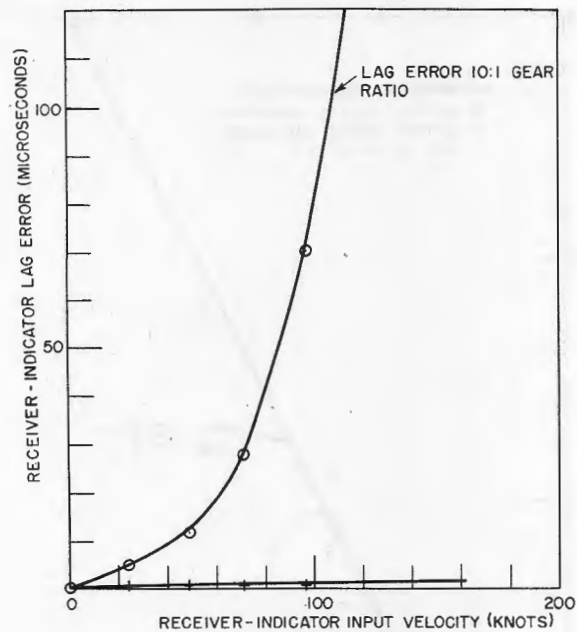


Fig. 26 - Lag error as a function of input velocity

Several changes were made in the phase detector to improve the operation. It was found that the commutator segments did not properly shift the phase-detector output to the A and B integrators. The circuit was changed so that the commutator controlled relays which performed this operation satisfactorily. Originally, only one chopper was used and its input was switched back and forth between the A and B integrators. This caused a transient and gave unsatisfactory results. Two choppers are now used and the outputs switched. This eliminated the transient caused by switching at the integrators.

The receiver was found to have excessive phase shift with signal amplitude. Several changes were made and some improvement was realized, but the Navy Electronics Laboratory has developed receivers for the synchronizers which have little phase-shift and these receivers have been copied with improvements and are now used for the Radux monitors.

#### SUMMARY AND RECOMMENDATIONS

This equipment is now being used in the field for obtaining data on the performance of the experimental Radux system. The data are being analyzed at the Navy Electronics Laboratory to supply information for the evaluation and development of the system. Preliminary results show that the system operation is in agreement with the predictions of J. A. Pierce's proposal. It is recommended that navigators equipment be developed for operational use in accordance with plans and decisions as formulated by the Radux Steering Committee.

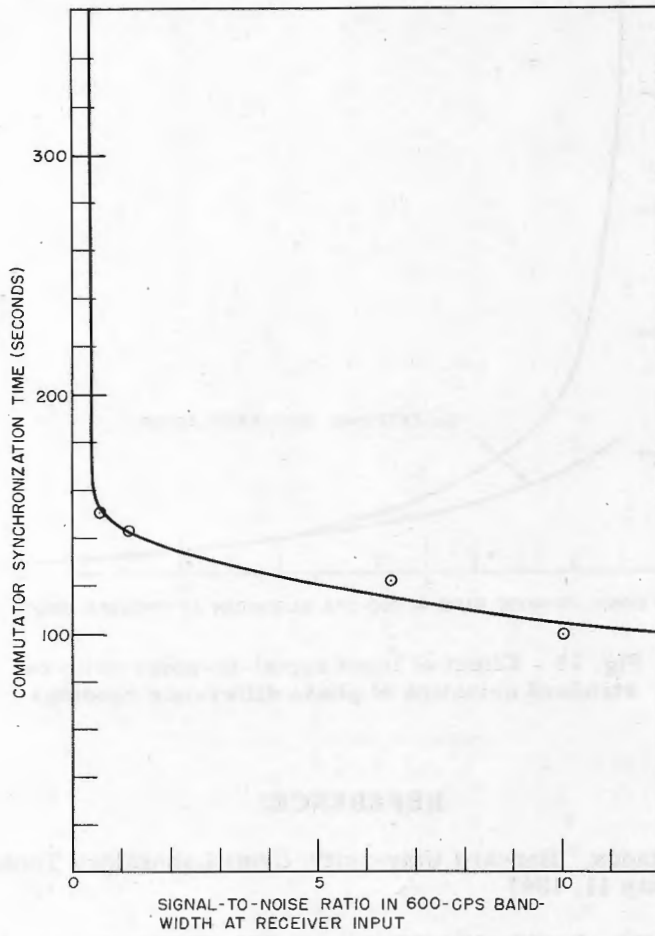


Fig. 27 - Effect of input signal-to-noise ratio on commutator synchronization time