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A PHASE RECORDER FOR USE WITH THE SONAR GRAPHIC INDICATOR

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ABSTRACT

The phase recorder described herein was developed to produce on paper tape the sonar signal pattern produced on the oscilloscope screen in the Sonar Receiver R404(XB-1)/UQ (Range Rate Indicator). The pattern is a plot against time or range in a rectangular coordinate system of the time of arrival of successive signal wave crests in a linear ordinate time scale running from 0 to 360 degrees of phase referred to a controlling reference oscillator which is adjustable in frequency through the sonar frequency range 20 to 30 kc.

The recording of the time of arrival of a signal wave crest within the period of the reference oscillator is accomplished in this chronographic instrument by a set of equally spaced styli in line across an electrochemical paper tape which moves at constant speed. The styli are in separate channels which are gated in time sequentially by a reference-oscillator-controlled sawtooth wave through an amplitude discriminator, so that the styli channels are "open" in sequence through equal parts of the total reference period. Arrival of the wave crest when a channel is "open" causes its stylus to mark the tape with a dot as a result of the coincidence pulse.

The recorded sonar signal pattern, presenting the same information as that in the transitory display on the R404(XB-1)/UQ oscilloscope screen, is a permanent graphic display providing unlimited time for detection of the signal in its background and for analysis of the signal pattern for full appreciation and acquisition of the target information it contains.

PROBLEM STATUS

This is a final report on one phase of these problems; work is continuing on other phases.

AUTHORIZATION

NRL Problems C06-16 and S07-16
Project Nos. NR 406-160 and NR 527-160

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A PHASE RECORDER FOR USE WITH THE SONAR GRAPHIC INDICATOR

INTRODUCTION

The Sonar Graphic Indicator (Sonar Receiver R404(XB-1)/UQ) presents on a cathode-ray-tube screen the developing sonar signal pattern as a transient plot of signal phase versus time or range, the reference of phase being that of a stable reference oscillator set at near signal frequency. Transmitted ping, reverberations, echo, and noise are displayed in time sequence through successive equal increments of range in the same screen area. The echo appears transiently as a distinct pattern in random or contrasting background (Figs. 1 and 2).



Figure 1 - Noise



Figure 2 - Signal and noise

Since the eye is capable of retaining complex observations for only a very limited time, it was realized early in the development of the Graphic Indicator that the addition of a device of longer memory would provide improved signal analysis.

A continuous strip presentation of the essential signal information by means of an electrochemical recorder system was an obvious approach to the problem. Such a system would provide a permanent visual record of the complete time history of the signal as it developed.

The development of this recording system was undertaken by the Applied Research Section, High Polymer Branch, Chemistry Division in close collaboration with the Special Projects Section, Transducer Branch, Sound Division.

The high writing speed required to follow accurately the characteristic phase-shift patterns produced by the Graphic Indicator precluded the use of the usual single moving pen or stylus. The high reference frequency sweep speed likewise made impractical the use of the familiar helix and printing bar arrangement common to facsimile systems. The printing problem was solved by the design of a new type of recording head containing a

row of twenty stationary styli mounted transversely across the tape and energized by an electrical sweep or commutator. This arrangement gives resolution corresponding to 18° of phase per stylus position.

Three means of energizing the multiple stylus recording head were investigated and two were built into completed recording systems. The other system was susceptible to noise interference and although it may have applications where noise is not a problem, it was unsuitable for this particular application. The two completed systems differed in that the first model depended on a series of twenty miniature phototubes arranged across the cathode-ray-tube screen of an oscilloscope slaved to the Graphic Indicator (reproducing the signal pattern through twenty stationary styli on the recorder tape), whereas the final model used a new type of commutating system which eliminated the cumbersome and often unreliable phototube arrangement. Qualitative performance tests have indicated that this system is capable of meeting the requirements of the problem.

It is believed that the method of commutation described in this report, or an adaptation of it, will find application in related fields; and that the recorder systems may be adaptable for the solution of similar recording problems.

The main text of this report is concerned primarily with a discussion of the final system. The first two systems are described briefly; more detailed descriptions are given in the appendix.

REVIEW OF THE SONAR GRAPHIC INDICATOR PRESENTATION

The Phase Recorder was developed specifically to be used with the Sonar Graphic Indicator; therefore a brief review of the principles of operation and method of display of the Sonar Graphic Indicator system is necessary to provide the background for a complete understanding of the problems involved in the development of the phase recorder, since the characteristics of the former determine the specifications for the latter. The following description is quoted from an earlier report (1).

"The Graphic Indicator incorporates a number of features which distinguish it from other sonar systems. First, the signal information is presented and compared from cycle to cycle rather than from pulse to pulse, as in conventional sonar systems. Second, the system differs basically in that the nature of the information presented is dependent primarily on the time-history of the signal rather than on its amplitude characteristics. In other contemporary systems, the signal amplitude energy is treated as the primary parameter, the time or phase character as a secondary one. Finally, the visual presentation used permits perception of very small and transient variations with time in signal phase or frequency, and thus enables an operator to gain information which cannot be obtained by the other methods.

"The simplest form of the system is that illustrated in the block diagram of Figure 3. A sound wave of frequency, F_s , is imposed on the transducer, with the resulting output of the transducer a voltage of frequency, F_s , (Figure 4a). This voltage is amplified by a bandpass amplifier so that the amplitude is increased while the frequency remains unchanged. The output of the bandpass amplifier is applied to a pulse generator which forms pulses of equal amplitude and of the same polarity at the positive crests of the alternating voltage (Figure 4b). The intelligence in the sound wave is thus converted into a train of pulses significantly spaced in time, and the spacing between pulses is the period of the signal wave. The pulses are operated on by a pulse lengthener which expands them individually to the length desired without affecting the time-spacing or repetition

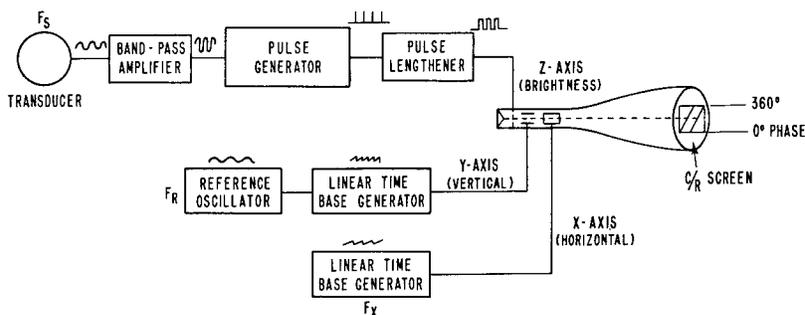


Figure 3 - Sonar Graphic Indicator (simplified)

frequency of the pulses (Figure 4c). The expanded pulses are applied to the Z or intensity axis of a cathode-ray oscilloscope, so that the intensity of the spot on the scope screen is raised to the level of visual perception each time a pulse occurs (Figure 4d).

“Application of linear sweeps of appropriate frequencies to the X- and Y-axes of the oscilloscope, then, results in the combination of individual spots appearing as a continuous line or lines (Figure 5). If the frequency applied to the Y-axis, which may be designated the reference frequency, F_r , is the same as the incoming signal frequency, a horizontal line appears on the cathode-ray screen (Figure 5). Under this condition, a zero rate of change of phase exists, or a zero frequency difference, between the reference frequency and the incoming sinusoidal signal frequency.

“Since the spot deflections in the Y or vertical direction are against a linear phase scale extending from 0° to 360° , referred to F_r , the position of the line on the screen remains constant if the phase difference between the incoming signal and the reference signal is constant. If ΔF (which is equal to $F_r - F_s$) is less than or greater than 0, the line assumes a slope whose difference from zero depends on the extent of the frequency difference. For example, if the frequency of an incoming signal is one cycle per second greater than the reference frequency, the phase will advance 360° during a one-second interval, or at the rate of one cycle per second over the reference signal. With an X-axis sweep of one cycle per second and a square raster, a line will be produced making a negative angle of 45° with the X-axis, as shown in Figure 6a. Likewise, when the incoming signal frequency is one cycle per second less than the reference frequency, the line will make a positive angle of 45° with the X-axis as shown in Fig. 6b.

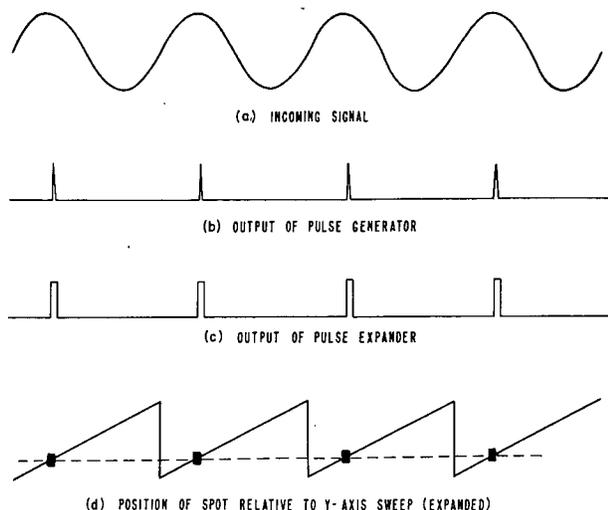


Figure 4 - Graphic Indicator waveforms

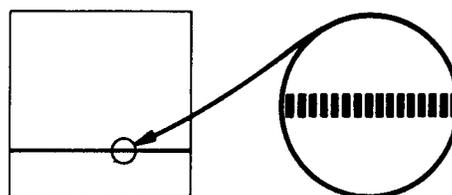
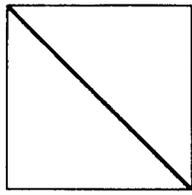
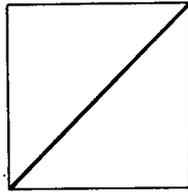


Figure 5 - Composition of presentation $F_s = F_r$



(a) F_s is 1 cps
greater than F_r .
 $F_x = 1$ cps



(b) F_s is 1 cps
less than F_r .
 $F_x = 1$ cps

Figure 6 - Frequency indication

considered the edge of the visual bandwidth. As ΔF increases above or below a center frequency ($F_0 = F_r$), a definite frequency range from which intelligence can be perceived is traversed. This is defined as the visual bandwidth; any information not resolved by the observer is outside of the visual bandwidth.

"----- The lines (or traces) in the signal pattern may deviate from the clear sharp line or lines characteristic of a strong signal of fixed frequency and constant cycle-to-cycle period. Such deviations are caused by variations of phase or period within the signal's duration, or by apparent variations due to distortion by noise of the signal phase or periodicity (Figure 8).

"With signal in a high noise background, the writing dots do not fall precisely at the signal wave crests, and the signal trace is a broadened line or band of randomly spaced dots, the dispersion tending to center on the line which would have been developed had the noise level been lower relative to the signal."

THE PHASE RECORDER

The principal problems involved in the reproduction of the Graphic Indicator signal display on paper tape were the design of a suitable recording mechanism and the processing of the signal. The usual recorder designs, such as moving pen or stylus or a helix

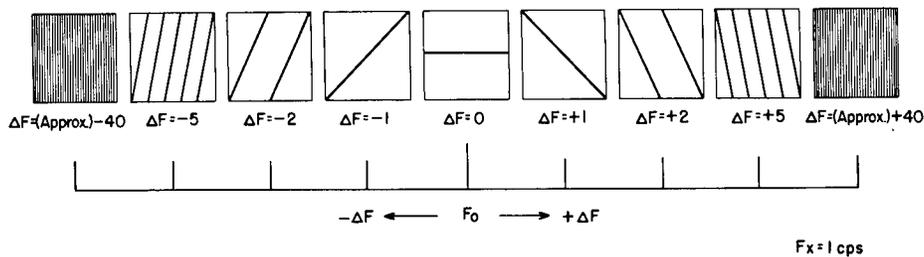


Figure 7 - Presentation over a frequency range

and printing bar arrangement, were not adaptable because of the high writing-speed requirement. A multiple-stylus recording head was designed which was capable of very fast response, since it had no moving parts and operated by the application of electrical energy to the appropriate stylus at the proper time. This fast response accurately follows the transient phase-shift characteristics of target echoes within the basic limitations of the system.

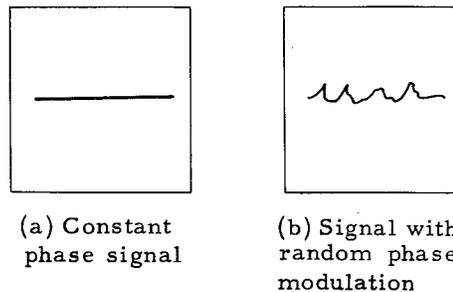


Figure 8 - Phase presentation

The problem of properly energizing the multiple styli involved a system of synchronization and distribution - i.e., commutation. Several possibilities were considered but were rejected because of the excessive and complicated circuitry involved. These included the use of a multiple-electrode radial beam tube, an experimental multiple-anode cathode-ray tube and a ring-type multivibrator system or scaler. Another approach was the use of a series of miniature phototubes arranged across the face of an oscilloscope slaved to the Graphic Indicator as the distributing element for the printing-stylus channels. A twenty-channel recording system based on the latter method was designed, built, and tested. Although the display pattern of the Graphic Indicator was reproduced with sufficient accuracy on the recorder tape, the phototube arrangement proved to be cumbersome and unreliable. A relatively simple means of commutation was then explored involving an adaptation of a multiple-channel, pulse-height discriminator or "ladder" arrangement of step-biased multivibrators in conjunction with an adaptation of the Kretzmer phasemeter (2). This system of commutation was successful but the phasemeter proved to be noise limited and was never used in a completed recording system.

The final development used the discriminator type of commutator in conjunction with channel-coincidence stages to reproduce the Graphic Indicator display by sweeping the commutator with a reference-frequency sawtooth waveform while injecting the signal pulse into the common coincidence grid input.

Physical Design

The phase recording system consists of five units, rack-mounted in a five-foot metal cabinet as shown in Figs. 9 and 10. Each unit is easily removable for maintenance and transportation.

Theory of Operation

A block diagram of the recording system is shown in Fig. 11. A reference frequency sawtooth waveform is taken from the Graphic Indicator and fed to the twenty-channel discriminator common input. This linearly changing voltage sweeps the step-biased multivibrators, producing an output pulse from each of them in succession. These pulses are applied in sequence to one input of the twenty coincidence tubes while the signal pulse from the Graphic Indicator is fed to the common connection of the other coincidence-tube inputs. Thus a given phase difference between signal and reference frequencies produces coincidence output pulses from a particular stage, and changing phase difference produces coincidence output pulses from successive stages in 18° steps. These pulses are fed into twenty Schmitt triggers and thus inverted, widened, and amplified into positive square

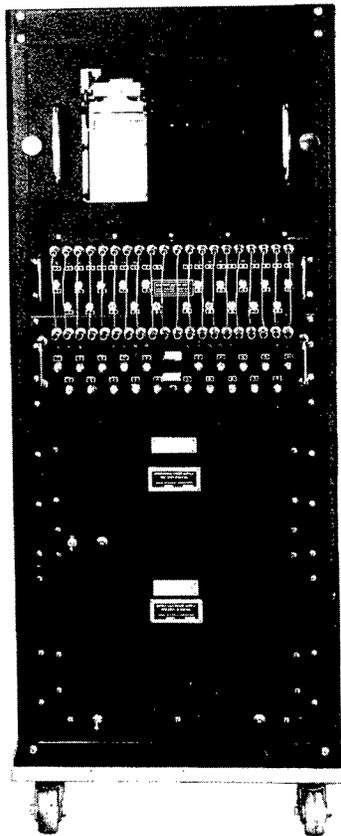


Figure 9 - Phase recorder assembly (front view)

RECORDER UNIT
 OUTPUT UNIT
 COINCIDENCE UNIT
 COINCIDENCE UNIT POWER SUPPLY
 OUTPUT UNIT POWER SUPPLY

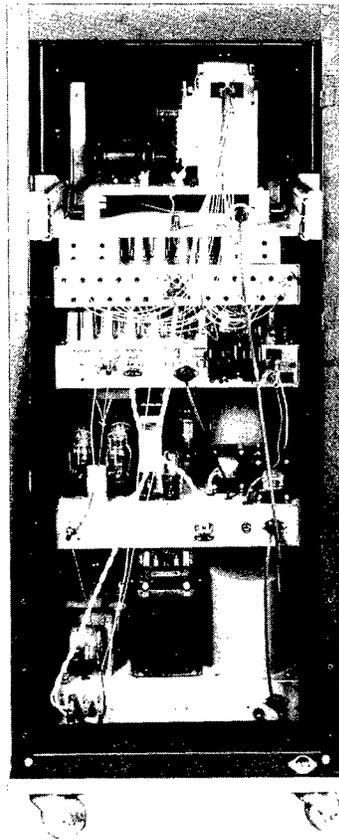


Figure 10 - Phase recorder assembly (rear view)

RECORDER UNIT
 OUTPUT UNIT
 COINCIDENCE UNIT
 COINCIDENCE UNIT POWER SUPPLY
 OUTPUT UNIT POWER SUPPLY

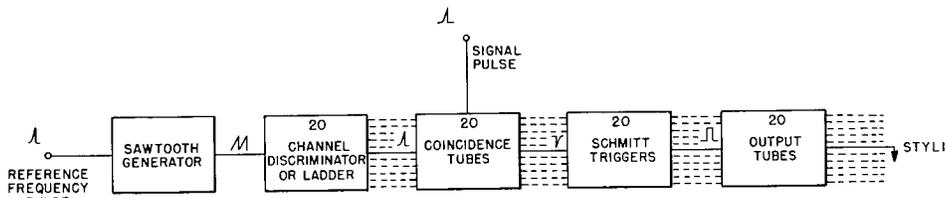


Figure 11 - Block diagram of phase recording system

waves suitable for unbiasing the output tubes to produce the required heavy current pulses for marking the paper tape.

Electronic Design

The use of standard electronic components in the most compact assembly possible dictated the use of two units to provide the required twenty channels. These have been named the coincidence unit and the output unit.

Coincidence Unit--The schematic diagram of one channel of this unit, and photographs of the unit assembly are shown in Figures 12, 13, and 14.

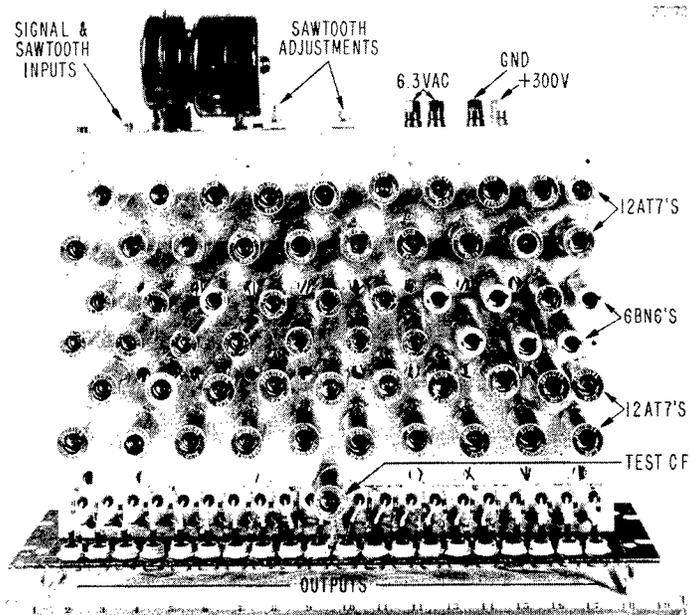


Figure 13 - Coincidence unit (top view)

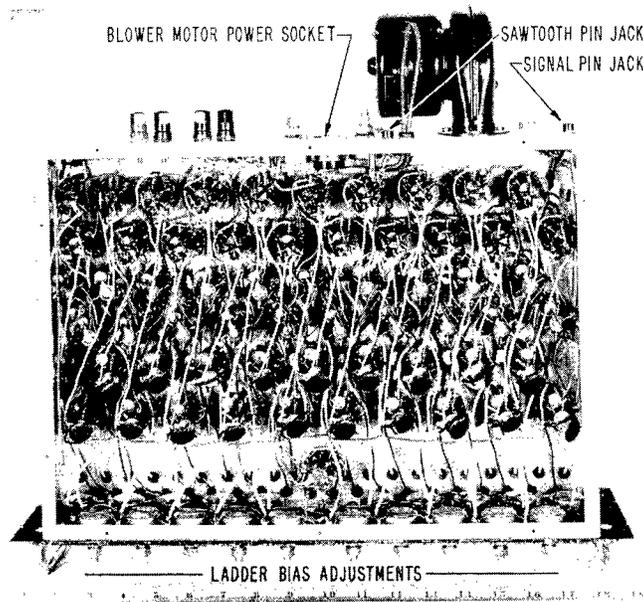


Figure 14 - Coincidence unit (bottom view)

The reference-frequency sawtooth sweep voltage is fed into the microphone connector on the rear apron (Figure 13) to activate the twenty triggers comprising the twenty-channel, step-biased, multiple discriminator or ladder. DC coupling is required to make the full sweep available. The square-wave pulses from the trigger have a fast rise-time which is preserved and inverted by means of a phase-splitter stage, so that this inverted pulse can be applied to the trigger output of the next lower biased channel to provide an equally fast decay time for a combined pulse having a width controlled by the respective bias settings. A simple resistance coupling is used in combining these two square waves and, with this arrangement, the sawtooth flyback does not produce any output pulse. This combined pulse is fed to one control-grid of the 6BN6 gated-beam tube and can be checked at the pin jack on the front panel. The signal pulse from the Graphic Indicator is fed to the other control grid through the other microphone connector on the rear apron (Figure 13). When coincidence occurs, a 6 v negative output pulse is obtained from the 6BN6 tube, appearing at the output connector on the front panel (Figure 13).

The ladder-bias potentiometers are readily accessible on the front panel (Figure 14) for the original setup or subsequent adjustment. Input test pin jacks are mounted on the rear apron along with the power-supply binding posts. Also on the rear apron are the 7500-ohm sawtooth amplitude control and the 1000-ohm bias-level control. These controls are used to fit the sawtooth to the ladder, once the latter has been set up while they are at or near mid positions. The trigger output of channel #20, having the highest bias in the ladder, is used without benefit of an inverted pulse to form the decay side of the combined pulse. Instead, the bias is adjusted so that the sawtooth flyback will limit the trigger pulse to the same width as the other combined pulses. This is done to avoid the additional trigger and inverter that would be required for the usual combined pulse formation.

The commutator sweep rate is limited in the present design to approximately 60,000 cycles/sec, representing the maximum usable reference oscillator frequency. This limit may be increased, or operation can be secured at any desired lower sweep rate by suitable choice of circuit parameters.

For lineup and test, a cathode follower using 1/2 12AT7 tube is wired in the unit and connected to input and output pin jacks on the front panel. This prevents heavy loading of the high impedance test points with oscilloscope input capacitance and resistance values, thus preserving pulse waveforms.

In setting up the ladder, the essential purpose is to divide the sawtooth sweep equally between the channels. It is first set to a value of approximately 100 v at the test point or common connection by means of the sweep amplitude control. The bias level control is set to its mid point. Then, with all bias potentiometers set to maximum bias, #20 is advanced until an oscilloscope connected to #20 pin jack (combined pulse output test point) through the cathode follower shows a pulse having a width equal to 1/20 of the sawtooth sweep time. If the reference frequency is 25 kc, for example, it will take 40 microseconds for the sawtooth to sweep the triggers. Therefore, if the sweep is divided equally between the channels, each combined output pulse will be 2 microseconds wide. The cathode follower is then plugged into #19 pin jack and #19 bias potentiometer is advanced until a similar pulse is obtained. This adjustment is repeated on successive channels until they all show a uniform combined output pulse. With reasonable accuracy, any discrepancy at channel #1 can be corrected by adjusting the bias level control and then adjusting the sawtooth amplitude control (if necessary) to make sure that #20 pulse remains as originally set up.

It will be noted that the ladder commutator set up in this manner is fundamentally independent of frequency. This characteristic may be useful in applications for which tuned circuits are inadequate or incompatible.

Output Unit—The circuit design of one channel of this unit is shown in Fig. 15. The coincidence output pulse is fed into the corresponding microphone input connector on the front panel (Fig. 16). It activates a Schmitt trigger to produce a square-wave output that unbiases the output power stage.* This stage is biased off to -50 v and a corresponding 1 or 2 microampere cutoff current which is insufficient to mark the tape. With signal, the output current averages 50 ma from 1 or 2 channels at a time. With noise, it averages from 10 to 15 ma from each channel when the trigger biases are adjusted to give a uniformly light intensity of marking at maximum paper speed. This adjustment will show signal patterns in the noise and still hold the current drain within the capability of the output power supply unit. The trigger-bias potentiometers (Fig. 17) can be adjusted to compensate for tube or component variation by changing the square-wave pulse width, thus producing equal marking currents in the output stages and giving uniform printing on the tape. The output connectors and power-supply binding posts are mounted on the rear apron (Figure 16).

Power-Supply Units—The coincidence-unit power supply shown in Figs. 18, 19, and 20, consists of an ac heater transformer supplying 6.3 v at 20A and a standard electronically regulated dc supply giving +300 v at 500 ma. The effectiveness of the circuit is considerably improved by the addition of a 500,000-ohm potentiometer as a regulator feedback control in the 6AC7 voltage amplifier screen grid circuit. This can be adjusted for maximum regulation against line voltage fluctuations. The 250,000-ohm potentiometer is used to set the proper screen grid voltage after setting the regulating control.

The output-unit power supply (Figs. 21, 22, and 23) is practically a duplicate of the coincidence-unit power supply except that it has a 30A heater capacity and a -150 v dc bias supply designed for a 20 ma load. This supply is regulated with a gas-type regulator tube (VR 150).

Recorder Unit Design

The recorder unit is compact and simple in design, combining three major components: the recorder paper magazine, the drive mechanism, and the stylus head assembly.

Recorder Paper Magazine—The magazine is designed to accommodate a five-inch diameter roll of recorder paper ** (Fig. 24). The paper roll core fits over a freely turning flanged hub attached to the inner wall of the chamber. It is secured on the outer side by a spring-loaded hub mounted on a plate, hinged at the bottom, which drops to a horizontal position to permit loading rolls and removing cores. This plate is locked in the

*The printing intensity is greatly increased by broadening the coincidence output pulses from 5% to 50% of the sweep frequency period in this manner. At the usual sonar operating frequencies the resulting square waves give adequate average printing current and continuous marking on the paper at all available speeds.

**The ECR Recorder Paper (NRL Report No. 4001) was used in this development. Its properties of high sensitivity, wide dynamic range, fine definition, and high wet strength were especially suited to meet the rigid requirements of this system.

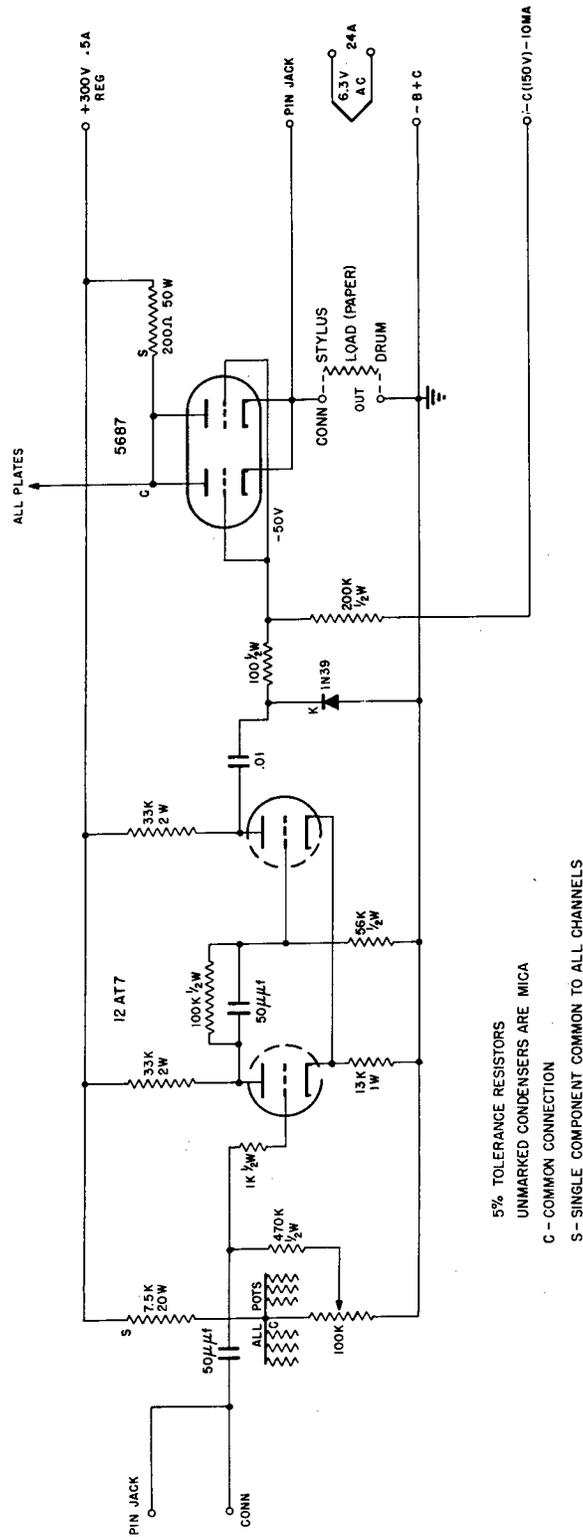


Figure 15 - Circuit diagram of one channel of output unit

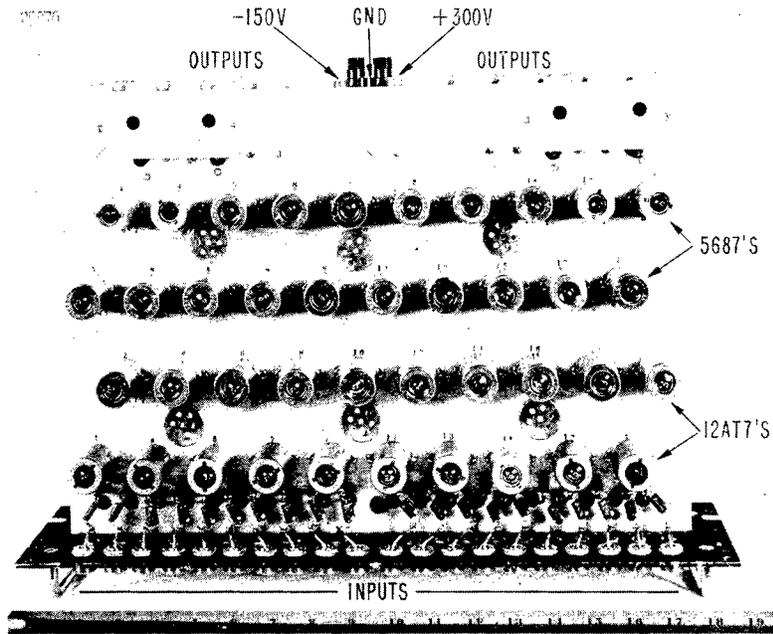


Figure 16 - Output unit (top view)

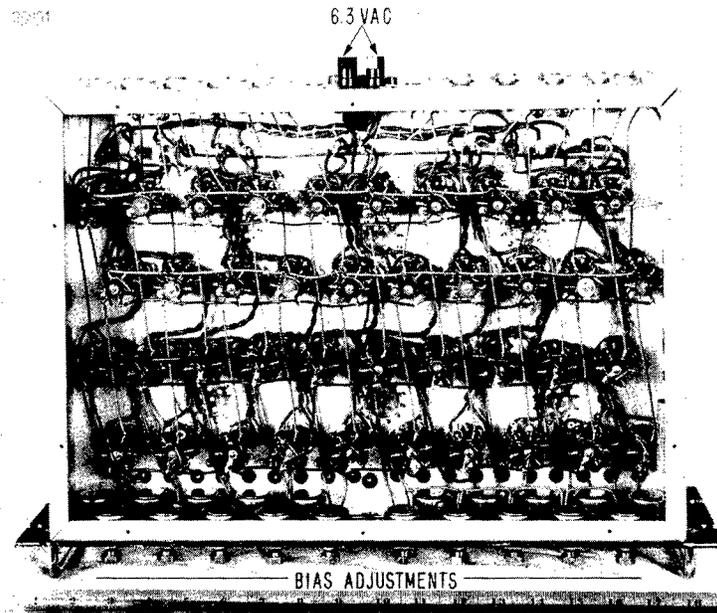


Figure 17 - Output unit (bottom view)

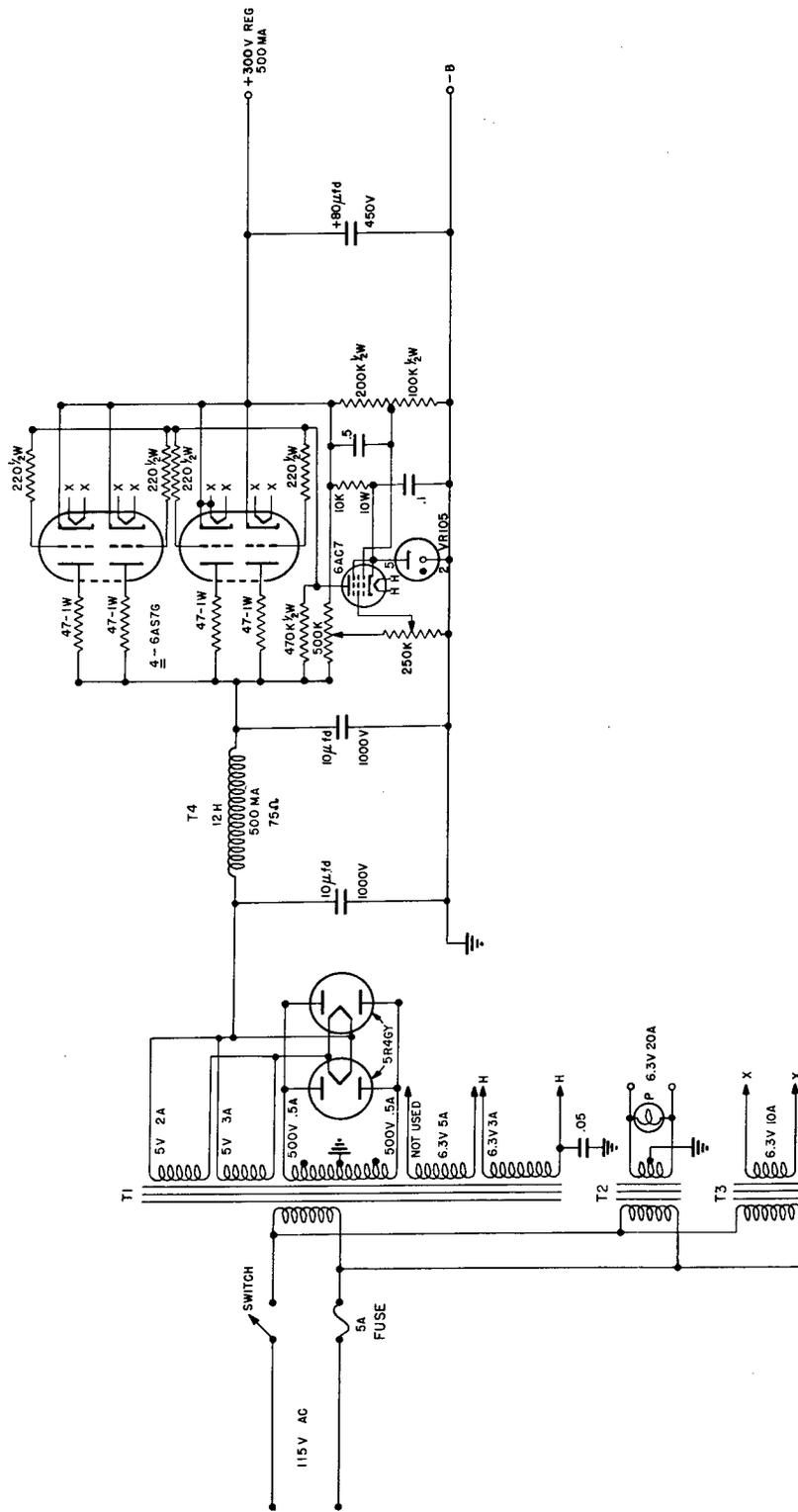


Figure 18 - Schematic diagram of coincidence unit power supply

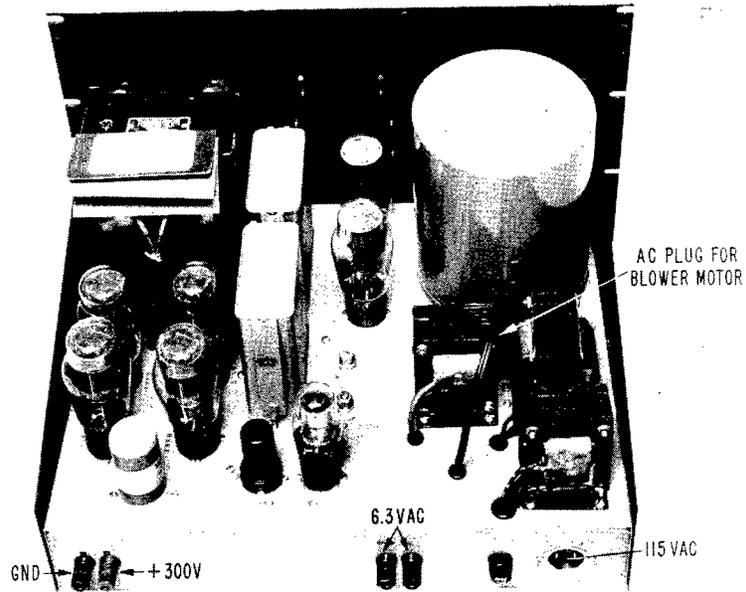


Figure 19 - Coincidence unit power supply (top view)

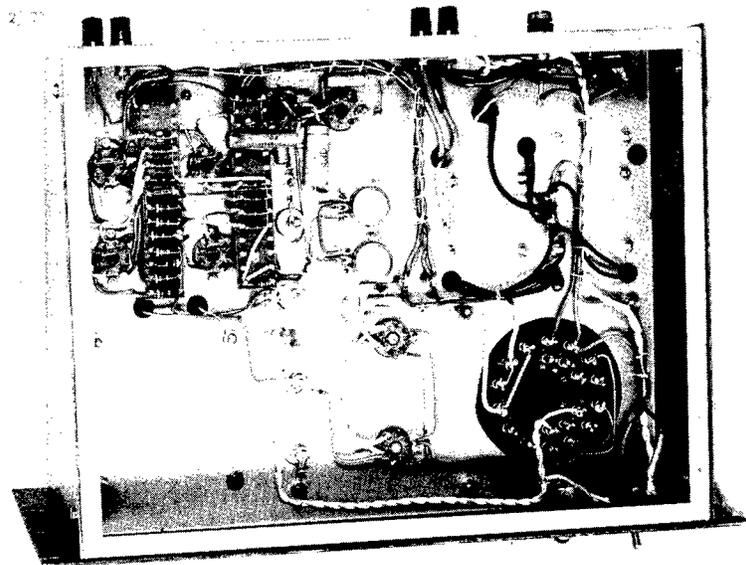


Figure 20 - Coincidence unit power supply (bottom view)

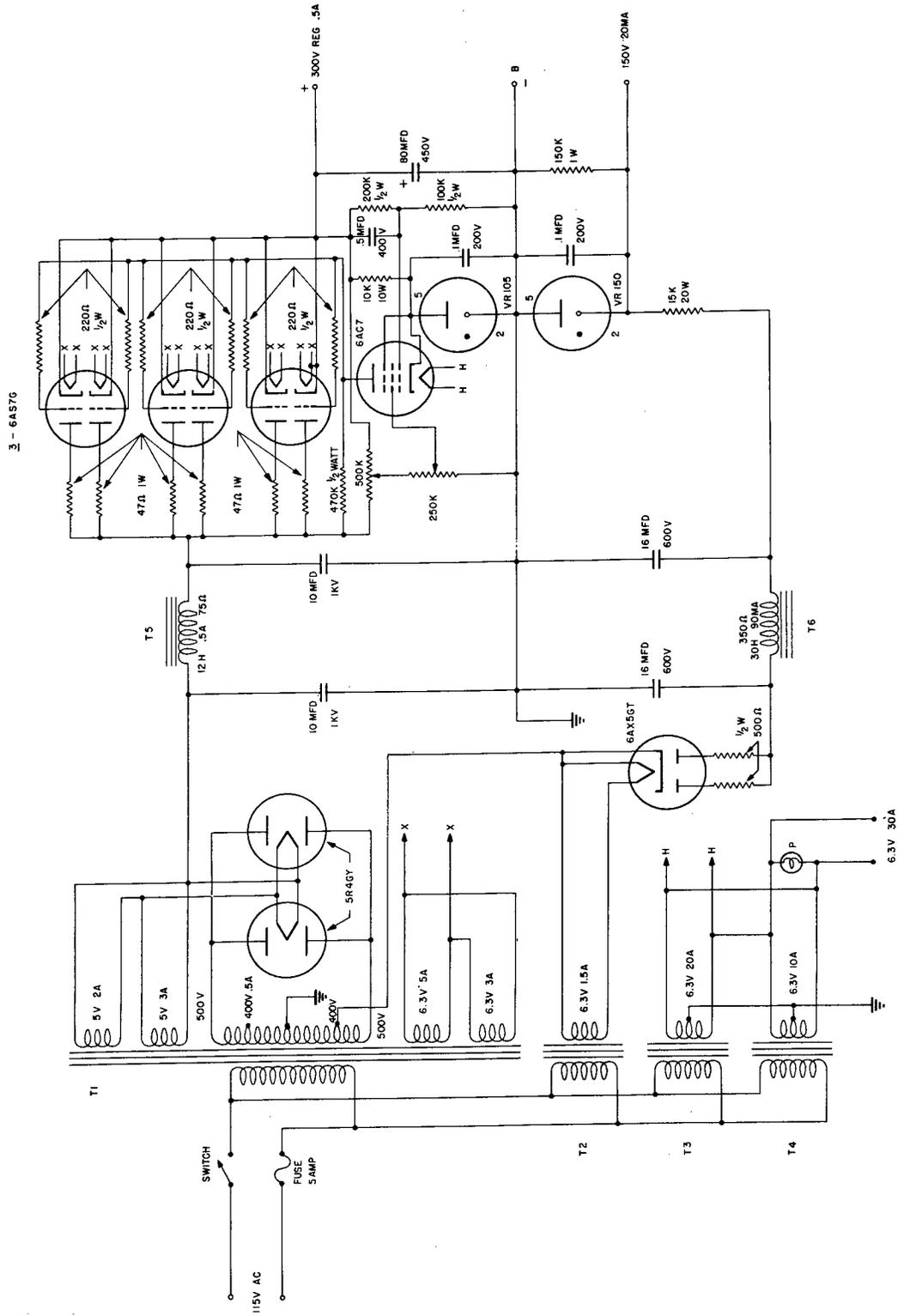


Figure 21 - Schematic diagram of output unit power supply

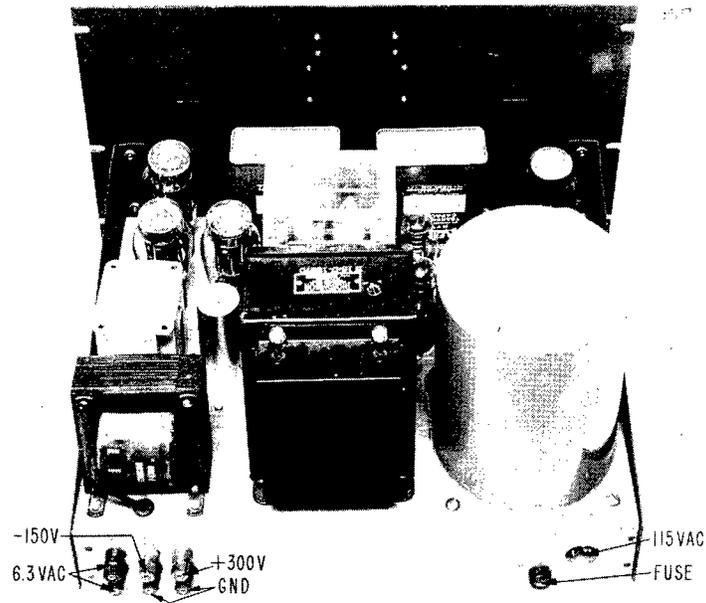


Figure 22 - Output unit power supply (top view)

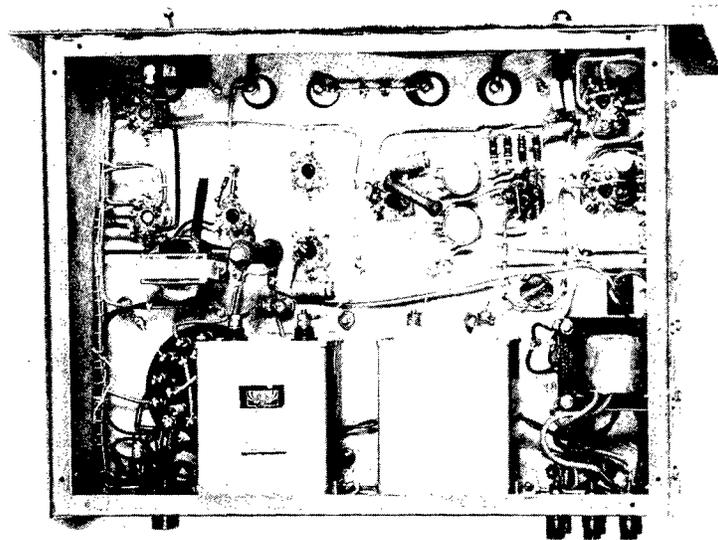


Figure 23 - Output unit power supply (bottom view)

upright or operating position by spring catches at the sides (Fig. 25). A narrow trough containing a wet sponge is attached to the inner wall of the chamber to maintain the required humidity. The door on the side of the magazine is sealed with a rubber gasket, and rubber flaps resting against the recording drum aid in preventing serious loss of moisture.

Drive Mechanism—The paper tape is pulled from the roll by means of a rubber-covered drive roll which presses against the paper as it passes over the recording drum (Fig. 25). The drive roll is mounted in a frame and driven through interchangeable gears on the left-hand side of the unit so as to provide tape speeds of 6, 9, 12, 18, or 24 inches per second. The lower end of the frame is pivoted on the driving gear shaft and both driving and roll gears are constantly in mesh. This arrangement allows the upper end of the frame to swing forward and down through an arc of approximately 45° from the drive position to the "OFF" position, in which drive roll shaft collars strike the side panels of the recorder body. This movement is accomplished by means of a curved, sheet-metal handle accessible through the opening in the front panel from which the paper emerges. The midpoint of the swing is dead center for a spring-loaded plunger attached to the lower crossbar of the frame and providing drive pressure on the roll in the "ON" position, and positioning pressure in the "OFF" position. The driving gear shaft is geared into a sealed gear-box which is driven by a 1/75-hp synchronous motor through a flexible coupling (Fig. 26). The recording drum is a freely-turning, chromium plated, brass pulley matching the drive roll in general dimensions and located below and behind it. The row of styli contact the paper along the top of the drum and the drive roll line of contact is in front, just above the level of the axle. (Fig. 25). As the tape leaves this line of contact, it is prevented from clinging to

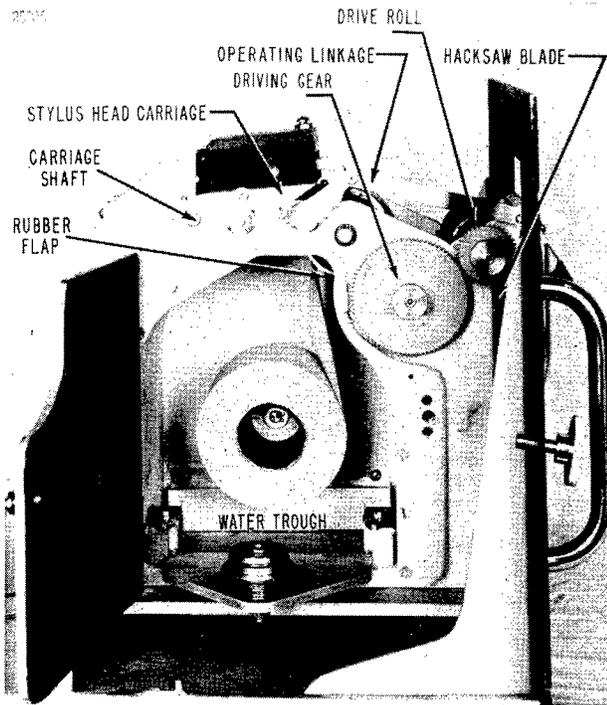


Figure 24 - Recorder unit(left-hand side view). Paper magazine is open showing paper roll mountings in loading position. Paper drive mechanism is in "Off" position.

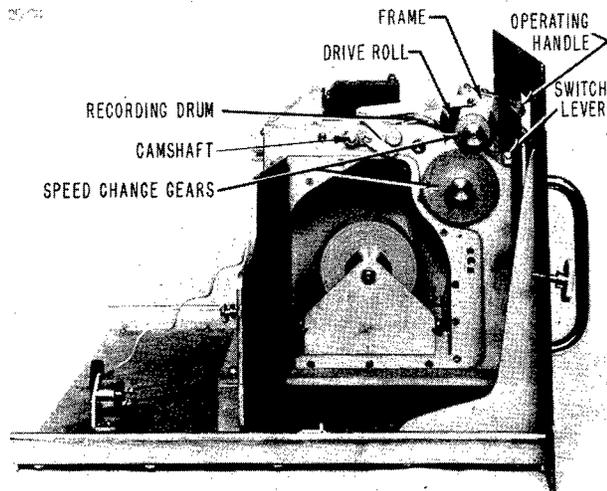


Figure 25 - Recorder unit(left-hand side view). Paper roll is in loaded position. Paper drive mechanism is in "On" position.

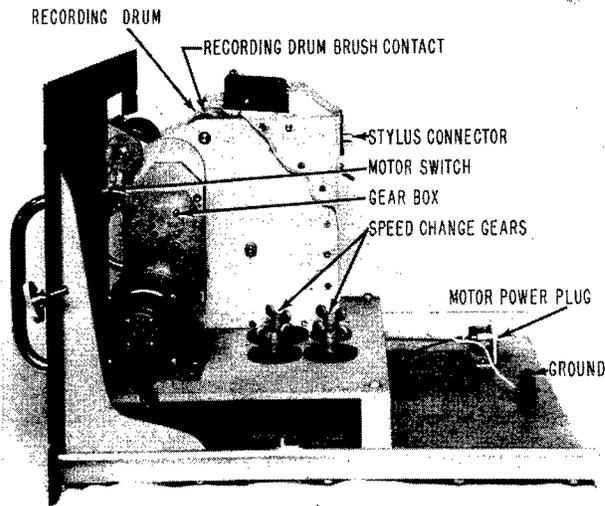


Figure 26 - Recorder Unit (right-hand side view). Drive roll is in "Off" position.

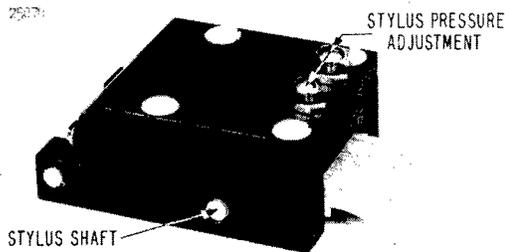


Figure 27 - Stylus head assembly (top view)

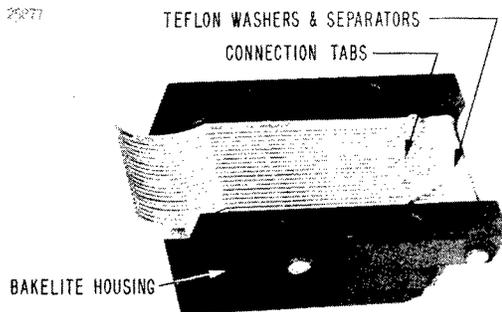
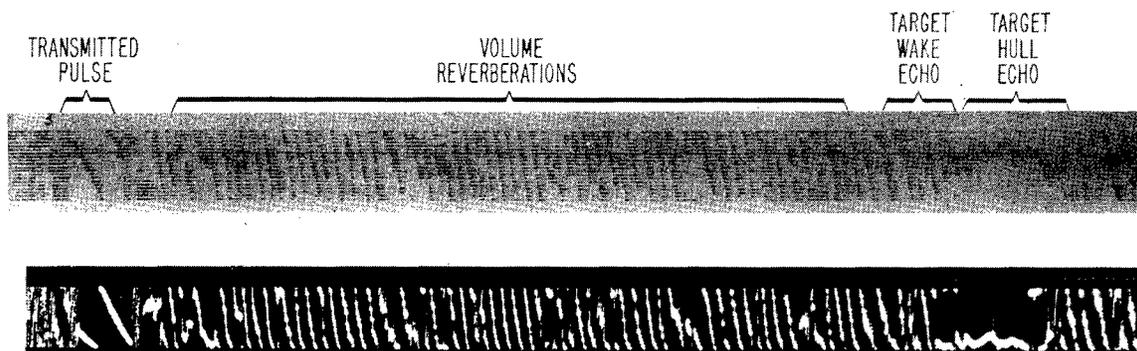


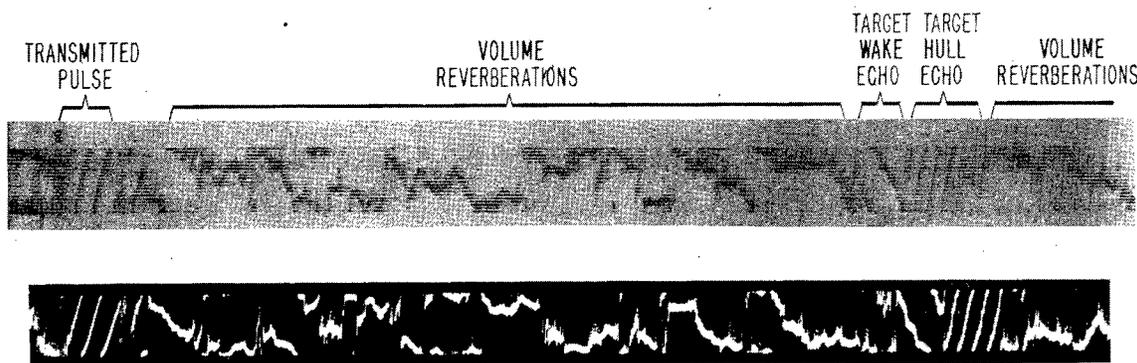
Figure 28 - Stylus head assembly (bottom view)

either the drive roll or the recording drum by sheet-metal guides placed close to the rolls. The recording-drum shaft is mounted in bakelite collars to permit a separate, low-resistance stylus-return connection by means of an insulated brush resting on one edge of the drum. A section of hacksaw blade is mounted just above the point where the tape leaves the machine, to be used in tearing off desired portions. A linkage connects the drive-roll frame to the operating cam of the stylus-head carriage in such a manner that when the drive roll is pulled from the recording drum, stopping the tape, the styli are simultaneously lifted. Motor control is incorporated in this arrangement by having a projection on the drive-roll frame open a microswitch just before it comes to rest in the "OFF" position. Thus the motor is started in a no-load condition as soon as the frame is lifted from the "OFF" position, and it attains full speed unloaded. The load is applied when the drive roll is allowed to spring against the paper on the recording drum. This, in effect, provides a manually operated clutch mechanism.

Stylus Head Assembly—The stylus head assembly consists of a row of 21 nickel-plated, platinum-iridium tipped, 1/32-inch, flat, brass blades mounted in a bakelite housing (Fig. 27). (An extra stylus is provided for future connection to a timing device.) They are separated by 0.010 in. sheet teflon and mounted on a horizontal, teflon-covered, steel pivot shaft (Fig. 27). A roll of gum rubber presses across the tops of the blades, between the pivot shaft and the tips, to provide adjustable printing pressure by means of two screws in the top of the housing. A bakelite crossbar above the rear ends of the blades affords a stop to forward motion of the styli when they are lifted off the paper tape on the



(a) Reference frequency oscillator set to target hull echo frequency



(b) Reference frequency oscillator set to average reverberation echo frequency

Figure 29 - Phase Recorder reproductions of Sonar Graphic Indicator display patterns

recording drum. The assembly is mounted on a carriage plate, hinged at the rear and riding upon a cylindrical cam or offset roller (Figs. 24 and 25). The carriage is held down against the cam by a coiled spring attached to its underside and suspended from the back plate of the recorder. Rotation of the cam raises the styli from the tape sufficiently to permit threading the paper when loading. The back plate also carries the 21-pin Jones plug which is wired to the stylus connection tabs.

PERFORMANCE AND RESULTS

The ability of the Phase Recorder to reproduce the display pattern of the Sonar Graphic Indicator is illustrated in Fig. 29. These pulse-reverberation-echo sequences were recorded from magnetic-tape recordings of sonar runs made with the Graphic Indicator during maneuvers at sea; while simultaneous photographs of the Graphic Indicator display were taken with a 35-mm strip camera.* Fig. 29a shows a comparison

*In taking these photographs, the horizontal sweep time base normally used in the cathode-ray-tube display was replaced by film movement in front of the tube screen, producing a trace similar to the recorder presentation.



Figure 30 - Full-size detail of target echo trace

of the displays when the Graphic Indicator reference frequency oscillator is set to the same frequency as the target hull echo. Fig. 29b shows a similar sequence in which the oscillator is set to the same frequency as the average reverberation.*

A full size detail of the target echo area of one sequence is shown in Fig. 30.

It was found that the signal recognition differential of the tape-recording presentation was decidedly greater than that of the original Graphic Indicator display. This is due to the memory characteristic of recordings, permitting simultaneous comparisons of the features of a single ping sequence or of one sequence with subsequent sequences.

The system was tested at Ft. Monroe, Virginia on the Harbor Defense Unit installation consisting of two QBH Herald units. This field test was intended to give a qualitative indication of the performance of the system under actual operating conditions. Targets were successfully tracked out to ranges of 2 to 3 thousand yards by taking recordings of single pings at suitable intervals. Range rate obtained from measurements made on a single ping sequence could be determined with an accuracy of 0.5 knot or better.** Mechanically and electronically, the equipment operated satisfactorily. The installation and check of the bias adjustments were completed in less than an hour. During approximately 30 hours total operating time, only a few minor adjustments were necessary. This, plus subsequent performance over longer periods, indicates a degree of stability sufficient for practical use.

*It will be noted that a constant phase displacement of approximately 180° ($1/2$ of the sweep) exists between the two traces. This condition is due to the fact that both reference frequency sweeps were not triggered by the same pulse. It was not convenient to do this with the experimental setup used in taking the photographs.

Close inspection will reveal a slight break or gap occurring at the start of the recorder trace sweep. This represents flyback time due to an imperfect ladder sawtooth waveform.

**It is noteworthy that targets were seldom distinguishable on the tactical range recorder because of the high noise and reverberation level present in the shallow waters of this area. At the same time, targets were easily detected on the Graphic Indicator and Phase Recorder presentations.

CONCLUSIONS

The Phase Recorder display has proved the ability of the 20-stylus recording head to reproduce the Graphic Indicator presentation with sufficient resolution to provide all of the usable information available from the system. At the tape speeds and operating frequencies required for this purpose, the recorder trace is the practical equivalent of a photographic record.

The permanent, strip presentation obtained from the recorder is inherently capable of conveying more information than the transitory Graphic Indicator display for the following reasons:

1. Precise physical measurements can be made on the trace, providing quantitative values of target range and range rate.
2. The record can be examined closely for any required length of time, permitting detailed study and analysis of phase changes in target echoes and in reverberations.
3. Widely separated sequences can be simultaneously compared side by side or against reference patterns so that minute changes can be detected or accurate classification and identification established.

These operations are not possible with the R404(XB-1)/UQ presentation since successive patterns occur in time sequence over the same display area and cannot be reviewed.

The unique combination of high-frequency response, permanence, and immediate availability afforded by this paper tape record suggests the following field applications:

1. The determination of target range and range rate by means of the single ping technique now being investigated for prosubmarine fire-control purposes.
2. Secure sonar communication and IFF identification, using pulse phase-modulation techniques.
3. The precise determination of set and drift of ocean currents.

In addition to these specific sonar applications, the Phase Recorder shows promise as a laboratory tool providing immediate accessibility to data for comparison, deliberate study, or detailed analysis. This is particularly desirable for development work in which quick comparisons of the effects of minor component changes are needed, but cannot be made within the persistence time of cathode-ray-tube screens, where a side by side comparison of successive traces is not possible. Compared with typical moving pen recorders now available, the higher frequency response of this system gives a more accurate trace of complex wave components and transients, along with accurate amplitude display of such frequencies.

One limitation, of course, is in the degree of resolution afforded by the 20 channels. For many purposes this would not be too serious. The other limitation lies in the present maximum tape speed of 24 in./sec.

RECOMMENDATIONS

1. It is recommended that further development and evaluation of the Phase Recorder be carried out by those activities interested in its applications.
2. It is further recommended that any future engineering development of the recorder include:
 - a. The use of "plug-in" stages in the coincidence and output units to facilitate servicing.
 - b. An investigation of the use of commercially available tapped delay lines as a substitute for the "ladder" commutator in the present system for fixed-frequency applications. This modification should improve stability, reduce critical adjustments, and provide a simplified and more compact design.

ACKNOWLEDGMENTS

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Mr. John M. Reece and Mr. Charles Stinger of the Engineering Services Division, for the construction and modification of the multiple-channel electronic units and power supplies.

* * *

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- (2) Kretzmer, E. R., "Measuring Phase at Audio and Ultrasonic Frequencies," *Electronics*, 22, 114-118 (Oct. 1949)
- (3) *Electronics* Vol. 22, October 1949, p. 114

* * *

APPENDIX A

System Progress and Development

MODEL I SYSTEM

Discussion

The design of the first recording system was largely influenced by the immediate need of any arrangement that would test the feasibility of the multiple-stylus recording head for use in this project. Consequently, equipment already on hand was pressed into service where possible. The use of a standard oscilloscope, slaved to the Graphic Indicator, as the means of both distributing and gating, immediately simplified the design problem to one of amplification and conversion of phototube pulses to current pulses suitable for marking the paper tape. With the "External Sync" connected to a pulse from the vertical sweep circuit of the Graphic Indicator and with the Z-axis inputs connected in parallel, the movement of the paper tape took the place of the slow-speed horizontal sweep of the original cathode-ray-tube display. The experience with this system proved the value of the multiple-stylus recording head for this application, and also proved that a minimum of 20 styli were necessary to give an adequate degree of resolution.

Description

A block diagram of this Phase Recorder is shown in Figure 31. Figure 32 shows the phototube collector head. The multiple-channel equipment was constructed in two units of ten channels each (Figures 33 and 34) and a third chassis contained a power supply consisting of a heavy-duty, electronically regulated dc plate supply, a gas-tube-regulated bias supply, and a heavy-duty filament heater transformer.

The schematic diagram of this system is shown in Figure 35. The channel amplifier circuit uses a cascade-connected 12AX7 tube as a pulse amplifier with emphasis on gain rather than waveform. A voltage divider-filter network supplies +170 v to the plate of the 1P42 phototube through a 1-megohm load resistor. The negative output pulses are fed to the pulse amplifier, whose output triggers a 12AU7 tube connected as a Schmitt trigger. With proper constants, this multivibrator is not free running, so that a channel cannot "take off" by itself without signal excitation. In this manner, a pulse of indifferent shape and varying amplitude is converted into a clean, sharp, square-wave pulse of constant amplitude suitable for obtaining maximum average current through the paper tape.

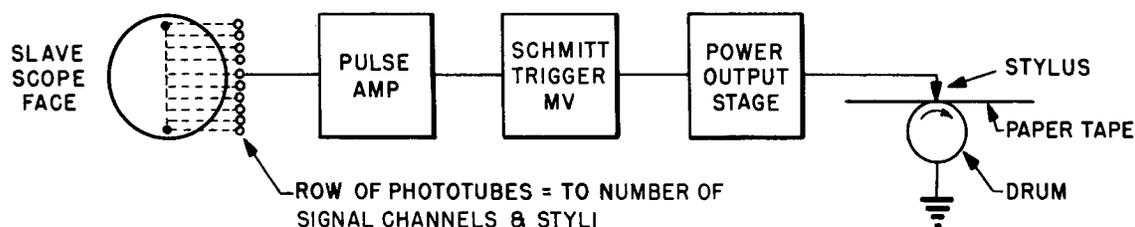


Figure 31 - Block diagram of Model I system

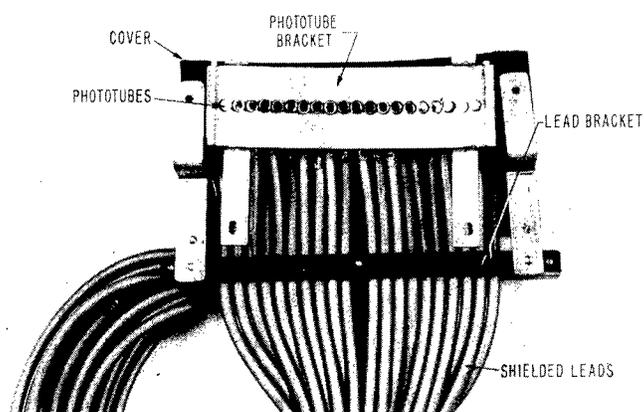


Figure 32 - Phototube collector head of Model I system

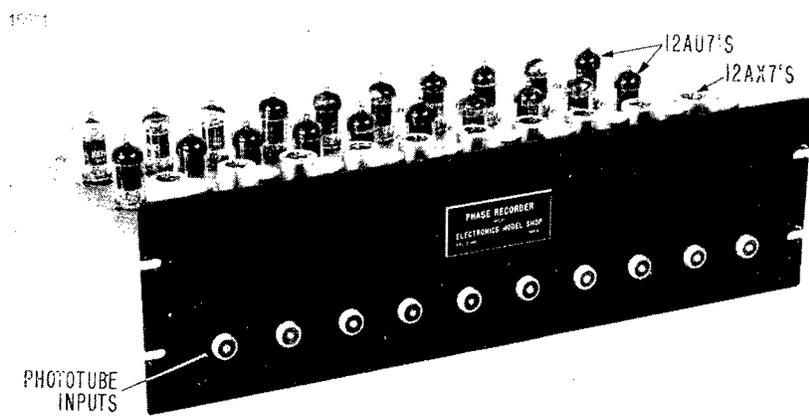


Figure 33 - One of two channel amplifier units, Model I system (top view)

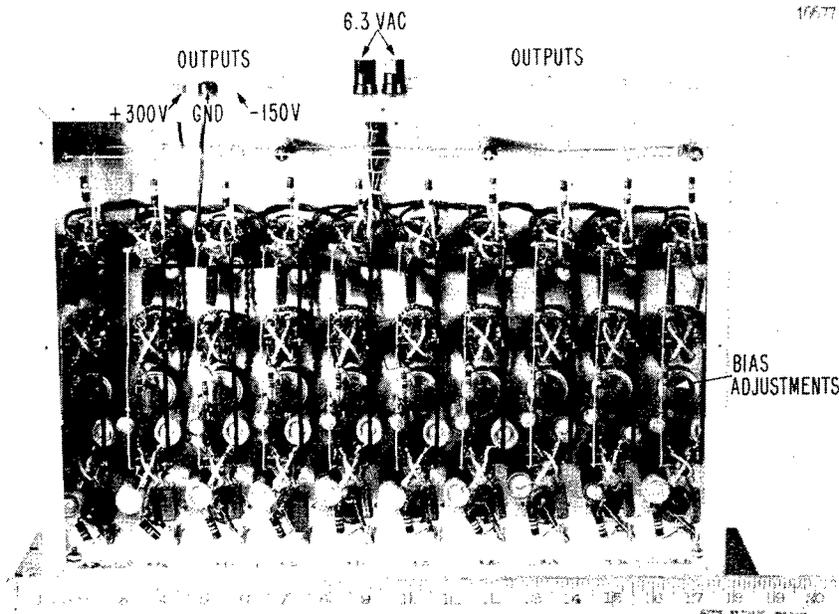


Figure 34 - One of two channel amplifier units, Model I system
(bottom view)

A trigger pulse for each phototube pulse is obtained if the trigger input pulse level is sufficiently high. At a lower level, approximating normal operation, the trigger operates on a subharmonic of the reference frequency because of the comparatively large time constant of the trigger coupling circuit. This is still high enough to give continuous marking on the tape. Such subharmonic operation was found to provide a convenient sensitivity adjustment. The trigger bias adjustment is a pulse height selector which has the effect of varying the sensitivity of the channel by changing the effective input signal. While serving the obvious purpose of compensating for trigger tube and circuit component variation, it thus turned out to be also a compensating adjustment for variations in phototube sensitivity and amplifier gain which would cause uneven printing on the tape due to unequal pulse amplifier output, differing subharmonic trigger pulse widths and frequencies, and consequently, uneven average current in the output stages. The first half of the output 12AU7 tube is connected as a diode rectifier to give positive pulses that will unblock the second half 12AU7 triode. The latter is biased to -50 v from the bias supply, limiting the plate current to less than 5 microamperes, a value insufficient to mark the tape under conditions of normal use. When the channel is energized by a series of 1-mv phototube output pulses, the output stage triode draws about 5-ma average current through the paper tape connected in its cathode circuit. The 6,800-ohm plate resistor is used as a current limiter.

It was found that the least usable oscilloscope spot intensity required for triggering the multivibrators produced a subharmonic frequency of about 200 cycles. Although this frequency may be borderline from a consideration of continuous marking at maximum tape speed, the average, medium-intensity spot that was normally used generated a subharmonic frequency of about 2000 cycles, and this was entirely satisfactory.

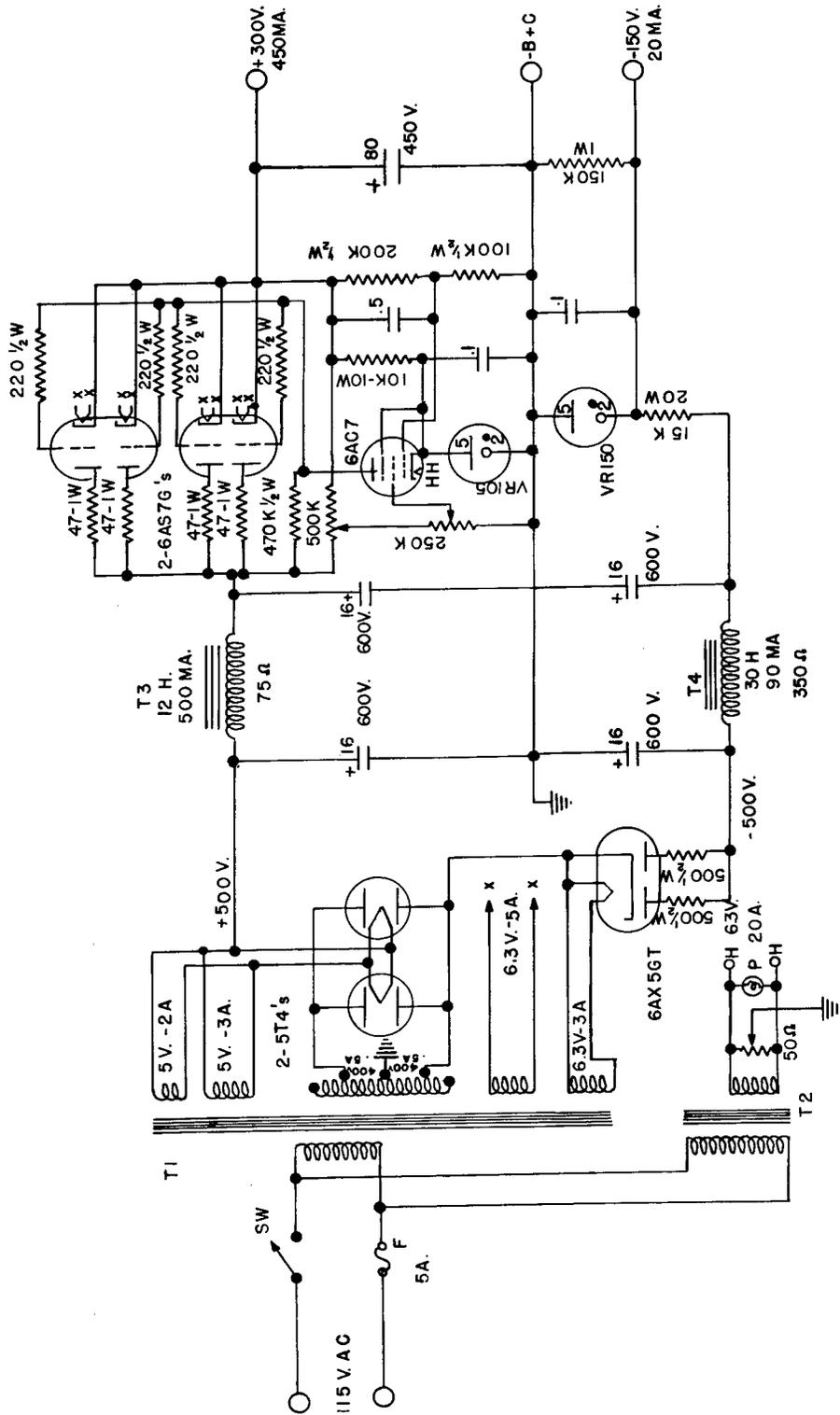


Figure 36 - Schematic diagram of power supply (heavy-duty regulated), Models I and II

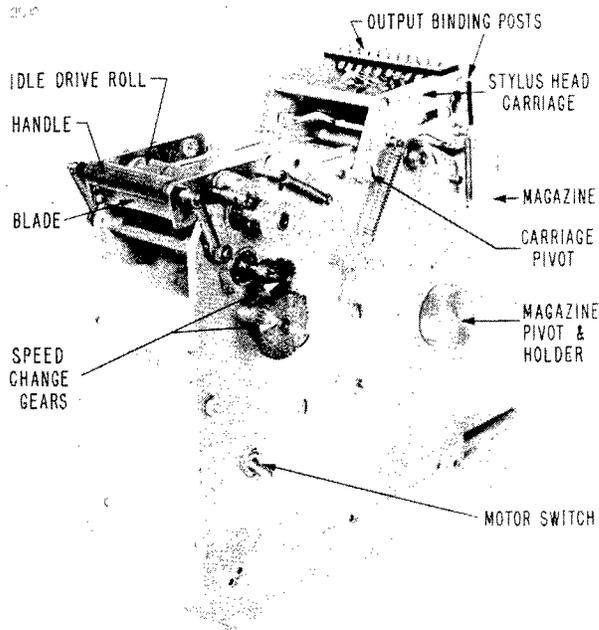


Figure 37 - Recorder unit, Models I and II

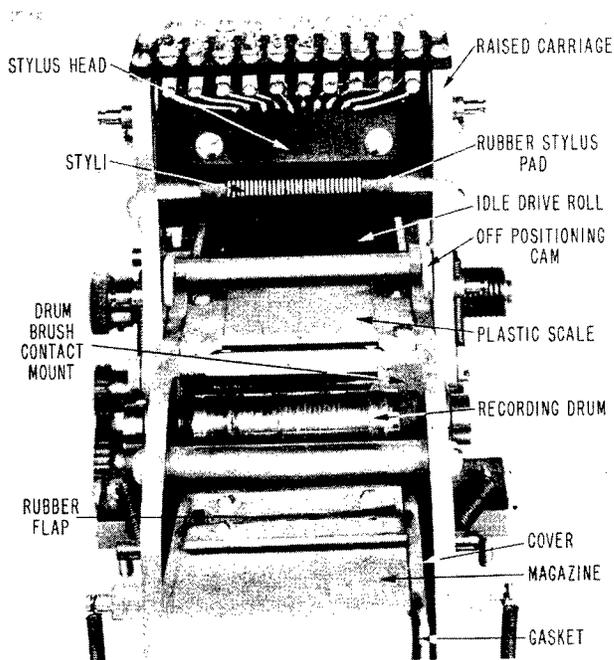


Figure 38 - Stylus-type recording head, Models I and II

The power supply was designed to handle a maximum of twenty channels (Fig. 36). It provides a regulated +300 v at 450 ma, 6.3 v at 20A, and a regulated -150 v at 20 ma. The circuitry is simple and standard save for the use of a 500,000-ohm potentiometer as a regulator feedback control in the 6AC7 screen-grid circuit of the high-voltage supply. This can be adjusted for either minimum ripple voltage or maximum regulation against line voltage fluctuations; and in either case, it considerably increases the effectiveness of the circuit. The 250,000-ohm potentiometer is used to set proper screen-grid voltage after the regulator control has been set.

Recorder Unit—The paper tape is pulled from a 500-foot roll contained in a demountable box magazine and fed over the recording drum (Figs. 37 and 38) where it passes under the row of styli mounted in the stylus head. Leaving the printing elements, it travels horizontally for approximately 5 inches under a ruled, plastic scale intended as a reference or calibration means and illuminated from beneath; thence to a pair of steel drive rolls which pull the tape through the recorder. Beyond these rolls the tape leaves the machine, at which point a blade is mounted over it to assist in tearing it off. The lower drive-roll is rotated by means of a small, 8-1/2-watt synchronous motor through a set of spur gears, two of which can be interchanged or replaced in order to provide tape speeds from 3/4 in. to 3 in./sec. Pressure on the tape between the drive rolls is maintained by steel springs attached to each side of the idle drive roll carriage. The carriage can be lifted and held against this tension by pulling the operating handle forward, up, and back - thus separating the drive rolls sufficiently to permit threading the tape. The recording drum is a free-turning,

chromium-plated, brass tube mounted on, and insulated by, bakelite end plugs. A brush contact bears on the underside at one end, providing a common return connection for the styli. The stylus head was designed with 30 styli to accommodate any probable experimental requirement, although only 20 were actually used. It consists of a row of platinum-tipped, phosphor-bronze wires mounted in bakelite and connected to binding posts attached to two bakelite terminal strips bolted to the stylus-head carriage. A rubber roll or pad rests upon the stylus tips, providing resistance to printing pressure and maintaining normal separation between styli. Stylus printing pressure is adjustable by means of steel springs attached to the sides of the stylus-head carriage. If the carriage be lifted against this tension, it will be held in a fixed, elevated position by two gravity-operated cams, so that the tape can be threaded between the styli and the recording drum. Pushing the cams to the rear releases the carriage to the normal recording position. The magazine is held and positioned by two retractable centers engaging the ends of a central shaft on which a Lucite paper-roll spool is mounted. The spool hub and inner flange turn freely on the shaft and are affixed permanently; the outer flange is removable. Spring rings around the hub provide a firm fit in the roll core. A short hub on the outer flange slides into the main hub when assembled on the paper roll. It contains a recess, holding a helical spring which is compressed against the cover when the magazine is closed. This puts a slight drag on the spool to prevent overrun. The cover is sealed by a rubber gasket. The tape emerges through a slot in the top of the box where it passes over a Lucite guide having a beaded edge. A rubber flap rests lightly on the tape at this point to prevent loss of moisture through the slot.

This unit was originally equipped with a recording head consisting of a pile of thin, insulated, chromium-plated, stainless-steel discs (like a compact disc harrow) mounted on a free-turning shaft and positioned directly over the recording drum (Fig. 39). Connection from each channel output to its respective disc was accomplished by means of a small, spring-loaded pin acting as a brush on the edge of the disc. This design suffered severely from decreased conductivity due to the accumulation of lint from the paper; so it was discarded in favor of the stylus type described above.

Test and Performance—Model I Phase Recorder was taken to Key West for test during the latter part of February 1951 and installed on the USS WILKE, where it was operated during a number of submarine attack runs.

It was found that the fastest tape speed available (3 in./sec) produced a trace corresponding to a Graphic Indicator horizontal sweep rate lower than normally used, giving a jagged type of trace having a transverse movement too great in relation to its longitudinal displacement. This condition resulted in a signal echo too short for optimum identification even though phase changes and frequency shift were quite evident. The density of the printing on the tape was barely sufficient for use at the fast tape speed. The 1P42 phototubes proved to be rather delicate, indicating a high rate of replacement. Furthermore, their small diameter made it difficult at times to keep the oscilloscope

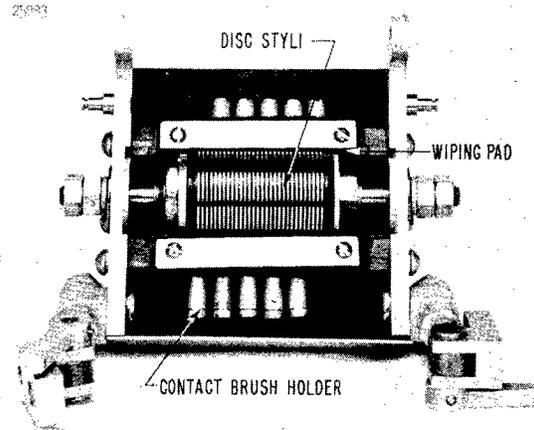


Figure 39 - Disc-type recording head, Model I

trace aligned on them. A small vertical displacement of the horizontal sweep trace due to the effect of line-voltage variations on the 304H oscilloscope immediately dropped the signal level and consequently the tape printing intensity.

The recorder-unit design proved unsatisfactory in several respects. The most annoying feature was the difficulty experienced in getting the tape to remain centered on the recording and driving rolls. The problem of alignment of these rolls and of the paper feed roll to make the tape run true over a 5-inch span obviously required adjustments that were not available. In addition, lack of uniformity in paper roll cores caused a variable tape-feed position (laterally) as it left the magazine, which in some cases was an overpowering factor. The other difficulties could be grouped under the general heading of operational drawbacks. These included tedious magazine refilling, critical magazine positioning, full-load starting or else awkward stylus head carriage manipulation, breaking off of output leads from the terminal board, variation of pressure on styli with tension on output leads, and occasional shorting between styli.

This experience demonstrated the need for higher paper speeds and along with them, greater power output. A consideration of these additional requirements in conjunction with the existing deficiencies made it apparent that a complete redesign of both recorder unit and system was in order.

MODEL II SYSTEM

The oscilloscope and phototubes required by the Model I Recording system presented problems because of their bulk and fragility. The most promising alternate method of commutation made use of an adaptation of a multiple-channel pulse height discriminator -- a step-biased arrangement of multivibrators which has been termed a "ladder." With this system, the application of a changing voltage to a common input will energize successive channels in the same way that the moving spot on the cathode-ray-tube screen activates successive phototubes.

A simple but effective means of obtaining current proportional to phase shift has been utilized in the phasemeter developed by E. R. Kretzmer (3). In this instrument two sine waves or other recurrent signals are shaped and converted through parallel, identical channels into two short, negative, 6 v-pulses. These are applied to the grids of a bistable multivibrator to produce square waves whose width corresponds to the phase displacement between the signals. A meter then measures the average current in the cathode circuit of one of the tubes. This is proportional to the duty cycle or width of the square waves. With suitable pulses readily available from the Graphic Indicator unit, it appeared to be a comparatively simple matter to obtain a voltage proportional to the phase shift between reference and signal frequencies by rectifying and filtering the output of such a bistable multivibrator. The disparity between the operating frequency range and the maximum usable frequency difference was sufficient to make this treatment feasible. An experimental setup showed that a reasonably good sawtooth waveform representing the difference frequency could be obtained at the filter output. This was applied to a twenty-channel "ladder" discriminator of dc design directly connected to power output stages and thence to the styli. A block diagram of the system is shown in Fig. 40. Thus a given phase shift between two signals can be converted into a corresponding voltage value or level which, when applied to the "ladder," will produce single-channel output, energizing a corresponding stylus position and making an appropriate trace on the tape.

This system worked well in preliminary tests - with only one apparent drawback. In sweeping through more than 360° of phase shift (1 cycle), a small flag or dash was

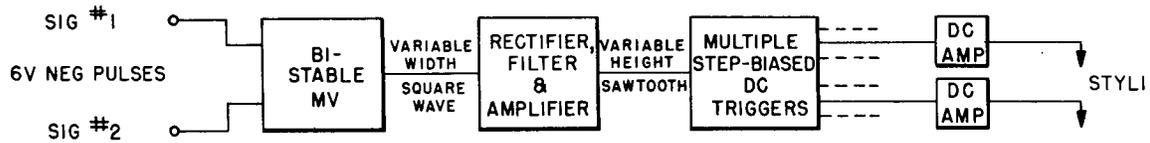


Figure 40 - Block diagram of Model II system

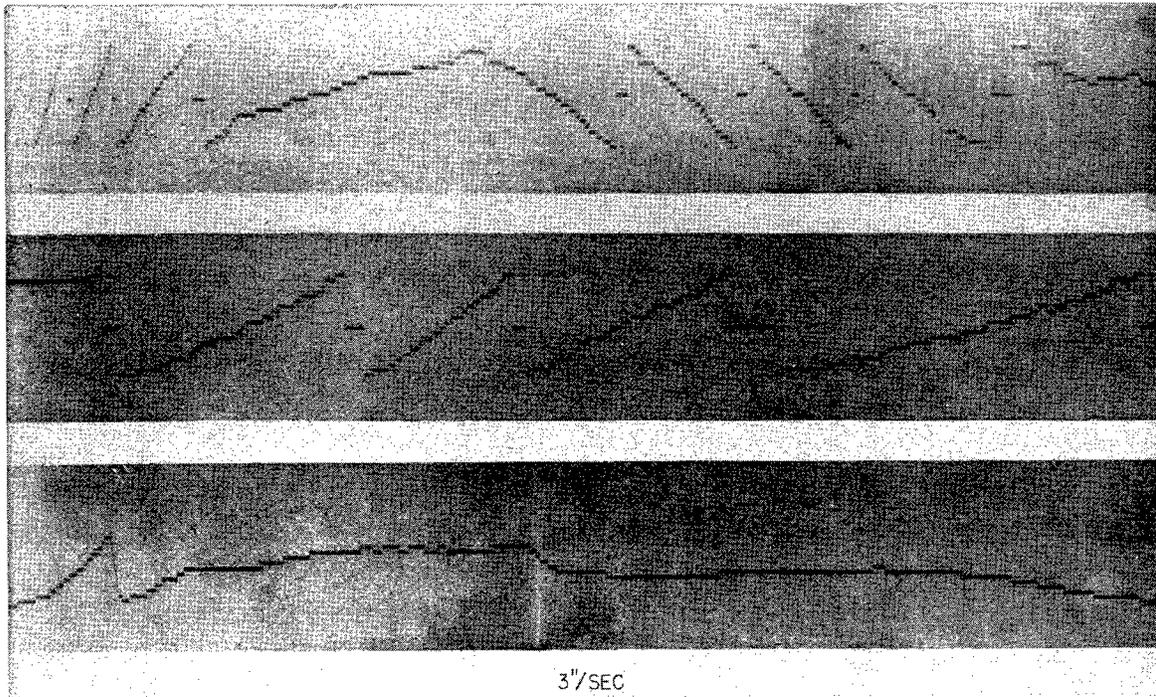
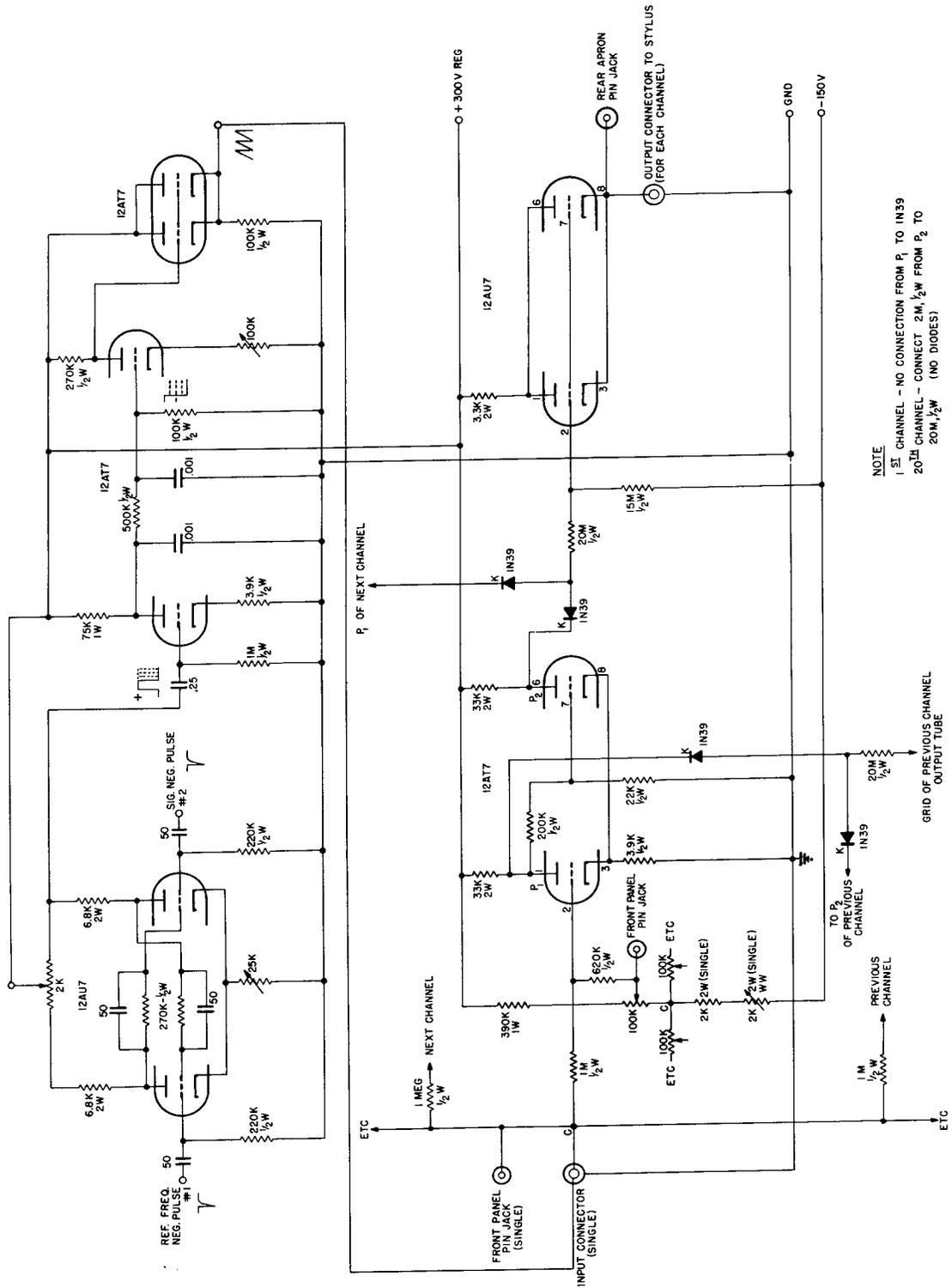


Figure 41 - Sample trace of Model II system

generated in the middle of the flyback when the bistable multivibrator reversed itself (Fig. 41). The flyback trace itself was not visible, but the series of short dashes between the sawtooth sweeps made the pattern somewhat confusing in the presence of an irregular, multiple-phase-shift echo. It might have been possible to eliminate this undesirable marking but the attempt was not made because a fatal characteristic of the system developed when tested on signals having high noise content. This characteristic was simply that the presence of noise with the signal acted to trigger the bistable multivibrator ahead of the desired signal. Thus the greater the phase shift (the wider the square-wave pulse), the greater the opportunity for random noise pulses to occur ahead of the desired signal and thus eliminate its effect for that particular cycle. Since high phase angle (wide pulse) produces high multivibrator output voltage, this effect was apparent as a progressive elimination of the high-phase-angle stylus channels on one side of the paper tape because the voltage did not rise high enough to trigger these channels. This manifestation was incompatible with the Sonar Graphic Indicator system and it brought the development of Model 2 to an abrupt termination.



NOTE
 1ST CHANNEL - NO CONNECTION FROM P₁ TO IN39
 20TH CHANNEL - CONNECT 2M, 1/2W FROM P₂ TO 20M, 1/2W (NO DIODES)
 C - CONNECTION COMMON TO ALL CHANNELS

Figure 42 - Schematic diagram of Model II system

Description

The bistable multivibrator, detector, and amplifier portion of this system was wired up experimentally but never made into a finished unit because the limitations of the system were discovered in time. However, the 20-channel discriminator and output-stage unit was made up on a standard chassis with a 5-inch rack panel just like the original ten-channel chassis of Model I. The power supply designed for Model I was used without alteration for the Model II system along with the Model I Recorder Unit.

The schematic diagram of this system is shown in Figs. 42 and 43. A 12AU7 tube is used in the bistable multivibrator circuit having low plate resistors to give fast response. Six-volt negative pulses of 1 to 2 microseconds duration are obtained from the Graphic Indicator signal and reference-frequency circuits and applied to the two grids of the multivibrator. Optimum operating conditions are obtained by varying the plate balancing potentiometer and the cathode rheostat. The variable-width square-wave output pulse is taken from a portion of one plate load resistance and applied to the grid of the first 1/2 12AT7 tube used as a biased detector. This is directly connected through a π -type RC filter to the second 1/2 12AT7 serving as a voltage amplifier and using a 100,000-ohm cathode rheostat as a linearity control. This, in turn, is directly connected to another 12AT7 tube connected in parallel as a cathode follower. At this point, an 80 v sawtooth voltage corresponding to the difference frequency is obtained. This is then applied to the ladder discriminator input by direct connection. It should be noted that for a constant value of phase shift (synchronism), the output of the RC filter will be a constant dc voltage requiring dc coupling from this point on. For this reason, the ladder triggers are so coupled, and they must operate with equal facility on a rising or falling input voltage. Consequently, their constants are chosen carefully to give fast action on a small, slow voltage change, with a minimum of hysteresis. The triggers are interconnected so that an output voltage high enough to unbias the output tube is obtained only when one of two adjacent triggers is "On" while the other is "Off" — a condition existing only when the input voltage is just triggering one of them. Therefore, no output stages above or below this level will be energized, and only one stylus at a time will be activated. The crystal diodes are used instead of simple resistance coupling in order to give a larger output voltage swing. The output stage is a parallel-connected 12AU7 tube having a 3,300-ohm current-limiting plate resistor.

It was necessary to use rather high resistance values in the input coupling circuit of the output stage in order to hold down the current drain on the bias supply. Although the latter could have been altered to accommodate lower grid resistors, the low operating frequencies made it feasible to use the higher values. For obvious reasons, the Model II system was not tested in the field under actual operating conditions.

CONCLUSIONS

The commutator-output unit of this recording system provides a very convenient record of any single signal wave form of dc or low-frequency value. Intense marking on the paper is obtained by dc operation (100% duty cycle or marking time). Operation of this unit was checked up to a few hundred cycles (the usual maximum usable frequency difference of the Graphic Indicator system) and the components were selected accordingly. It is possible to make this circuit design responsive to the full audio-frequency range by proper choice of alternate tubes and components. Obviously, still higher tape speeds would be required to display frequencies higher than a few hundred cycles.

* * *