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ABSTRACT

The Sonar Graphic Indicator is an electronic equipment providing new and detailed information about sonar targets and their movements. In the equipment as developed, [illegible] display techniques and methods of signal processing are utilized to present this information to the visual display in an appropriate manner for quick appreciation of [illegible] [illegible] and measurement.

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Tests performed with the Graphic Indicator have demonstrated the ability of the instrument to present more and different types of information [illegible] targets and conditions than [illegible] [illegible] [illegible] and far [illegible] [illegible] warfare [illegible] [illegible]

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Manuscript submitted [illegible]

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Naval Research Laboratory. Report 4028.
SONAR GRAPHIC INDICATOR, by G. F. Asbury, Sr.
T. O. Dixon, B. G. Hurdle, E. J. Kohn, and R. J. Mackey, Jr.
113 pp. & figs., August 6, 1952.

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The visual display is basically a plot, versus time or range, of the phase of each successive wave crest in
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Tests performed with the Graphic Indicator have demonstrated the ability of the instrument to present more and different types of information about sonar targets and conditions than have heretofore been available. It has practical and far-reaching applications in the field of underseas warfare, in navigation, and as an analytical tool for sonar research.

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CONTENTS

SONAR GRAPHIC INDICATOR

INTRODUCTION

In connection with work on the development of improved electrochemical recording paper for the tactical sonar range recorder, an empirical study was made of problems in the graphical presentation of signal information. From this study it was apparent that factors which contribute to intelligence perception by the eyes were not being fully utilized, if at all, in existing sonar systems.* Exploratory research was directed toward demonstration of this fact with laboratory-type equipment. This effort resulted in the Sonar Graphic Indicator which is the subject of this report.†

This new electronic instrument is a means for presenting more of the information carried in a sonar signal, in such a manner that the observer can perceive and grasp the intelligence despite severe noise or reverberation interference, or complexity in the tactical situation. The additional information is needed to increase the efficiency of sonar in target detection, classification, and tracking, and in fire-control-data acquisition.

In the Graphic Indicator, signal and the attendant noise (or reverberation) are presented simultaneously to the eye on a cathode-ray-tube screen, and the signal is perceptible as order in disorder, the signal forming a sensible pattern in the random or contrasting background. Thus the instrument exploits the fact that the eye, as a detecting and analyzing sense organ, uses pattern and pattern motion as the most important aspects of "signal."

Formation of the Picture

The display on the Graphic Indicator screen is rectangular, Y- and X-axis sweeps being provided with independently controllable rates, and is basically a plot of phase versus time or range. The incoming signal and noise (or reverberation), a complex wave, triggers a pulse generator in such a manner that spikes are produced at the positive

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* A discussion of some of the fundamentals of visual presentation is included in the Appendix.

† This instrument in the course of its development has been given different names. The first six units constructed for technical and operational evaluation were called G I's, or Graphic Indicators, or, still more formally, Sonar Graphic Indicators by the parent group at the Naval Research Laboratory. These are the names used in this report. An additional twelve units constructed by the Laboratory for the Bureau of Ships under Project No. NE 050950 were called Range Rate Indicators by the Bureau and assigned the "AN" nomenclature, Sonar Receiver R-404(XB-1)/UQ.

wave crests. These spikes are converted to short rectangular pulses without disturbing the spacing in time and are then applied to the Z or intensity axis of the cathode-ray tube, raising the intensity of the spot to the writing point each time a pulse occurs. If the Y sweep is properly timed, the spots in the picture originating in wave crests from a sine-wave signal appear as a line or set of parallel sloping lines because of inherent periodicity in fixed relation to that of the Y-axis sweep. Spots originating in wave crests from noise are randomly distributed. Spots originating in wave crests from reverberation, having inherent but unevenly sustained periodicity, appear as line segments producing sensible striations in the picture background.

Information Supplied

Fundamentally a cycle-to-cycle phase comparator, the Graphic Indicator is made by calibration and adjustment of the sweeps into a quantitative meter of the frequency difference between the signal and the reference oscillator which controls the Y-axis sweep. The meter is particularly sensitive if this frequency difference is small, and its indication is readily used in fast adjustment of the difference to zero or to frequency match.

The intelligence which the Graphic Indicator supplies includes then, not only the fact of signal presence, but also the information contained in the frequency difference between signal and reference, or, through the common reference, between the several parts of "signal." These may within a single frame or range interval (that is, within a single X-axis sweep) include the returns from static wake, dynamic wake, and hull, respectively, of a moving submarine target. It is these frequency differences, due to differing doppler shifts, which give the target signature recognizable and identifying character as an aggregate pattern in the Graphic Indicator presentation. Specific doppler shifts, if selectively measured with the instrument, supply range rate and the components thereof contributed by own ship and target.

Applications

In extensive field tests the Graphic Indicator has proved to be a valuable aid in the field of undersea warfare (both pro- and antisubmarine), in navigation, and in oceanography.

Undersea Warfare - Prosubmarine. - The Graphic Indicator, in conjunction with standard ultrasonic sonar listening equipment, may be used passively by a submarine: (1) to determine accurately from ping to ping the change of range rate between the submarine and an opposing echo-ranging vessel, the determination being possible at safe ranges (far beyond the detection range enjoyed by the opposing vessel) and disclosing promptly a change of course or speed; (2) to determine quickly, by means of plots of the relative range-rate and bearing, the maneuvers of an echo-ranging vessel with respect to changes of course and/or speed, these disclosing the plan of search or intention to attack; and (3) to determine by the character of the displayed pattern the type of echo-ranging equipment used (searchlight or scanning), and also, at close range, the instant of contact loss by the attacking echo-ranging vessel.

The Graphic Indicator with simple recording and gating devices may be used in conjunction with a standard active sonar by a submarine to determine in a single ping the range-rate and the range to the hull of a target and, to validate the bearing accuracy.

It has also been demonstrated with the Graphic Indicator that each echo-ranging ship puts out a pulse having reproducible phase characteristics which identify the pulse from other ships' signals. This "signature" provides a means of identifying each of several echo-ranging ships and permits the submarine to follow their maneuvers individually.

Undersea Warfare - Antisubmarine. - The Graphic Indicator in conjunction with a standard active sonar is a means: (1) for target classification, since, by the character of the display and the indication of target motion or lack of motion, it enables the hull of a submarine to be classified or separated from the thrust area immediately aft of the screws, from the stabilized wake in the medium, or from a "knuckle" produced by the submarine; (2) for differentiating between a submarine's hull, a reef, reverberations, or a school of fish; (3) for accurate measurement of the range rate of a target in a single ping and for measurement of a change of range rate from ping to ping, a change of target course or speed being thus instantly indicated; (4) for improvement in target bearing accuracy and range accuracy if a range gate is used in conjunction with the instrument; and (5) for tracking a target while own ship is towing FXR gear, the noise of which jams most conventional visual displays of signal.

Navigation. - The Graphic Indicator in conjunction with a standard active sonar is a means: (1) of measuring a ship's speed over the bottom and through the water with an order of accuracy of ±0.1 knot; (2) of rapdily measuring a ship's set and drift due to wind, slippage, and unsymmetrical drag through the water; (3) of determining set and drift of local ocean current, with the same order of accuracy as ship's speed; and (4) for calibrating a ship's pit-log accurately and quickly in any waters where the pit-log accuracy is not affected by the depth of the water.

Oceanography. - In the field of oceanography, the Graphic Indicator shows promise of being a valuable tool to provide a simple and rapid means of measuring the magnitude and direction of ocean currents, and for use in studies of phenomena associated with propagation of sound energy through the medium.

Current Work on the Problem

Results experienced with the Graphic Indicator have proved the validity of its principles and techniques. These results now form a foundation for extended and intensive research. The development of new components which, it is believed, will improve the effectiveness of the instrument in its applications to pro- and antisubmarine warfare with emphasis on both target classification and fire-control-data acquisition is being undertaken. These developments are progressing as rapidly as is possible with the limited number of personnel presently available for this project.

Future Plans

Future plans include additional research on graphic sonar signalling and development of equipment applicable to problems in the detection and location of distant ships and submarines in both active and passive low-frequency systems. The applicability of the equipment, or of the techniques developed, for mine detection will be investigated.

Although the Graphic Indicator has thus far been limited in its application to the sonar field, it is believed that the basic principles and techniques which it illustrates may be applicable to problems in other fields.

THEORY

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 or 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.*

Theory of Presentation

The simplest form of the system is that illustrated in the block diagram of Figure 1. 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 2a). This voltage is amplified by a bandpass amplifier so that the amplitude is increased while the frequency remains unchanged. The output of the band-pass 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 2b). 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 frequency of the pulses (Figure 2c). 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 2d).

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 3). 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 3). 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

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* A separate report, now being prepared at NRL, will include a detailed mathematical analysis of some of the theoretical aspects of the Sonar Graphic Indicator and its use in detecting signals in the presence of reverberations and background noise.

† Pulse: A variation of a quantity (voltage) whose value is normally constant; this variation is characterized by a rise and decay, and has a finite deviation (1).

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 4a. 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 Figure 4b.

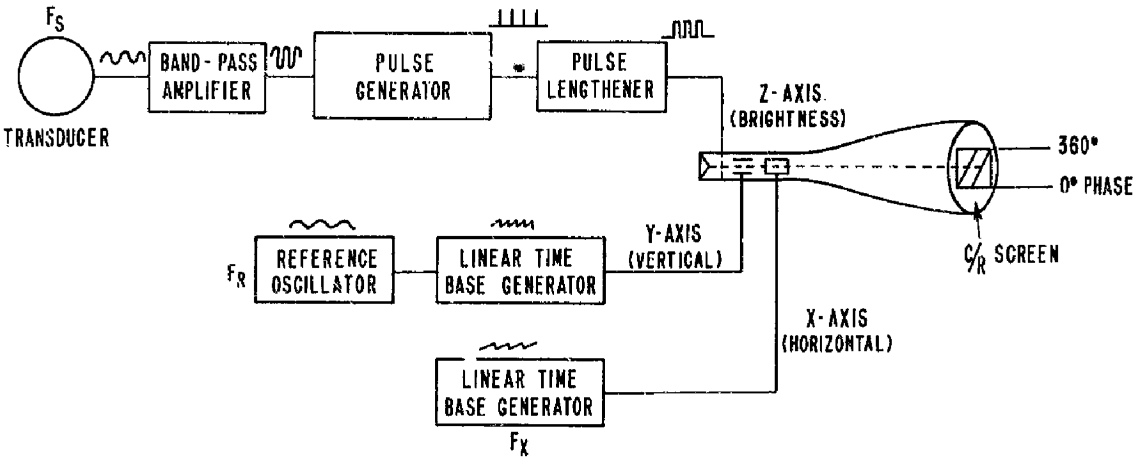
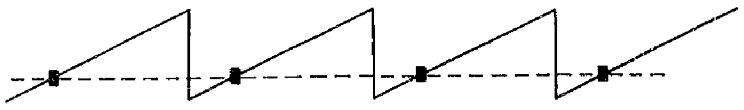


Figure 1 - SonarGraphic indicator - simplified

(a) INCOMING SIGNAL

(b) OUTPUT OF PULSE GENERATOR

(c) OUTPUT OF PULSE EXPANDER



(d) POSITION OF SPOT RELATIVE TO Y-AXIS SWEEP (EXPANDED)

Figure 2 - Graphic Indicator wave forms

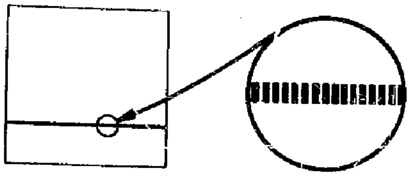
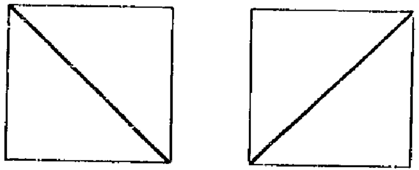


Figure 3 - Composition of presentation $F_s = F_r$



(a) F_s - 1 cps GREATER THAN F_R. F_X = 1 cps

(b) F_s - 1 cps LESS THAN F_R. F_X = 1 cps

Figure 4 - Frequency indication

As ΔF increases beyond one cycle per second, the rate of phase change becomes greater than 360° per second and, for a one-second horizontal sweep, additional sloping lines in a parallel set appear in the square raster. The angles from the horizontal which are characteristic of this set for several values of ΔF are shown in the following tabulation:

ΔF (cps)	Approximate Angle ϕ (degrees)
1	45
2	63
3	71
10	84

The slope or tangent of the angle ϕ is directly proportional to the frequency difference, ΔF.

As the slope increases, the number of lines increases, and the spacing between the lines decreases until the eye is unable to resolve an individual line, as illustrated in Figure 5. From the standpoint of an observer, this can be considered the edge of the visual bandwidth. As ΔF increases above or below a center frequency ($I_0 = F_r$), 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.

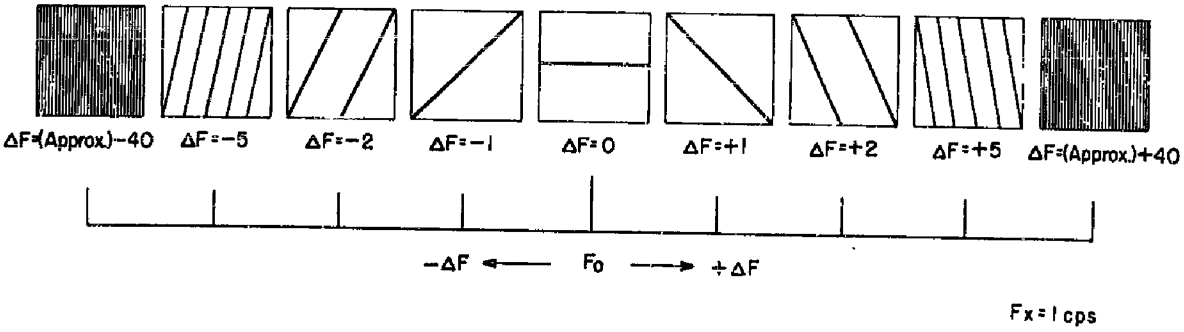


Figure 5 - Presentation over a frequency range

If the angle measured from the horizontal is designated as ϕ, the frequency difference as ΔF, and the horizontal sweep frequency as F_x, then

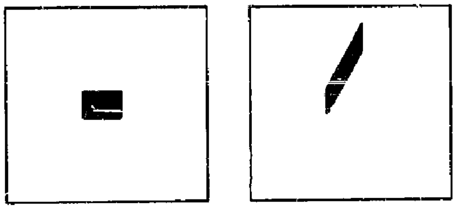
$$\Delta F = F_r - F_s$$

and $$\phi = \tan^{-1} \frac{\Delta F}{F_X}.$$

Thus the slope of the line, in a square raster, is directly proportional to the frequency difference, ΔF, and inversely proportional to the horizontal sweep frequency, F_X. Hence, if the slope is adjusted to zero by varying F_r, F_r is matched to F_s. Thus F_s is measured. Similarly, change in F_s may be matched by change in F_r, and thus measured. Since the slope is inversely proportional to the horizontal sweep frequency, the horizontal sweep frequency may be varied and used to control both the visual bandwidth and the sensitivity in frequency match or measurement. The sweep control provided allows for adequate selection for any practical doppler shift.

With respect to the appearance on the screen, an r-f pulse* signal input differs from a c-w input only in the length of the signal trace; otherwise the conditions are precisely the same as for a c-w signal input. The slope of the signal line remains the same, but the length of the line segment varies with the r-f pulse length. This length can be controlled by the horizontal sweep. For example, in Figures 6a and b, if a signal of 0.2 second duration is applied with the horizontal sweep at one cycle per second, the signal line will extend, in projection on the X-axis, through approximately 0.2 of the horizontal width of the raster. If a change in the frequency of the received signal occurs, for given r-f pulse length, changes result in the length and slope of the signal line or lines in the pattern observed. The change of pattern is utilized by the eye in sensing the frequency change in the acoustic signal. Motion is introduced in the display by angular rotation of the signal line.

The pulse expander, which gives control over the duration of the pulses applied to the Z or intensity axis of the scope allows for the choosing of an optimum length of pulse to brighten the spot used to develop the signal trace or line on the cathode-ray screen – because the brightness of an individual dot is a function of the acceleration voltage on the tube and of the length of time the voltage is applied. When the pulses are lengthened in time, the individual dot on the screen is elongated from a dot to a line, and the signal line, composed of many elongated dots, is broadened in the vertical direction. The width of the composite signal line is also a function of the frequency difference, ΔF. When ΔF is small, the presentation appears as a broad line (Figure 7a); as ΔF increases, the line assumes a slope, and is narrowed by the method of plotting on the screen (Figure 7b). In some cases, when the pattern is composed of a set of parallel lines at a large slope, the ability to achieve instantaneous detection of the pattern is enhanced by the use of expanded pulses, thus increasing the width and the effective brightness of the signal traces.



(a) HORIZONTAL SWEEP, 1 cps PULSE LENGTH. 200 M sec. $\Delta F = 0$

(b) HORIZONTAL SWEEP, 1cps PULSE LENGTH 200 M sec. $\Delta F = 2$cps

Figure 6 - Effect of expanded pulse on a signal

Phase Character

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

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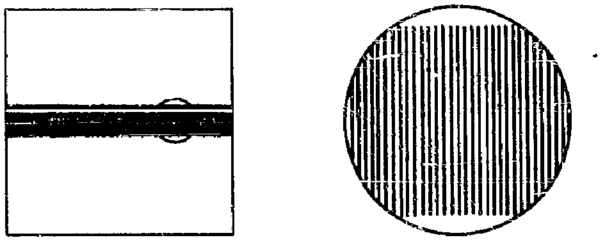
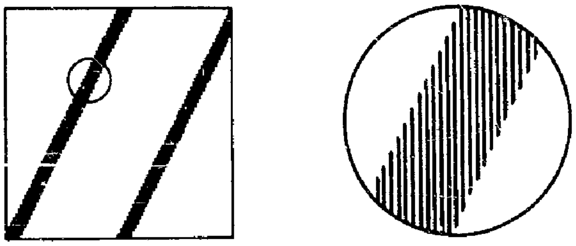
*"Radio-frequency pulse: a radio-frequency carrier modulated by a pulse. . . . ." (1).

by apparent variations due to distortion by noise of the signal phase or periodicity (Figure 8).



(a) BROAD TRACE - HORIZONTAL ΔF=0

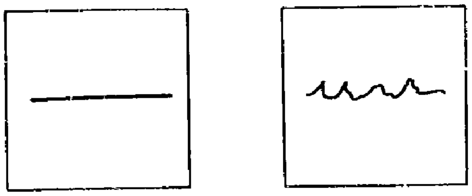
CIRCLED PORTION EXPANDED



(b) BROAD TRACE - SLOPED ΔF=2cps

CIRCLED PORTION EXPANDED

Figure 7 - Composition of display with expanded pulse



(a) CONSTANT PHASE SIGNAL

(b) SIGNAL WITH RANDOM PHASE MODULATION

Figure 8 - Phase presentation

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.

If the signal is volume reverberation, or bottom reverberation, changing variations of phase are real and appear in the signal traces or pattern. In the case of volume reverberation, line segments of moderately varying slopes are developed. The breaks from one segment to the next tend to be sharp showing phase discontinuities. Despite the breaks and the varying slopes of the signal line segments, a characteristic or mean slope is well enough defined for measurement of the reverberation frequency.

Thus the phase character in the signal presentation has meaning and enables the trained observer to differentiate between signals. Between volume and bottom reverberations,qualitative differences in the phase character are less pronounced than the quantitative. In bottom reverberation there is less phase variation and it is contained within narrower limits.

Bandpass Amplifier and Pulse Generator

In processing the signal for the generation of the indexing pulses at the signal voltage crests, the bandpass amplifier serves three purposes: first, to provide sufficient gain;* second, to provide adequate bandwidth to accommodate signal phase variations in a 3-kc band with negligible phase distortion; and, third, to provide automatically a signal, undistorted except for compression, to the base clipper in the pulse generator, satisfying its limited dynamic range even though the input signal varies in level over an 80-db range. By the fast automatic gain control (AGC) action, variations of the signal amplitude with time are compressed or reduced.

In the pulse generator the first component is a base clipper, which selects a threshold (e in Figure 9a) very near the positive crest of each cycle of the sine wave, and isolates the peak as indicated in Figure 9b. The threshold level (e) is determined by the peak amplitude (E) of the incoming signal, by grid rectification, and is set within a period of time equal to a few cycles of the signal. The threshold level (e) is effectively an adjustment of the bias in such a way that a vacuum tube will conduct only when the instantaneous signal voltage rises above this bias. The clipped crest of each cycle of the sine wave (Figure 9b) is amplified as shown in Figure 9c. After amplification, the pulses are differentiated, and a wave form is obtained as shown in Figure 9d. The lower half of the wave is discarded to give the wave form illustrated in Figure 9e.

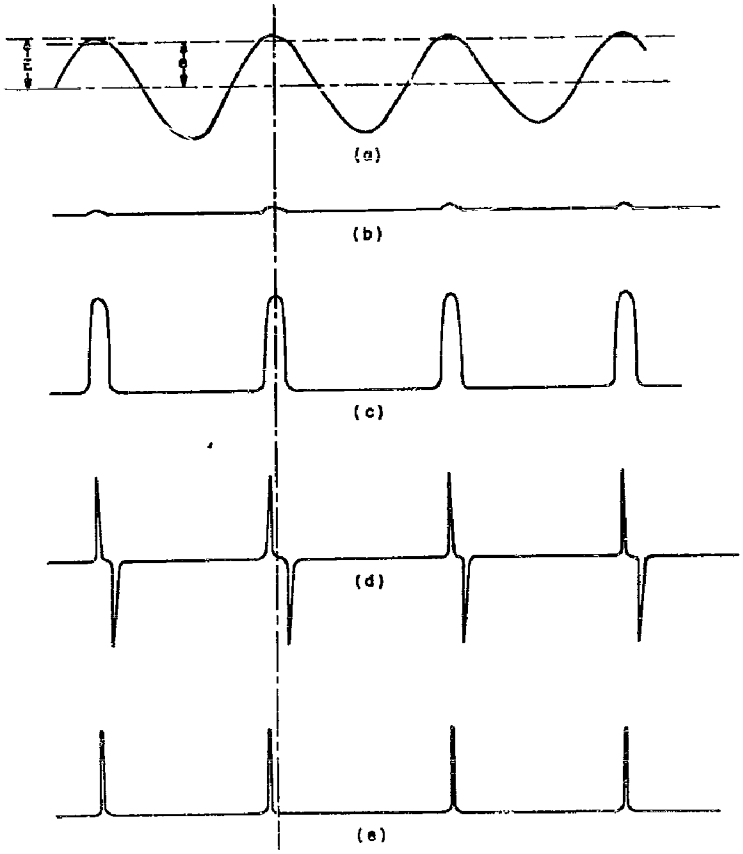


Figure 9 - Wave forms in signal channel

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*At the lower end of the dynamic range the gain is sufficient to give a clearly defined scope presentation for an input signal of 0.5 microvolt.

Tests have shown that the pulse from the pulse generator shifts less than 2 degrees in phase when an 80-db amplitude variation is imposed on the input signal. Theoretically, the pulse is not generated from the zero slope of the crest, but, for practical applications, it may be so considered over reasonable dynamic ranges. Research is presently being conducted to improve this feature of the pulse generator.

Doppler Shift and Range Rate Measurement

The Graphic Indicator is used to measure the frequency shift, produced by the doppler effect, resulting from motion of the sound source, receiver, or reflector. The effective motions are the respective velocity components along the sound ray path and consequently the respective components of range rate. For this reason the Graphic Indicator has been called a Range Rate Indicator.

With a fixed source and a moving receiver, the frequency change or doppler shift is directly proportional to the velocity of the receiver. With a moving source and a fixed receiver, it is a less simple function of the velocity of the source, but, since the velocities of practical interest – that is, ship's motion through the medium – are small compared to the propagation velocity of sound in the medium, the two functions are for most practical purposes identical.

The controlling equations are:

Observer in motion:
$$F = F_o\left(1 \pm \frac{V_o}{C}\right) \text{ or } F - F_o = \pm F_o\frac{V_o}{C} \qquad (1)$$

Source in motion:
$$F = F_o\left(\frac{1}{1 \pm \frac{V_s}{C}}\right) \qquad (2)$$

General case, including motion of the medium and motion of both observer (receiver) and source is;

$$F = F_o\left(\frac{C + V_m \pm V_o}{C + V_m \pm V_s}\right) \qquad (3)$$

where

F = received frequency

F_o = transmitted frequency

V_o = velocity of observer

V_s = velocity of source

V_m = velocity of medium

} along the sound path between source and observer (receiver)

C = phase velocity of sound in the medium

The positive sign is used for V_o when V_o is toward the source; the negative sign is used when V_o is away from the source. The positive sign is used for V_s when V_s is away from the observer: the negative sign is used for V_s when V_s is in the direction of the observer.

In sonar applications the doppler shift of frequency is a result of the velocity components along the sound path between the source and reflector or receiver, i.e., between the echo-ranging vessel and the reflecting target or listening vessel. These velocity components are given in each case by the product of forward speed and the cosine of the relative angle.

Three principal forms of the above equations are applied in using the Graphic Indicator in echo ranging. In each case it is assumed that the velocity of the medium, V_m, is zero since in practice the velocity measurements are made relative to the medium.

In the first or general case, for a ship echo ranging on a submarine target with both the ship and reflector (target) in motion, the sum of the velocity components or range rate is obtained. Assuming velocity component V_1 for the echo-ranging vessel and V_2 for the target, toward each other, and a transmitted frequency F_o, one finds that the observed frequencies for the various steps are:

Observing F_1, the frequency at a point on the transmit path in the medium,

$$F_1 = F_o\left(\frac{1}{1 - \frac{V_1}{C}}\right) \tag{4}$$

Observing F_2, the frequency at the target or reflector,

$$F_2 = F_o\left(\frac{1 + \frac{V_2}{C}}{1 - \frac{V_1}{C}}\right) \tag{5}$$

Observing F_3, the frequency at a point on the return path in the medium,

$$F_3 = F_o\left(\frac{1 + \frac{V_2}{C}}{1 - \frac{V_1}{C}}\right)\left(\frac{1}{1 - \frac{V_2}{C}}\right) \tag{6}$$

Finally, observing F_4, the frequency at the echo-ranging vessel,

$$F_4 = F_o\left(\frac{1 + \frac{V_1}{C}}{1 - \frac{V_1}{C}}\right)\left(\frac{1 + \frac{V_2}{C}}{1 - \frac{V_2}{C}}\right) \tag{7}$$

$$F_4 = F_o \left(\frac{1 + \frac{V_1 + V_2}{C} + \frac{V_1 V_2}{C^2}}{1 - \frac{V_1 + V_2}{C} + \frac{V_1 V_2}{C^2}} \right). \quad (8)$$

If the last term in both the numerator and the denominator is discarded as insignificant,* Equation (8) reduces to

$$F_4 = F_o \left[\frac{C + (V_1 + V_2)}{C - (V_1 + V_2)} \right] \quad (9)$$

or

$$V_1 + V_2 = C \ \frac{F_4 - F_o}{F_4 + F_o} = \text{Total Range Rate}. \quad (10)$$

Equation (5) applies for a submarine passively receiving the signal from an echo-ranging surface vessel. It may be written

$$V_1 + V_2 = C \left(\frac{F_2 - F_o}{F_o} \right). \quad (11)$$

The second case is that of measuring own-ship's speed or measuring the velocity toward a reflector at rest with respect to the medium. In this case $V_2 = 0$.

$$F_4' = F_o \left(\frac{1 + \frac{V_1}{C}}{1 - \frac{V_1}{C}} \right) \quad (12)$$

or

$$V_1 = C \ \frac{F_4' - F_o}{F_4' + E_o}. \quad (13)$$

The third case is the measurement of the velocity component of a moving target. In practice, the reference frequency of the Graphic Indicator is initially set to the volume reverberations, F_4', and the received frequency from the target, F_4, observed. If Equation (9) and (12) are combined by eliminating F_o and the squared term discarded as in Equation (8),

$$F_4 = F_4' \left(\frac{C + V_2}{C - V_2} \right) \quad (14)$$

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*The discarding of the squared term results in an error of only 0.01 knot at a range rate of 70 knots with each vessel's velocity component equal to 35 knots.

or

$$V_2 = C\left(\frac{F_4 - F_4'}{F_4 + F_4'}\right). \tag{15}$$

Thus the general form of the equation applied in the Graphic Indicator is

$$V = C\left(\frac{F_{rf} - F_{ri}}{F_{rf} + F_{ri}}\right). \tag{16}$$

In this equation, V represents the individual velocity component or the sum of the velocity components to be measured as dictated by the initial (F_{ri}) and final (F_{rf}) setting of F_r, the reference oscillator frequency. F_{ri} is set to equal the transmitted-pulse frequency for measuring range rate and ship's speed and to equal the volume reverberation frequency for measuring the velocity component of a reflecting target. F_{rf} is set to equal the frequency of the doppler-shifted-signal under measurement.

In calibrating the range rate dial of the instrument, the doppler-shifted frequencies are calculated from Equation (16) for a number of range rate points in the operating range covered (0-35 knots, opening and closing, for echo ranging and 0-70 knots, opening and closing, for listening to another ship's sonar signal). In these calculations the F_{ri} used is the operating frequency of the sonar equipment with which the instrument is to be associated. These calculated frequencies are then introduced into the instrument from a standard frequency source and a plot is made of the range rate versus angular position of the dial (for horizontal signal line). From this plot a direct reading range rate dial is engraved. This method of calibration includes corrections for small variations of the electronic components in the system. For operation at other frequencies and sound velocities than those for which the instrument is calibrated, a set of correction curves is provided. Two range rate dials are incorporated in the instrument, one for echo ranging, and the second for passive operation (listening).

In a review of inherent limitations in the preservation of phase and rates of change of phase over a transmission path or paths in the sea, consideration must be given to the thermal microstructure and other boundary conditions (3) and how fluctuations in these affect the ultimate accuracy obtainable in the utilization of Doppler's principle as in the Graphic Indicator method.

It is assumed in the calibration of the instrument that the effects of variations resulting from propagation phenomena in the medium are negligible and the velocity components measured are attributed solely to the motion of the source, receiver, or reflector. It is recognized that the ultimate accuracy obtainable with the Graphic Indicator method in range rate and ship speed measurements may be limited by variations in the medium along the sound path or in the path itself.

PHYSICAL DESIGN

The design of the Graphic Indicator was governed primarily by three factors: time limitations, space requirements, and the need for as great a degree of simplicity as was consistent with the necessity of meeting performance specifications. The first factor, time, was limited by problem demands to about 10 days, so that research and development for design purposes were severely restricted. The result was that the equipment described here represented something less than an optimum solution to the problem. Nevertheless, it so fulfilled its function that sufficient operational data were obtained to serve as guides to redesign and development for optimum performance. This development is under way at present. The second factor, space, required the equipment to be as compact as possible to permit installation in the close quarters of submarines and sound compartments without disturbing normal operation of the vessel. The third factor, simplicity, while meeting performance specification, was affected by the first and by the desire to maintain performance reliability, and to provide facility for servicing and for the making of field modifications.

The Graphic Indicator and the associated equipment necessary for its operation are shown in Figure 10. The Indicator alone measures 12-1/4" x 16" x 17" and weighs 45 pounds. Power consumed by the equipment is 125 watts. All operational controls are on the front panel of the Indicator, the plugs on the rear of the unit being for primary power input, remote power supply, Own Doppler Compensator (ODC) (Figure 24), and signal input.

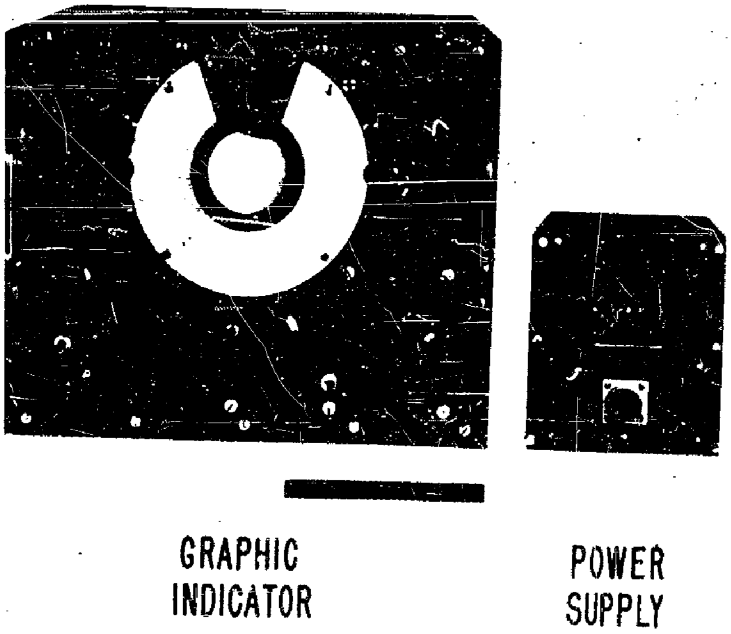

Figure 10 - Sonar Graphic Indicator equipment

ELECTRONIC DESIGN

Individual components of the indicator, shown in the block diagram of Figure 11, have been designed to perform respectively the functions set forth in the theory. Basically, the indicator is divided into three channels. The first consists of the bandpass amplifier with automatic gain control (AGC), the base clipper, the pulse generator, and the pulse lengthener. The second contains the reference oscillator, the vertical sweep generator, the associated amplifiers, and blanking generator. The third consists of the horizontal sweep generator and the horizontal amplifiers.*

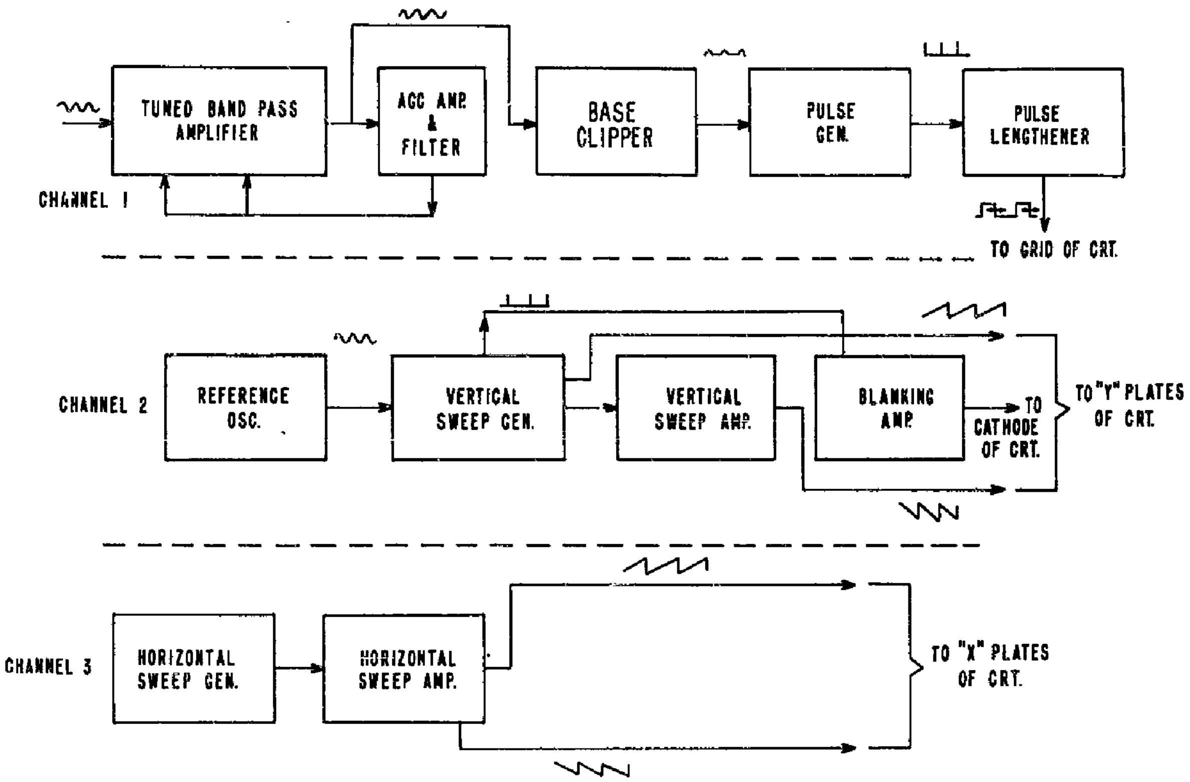

Figure 11 - Sonar Graphic Indicator

Channel 1

<u>Bandpass Amplifier</u> - The bandpass amplifier is illustrated in the schematic diagram of Figure 12. It consists of an input transformer affording a balanced or unbalanced input at 600 ohms impedance and two tunable stages (V301 and V302) covering the frequency range from 20 to 30 kc. The over-all bandwidth is 3 kc between the 3-db points. The gain and noise figure are such that a cw signal of 0.5 microvolt may be resolved on the cathode-ray-tube indicator.

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* At this point the reader may benefit by skipping to page 35 and returning later for the details of the electronic design.

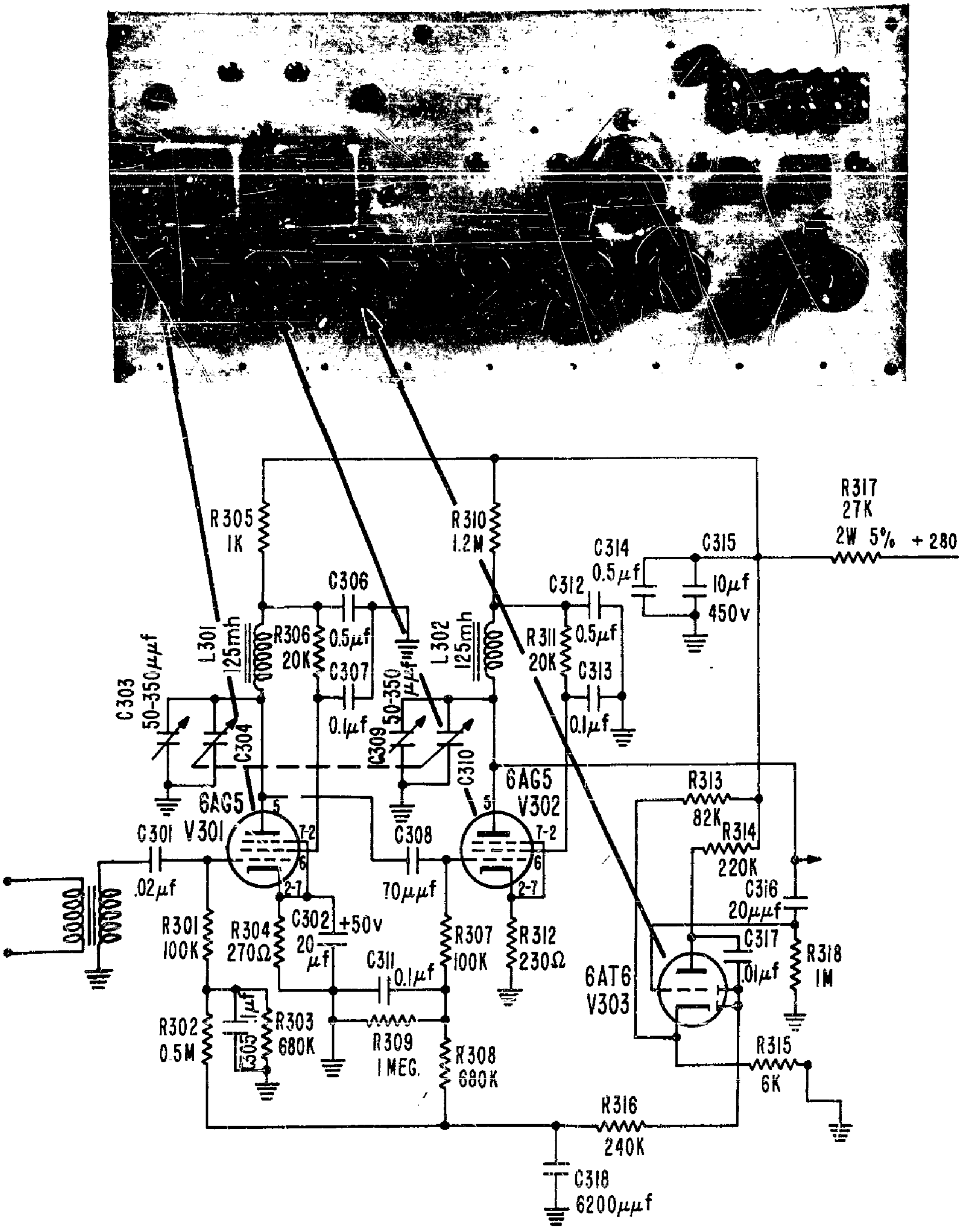

Figure 12 - Bandpass amplifier

AGC Amplifier and Filter - The AGC amplifier (Figure 12) is a 6AT6 triode, dual-diode tube (V303). The triode section is used to amplify the output of the bandpass amplifier. The triode output is then rectified by the diodes, and the rectified output, after being filtered, is applied as a gain-control voltage to the grids of the amplifier stages. An AGC delay bias is developed and is applied to the common cathode of the multisection tube, thus setting the input level at which AGC action begins. A manual gain control is also provided.

Automatic Threshold or Base Clipper - The base clipper (Figure 13) selects a portion of a positive going signal near the crest of the wave, the portion selected being amplified and differentiated in order to form a sharp trigger for the pulse generator in V305B. The circuit shown in Figure 14 fulfills the function of the base clipper. Tube V304, a 6AU6 broadband amplifier, raises the signal level for use in the base clipper. The first half of the 12AU7 (V305A) is operated at low plate voltage and no fixed bias, the grid bias being set by the value of the signal or of the signal plus noise. A positive going impulse greater than the average grid bias is amplified in (V305B) and differentiated to form a trigger for the blocking oscillator.

The time constants in the grid of the base clipper are important in that they determine the nearness of clipping to the crest of a signal. This is shown in the following discussion of base clipper operation.

The triode grid circuit shown in Figure 14 is a modification of a grid leak detector and operates in a manner similar to an automatic switch; that is, during an impulse of positive excursion, the grid of the triode is driven positive. This causes condenser C322 to charge because of grid current through the low-impedance path, R_G. The condenser becomes so negatively charged that the grid of the triode remains at "cut-off" at the removal of the charging pulse. The "cut-off" voltage effectively opens the low-impedance grid-charging circuit and substitutes in its place resistor R322 of much higher impedance than that effective during the charging interval. This resistor then becomes the discharge path for condenser C322.

In the following discussion the symbols shown below will be used:

R_G = grid resistance when grid is driven positive

R = grid resistor governing discharge time of C

C = charging capacitor

T_1 = charging time

T_2 = discharge time

T_S = time between charging pulses

e_p = peak amplitude of signal or noise, or signal plus noise

e_1 = charged voltage of capacitor C

Since R_G is very much less than R, R may be neglected with respect to the charging time and T_1 becomes $R_G C$.

In the case of a positive grid, R_G is small, approaching 1000 ohms for a type 12AU7 triode. The charging time constant is therefore short, approaching 10 μsec, or less than

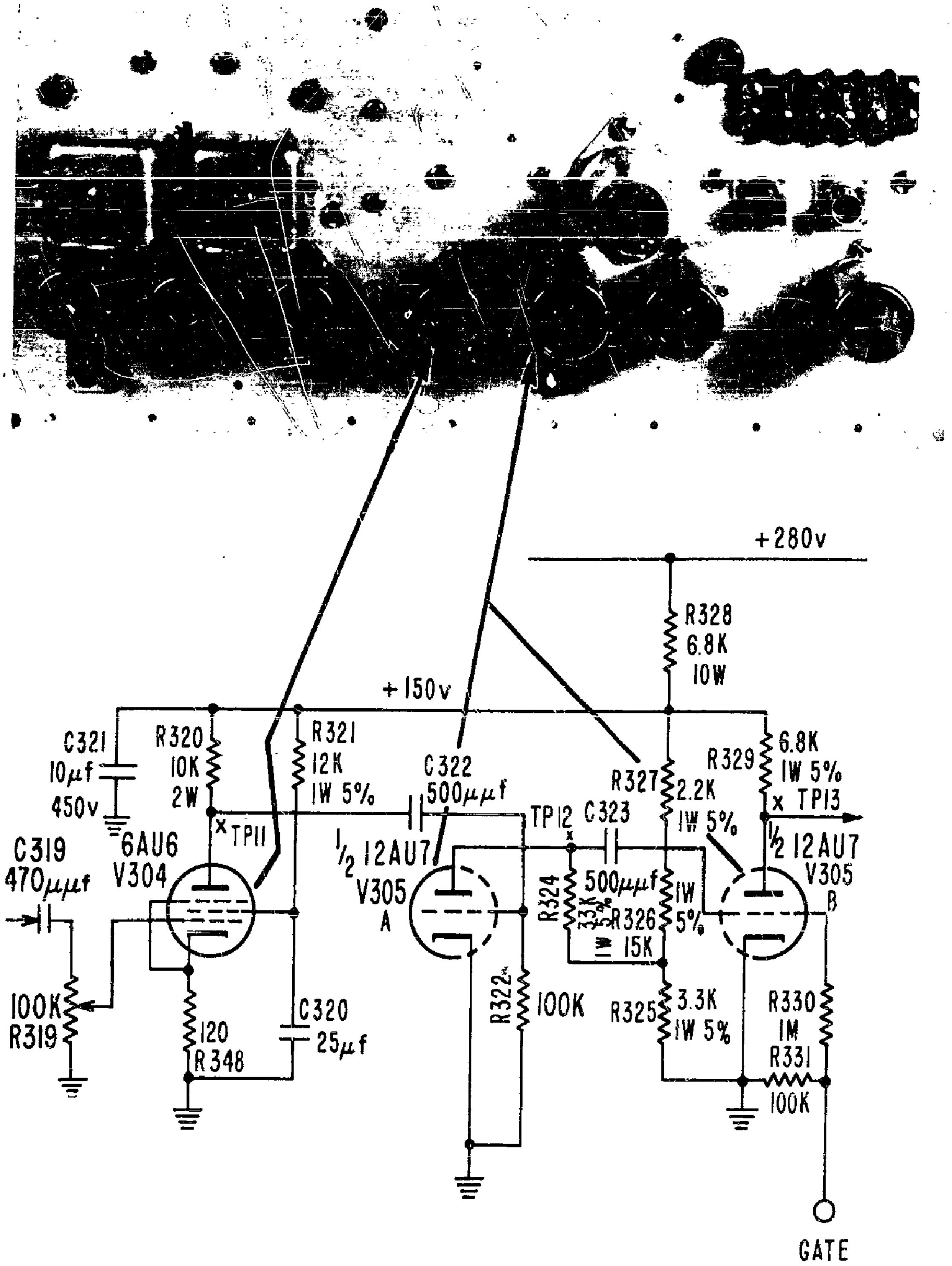

Figure 13 - Automatic threshold circuits

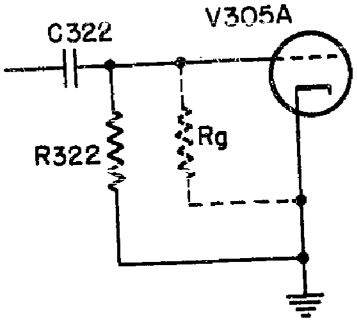

Figure 14 - Grid circuit of automatic threshold

1/2 cycle at signal frequencies. This means condenser C will charge, because of grid current, to a voltage very near the peak value of the signal voltage in a few signal cycles, if the discharge time, T_2, is made much larger than the period between charging pulses, T_S.

If T_2 is in the order of ten times T_S, e_1 will reach a value within a few percent of peak signal, e_p. This means only the crests of the signal wave will be passed by the base clipper.

The larger T_2 is, the closer e_1 approaches e_p. It has been found, however, that if T_2 is made too large, strong water-noise pulses cause grid blocking. This results in a loss of signal crests of lesser amplitude occurring during the time the grid is cut off, i.e., before e_1 decays to the level of the weak signal. This condition is quite apparent in harbors and shallow water and is less prevalent in open water. If this grid blocking action is to be avoided, T_2 should be made small enough so that the grid can recover in a fraction of the transmitted pulse length, i.e., in two to three milliseconds.

With a time constant of this order of magnitude, the decay rate of e_1 will be insufficient to adjust e_1 to clip all the successive wave crests, following each other with a periodicity near that of the signal, unless downward variations in crest height from one to the next never exceed the decay rate (T_S product). In practice they do, and the result is the nonpassage of wave crests resulting in absences of dots in the presentation on the screen. If such absences are periodic, perceptible patterns of darkness may be formed and have interpretable meaning. Thus, with weak signal added to noise, the absences – at least in greater numbers – occur when the signal excursions are in the negative direction. Such excursions are periodic, and the formation of a pattern of darkness may be the first perceptible indication of signal presence. Similarly, a weak signal in the presence of a stronger unwanted signal (especially when the two signals are close in frequency) may be perceived as a pattern of darkness formed by periodic absences due to the rapid fall-off in the envelope of the combined signals near the cusps, where the two are out of phase.

For this reason, T_2 should be made variable from 2 milliseconds for conditions of high-noise level and short transmitted pulses (25 ms) to 0.1 second for low-noise levels and long transmitted pulses. No optimum value for T_2 can be fixed, for such a setting depends on a large number of operating factors such as noise conditions, pulse length, sea conditions, etc. It is necessary, therefore, for the operator of this instrument to determine T_2 empirically, for any given set of operational conditions, by observing the cathode-ray-tube presentation and adjusting T_2 for optimum performance.

Pulse Generator - The wave crests passed by the base-clipper trigger a blocking oscillator (V306 in Figure 15) and the shape of the blocking-oscillator pulse depends largely upon the character of this initiating trigger. Usually the gain around the feedback loop in the blocking oscillator is not very large before heavy grid current is drawn. The gain is low because of the low impedance of the transformer. Rise in potential follows a positive exponential curve until limiting takes place. In order to achieve a fast rise time, "parallel" triggering is used in the blocking oscillator.

When parallel triggering is employed, the ideal constant-current generator may be approximated even by a triode. For example, a 12AU7 has a minimum R_p of about 7000

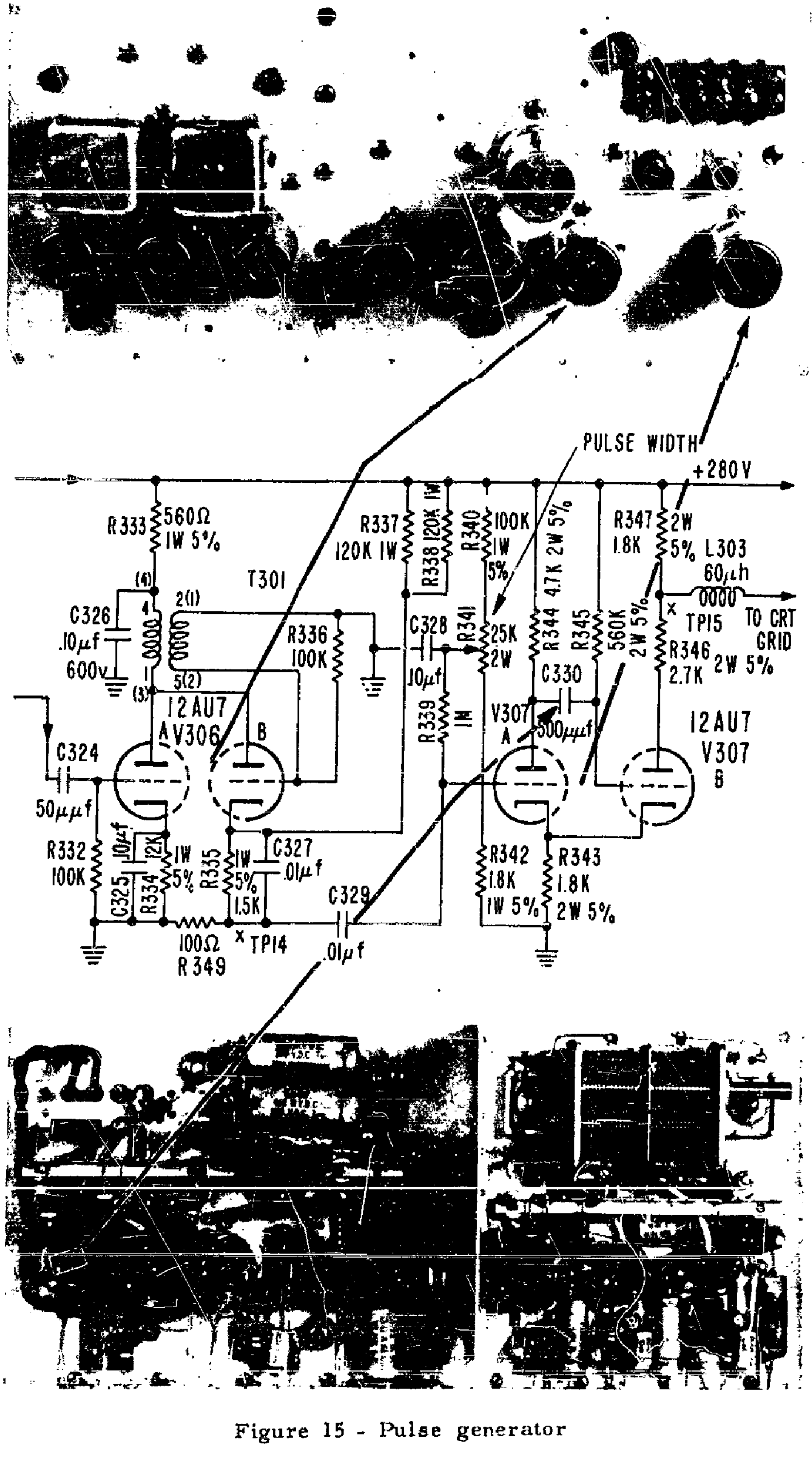

Figure 15 - Pulse generator

ohms in the neighborhood of zero bias – a large value in comparison with the impedance of the blocking-oscillator tube and transformer. The effective R_p is made even greater by cathode degeneration. Since sharp negative triggers are more easily obtained in the plate circuit of a triggering tube, it is common practice to apply a negative trigger to the plate of the blocking oscillator. Because of phase inversion in the pulse transformer, however, this trigger appears as a positive pulse in the grid. If the trigger is of long duration, it will be partially "differentiated," since the transformer will not pass the low-frequency components. In short, this method of triggering introduces minimum interference with the blocking oscillator, practically eliminates reaction on the trigger source, reduces the time delay between the trigger and the blocking-oscillator pulse, and permits convenient control of the amplitude of the trigger by proper choice of circuit constants.

The blocking oscillator (Figure 15) is biased to cut off by virtue of the positive bias applied to the cathode. A positive pulse output is obtained across the unbypassed 100-ohm resistor (R349) in the cathode circuit. With the transformer T301 (132AW) and time constants used, the output pulse is 0.25 μsec.

Pulse Lengthener – The output of the blocking oscillator is used to initiate the "one-shot" multivibrator, V307 (Figure 15), which affords a variable-length pulse (0.5 μsec to half the repetition period) for driving the grid of the cathode-ray tube.

The circuit is a "one-shot" multivibrator because, in the absence of trigger pulses, the second half of the 12AU7 triode, V307B, having the positive grid return, conducts and raises the potential on both cathodes. The grid voltage of V307A is adjusted to a fairly low value by the choice of the resistor-divider network. Since the cathode is positive with respect to this grid bias, V307A is cut off.

The first section of V307A is driven into conduction by a short, positive pulse from the blocking oscillator on the grid. Thereupon, a switching process occurs. Current in V307A causes the plate-to-ground voltage to drop. Because of the 500-$\mu\mu$f coupling capacitor, the grid-to-ground voltage drops equally; and since V307B is connected as a cathode-follower, the cathode voltage likewise decreases. The result is an increase in grid-to-cathode voltage for V307A, an increase in current in V307A, and a decrease in V307B. The regenerative action thus causes the circuit to "flip."

It might at first appear that a current increase in V307A would offset the current decrease in V307B, and that there would, therefore, be no change in cathode voltage, and no switching process. With, however, constant grid voltage for V307A, and with decreasing grid voltage for V307B, the total current through the cathode-resistor must decrease, and therefore the voltage-drop across the cathode-resistor decreases. The current changes in V307A cause cathode-follower V307B to operate into a very low load resistance. Therefore, the changes in grid voltage of V307B are much greater than changes in the cathode voltage. Once cut off, V307B remains cut off, while the 500-$\mu\mu$f coupling capacitor discharges until the cut-off point is reached and plate current begins to flow. The current in V307B raises the cathode voltage enough to cut off V307A, and the high plate voltage of V307A helps to turn on V307B. This causes the circuit to "flop" back to its quiescent condition.

If the grid bias on V307A is varied, the voltage, and hence the time at which V307A begins to cut off, may be varied. The multivibrator pulse is made shorter by decreasing the voltage at the grid of V307A, and longer by raising it. The small series-peaking inductance, L303, in the output of the pulse lengthener is used to resonate cable and other stray capacity. This process is commonly followed in video amplifiers to maintain a "fast" rise time in the pulse.

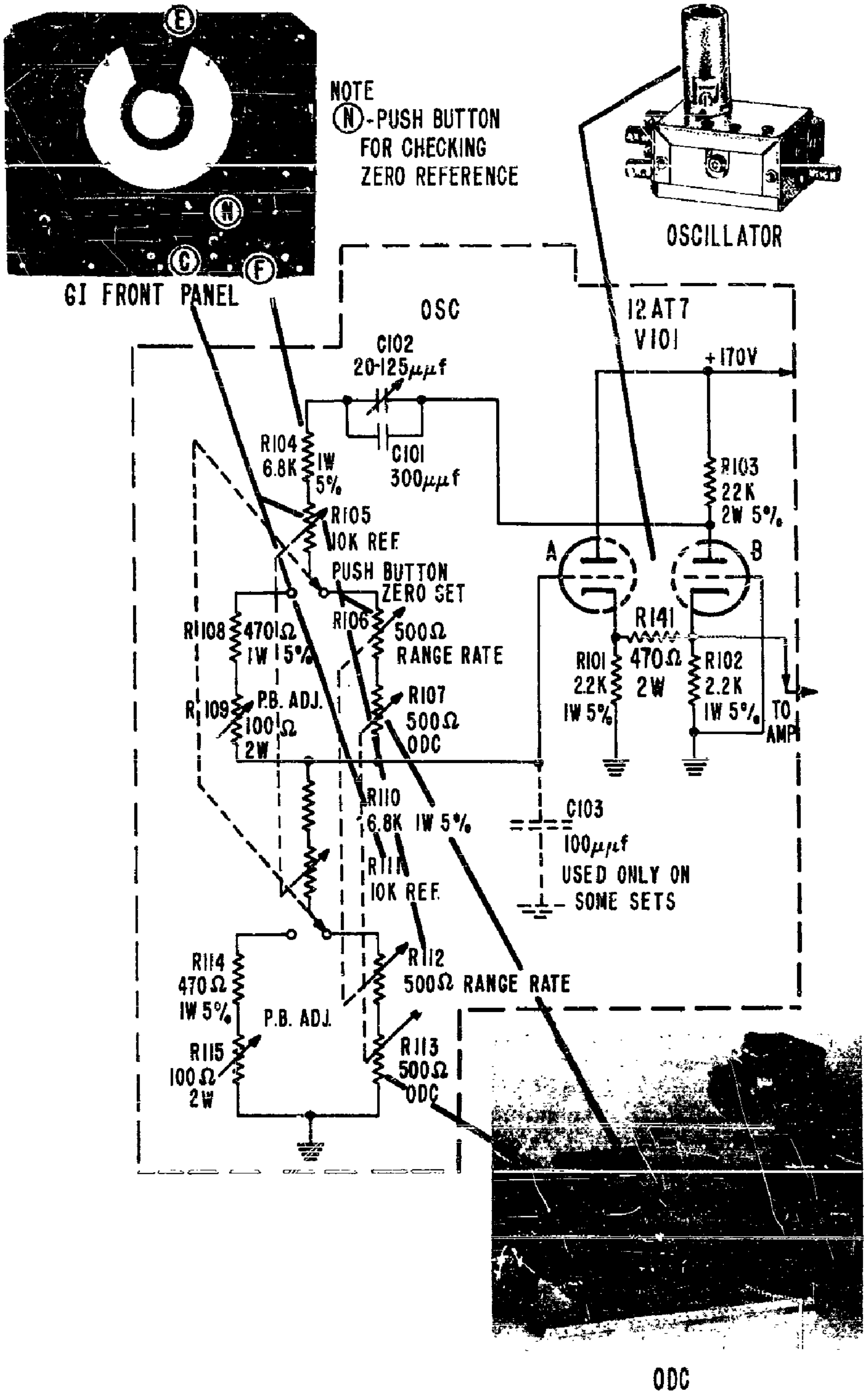

Figure 16 - Reference oscillator

Channel 2

Reference Oscillator - The oscillator used to control the vertical sweep frequency is shown in Figure 16. It is tunable over a range of 16 to 32 kc, all tuning being accomplished by adjusting a series of resistor networks. Resistors R105 and R111 provide a coarse-tuning control by means of a 10-turn helipot. The combination of resistors R106 and R112 provides a fine-tuning control, here referred to as the "tracking" control since it is this resistor combination which is varied by the operator in accordance with the presentation on the cathode-ray-tube indicator. Resistors R107 and R113, contained in the ODC, are varied in accordance with own-ship speed and projector bearing. Resistors R107 and R113 may be replaced by fixed resistors when ODC operation is not desired. By means of a front-panel push button, resistors R108, R109, R114, and R115 may be switched in or out, if the operator desires to check the zero reference of the coarse tuning.

In the reference oscillator, the frequency is determined by a resistance-capacity network that provides regenerative coupling between the output and input of a feedback amplifier. For proper results, the amplifier, V101A, associated with the resistance-capacity networks must have negligible phase shift. The phase shift has been made negligible by the elimination of by-pass condensers and by designing the amplifier for wideband response.

Consider the impedance network shown in Figure 17. Since

$$E_0 = E_1 \frac{Z_1 Z_2}{Z_1^2 + 3Z_1 Z_2 + Z_2^2}, \tag{1}$$

the transfer function,

$$T = \frac{Z_1 Z_2}{Z_1^2 + 3Z_1 Z_2 + Z_2^2} = \frac{1}{\frac{Z_1}{Z_2} + 3 + \frac{Z_2}{Z_1}}. \tag{2}$$

Then letting $\frac{Z_1}{Z_2} = k$,

$$T = \frac{1}{k + 3 + \frac{1}{k}}. \tag{3}$$

Since Z_1 and Z_2 have phase angles differing by 90 degrees, k is always imaginary. Therefore the first and third terms in the denominator of Equation (3) are imaginary. In order for T to have a phase angle of zero degrees, the sum of the imaginary terms must vanish. This is required by one condition for oscillation in a cathode-coupled $\mu\beta$ circuit. That is,

$$k_1 + \frac{1}{k_1} = 0 \tag{4}$$

$$k_1 = j1. \tag{5}$$

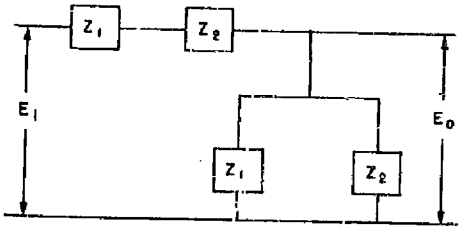

Figure 17 - Reference oscillator impedance network

Here k_1 is the value of k at the oscillation frequency f_1 and Equation (4) is the frequency-determining equation.

$$k_1 = \frac{Z_1}{Z_2} = j1. \tag{6}$$

If $Z_1 = R$ and $Z_2 = \frac{1}{j\omega C}$, Equation (6) becomes

$$\frac{R}{\frac{1}{j\omega C}} = j1 \quad \text{or} \quad 2\pi fRC = 1$$

and

$$f = \frac{1}{2\pi RC}. \tag{7}$$

The oscillator frequency is therefore an inverse function of either R or C. In the oscillator in question, tuning was accomplished by varying R. Because the frequency change required to match (or measure) a doppler frequency shift is a small fraction of the initial reference frequency, $\Delta R/R$ is small, and the departure from linearity in the range rate calibration on the dial of this oscillator is therefore negligible.

If T_1 is the value of T at the frequency of oscillation, $T_1 = 1/3$. In the generalized, simple feedback oscillator (Figure 18), the required condition for sustained oscillation is that $A\beta \geq 1$. In the simple, one-tube oscillator used here, the transfer function is essentially β, that is, $T_1 = \beta = 1/3$. In order to satisfy the oscillation requirement, $AT_1 = 1$, and $A = 3$. Since the gain is a function of signal amplitude, the amplitude of oscillation will be stabilized at the value which makes the gain $A \geq 3$. Therefore, if the $\mu\beta$ network has a gain ≥ 3, oscillation will be sustained.

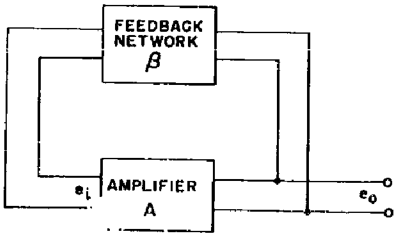

Figure 18 - Feedback oscillator network

The circuit shown in Figure 19 is used to amplify the output of the reference oscillator and to generate square waves which are differentiated in the grid circuit of the blocking oscillator to form a trigger for initiating the vertical sweep circuit. Tube V102 is a type 6C4 triode. Used as the amplifier, it provides ample signal for driving the square-wave generator. The square-wave generator (V103) is a type 6BN6 gated-beam tube, whose characteristics make it an excellent squaring device and one capable of producing a square wave of steep edge, regardless of frequency and amplitude variations.

Vertical Sweep Generator - The circuit diagram of Figure 20 shows the method employed to generate a fast, linear sawtooth of high amplitude for scope deflection. By use of positive feedback, a constant potential is maintained across the resistor, R129, through which the condensers C120 + C113 charge. This condition is achieved by the unity-gain cathode-follower amplifier, V105B, which takes its input signal from the condenser end of the resistor and impresses its output signal at the supply end of the resistor.

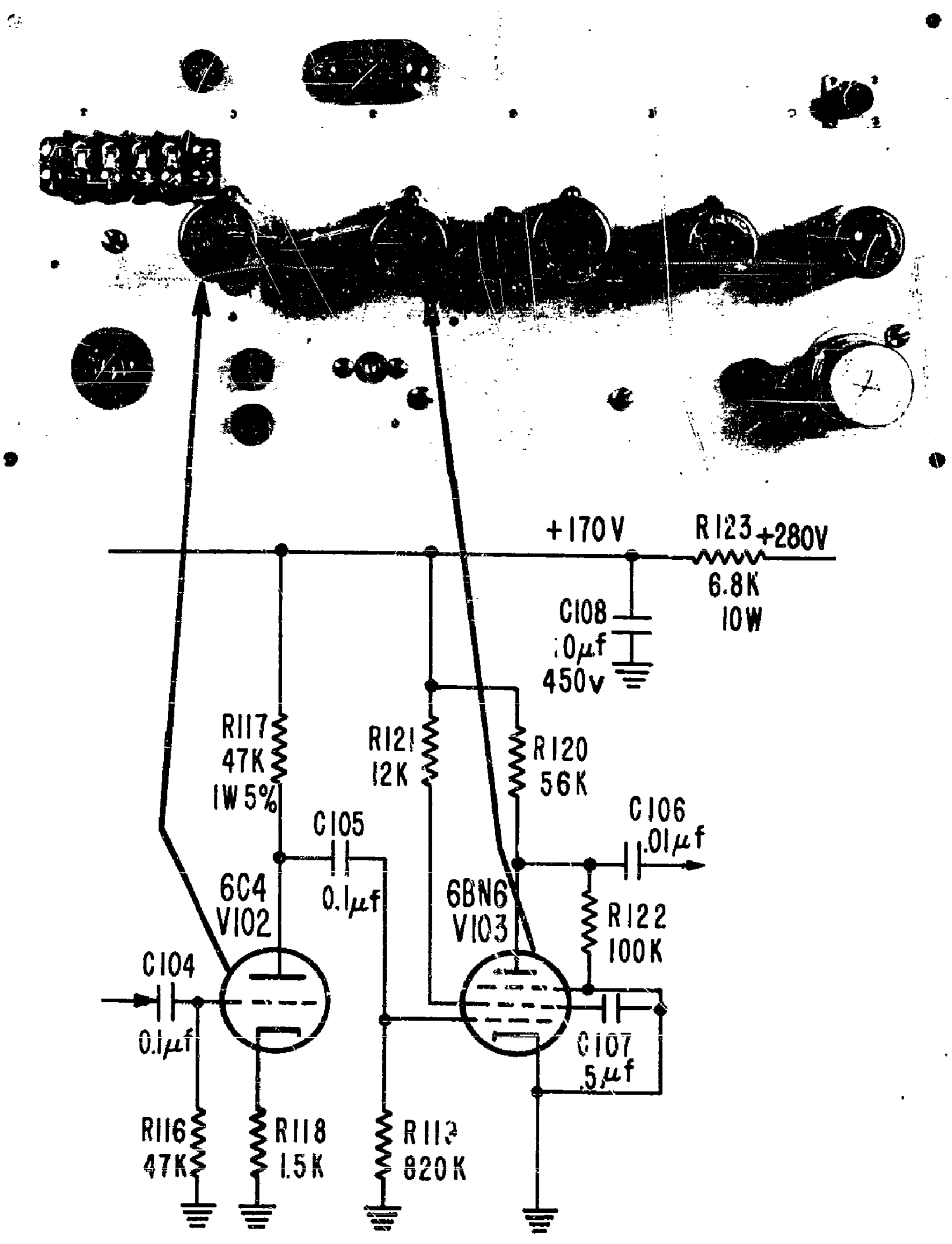

Figure 19 - Reference oscillator limiter circuits

If the cathode-follower has a gain, g, an infinite input impedance, and a zero output impedance, the charging current, i, has the form

$$i = I_0 \, e^{-\left[\frac{t\,(1 - g)}{RC}\right]} = \frac{E}{R} \, e^{-\left[\frac{t}{RC}(1 - g)\right]} . \qquad (8)$$

The cathode-follower grid voltage is

$$e_c = \frac{E}{1 - g}\left[1 - e^{\frac{-t}{RC}(1 - g)}\right] . \qquad (9)$$

By expansion,

$$e_c = \frac{E}{RC}\left[t - \frac{(1 - g)}{RC}\,\frac{t^2}{2!} + \frac{(1 - g)^2}{(RC)^2}\,\frac{t^3}{3!} - \dots\right] . \qquad (10)$$

If $g = 1$, the current will be constant, and e_c will be a linear function of time. The effect of the positive feedback is the same as that which would be achieved by charging a condenser through a resistor $1/(1 - g)$ times as large as R from a supply voltage $1/(1 - g)$ times as large as the actual supply voltage (5).

If, at the beginning of the charging interval (see circuit in Figure 20), no current is flowing into feedback capacitor C112 or through R128, the initial current into C113 + C120 is the supply voltage divided by R128 + R129. If the cathode-follower has a unity gain, and if condenser C112 does not discharge appreciably during a sweep interval, initial current will be maintained. Condenser C112 will not discharge appreciably since C112 >> C113 + C120 and since the time constants, R128 with C112, and R129 with C112, are large compared to a single sweep.

Discharge of C113 + C120 is through tube V105A when the blocking oscillator is triggered from the differentiated reference square wave. Tube V105A, normally cut off owing to negative grid voltage developed by grid current flowing during the blocking-oscillator, V104, discharge pulse, is driven into heavy conduction by the positive pulse from the blocking oscillator during the discharge time. The sawtooth amplitude developed by this circuit is approximately 150 volts peak to peak (adjustable by increasing or decreasing C113) and has a retrace time of about 4 microseconds. The sawtooth output is taken across the cathode-follower and applied through a coupling condenser to one plate of the cathode-ray tube.

Vertical Sweep Amplifier – Tube V106A is an amplifier which inverts the cathode-follower sawtooth. Its output drives the other vertical deflection plate of the cathode-ray tube through a coupling condenser to provide push-pull deflection.

Blanking Amplifier – Tube V106B is the blanking amplifier. It receives a positive pulse from the blocking oscillator during the retrace time. This pulse rings the tuned circuit in the cathode of the amplifier, the negative cycle of the ring being damped out by cathode-follower action. The large positive pulse thus produced across this tuned circuit

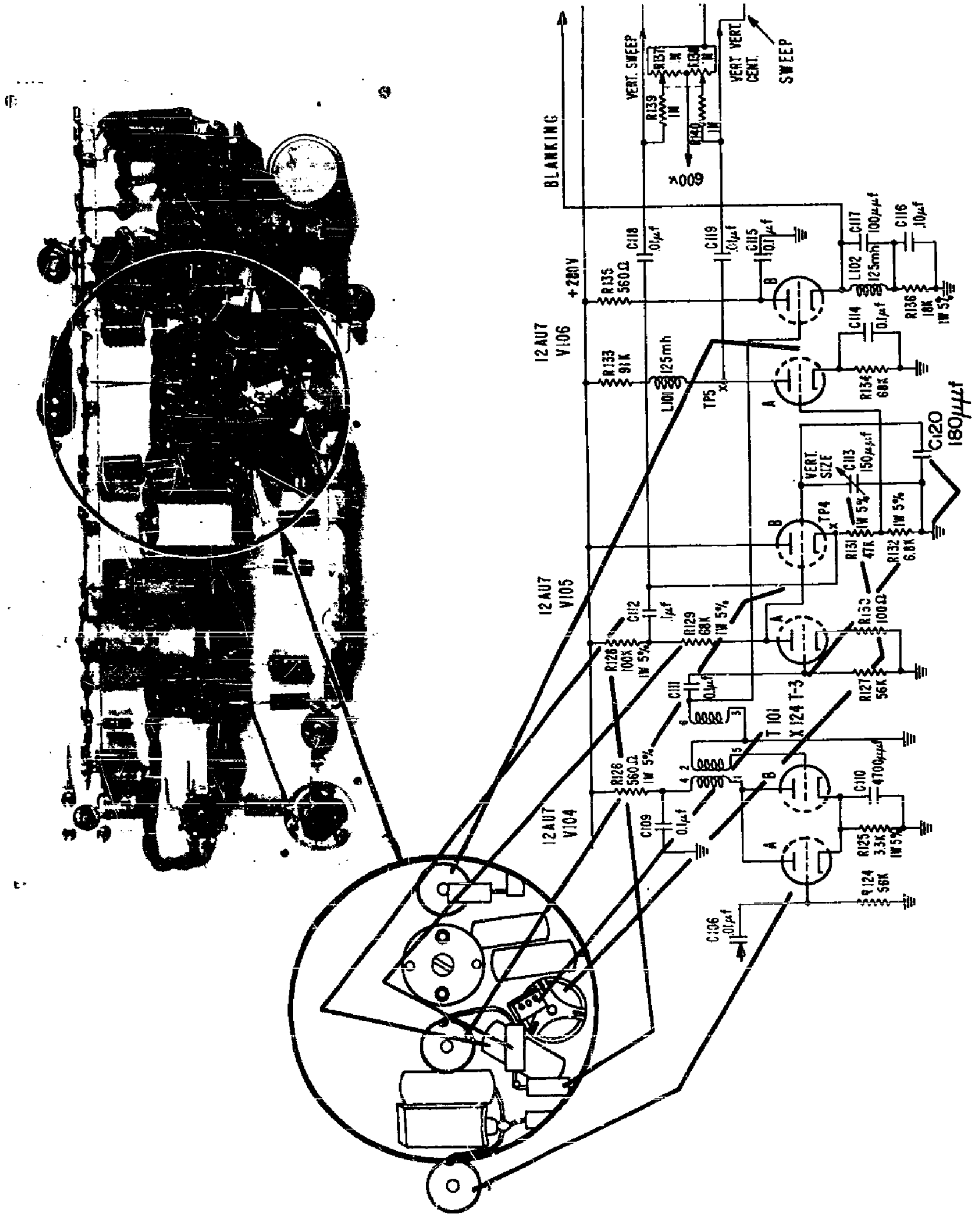

Figure 20 - Vertical sawtooth sweep generator and blanking amplifier

is applied during the retrace time of the sawtooth to the cathode of the cathode-ray tube. If the choice of circuit components is varied, the tuned circuit may produce a variable-width blanking pulse to assure adequate blanking during the entire retrace time.

Channel 3

Horizontal Sweep Circuit – The circuit diagram of the horizontal-sweep oscillator and cathode-follower outputs is shown in Figure 21. The oscillator and sawtooth generator, V201, is a conventional thyratron-type 2D21 tube. A small portion of the available charging potential is sufficient to generate a substantially linear sawtooth. The sawtooth frequency is controlled by the charging resistor and condenser, and the frequency has been made adjustable (in four steps: 4, 8, 16, and 50 cps) by switches in individual resistor and condenser combinations.

The cathode-follower, V202, is used to permit the sawtooth oscillator to operate into a high impedance, and its output is fed to a dc-coupled amplifier. A potentiometer control, R212, in the cathode of the cathode follower permits adjustment of horizontal size.

Horizontal Sweep Amplifier – Tube V203 is a 6J6 used as a dc-coupled amplifier to provide push-pull deflection to the horizontal plates of the cathode-ray tube. To obtain sufficient sweep voltage, large load resistors are used, and the plate supply is obtained from the 1500-volt accelerating potential for the cathode-ray tube.

Cathode-Ray-Tube Circuits (Figure 22)

Tube V501 is a type 3JP7 cathode-ray tube, a type with a blue fluorescence, a greenish-yellow phosphorescence, and long persistence. The necessary operating potentials are obtained from a resistance voltage-divider network. The intensity of the beam is adjusted by potentiometer R507 so that the negative potential on the grid may be controlled with respect to the cathode. Focusing is accomplished by adjusting potentiometer R505 to provide the correct potential for the first anode.

The horizontal deflection plates are direct-coupled to the plates of the horizontal amplifier, and are at an average potential of 600 volts. In order to avoid astigmatism, the vertical deflection plates are biased to approximately the same potential. They are condenser-coupled, and the bias voltage is obtained from a resistance voltage-divider network from the intensifier voltage supply.

The cathode is operated at a high negative potential of approximately -1400 volts. With 600 volts applied to the second anode, the second anode-to-cathode potential becomes 2000 volts. But since the intensifier of the cathode-ray tube operates at 1600 volts, the total over-all accelerating potential is 3000 volts. Signals are applied to the grid and cathode for intensification and blanking.

Power Supply

The complete and separate power supply (Figure 23) for the Graphic Indicator is made up of two sections: 1) A low-voltage, regulated, positive supply which provides power for operating the three channels, and 2) a high-voltage, positive and negative supply which provides potentials for operating the cathode-ray tube. A single transformer supplies both low- and high-voltage power supplies.

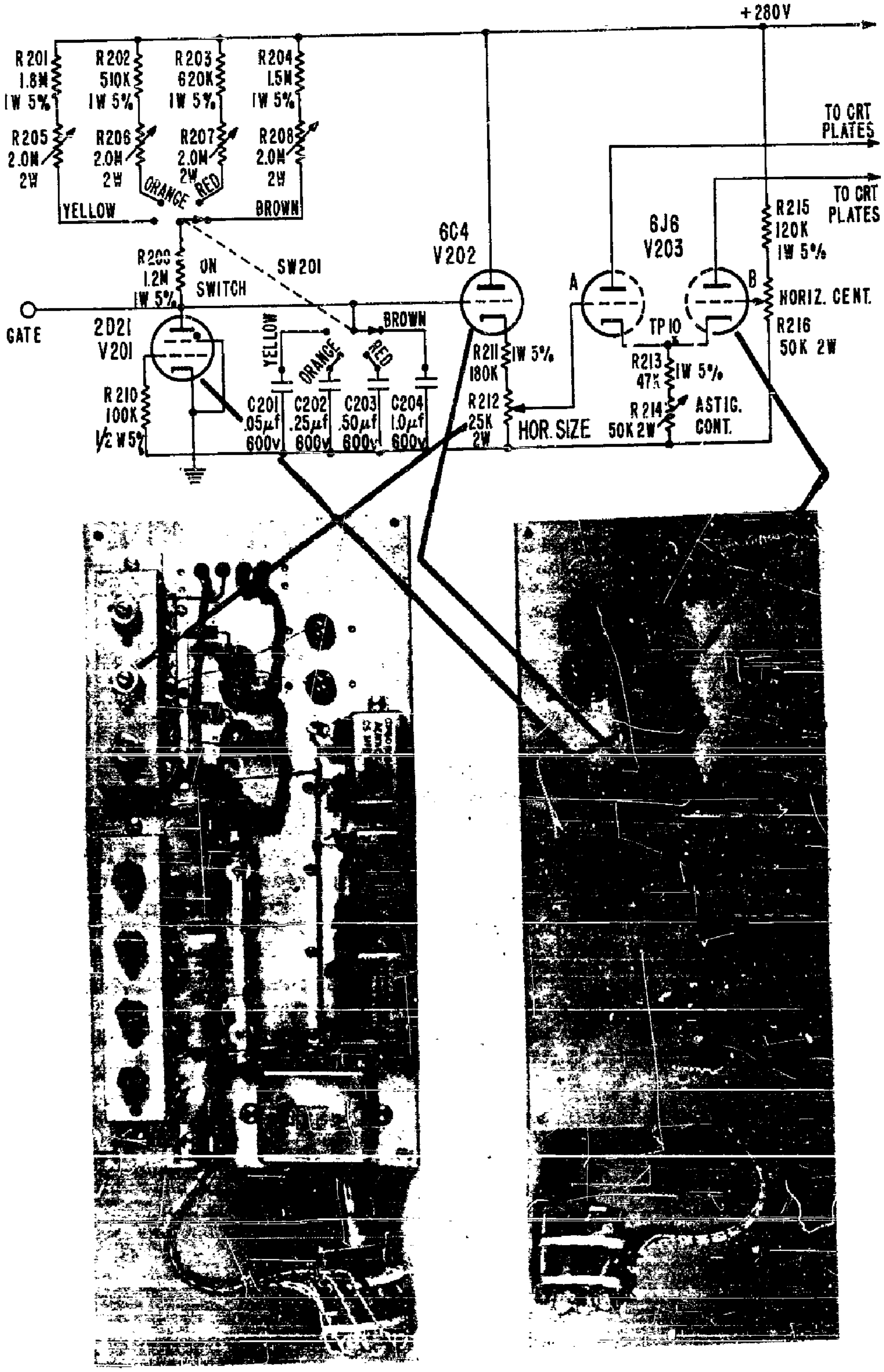

Figure 21 - Horizontal sweep circuits

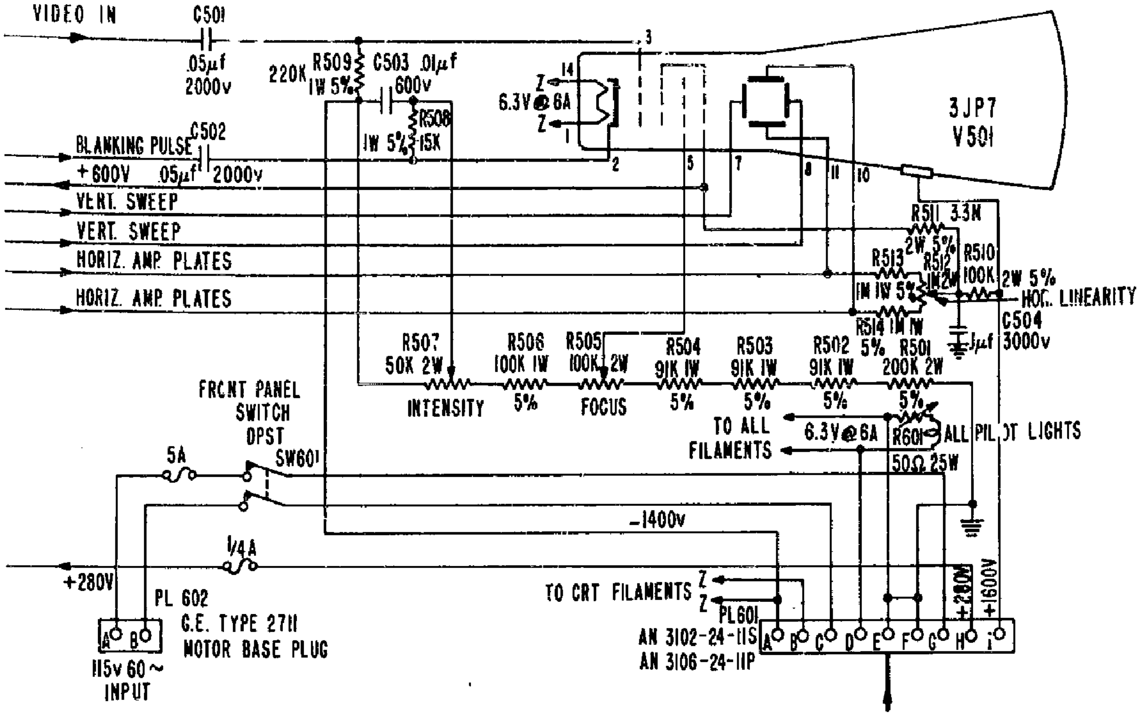

Figure 22 - Cathode-ray-tube circuits

The Low-Voltage, Regulated Supply - The low-voltage power supply consists of V401, a 5V4G full-wave rectifier. Its output is filtered by a capacitor input filter consisting of the 10-μf condenser C401A, the 10-H choke L401, and the 10-μf condenser C401B, which supplies a series-type electronic regulator similar in design to those used in commercial regulated power supplies. With an output of 280 volts, there is less than 1.5 volts drop from no-load to full-load (100 ma). When properly adjusted, the output voltage will not vary more than 1 volt with a line voltage fluctuation from 105 to 125 volts. The hum level at the output is less than 10 millivolts with a load of 100 ma.

The High-Voltage Supply - The negative high-voltage supply, employing a 2X2A half-wave rectifier, V407, produces 1400 volts. The output of this rectifier is filtered by a resistance-capacitance filter. The intensifier supply is similar to the negative supply except that a positive 1500 volts is developed.

A separate filament transformer, T402, is used to supply all filament and pilot-light current drawn by the Indicator and by the 6SH7 regulator tube, V404, in the power supply. Alternating current is supplied through the Indicator to the power supply by means of cabling, the a-c switch being located on the front panel of the Indicator. The same cable supplies all filament and low- and high-voltage supplies to the Indicator.

Own Doppler Compensator (ODC)

As was shown by the general doppler equation in the Theory Section of this report, the total doppler shift observed by the echo-ranging vessel is a function of the target velocity component as well as of the echo-ranging vessel's velocity component. In order to measure the velocity component contributed only by the target, a method must be

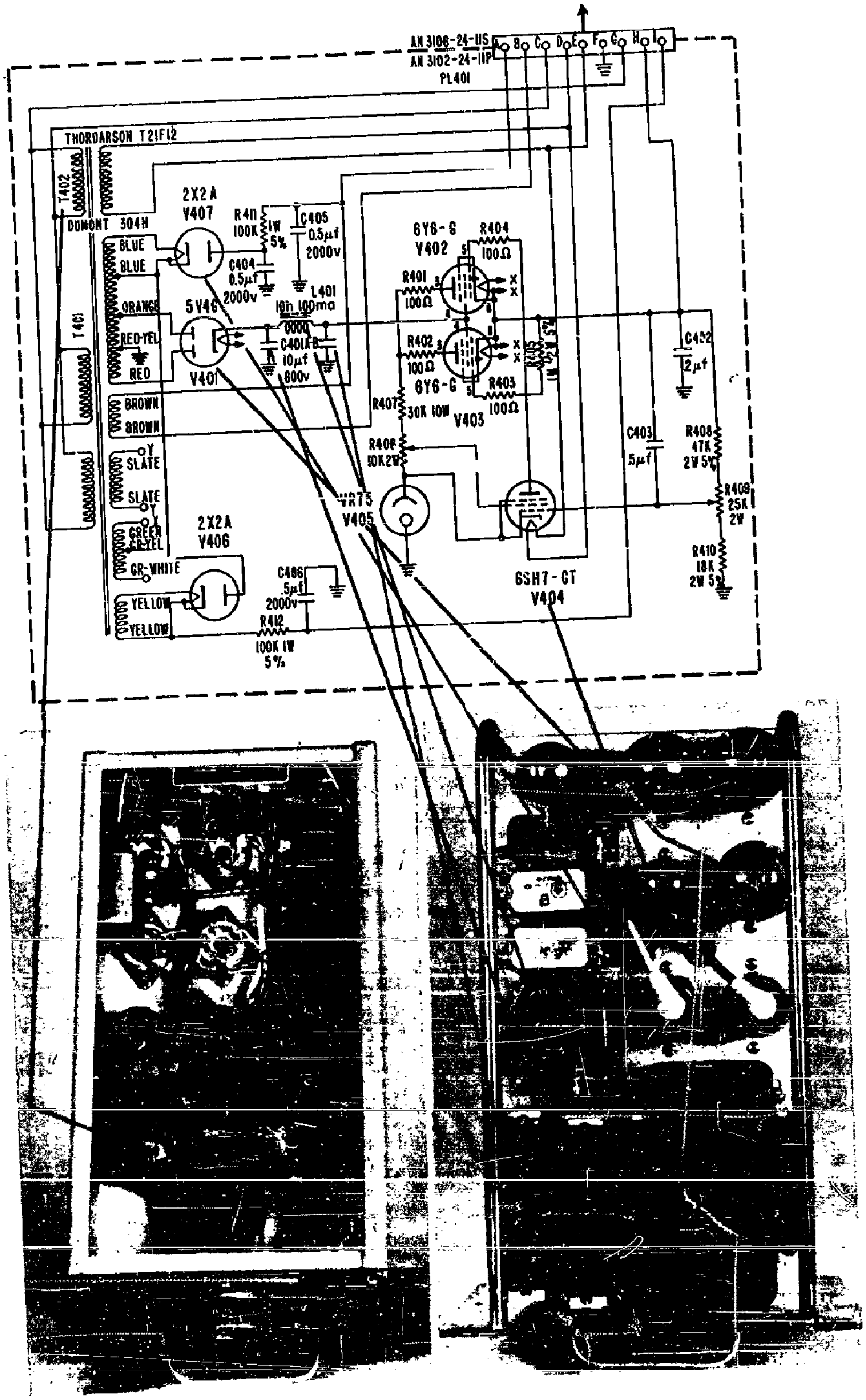

Figure 23 - Graphic Indicator power supply

provided to compensate for the velocity component of the echo-ranging ship. This velocity component is well known to be a function of the projector bearing; that is, to compensate for own-ship velocity component, the own-ship speed must be multiplied by the cosine of the projector bearing angle.

The ODC, shown in Figures 24 through 26, was developed to determine if it was feasible to accomplish own velocity compensation in the Graphic Indicator.

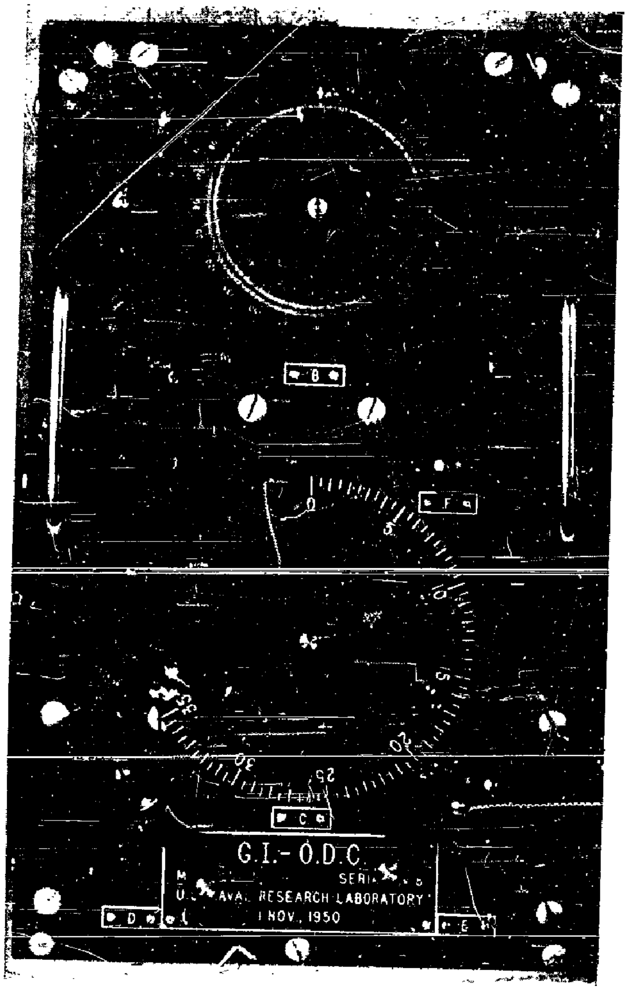

Figure 24 - Own doppler compensator

The own-ship velocity and projector bearing angle are fed into the computer manually. A cosine resolver in the computer multiplies these two values and translates the product into a mechanical motion which adjusts the reference frequency in the Graphic Indicator as required for compensation. Projector bearing is indicated on the bearing repeater dial (see Figure 25). The ODC bearing dial indication is matched to the bearing repeater dial indication by pointers which are brought into coincidence, by rotating the hand-crank E.

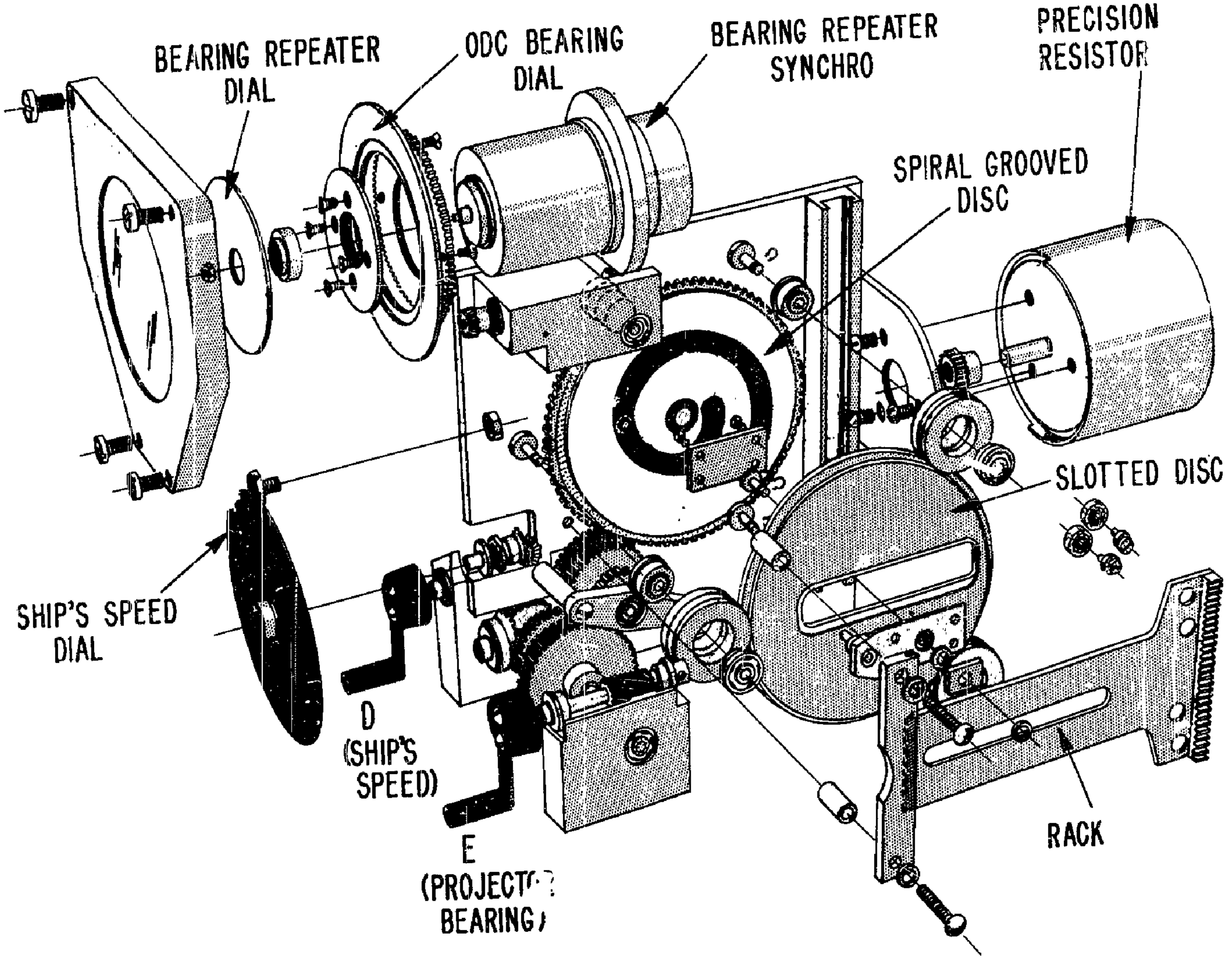

Figure 25 - Own doppler compensator, exploded view

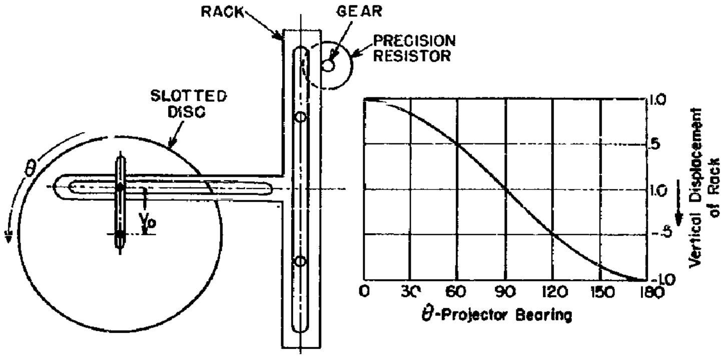

Figure 26 - ODC, cosine resolver

Own-ship's speed, as obtained from a pitometer log or initial G. I. measurements, is fed into the computer by rotating hand-crank D until the calibrated ship's speed dial is in agreement with the pitometer log or G. I. speed. The ship's speed V_0 is set in as a radial value by means of the spiral grooved disc. By rotating both the spiral grooved disc and the slotted disc simultaneously, the vertical displacement of the rack in Figure 26 varies as the cosine of the angle of revolution. The vertical displacement of the rack is therefore a product of the angle of rotation of the disc and the radial value V_0.

Laboratory and sea trials have proved that the ODC fulfills the function for which it was intended. However, these tests have also shown it to be a superfluous item for most tactical uses. In cases where an ODC is deemed necessary, it should be made entirely automatic.

CHARACTERISTICS OF PRESENTATION

It has been found that when an observer first views the Graphic Indicator presentation, he is likely to be perplexed as to the interpretation of the patterns which form and disappear on the face of the cathode-ray-tube screen. These first reactions are quite normal since most observers have been trained to interpret displays simply showing variations of average signal intensity (controlling spot brightness) in a compressed time scale, as in a Plan Position Indicator. Such visual presentations do not utilize all the information contained in a signal since they are essentially one parameter systems.

The Graphic Indicator, however, treats several parameters of signal, placing primary emphasis on phase and frequency, and secondary emphasis on amplitude and energy. This is done by a method of signal processing which enables all bits of information contained in the frequency band passed by the system to be displayed in such a manner that bit groupings may be compared and analyzed. This makes it possible in echo ranging to "see," analyze, and grasp information contributed by individual reflectors or targets which are separable because of the perceptible differences in the bit groupings or patterns as they develop in time or range. Pattern differences which characterize the different signatures in the phase-time plot are basically differences in signal frequency or phase character, as described in Section II of this report.

In this display or presentation of signal many characteristics of modes of appearance on a surface are used. These are size, shape, location, brightness or darkness, and the degree of saturation by bit groups in unit area. The structure of the pattern and its changes make possible the rapid perception and analysis of the target situation. In the development of the signal trace or pattern, systematic changes of slope may produce sensation of motion which contributes to the perception of signal presence and may disclose the source of the systematic signal frequency variation.

The brightness of the signal trace or pattern is produced by an output of energy in the form of pulses (bits) of equal amplitude and width that are generated at the successive positive crests of signal or noise if these are above a threshold or bias controlled by rectification of the signal and noise. This brightness is a constant for each pulse (bit) but varies as the distribution of bits or bit groups.

The amplitude of the generated pulse is independent of the amplitude of the signal from which it is generated. However, if the amplitude of the signal decreases at a rate too great for the time constants that affect the automatic adjustment of the threshold, then there will be an absence of pulses during the signal decrease. Absences produced, if periodic, will present perceptible patterns of darkness, which will indicate the phenomenon that produce them, either in the signal or the noise-signal mixture. See page 19 of this report.

This presentation of signal as pattern in a phase-time plot allows an observer to discriminate between reverberations and the hull echo of a target.

Figure 27, which is an example of the Graphic Indicator presentation when there is no signal input to the instrument, represents the characteristic appearance of receiver noise and/or water noise. It is identical to that of a television raster when no signal is received with the receiver video gain at maximum. Close examination of the raster reveals that it is made up of many bits of brightness distributed in a random manner. Any departure from the random distribution of these bits will cause bit groups to be formed. This results in a redistribution of the bright areas bounded by dark areas and forming patterns. Such is the case when a c-w signal equal to noise is added, as shown in Figures 28a and 28b. Close examination of Figure 28 reveals that the pattern produced is made up of many bits which have begun to group. The grouping is not yet completely coherent since the signal is not strong enough to overcome all the noise peaks and a wide distribution of the coherent bits result. As the signal-to-noise ratio decreases, the bit distribution becomes wider because of the noise until the point of no visible coherent grouping is reached. When the signal-to-noise ratio increases, the bit noise distribution decreases until the bit grouping is completely coherent, forming a signal line as is shown in Figure 29. As the bits become more and more coherent, there is an appearance of increasing brightness. This is due to the fact that although the intensity is constant for each bit, the area over which the bits are distributed becomes less and less, and the intensity per unit area increases. As coherence increases, the bits fall closer and closer together until a limit of resolution is reached, and the individual bits cannot be resolved. This is a function of the cathode-ray-tube area and the spot size, as well as a characteristic of the patterns presented and of the acuity of the human eye, as is evidenced by comparing Figures 28 and 29.

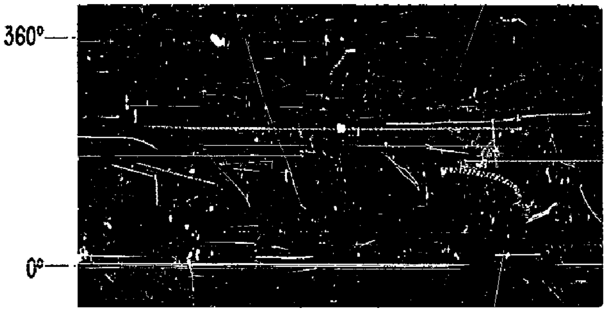

Figure 27 - Noise

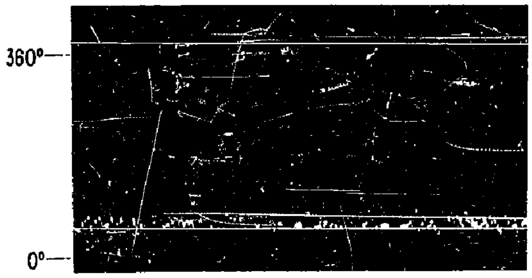

Figure 28a - Signal and noise $F_s = F_r$

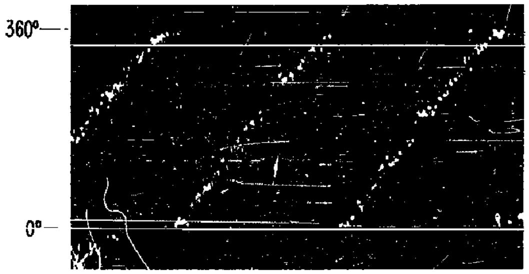

Figure 28b - Signal and noise $F_s < F_r$

These figures illustrate the amplitude parameter in the Graphic Indicator display. Figures 30 through 35 serve to illustrate how frequency differences are presented.

Figure 29 has shown the pattern produced by a c-w signal (F_s) greater than noise and equal in frequency to the reference oscillator frequency (F_r) in the Graphic Indicator. A horizontal coherent line is produced; bits cannot be resolved. If this signal were pulsed, the presentation would be the same except that the horizontal line would have a definite length proportional to the pulse length.

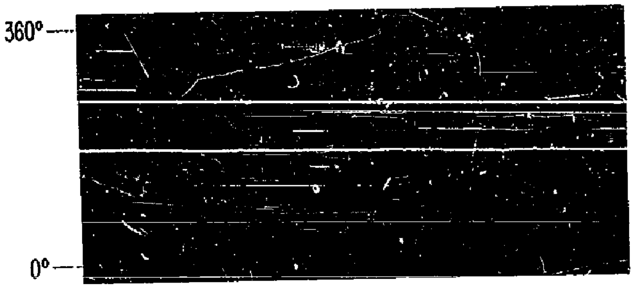

Figure 29 - Signal, $F_s = F_r$

If the signal frequency differs from the reference oscillator frequency, the line produced is not horizontal but assumes a slope; and if the frequency difference is great, several steeply sloping lines in a parallel set are produced as shown in Figures 30 and 31. The magnitude of the slope indicates the magnitude of the frequency difference, and its sign, whether the signal frequency is greater or less than the reference frequency. The greater the frequency difference, the greater is the slope and the number of lines in the set, and the closer are they spaced. If spaced too close, the individual lines cannot be resolved, the resolution limit being a function of the screen area and spot size and of the acuity of the human eye. As explained in the Theory Section, the frequency band within which line resolution is possible, is called the visual bandwidth.

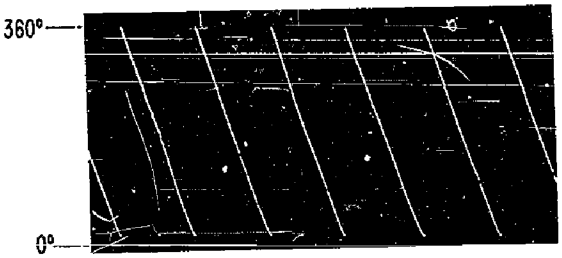

Figure 30 - Signal, $F_s > F_r$

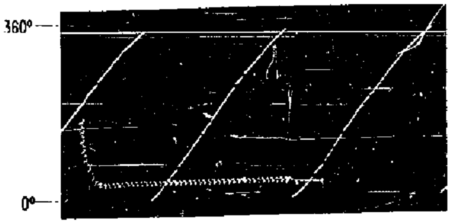

Figure 31 - Signal and noise, $F_s < F_r$

The ability to resolve and measure frequency differences is important, for it is this which makes possible the determination of such quantities as speed over the bottom and through the water, target velocity, and velocity of an ocean current.

It is interesting to observe what occurs when two signals are mixed linearly ahead of the Graphic Indicator input. Figure 32 is a photograph of the presentation when two c-w signals (F_1 and F_2) of nearly equal amplitudes but differing in frequency by 100 cps, (F_1 = 25.6 kc and F_2 = 25.5 kc) are added.* The reference frequency F_r in the Graphic Indicator was set equal to F_1. The F_1 signature appears as a broad horizontal pattern composed of a series of sloping lines. The period between each line is equal to the period of the frequency difference between the two signals. The positive slope of the lines indicates that F_2 is lower than F_1. Figure 33 is a photograph of the presentation when $F_r = F_2$. Notice the opposite slope of the lines indicating the presence of F_1.

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* Amplitudes of both signals were chosen to be within the linear range of the bandpass amplifier for all cases described.

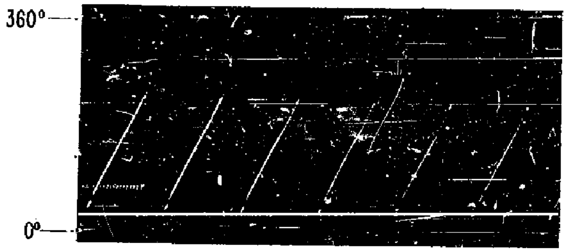

Figure 32 - Two signals linearly added
$A_1 \cong A_2$
$F_1 = F_r$

Figure 33 - Two signals linearly added
$A_1 \cong A_2$
$F_2 = F_r$

In Figure 34, the amplitude of F_2 has been decreased by 10 db and the reference frequency set equal to F_1 and in Figure 35, $F_r = F_2$.

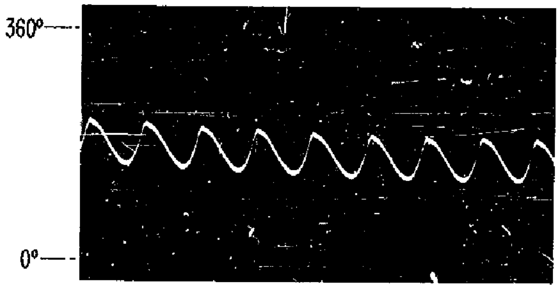

Figure 34 - Two signals linearly added
$A_1 > A_2$
$F_1 = F_r$

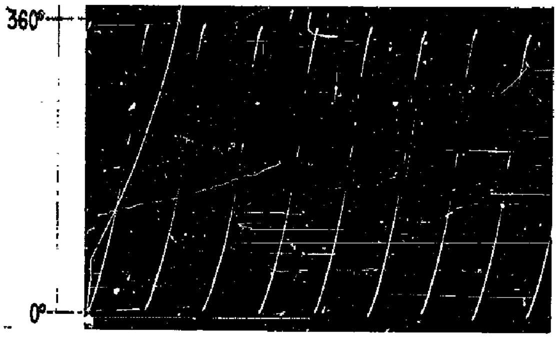

Figure 35 - Two signals linearly added
$A_1 > A_2$
$F_2 = F_r$

The capacity of the Graphic Indicator to resolve more than one frequency with mixed signals is important as will be shown later in the account of actual field results.

Probably the most important signal parameter displayed by the Graphic Indicator is phase. It is this parameter that enables properties of the targets to be determined for classification purposes. For instance, bottom reverberations have smaller phase variations than volume reverberations, and wake echoes are more random in phase than hull echoes.

Figure 36 illustrates a signal (F_S) equal in frequency to the reference and nearly perfect in phase coherence; Figure 37 shows the random phase variation characteristic of volume reverberations; and Figure 38 shows minor phase variations such as one observes in bottom reverberations.

The presentation of the three parameters of a signal has been shown. Now let us see how these parameters enter into the presentation in actual echo-ranging operations.

The series of photographs shown in Figures 39 to 43, inclusive, were made from tape recordings of actual field operations.* The series of "pings" shown was made during

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* A discussion of the method of photography is to be found on page 92 of "Test and Data"

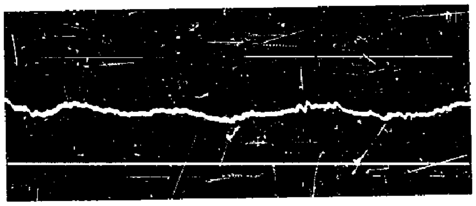


Figure 36 - Echo signal from submarine hull

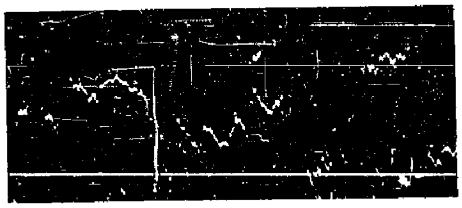


Figure 37 - Short range volume reverberation

Figure 38 - Bottom reverberations, long range

a surface-to-submarine simulated attack run in the Key West area in July 1951. The surface ship, USS SARSFIELD (DD 837), has located the submarine, USS CLAMAGORE (SS 343), and has already begun the attack run. The series of "pings" shown is from a portion of this run.

It is to be noted that the Graphic Indicator presentation in each strip, of the ping-reverberation-echo sequence, is developed from the same transducer output which the standard graphic range recorder presents as a line of varying darkness, drawn by the stylus on the recorder paper in one traverse. The difference in the amount of detail is striking, and, the more so, when the significant additional information provided is appreciated.

The speed of the surface ship was 23 knots and that of the submarine approximately 7.5 knots. Because of the projector bearing and target aspect, the resultant of velocity vectors gave, at the start of the run, a range rate of about 15 knots. The run was begun with the submarine 15° off the starboard bow with bearing changing quite rapidly as the surface ship closed on the submarine.

For the pings shown in Figures 39, 40, and 41 the reference oscillator in the Graphic Indicator was set to the hull echo frequency of the submarine target and was caused to track the hull frequency throughout the run; for the pings shown in Figures 42 and 43, the reference oscillator was caused to track the volume reverberation frequency. The two sets of pings shown are for the same run, and those bearing the same number are the same ping. Thus a comparison of the two presentations for a given ping is possible.

Note the first ping in Figures 39 and 42, respectively, and observe that information in the following chronological order is presented:

1. Transmitted pulse
2. Transfer relay throw time
3. Echo from own-ship's hull
4. Volume reverberation
5. Noise
6. Echo from submarine wake
7. Echo from submarine hull
8. Noise
9. Ping from another echo-ranging ship in the area.

Figure 39 - High-speed attack run - target horizontal

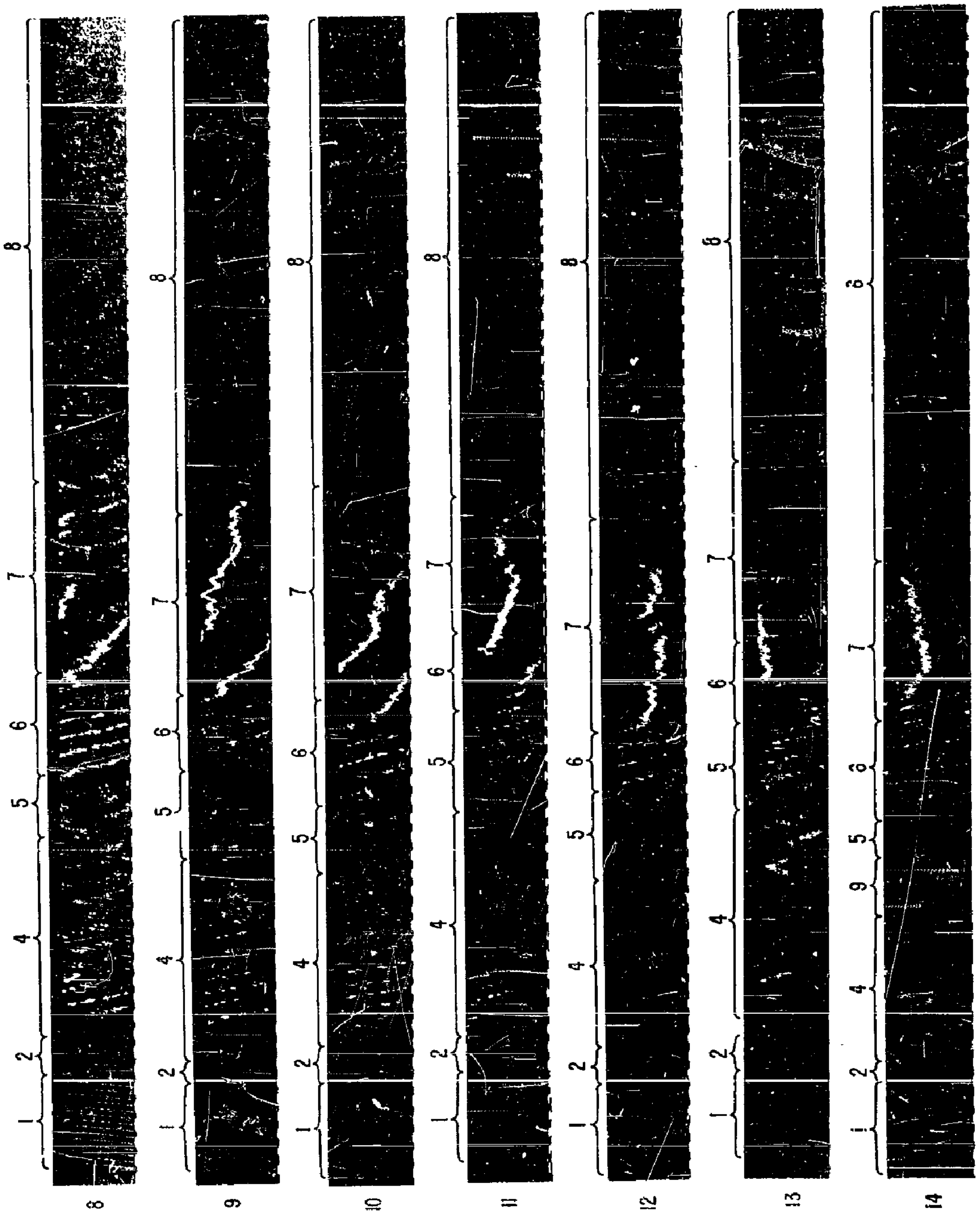


Figure 40 - High-speed attack run - target horizontal

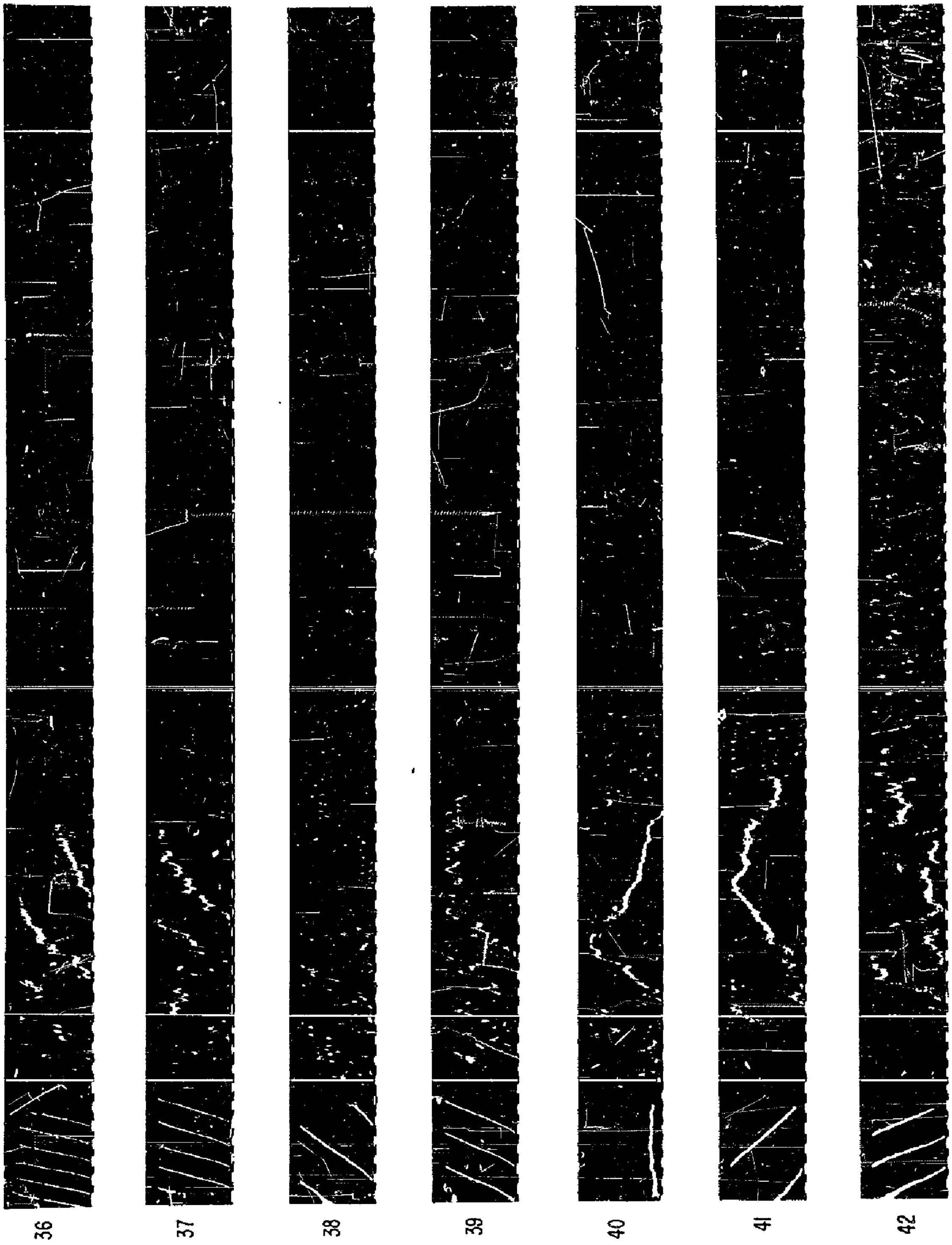


Figure 41 - High-speed attack run - target horizontal

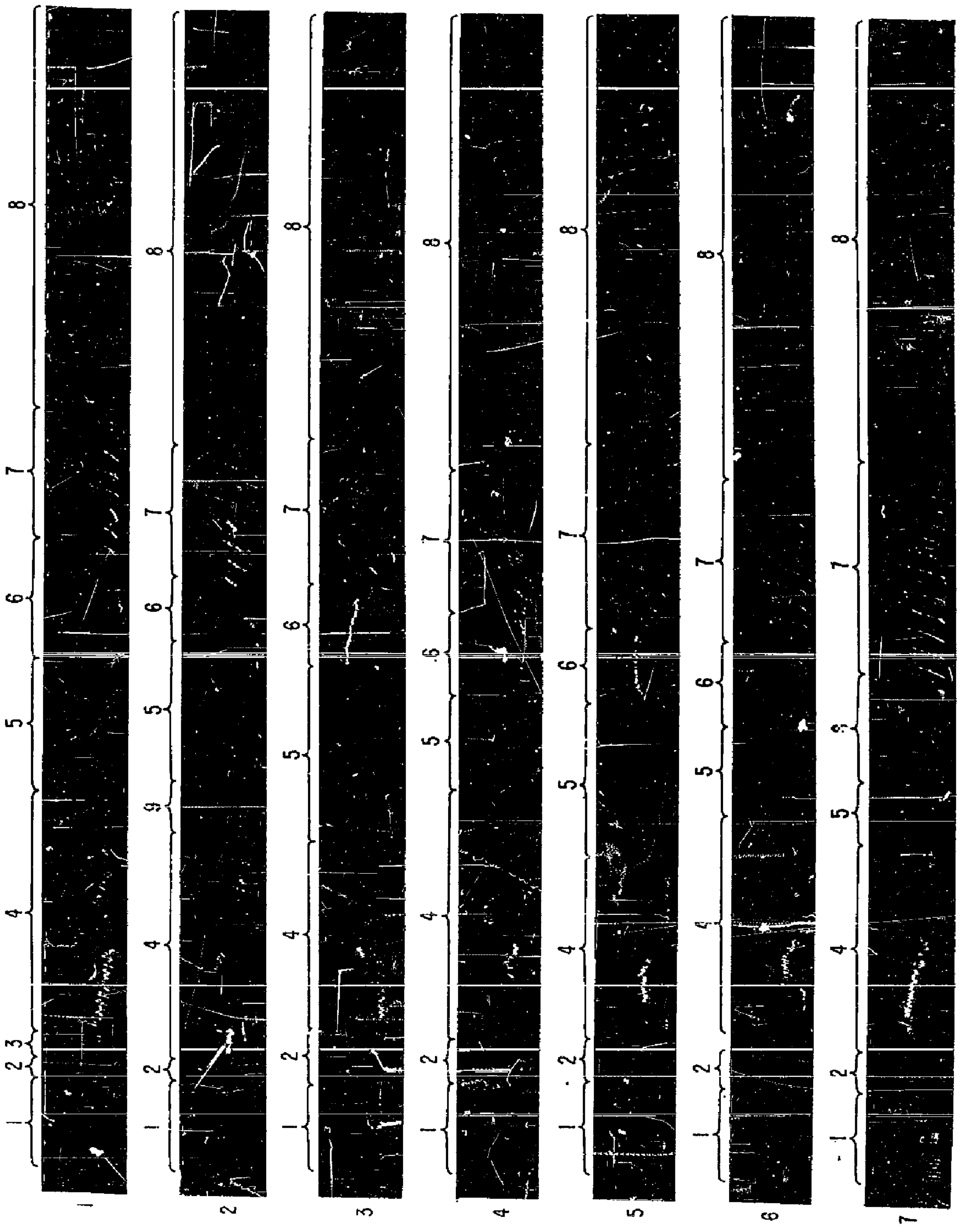


Figure 42 - High-speed attack run - volume reverberations horizontal

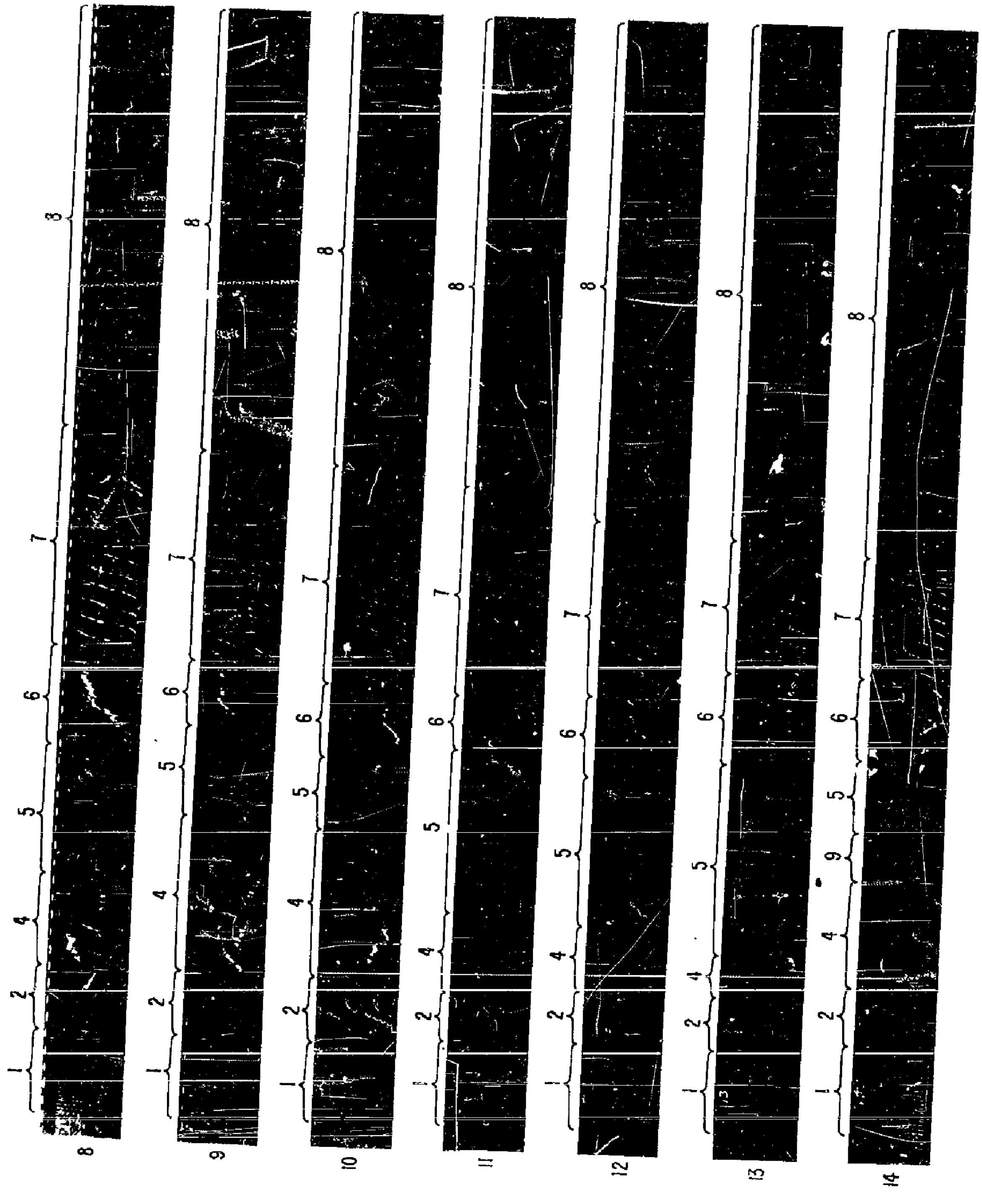


Figure 43 - Volume reverberations - horizontal

It is apparent from the sloping lines in the transmitted pulse presentation of the first pings in Figure 39 that a large frequency difference exists between the transmitted pulse and the target-hull-echo frequency. This is a result of the doppler effect. The direction of slope of these lines indicates that the transmitted pulse is lower in frequency than the hull echo and shows a closing range rate to the target.

The absence of any signal immediately after the transmitted pulse indicates the transfer (throw) time of the transfer relay. The series of sloping lines, which are equal in slope to the transmitted pulse lines appearing directly after this dead time, is an echo from the hull of the echo-ranging ship. Note in the succeeding pings that this condition disappears when the projector is trained more and more abeam.

In the first pings of Figure 39, the volume reverberations are seen as lines sloping closely together with the slope opposite in sign from that of the transmitted pulse lines. This indicates that the echo-ranging ship has a large closing range rate with respect to the water. The indication that this is a closing range rate is shown directly by the same ping in Figure 42. Here the reverberation frequency is equal to the reference frequency. Note also that the ship's closing range rate with respect to the water is greater than her closing range rate on the submarine. The difference is the opening range rate of the submarine with respect to the water.

After the reverberations die out in the first pings of Figures 39 and 42, noise becomes apparent and then what seems to be more reverberation appears. These are not reverberations, however, but echoes from the submarine's wake. Notice how the slope of this wake is the same as the slope of the volume reverberations since the wake is dead in the water. This wake return is high in amplitude but has a random phase character. Because of its amplitude, it is often mistaken with conventional sonars for the hull of the target. As a result, the sonar operator trains the transducer on this area. The error results in incorrect target bearing and range information. This condition is evident in a large number of the pings shown. The hull of the target can be seen as a nearly horizontal line following the wake area.

In the pings shown in Figures 39, 40, and 41, the hull echo of the target can be seen as a nearly horizontal line following the wake signature. Because of the fact that the projector is not trained directly on the hull, in some of the pings shown the hull echo is modulated in phase and in amplitude by the wake echo, and the line is not straight. Notice the similarity between the pattern of the mixed wake and hull echoes and that of the addition of two signals shown previously. (Figures 32 to 35).

The range rate reaches a minimum in ping No. 40, Figure 41, as the closing range rate decreases to zero. An increasing opening range rate is shown in succeeding pings. In pings Nos. 5, 6, and 7, the transducer has been trained more on the hull echo so that the modulation due to wake is considerably lessened and a cleaner hull echo is obtained.

In ping No. 13, Figure 43 (reverberations horizontal), an indication of dynamic wake (propeller thrust region) may be seen just before the hull echo as segments of lines of slope which are opposite to those of the hull echo lines. This indicates a velocity opposite to that of the hull.

In ping No. 2, Figure 39 or 42, near the end of the reverberation, a series of fine lines of large slope may be seen. These are the result of echo-ranging from another ship and represent that ship's transmitted pulse.

APPLICATION AND RESULTS

Extensive field tests have demonstrated the Graphic Indicator to be a useful and versatile tool in the fields of marine navigation, prosubmarine warfare, antisubmarine warfare, and oceanography. A formal operational evaluation has been conducted on the initial model of the Graphic Indicator by the Surface Antisubmarine Development Detachment of the Operational Development Force (6). In addition, units have been supplied to ComSubLant, ComSubPac, Naval Electronics Laboratory, Woods Hole Oceanographic Institute, Bureau of Ordnance, David Taylor Model Basin, Fleet Sonar School (Key West), and Fleet Sonar School (San Diego), for evaluation.

Fleet Sonar School, San Diego, California, has reported on the results of operational use of the Graphic Indicator in applications to target classification and tracking (7).

The results of tests both in the laboratory and in the field carried out by NRL personnel in conjunction with operational units of the Navy will next be discussed.

Navigation

Determination of Ship's Speed over the Bottom - The speed in knots of an echo-ranging vessel is measured for each returning pulse by comparison of the frequency of the bottom reflections or reverberations with the frequency of the outgoing pulse. For any particular frequency, the shift in frequency or doppler produced by the forward motion of a vessel is a function of the speed of the vessel. The accuracy in the determination of the speed over the bottom, as well as could be ascertained by comparison with navigational-fix data and with time and distance data recorded on runs between buoys, is in the order of ±0.1 knot. This accuracy, within the limits of operational speeds, is a constant, independent of velocity.

The Graphic Indicator measures the magnitude of a velocity vector lying along the sound-beam axis of the projector. Therefore, the lateral speed over the bottom, as well as the forward velocity of the vessel, can be measured by appropriately training the projector. The speed abeam will include drift due to wind and current. These measurements have been obtained at all echo-ranging speeds in water depths up to five hundred fathoms.

These results have been obtained with standard-sonar-equipped vessels in which the beam of the transducer is fixed in the horizontal plane. The BT conditions were such that the sound beam in the medium was refracted to the bottom. However, if water or depth conditions are such that the signal does not reach the bottom, it is obvious that a speed measurement over the bottom is impossible. To insure that the sound beam strikes the bottom, the transducer can be tilted to some angle between 0° and 45°. Then, by taking into account the cosine of the tilt angle, the speed can be calculated.

Determination of Ship's Speed through the Water - The speed through the water is measured with the Graphic Indicator in the manner described above for determining ship's speed over the bottom, except that in this case the volume reverberations from immediately ahead of the vessel are utilized. The accuracy of this measurement is of the same order of magnitude as that for ship's speed over the bottom.

The lateral motion of the vessel through the water is measured by training the sound projector to 090° or 270° relative bearing and observing the velocity along these bearings. Provided the characteristics of the beam pattern are known, the velocity or motion along any particular bearing may be measured by training the projector to that relative bearing. Thus, the lateral motion produced by wind, slippage, or unsymmetrical drag through the water is determined.

This determination is based on the proper alignment of the sonar transducer, since misalignment of the transducer can be interpreted as wind-drift. If conditions are controlled by taking a ship's heading with the wind so that no wind-drift or lateral motion occurs, the alignment of the axis of the transducer's beam can be checked at 090° and 270° relative for indication of zero speed. In addition, a comparison can be made of Graphic Indicator velocity measurements for equal angles on either side of 0° relative. If the transducer is properly aligned, the readings will be symmetrical on either side of zero.

Discrimination between Bottom and Volume Reverberations - Bottom reverberations are distinguished from volume reverberations by several criteria. The degree of discrimination varies with sea conditions (i.e., depth of water, temperature gradients, currents, and sea state) and speed of the vessel, but in most cases the different types of reverberation are easily resolved.

Bottom reverberations have a phase character which appears on the cathode-ray screen as a continuous line but with random change of phase. This variation in phase usually does not exceed a limit of 90°, as shown in Figure 44. On the other hand, volume reverberations appear as short line segments with breaks due to discontinuous phase variations. Their sources are the many reflectors in the total reverberating volume. Although these line segments are short, a general slope is easily distinguished. As the reference frequency is brought into coincidence with the volume reverberation frequency, the slope is brought to zero and a horizontal presentation becomes visible. Because of their time sequence with respect to the outgoing pulse, the volume reverberations always appear on the screen before the bottom reverberations. Whenever, as a result of currents, their is relative motion of the medium with respect to the bottom, the volume reverberations may be distinguished from the bottom reverberations by the difference in the slopes, produced by the differing velocities.

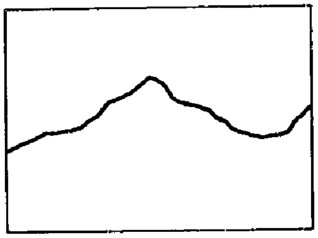


Figure 44 - Randomness f bottom reverberations

As an example of the precision attainable, one experimental operation is cited. On three different days, USS AMBERJACK (SS522), using only the data furnished by the Graphic Indicator and the compass, navigated submerged in Key West waters for periods of 6 to 8 hours at depths varying from 10 to 250 feet (8). The submarine maneuvered at speeds ranging from zero to 18 knots and in currents ranging from 1.5 to 3.5 knots. During one day's operation, the vessel hovered for a period of three hours. The vessel surfaced each day within 500 yards of its predicted position.

Determination of Ocean Current Velocity and Direction

The Graphic Indicator may be utilized in the measurement of the magnitude and direction of ocean currents near the surface. For this purpose, the component of the current's velocity along the sound-beam axis is found by measuring the difference between the vessel's velocity relative to the volume of the medium and that relative to the bottom. Measurement of deep currents is believed possible provided the angle of the ray path is known.

The accuracy of current data is believed to be of the same order of magnitude as that for ship's speed. Measurements of current velocities in depths down to 400 feet and ranging from zero to four knots have been made in the Key West area. Changes up to 32° in set and up to 0.5 knot in drift between the surface current and the current at 135-foot depth have been measured in this area.

Prosubmarine Warfare

As an instrument of prosubmarine warfare, the Graphic Indicator provides early information in terms of relative range rate, which assists a submerged submarine to follow the maneuvers of an echo-ranging surface vessel. It may also furnish information making possible an early determination of the change in course or speed of an attacking surface vessel, and, in this way, enable the submarine to take effective evasive action. When several ships are echo-ranging, the Graphic Indicator permits the submarine to distinguish between them by their individual pulse "signatures."

Determination of Range Rate - The relative range rate between a submarine and an echo-ranging surface ship is measured from pulse to pulse from the direct sonar signal of the surface ship. It may be obtained not only when the submarine is within the range of detection by the surface ship,but also when it is well beyond this range. The information presented in the submarine is in the form of relative range rate, that is, relative to the range rate at the time of initial contact. Although the value read is not an absolute range rate at that time, any change in range rate can be measured accurately. The absolute range rate may be determined if zero reference is obtained by: 1) adjusting the Graphic Indicator to a zero range rate reading when the submarine and the surface vessel are at a known zero range rate position (for example, whenever the two vessels are abeam and on parallel courses); 2) tracking the echo-ranging vessel in a maneuver which results in the range rate being presented in an equal amount opening and closing, thereby establishing the mean point and the zero reference (for example, when an echo-ranging surface vessel makes a turn of 180°); and 3) establishing the range rate by visual observation of the echo-ranging vessel. After relative-motion plots of a target are initiated, the information from the Graphic Indicator makes a continuation of the plot feasible with much less effort than the means presently available because of the ease of obtaining the "angle on the bow" of the target.

The most important consideration from the standpoint of the submarine is not the absolute range rate, but the change of range rate with time. Valuable information with respect to the maneuvers of an echo-ranging vessel may be obtained from relative-range-rate-versus-time plots. For example, characteristics of such a plot for a surface vessel which is attacking are quite different from those of a plot for a vessel which is searching.

"Pulse Signatures" - Field tests have shown that each echo-ranging vessel has an individual and easily distinguishable "signature" produced by the phase characteristics of its outgoing pulse.

The phase character of the direct outgoing signal is not altered during the transmission through the medium. Figure 45 illustrates the phase versus time presentation of an outgoing signal as observed with the Graphic Indicator aboard the echo-ranging vessel and the presentation of that signal as observed with a Graphic Indicator aboard a receiving vessel at ranges up to 10,000 yards.

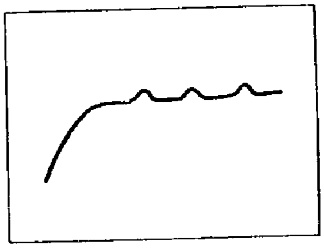


Figure 45 - Pulse "signature"

This "pulse signature" provides a submarine with a means of identifying, at any time, any one of several echo-ranging vessels in the vicinity. This information has been found to be particularly useful in the tactics involved in penetrating a convoy escort screen.

Discrimination of Types of Sonar Gear Used by Echo-Ranging Vessel - The frequency character of the reverberations display on the Graphic Indicator permits identification of the type of sonar equipment being used on an echo-ranging vessel. Scanning-type gear produces reverberations of changing frequency, whereas, with searchlight gear, the frequency is essentially constant.

Determination of Lost Contact Point - Field tests aboard USS SEA CAT (SS399) demonstrated that, by means of the Graphic Indicator, a submarine under attack by an echo-ranging vessel may determine the instant the attacking vessel loses contact at short range. This point of lost contact is recognized by a fluctuation in the phase character of the received pulse as the submarine moves into the region of transition between the major and minor lobes of the echo-ranging vessel's beam pattern. Actually the observers aboard the submarine are able to observe that the surface vessel is losing contact before it is known aboard the attacking vessel. This was indicated on several occasions when it was observed that the surface ship switched to the broad beam-pattern or MCC (Maintenance of Close Contact) to regain contact a considerable time after the contact was observed on the submarine to be lost. It was assumed that the surface vessel switched to MCC immediately upon losing contact,

The observed change in phase character is attributed to the 180° shift in phase when the submarine moves from the main sound beam into a minor lobe. (This 180° phase shift is true of sonar projectors installed in U. S. Naval vessels.) The region of fluctuation is probably caused by the varying relative contributions of energy from the major and the minor lobe. In addition, the amplitude in the region between the major and minor lobes depends critically on angle.

The advantage gained by the submarine from this information is the ability to ascertain the probability of being detected by the echo-ranging vessel. Also, when under attack, the submarine is able to determine the instant contact is lost at close range, thus improving the possibility of its escape by evasive maneuvers.

Determination of Type of Course of an Echo-Ranging Surface Vessel - It has been demonstrated by passive observations, utilizing the Graphic Indicator in a submarine, that the type of course (zig-zag or constant helm) of an echo-ranging vessel can be determined. In addition, the period of the course change can be accurately measured and the magnitude of the course change indicated. An example is illustrated in Figure 46. This information has value for prosubmarine attack planning.

Single Pulse Echo-Ranging - Tests are in progress at the present time to determine the usefulness of the Graphic Indicator in single-pulse echo-ranging tactics. This is done by recording the outgoing pulse from the submarine and the returning echo on a tape loop of a magnetic recorder. The recording is then played back into the Graphic Indicator

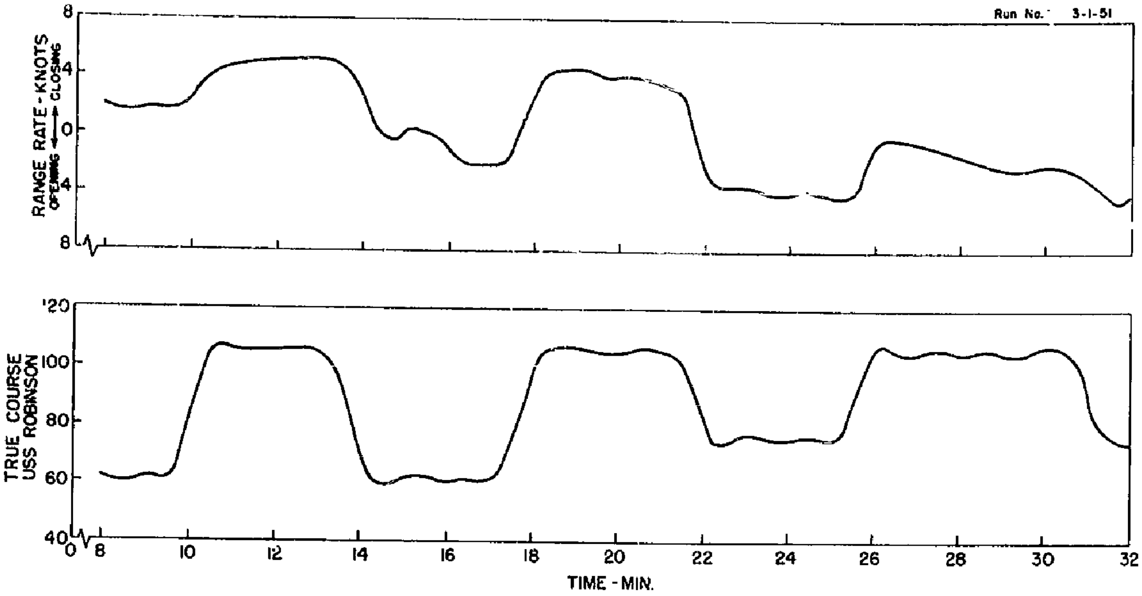


Figure 46 - Range rate and course versus time, zig course

several times to allow sufficient time (approximately 15 seconds) for an operator to make a measurement of range rate. Field tests have been made in which successful recordings were obtained, and the range rate measured to an accuracy of approximately a quarter knot. It is believed a very accurate range value may be provided by utilizing a range gate in conjunction with the Graphic Indicator.

Antisubmarine Warfare

The Graphic Indicator in its present form is of value in antisubmarine warfare in classifying a target, in obtaining accurate range rate data within the pulse and from pulse to pulse, in providing early indications of changes in course or speed of a target, and, potentially, in improving bearing and range accuracy.

Target Classification - Conventional range recorders present the range to the target from which the echo is reflected. A range rate is obtained from the slope of the range-versus-time plot by aligning a cursor to the tangent of a curve passed through the last few echoes. When energy is reflected from areas other than the submarine hull, having a fixed position relative to the submarine, the range rate of such targets is the same as that of the submarine. For example, the static wake follows the submarine, building up close behind the vessel and dying out further aft in the medium.

The wake is made up of acoustical discontinuities being generated continuously in successive areas along the vessel's path. There are two rates associated with the wake, the first is the rate at which successive areas become inhomogeneous, or the rate at which the wake is layed down by the vessel, and the second is the velocity of the inhomogenuities or bubbles in a reflecting area. The range rate from the static wake given by the range recorder is that of the changing position of the reflecting area and not the velocity of the reflecting medium in the area. Furthermore, when such areas reflect a higher energy than the submarine's hull, a false target may result, leading to an inaccurate range and bearing, even though the range rate specifies a moving target.

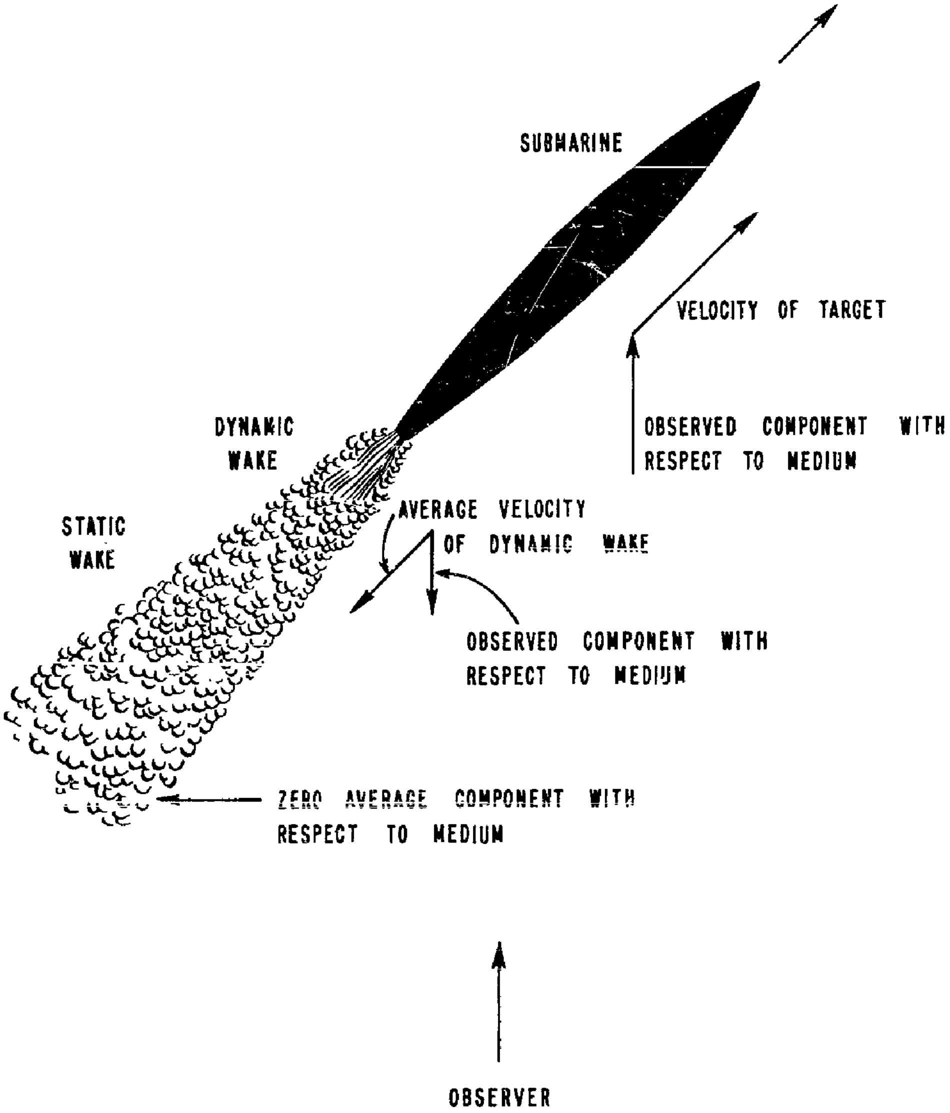


Figure 47 - Velocity components of sonar targets

The Graphic Indicator, on the other hand, measures an instantaneous velocity between the observer and the medium from which the acoustic energy displayed was reflected at the time of reflection (Figure 47). The static wake when observed on the Graphic Indicator shows no range rate with respect to the surrounding medium since the discontinuities of the wake producing the reflection have no net velocity. The range to this reflecting area changes with time in the same manner as indicated by the range recorder.

Therefore, the two means of obtaining range rate are entirely different, in that the range recorder measures the rate at which the range to a reflecting area changes with time, and not the change of range of an individual reflector; whereas the Graphic Indicator measures the instantaneous velocity between the observer and the individual reflector in the medium from which the acoustic energy is reflected.

It has been found in field tests that when only the hull of the submarine is presented as a target, the tactical range recorder and the Graphic Indicator range rate will be in agreement.

Observations in the field with the Graphic Indicator, while echo ranging on a submarine underway, have shown that three areas of reflected energy may appear as targets: the hull, or true target, and two false targets, the turbulent thrust area or dynamic wake immediately aft of the screws, and the stabilized wake further aft in the medium (Figure 47). The true range rate or velocity vector of the submarine is obtained from the hull and presents the most consistent phase character. Since the water is thrust in an opposite direction from that of the submarine path, the range rate obtained from the dynamic wake is opposite in sign to that obtained from the hull. The velocity and phase presentation is random from ping to ping. The range rate obtained from the stabilized wake is identical with that from the volume reverberations and has the same phase presentation character. Likewise, a "knuckle" produced by a submarine is identical to the volume reverberations since it possesses a zero velocity with respect to the medium. In the same manner, a reef or wreck on the bottom is indistinguishable in range rate or phase character from that produced by bottom reverberations. Therefore, these false targets are not observed as such, but appear as additional reverberations. Thus, the true target or hull of a submarine can be determined from other apparent targets by means of the Graphic Indicator.

Range Rate Determination - The Graphic Indicator has been demonstrated as a means of measuring the range rate of a submarine in a single pulse and of measuring a change of range rate from pulse to pulse. This information indicates immediately a change of course or speed of the target submarine to a high degree of accuracy. This accuracy is estimated to be of the order of ±0.2 knot.

Bearing Accuracy Improvement - Observations in the field indicate that a sonar operator, using the information supplied by the Graphic Indicator, is able to track a target in bearing with greater ease and accuracy than is possible with conventional systems. This is attributed to the well-defined manner in which a hull target is presented, when the transducer is accurately trained. Presentations including recognizable false targets, such as the wake or turbulent area immediately aft of a submarine, convey quick warning of an off-target transducer bearing. These observations have been qualitative, but tests to give a quantitative figure for improvement are underway.

Range Accuracy Improvement - It is anticipated that range accuracy will be improved, in the same manner as bearing accuracy, by identification in the total echo presentation of the returning energy from the submarine hull itself. This development will necessarily include a range gate in order to achieve this improved accuracy. An experimental model of such a range gate has been constructed at NRL, and initial experiments in the field indicate its feasibility.

An Instrument for Research

It is believed that a variety of applications will be found for the Graphic Indicator as an instrument of research. Observations have indicated that it will be useful in the study of signal propagation, study of currents in oceanography, and other problems involving wave-energy phenomena.

SEA TESTS AND DATA

This section summarizes sea tests and data obtained from the Graphic Indicator aboard naval vessels. The purpose of these tests was to establish technical performance of the Graphic Indicator in its application to prosubmarine and antisubmarine warfare and navigation and to aid in further development of the instrument. Table 1 summarizes the dates, operating areas and vessels in which these tests were conducted. The standard sonar equipments used in conjunction with the Graphic Indicator for these tests were the QHB, QJB, QGB, QCU, QCT, WFA, and WCA.

TABLE 1
Sea Tests of Graphic Indicator, July 1950 – July 1951

Date	Operating Area	Vessel
19 July 1950	New London, Conn.	USS SEA OWL (SS405), USS TRINGA (ASR16)
21-25 Aug. 1950	Key West, Fla.	USS FOSS (EDE 59), USS ROBINSON (DE-220), USS SEA CAT (AGSS-399)
23-27 Oct. 1950	Key West, Fla.	USS EPC-618, USS EPCS-1431, USS SEA CAT (AGSS-399)
6-9 Nov. 1950	Chesapeake Bay Potomac River	USS EPCS-1426
20 Nov. - 9 Dec. 1950	Key West, Fla.	USS SARSFIELD(EDDE-837) &UTU Ships USS SEA CAT (AGSS-399)
20 Feb. - 1 Mar. 1951	Key West, Fla.	USS WILKE (EDE-800), USS ROBINSON (EDE-220), USS GUAVINA (SSO362) USS SEA CAT (AGSS-399)
2-3 May 1951	New London, Conn.	USS CORSAIR (SS345), USS HALFBEAK (SS-352)
28 May - 1 June 1951	Key West, Fla.	USS AMBERJACK (SS-522)
9 July - 19 July 1951	Key West, Fla.	USS SARSFIELD (EDDE-837) USS GUAVINA (SSO-362) USS TRUMPETFISH (SS-425)

New London, Connecticut, 19 July 1950

The initial sea tests of the Graphic Indicator were prosubmarine in nature, and were conducted in USS SEA OWL with USS TRINGA as an echo-ranging target vessel. In these initial tests, laboratory-type equipment was used. The tests were purely qualitative in nature with no provision for the quantitative measurement of range rate. The major purpose of the tests was to establish that the approach from which the instrument evolved was a feasible one. This was adequately demonstrated by the following results: (1) A positive indication of range rate change was evidenced from ping to ping by the slope of the signal line in the oscilloscope presentation. (2) An accurate determination of zero relative motion was made between the target vessel (USS TRINGA) and own ship when both were abeam and on parallel courses. (3) Signals were clearly received from the echo-ranging target vessel at speeds of approximately 8 knots for the submarine and 10 knots for the target vessel. These signals were received along the direct path through the respective wakes of both vessels. (4) Reverberation signals were observed but did not alter the character of the direct signal.

Key West, Florida, 21-25 August 1950

The first tests at Key West were conducted by laboratory personnel employing the facilities of the Surface Antisubmarine Development Detachment under Assist Project BU/S172/A16-3, Task 5. The vessels used in these operations were USS FOSS and USS SEA CAT (21 August 1950) and USS ROBINSON and USS SEA CAT (22 through 25 August 1950). Two units of Model 1 of the Graphic Indicator were employed. The associated sound equipment was the QGB aboard the FOSS and the WFA aboard the SEA CAT.

The first objective of these tests was to determine the ability of the Graphic Indicator to measure, from a submarine, the range rate of an echo-ranging ASW vessel and to indicate, from changes in range rate, maneuvers by the echo-ranging surface vessel. These tests indicated that an operator could accurately measure range rate between a submarine and an ASW vessel and track the change of range rate from ping to ping. Any change of course or speed by the ASW vessel was indicated by the Graphic Indicator as soon as, and frequently earlier than, the maneuver could be detected by visual observations.

The second objective was to determine the capabilities of the Graphic Indicator for presenting echo information from a submarine target. The Graphic Indicator was paralleled to the QGB sonar receiving system in the USS ROBINSON. With the target submarine operating at periscope depth and maintaining either a steady or a zig-zag course, a series of runs were made on the target with ranges varying from 200 yards to 4000 yards. It was observed in these maneuvers that the Graphic Indicator was capable of maintaining contact with the submarine at all times that the QGB equipment had contact. On a number of occasions, the Graphic Indicator detected the target prior to detection by the QGB system. The range rate between the surface vessel and submarine, the velocity of the submarine through the water in the direction of the surface vessel, and the velocity of the submarine over the bottom in the direction of the surface vessel were measured.

Since these tests were primarily qualitative in nature, the conclusions reached, as to early detection of the target, were, 1) that the two systems (QGB and Graphic Indicator) were comparable as to the maximum range of detection and, 2) that the time required for detection was greatly reduced when the Graphic Indicator was used, and 3) that range rate could be measured more accurately by the Graphic Indicator than by the range recorder or by aural determination of doppler.

Additional observations made during these tests were:

(1) The Graphic Indicator, passively receiving aboard a submarine, maintained contact as the range between an echo-ranging ASW vessel and the submarine, increased to approximately 12,500 yards. The limit of the range was not determined as the run was

secured at this range. It was also noted that the WFA sonar equipment in the submarine did not lose contact at this range.

(2) Several runs were made with two vessels on parallel courses running in the same and in opposite directions. The minimum or beam range as the vessels passed was varied from 200 to 1000 yards. The range rate from the Graphic Indicator showed a closing range rate as the vessels approached, decreasing to zero in the beam position. As the vessels passed each other, the Indicator showed an opening range rate. For all ranges, the zero range-rate point occurred well within the length of the vessel as it passed abeam.

(3) A number of observations were made of the surface vessel's speed through the water and over the bottom. For this, the QGB transducer of the surface vessel was trained to zero degrees relative and the equipment set for 2000 yard echo-ranging. It was observed that the range rate between the surface vessel, and the water, as determined from the doppler shift of volume reverberations from immediately ahead of the vessel, corresponded well with the ship's pitometer log reading. Volume and bottom reverberations could be clearly separated by: (a) the difference in time of arrival, (b) the difference in range rate (one existed due to local current), and (c) the differing character of these reverberations when presented on the screen of the cathode-ray tube. Thus by measuring the range rate of the bottom reverberation, the speed over the bottom could be obtained. By taking the difference between this reading and the ship's speed through the water, as measured from volume reverberations, measurement of current velocity was made. By training the transducer to 090 or 270 degrees relative and repeating the procedure, a determination of set and drift could be made. Also by training the transducer to 000 degrees relative bearing and turning the ship until the maximum difference between the ship's velocity through the water and over the bottom was attained, the magnitude and direction of the current could be determined.

(4) During the operating period, sonar conditions varied widely. Ranges were found in excess of 4000 yards for good conditions to a minimum of approximately 1200 yards for poor conditions. It was observed for the good or long-range condition that the bottom reverberations were either nonexistent or occurred at a very long range. As the detectable range decreased, the range of the bottom reverberations tended to decrease. Thus, indication of the sonar range condition was obtained and a measure of range, to the point at which the sonar signal impinged upon the bottom, was possible.

(5) At various times during these operations it was observed that both volume and bottom reverberations occurred simultaneously with the returning echo. Although these reverberations altered the target signal's character, at no time was there any indication of reverberation limiting.

Key West, Florida, 23 - 27 October 1950

The second Key West test was conducted as an assist project employing the facilities of the Surface Antisubmarine Development Detachment under Project BU/S172/A16-3 (additional tests) Task Five. The vessels employed in these tests were the USS E-PC-618, during the period 23, 24, 25, and 27 October; the USS E-PCS-1431, during the period 23, 25, 26, and 27 October, and USS SEA CAT (AGSS-399) on 26 October 1950.

The Graphic Indicator as a Navigational Aid - The purpose of these tests was to investigate the Graphic Indicator as a navigational aid and as a range-rate and turn indicator for prosubmarine applications. Two units of Model One of the Graphic Indicator were employed. The associated sound equipment was the QJB in E-PCS-1431, and the QCU in E-PC-618, and the WFA in SEA CAT.

To obtain a figure for accuracy of the Graphic Indicator as a navigational aid in measuring ships' speeds through the water and over the bottom, it was decided to compare the speed over the bottom obtained from the Graphic Indicator with the speed obtained from navigational fixes. A series of eight runs were made with E-PC-618, running east and west approximately 7 miles south of Key West. During each run, navigational fixes were obtained from Sand Key and Key West lights at 5-minute intervals, with a total run duration of 20 minutes. Speed range during these runs was from 6 to 18 knots. The propeller RPM was held fixed throughout each run. Speed data from the Graphic Indicator was recorded at 2 to 5 second intervals throughout each run. Table 2 is a comparison of the speed data obtained from the Graphic Indicator with that obtained from navigational fixes for each corresponding increment of time between navigational fixes. Table 3 is a comparison of the speed obtained from the Graphic Indicator with that from navigational fixes for the average of each individual run. Figure 48 is a comparison of the average speed by navigational fixes with the average speed by the Graphic Indicator, for each run. A 45° line is drawn upon which all data should fall if the measurements are absolute. Since neither method is an absolute standard, a factor for the dispersion of each set of data was obtained. Standard deviation for each set of data was determined. The data obtained by the Graphic Indicator gave a standard deviation of 0.15 knot as compared with 0.55 knot for the data obtained from navigational fixes. The probable error for the Graphic Indicator data was 0.1 knot as compared to 0.4 knot for the navigational fixes. Thus, the data from navigational fixes indicates a factor of dispersion roughly four times as great as that obtained from the Graphic Indicator.

TABLE 2

Speed Between Each Navigational Fix Compared to Average Graphic Indicator Speed for Corresponding Time

Run No.	Avg. Speed-GI (Knots)	Nav. Fix Speed (Knots)	Run No.	Avg. Speed-GI (Knots)	Nav. Fix Speed (Knots)
1	7.53	7.22	5	14.35	14.27
	8.00	7.22		14.45	14.59
	8.16	7.76		14.70	15.91
	7.78	7.98		14.68	13.39
2	9.41	8.96	6	13.68	13.94
	9.24	9.29		13.99	15.25
	9.47	9.51		14.20	14.16
	9.89	9.18		14.10	14.43
3	9.45	9.07	7	17.71	17.71
	9.28	10.55		17.47	19.08
	9.35	10.28		17.67	17.05
	9.46	10.49		17.77	17.27
4	6.44	7.43	8	16.99	17.82
	6.54	5.85		17.00	17.27
	6.66	7.11		17.01	17.16
	6.58	6.61		17.15	18.37
	6.67	6.78			

In Figure 48 the maximum displacement of any point from the curve is approximately 0.7 knot. Since neither is an absolute standard, it is impossible to determine which is in error, the navigational fix or the Graphic Indicator data; but when compared on the basis the dispersion factors presented, a greater percentage of this error would fall in the navigational fix data.

TABLE 3
Speed Obtained by Navigational Fixes
Compared with Average Speed Obtained
by Graphic Indicator for Total Run;
Key West Area, 23-27 October 1950

Run No.	Speed by GI Knots	Speed by Nav. Fix Knots
1	7.83	7.60
2	9.49	9.18
3	9.38	10.02
4	6.57	6.66
5	14.56	14.50
6	13.95	14.43
7	17.68	17.74
8	17.57	17.60

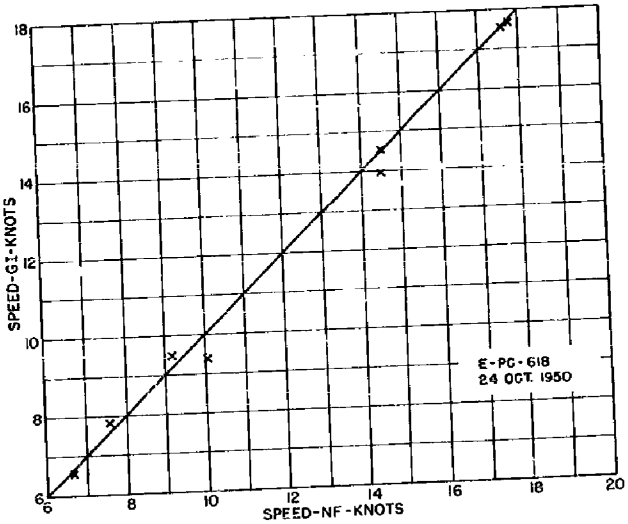


Figure 48 - Speed by Graphic Indicator versus speed by navigational fixes

It is therefore concluded that the Graphic Indicator will measure the speed of a vessel over the bottom with an order of accuracy of ± 0.1 knot.

Passive Range Rate Measurements - A series of simple maneuvers using USS E-PCS-1431 and USS E-PC-618 was designed to demonstrate the capability of the Graphic Indicator to passively track and measure the changes in range rate between a listening vessel and an echo-ranging vessel. Each ship (see Figure 49) conducted straight runs on reciprocal courses passing on parallel tracks abeam of each other at minimum ranges as recorded in Table 4. The absolute value of the range rate was established by making a calibration run prior to the starting of the tests. Each run started at a maximum closing range of

TABLE 4
Maneuver Data for Passive Range Rate Tests by Graphic Indicator Key West, Fla., 23-27 Oct. 1950

Run No.	True Course (deg)		Minimum or Abeam Range (yd)	Speed (knot)		Time of Zero Range Rate (min-sec)		Difference in Observed Time of Zero Range Rate; Optical vs. GI (sec)
	E-PCS-1431	E-PC-618		E-PCS-1431	E-PC-618	Optical	GI	
1A1	270	090	245	3.5	9.5	4:54	5:05	+11.0
1B1	090	270	460	4.5	9.0	6:00.5	6:04	+ 3.5
1B2	270	090	375	4.0	9.5	5:25.5	5:30	+ 4.5
1C1	270	090	1080	4.5	8.8	5:17	5:18	+ 1.0
2A1	090	270	245	9.8	14.6	3:45.5	3:48	+ 2.5
2B1	270	090	465	9.0	14.0	2:59.5	3:02	+ 2.5
2B2	090	270	435	9.8	14.6	2:08	2:07	- 1.0
2C2	090	270	1075	9.0	14.0	2:26.5	2:28	+ 1.5

approximately 3500 yards and continued until the vessels had passed well abeam of each other, at which time the run was terminated. Each vessel maintained constant shaft turns throughout each run. Ship's head, ship's speed (pit log), and relative bearing were recorded at 15-second intervals. Graphic Indicator readings were recorded at 2- and 3-second intervals. Table 4 is a summary of the data from these runs. Figures 50 and 51 are typical curves from these runs. The observed points are those obtained by use of the Graphic Indicator. The calculated range rate points were obtained by computing the vector component of velocity, along the line of sight, contributed by each ship. The vector component is a product of the cosine of the relative bearing angle and the ship's forward velocity. Therefore, the sum of the vector components for the two vessels is the range rate.

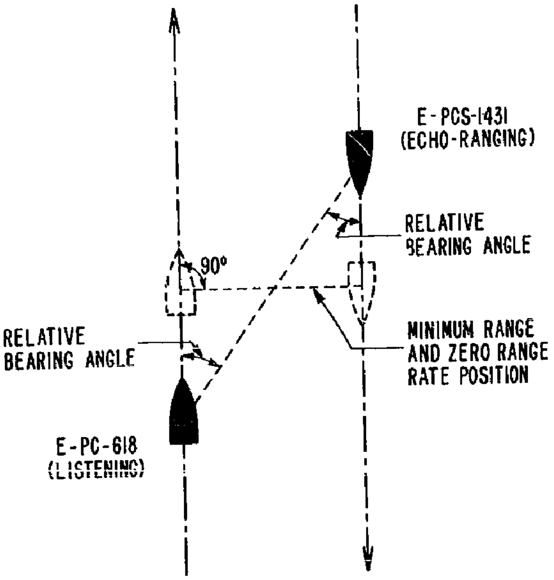


Figure 49 - Maneuver for range rate versus time measurements

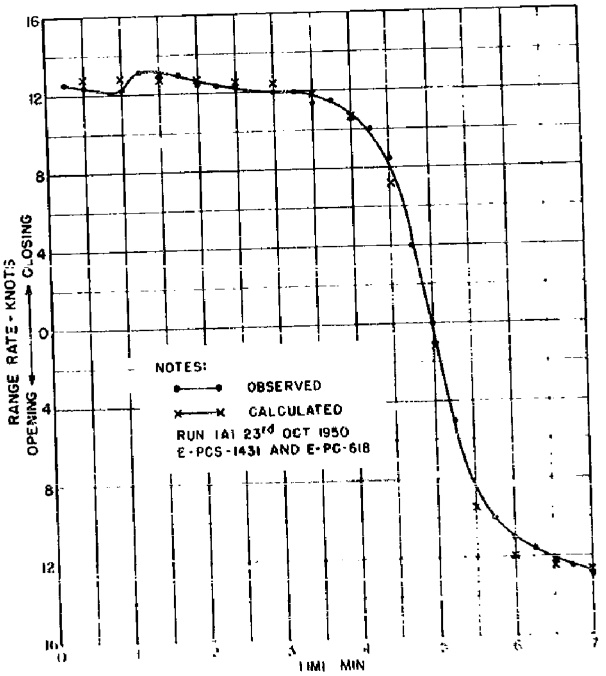


Figure 50 - Range rate versus time

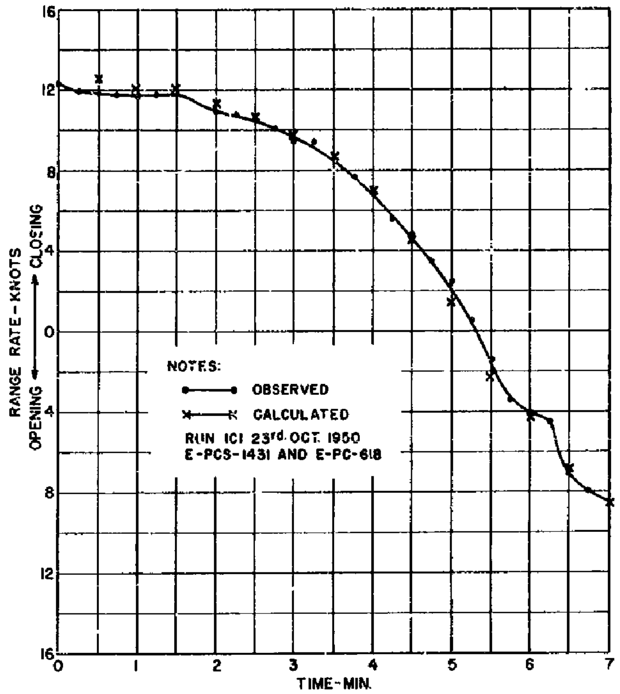


Figure 51 - Range rate versus time

It was observed that the two methods agreed within a few tenths of a knot. Table 4 also gives the time of zero range rate, optical, as compared with the time of zero range rate from the Graphic Indicator. The average time difference between these two readings, for all runs was three seconds. Corresponding bearing difference was 4° and the position (along the ship's track) was approximately 16 yards aft of the mast (used as the optical reference).

It is concluded that the Graphic Indicator can track changes of range rate from ping to ping with an estimated accuracy of the order of ± 0.1 knot.

The Graphic Indicator as a Turn Detector - A series of runs were designed to demonstrate the capability of the Graphic Indicator to detect turns of an echo-ranging surface vessel by passively observing the vessel's transmitted pings.

To test the instrument's capabilities fully, the most unfavorable condition for detecting turns by the Graphic Indicator was selected. As shown in Figure 52, the transmitting vessel was headed toward the listening vessel, because in this condition, a given change in the transmitting vessel's course will cause the least change in range rate. This is, however, the most favorable condition for detecting a change in course by visual observation. Conversely, the most sensitive condition for detection by the Graphic Indicator is that in which the transmitting vessel's course is at right angles to the line of sight, and this is the least sensitive condition for visual detection of turns.

In this maneuver each vessel opened to ranges varying from 2000 yards to 6000 yards.

An example will best illustrate this maneuver (see Figure 52). USS E-PCS-1431 and USS E-PC-618 opened range to approximate 4000 yards. The vessels then turned and closed on a collision course. Each vessel steadied on course and came to a prescribed speed. At approximately 2500 yards zero time was set and data recording was started. Then at 2000 yards E-PCS-1431 turned and steadied on a new base course. The run was terminated shortly after E-PCS-1431 had steadied on the new base course. The vessels then turned and opened in range for the start of a new run. Table 5 lists the course and speed of each vessel, course change of the turning vessel, and the range between the two vessels at time of turning. Ship's head, relative bearing, speed (pitometer log), and radar range were recorded in E-PCS-1431 at intervals of 15 seconds. The exact time of beginning a turn, as observed from the gyro, was recorded. Range rate from the Graphic Indicator was read each "ping." The speed, ship's head, and relative bearing of the listening vessel, E-PC-618, were recorded.

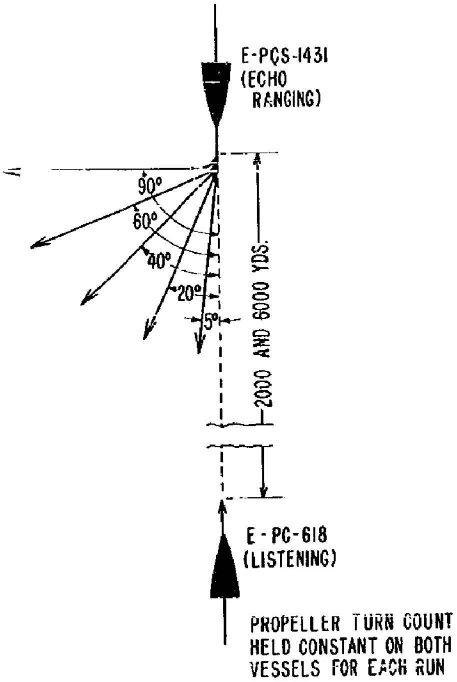


Figure 52 - Maneuver for detecting change of course by range rate

A state-2 sea prevailed during these maneuvers so that these vessels could not steer perfect courses. Therefore, the operator of the Graphic Indicator waited until an appreciable change of range rate had occurred before calling the turn. In some instances the turn could have been called earlier than it was. It has been observed that change of range rate of a high-speed vessel occurs prior to the actual change of bearing. This is explained by the fact that a ship loses headway when the rudder is applied. The range rate is therefore changed slightly prior to the actual turning of the vessel.

Table 5 lists the time that an observer could first detect change of course in E-PCS-1431 compared to the time that was called by the operator. The average time required for the detection of the turn in these runs was 7 seconds, which included approximately 3 seconds propagation time. This corresponded to 10° change of course of the turning vessel when the turn was called by the observing ship.

Figures 53 through 57 are representative curves of this series of runs. Each figure contains five curves; 1) range rate observed from the listening vessel, 2) ship's head, 3) relative bearing, 4) speed (pit-log), and 5) radar range from the turning vessel. All of these ordinate values are versus time. Note that the range-rate curve breaks shortly after the ship's head curve. These curves were plotted from certain typical runs as recorded in Table 5. In all cases, turns were detected by the Graphic Indicator as early as, and in a number of occasions earlier than, by visual observation from the bridge of the listening vessel.

It is concluded from these observations that an operator passively observing the pings of an echo-ranging vessel is able to detect a change of course or speed of the echo-ranging vessel within five seconds.

TABLE 5
Summary of Data from Graphic Indicator
When Employed as a Turn Detector
Key West, Fla., 23-27 Oct. 1950

Run No.	Base Course 618 (deg)	Base Course 1431 (deg)	Speed 618 (knot)	Speed 1431 (knot)	Course Change 1431 (deg)	Range at Time of Turn (yd)	Time Turn Detected on 1431 (min-sec)	Time Turn Called on 618 by GI (min-sec)	Difference (sec)
3A1	270	090	15.0	10.5	20	2500	1:10	1:12	2
3A2	270	090	11.5	10.5	20	2000	1:30	1:35	5
3A3	270	090	11.5	10.5	20	2600	1:06	1:14	8
3B1	270	090	13.5	10.5	40	2400	1:25	1:32	7
3B2	270	090	11.0	10.5	40	2500	1:07	1:20	13
3C1	280	090	15.0	10.5	60	1800	1:24	1:26.5	1.5
3C2	270	090	12.0	10.5	60	2500	:54	1:07	13
3D1	270	090	12.0	10.5	90	2000	1:07	1:15	8
3D2	270	090	11.5	10.5	90	2300	1:09	1:14	5
4A1	270	090	11.0	10.5	20	6000	:55	1:05	10
4B1	270	090	14.0	10.5	40	6200	1:12	1:16	4
4C1	270	090	13.0	10.5	60	6500	:49	1:02	13
4D1	270	090	10.5	10.5	90	6500	:58	1:01	3
S1	090	090	10.0	10.5	10	4000	2:28	2:30	2
S2	090	092	10.0	10.5	10	4000	4:07	4:10	3
S3	270	090	9.5	10.5	5	5500	1:22.5	1:27	4.5

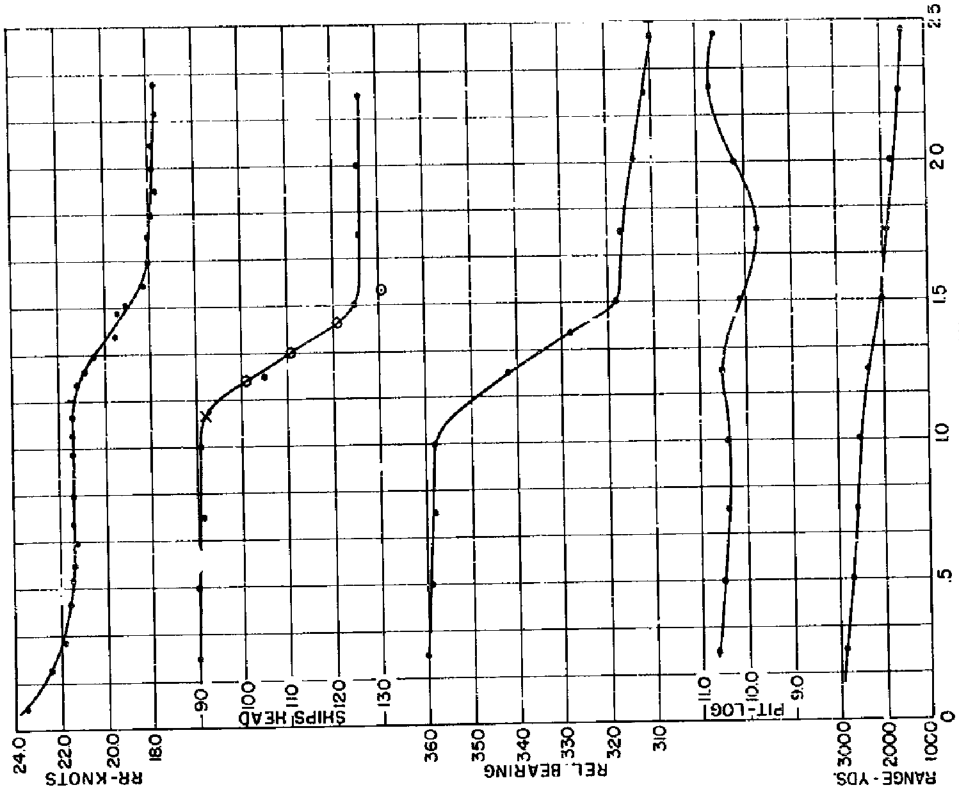


Figure 54 - Time plots of maneuver for detecting change of course by range rate

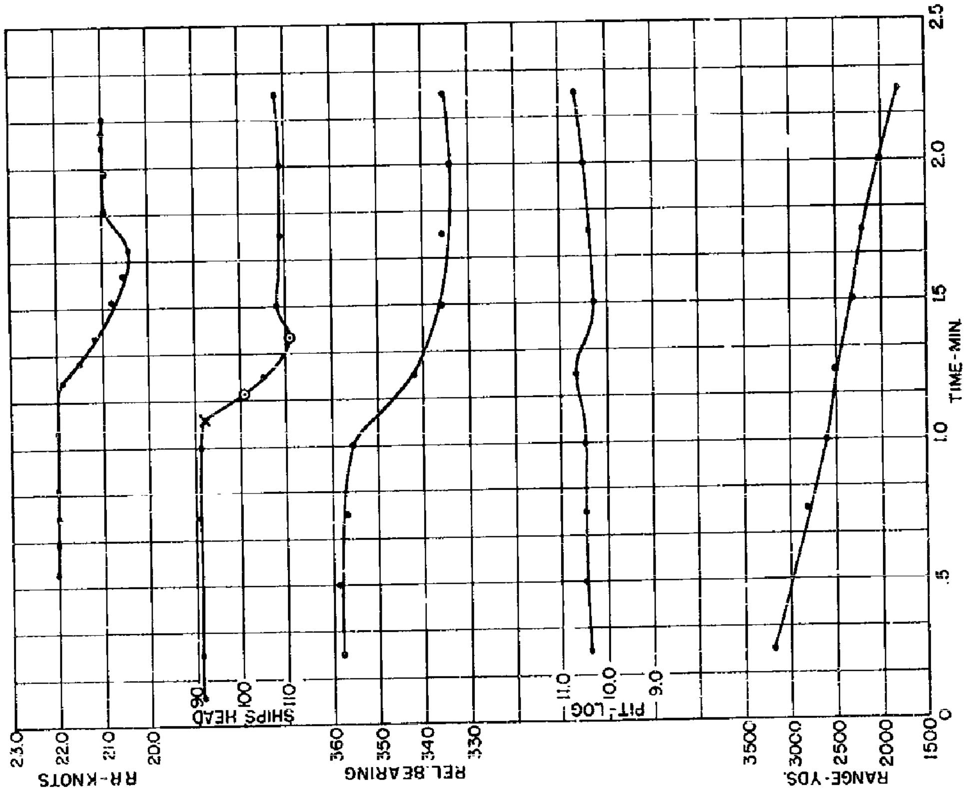


Figure 53 - Time plots of maneuver for detecting change of course by range rate

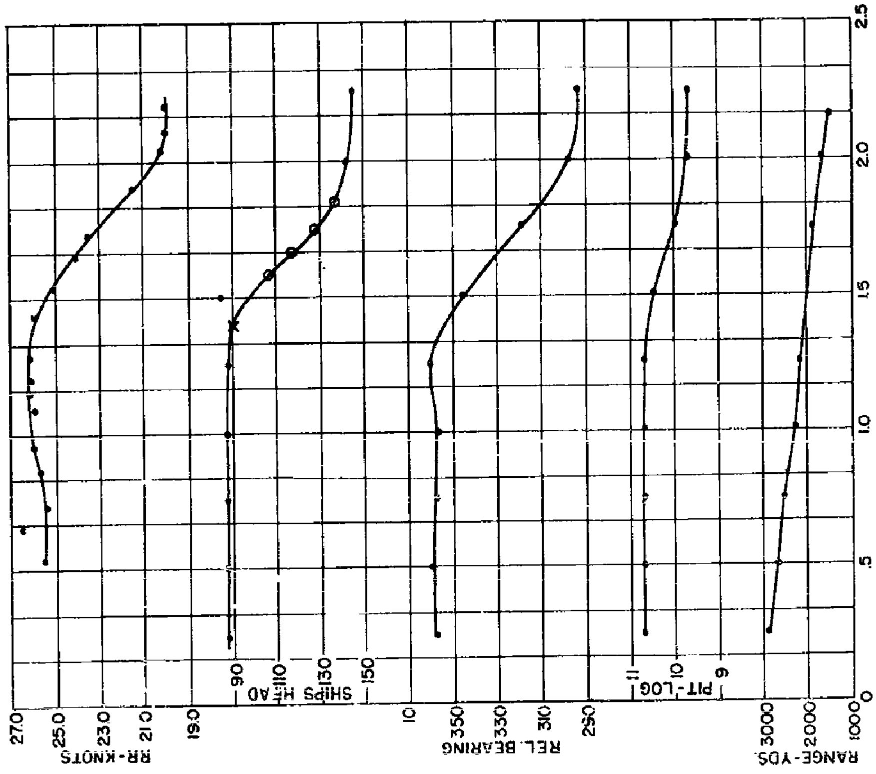


Figure 55 - Time plots of maneuver for detecting change of course by range rate

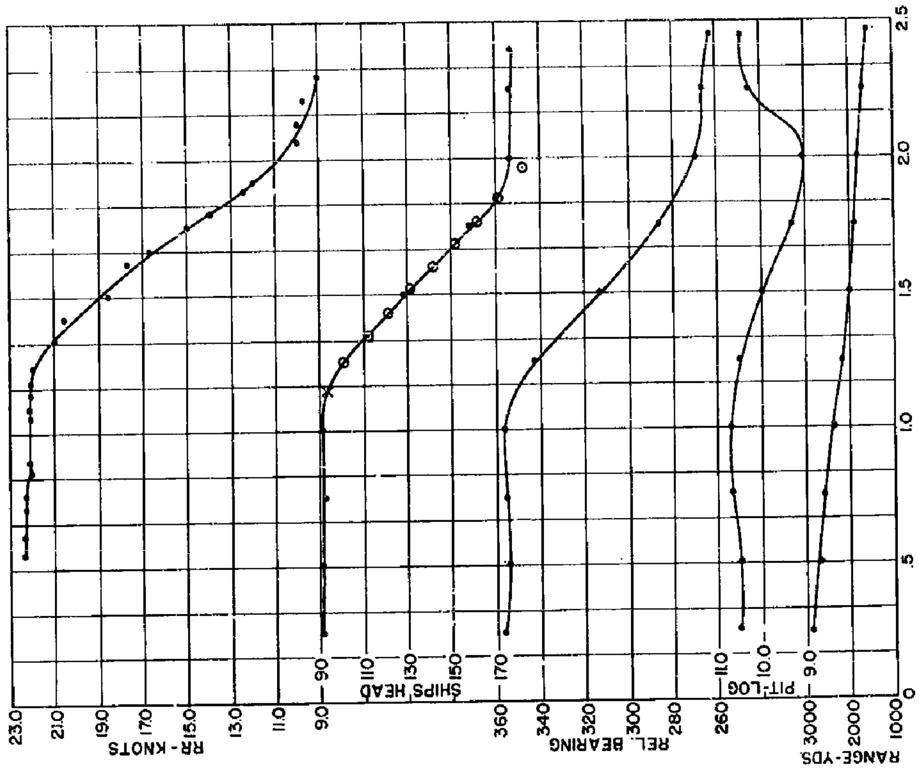


Figure 56 - Time plots of maneuver for detecting change of course by range rate

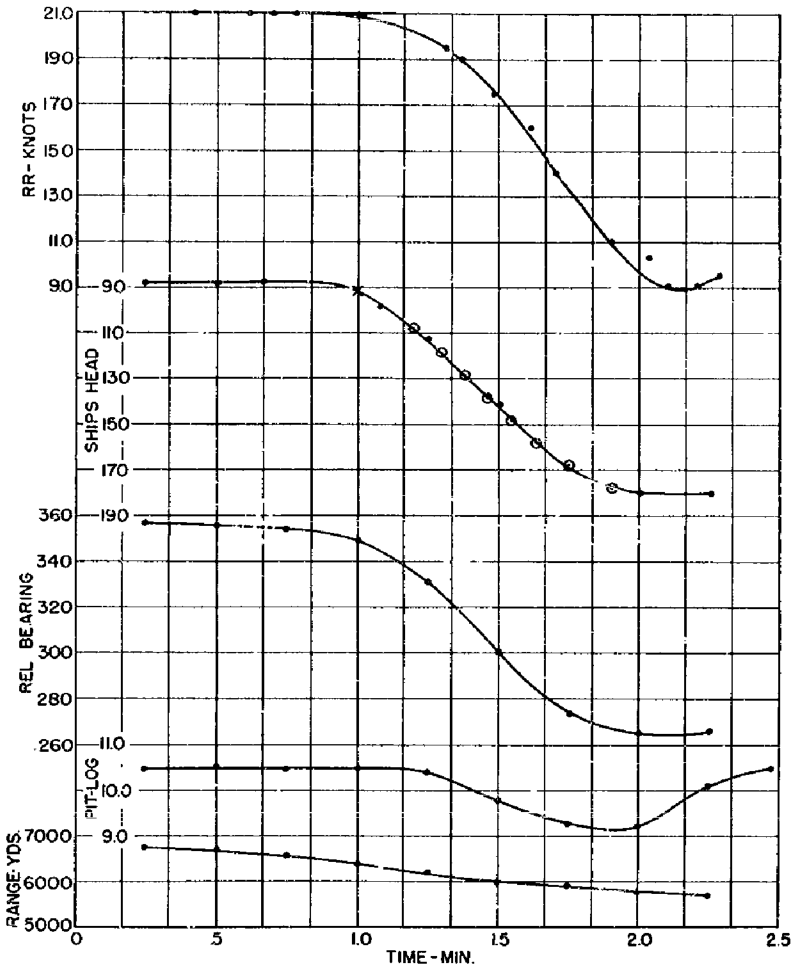


Figure 57 - Time plots of maneuver for detecting change of course by range rate

Phase Signatures - During the passive range rate measurements and turn detector tests of the Graphic Indicator, it was observed that the transmitted pulse of the sonar equipment in E-PCS-1431 did not produce a straight line presentation on the Graphic Indicator cathode-ray tube. The presentation as shown in Figure 58 consisted of a sloping forward portion with small humps appearing on the horizontal portion. This was termed the "signature" of the sonar transmitter. The same signature remained constant from ping to ping, and was also received without alteration at ranges up to 10,000 yards. This has significant implications; first, it is evidence that there is no appreciable phase modulation or distortion in one-way transmission over a path up to 10,000 yards, and second, it indicated a means of identifying particular sonar transmitters by passive listening. This is important in prosubmarine application when several surface vessels are echo-ranging in the vicinity of a submarine. By observing the signature of each vessel, the submarine is able to identify and track a particular vessel, thus avoiding any ambiguity as to the vessel being observed.

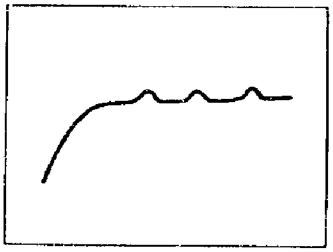


Figure 58 - Pulse signature

Use of the Graphic Indicator in Convoy Screen Penetration - A Graphic Indicator was installed in USS SEA CAT (AGSS-399) for the monthly ASW tactical demonstration conducted by the Commander of the Key West Task Force. SEA CAT was a member of the submarine force whose duty in the demonstration was to sink a target ship protected by a screen of five escort vessels. In order to penetrate the screen and come to within firing range of the target ship, the vicinity of one of the escort vessels was selected as the point of penetration. A visual observation of the escort vessel was made at approximately 8000 yards to estimate its absolute range rate. The Graphic Indicator operator set this information into the instrument and continued to track the vessel in its maneuvers. The range was closed to approximately 6000 yards and another vessel observation was made to check the validity of the initial range rate determination. This second observed range rate coincided with the Graphic Indicator range rate reading and it was concluded that the Graphic Indicator was giving accurate range rate readings.

The submarine submerged to 200 feet and closed on the escort vessel. During the time of closure, the range rate of the escort vessel was observed on the Graphic Indicator and plotted. When the escort vessel presented an opening range rate, indicating a turn (in the escorting zig plan), the submarine increased speed and penetrated the screen through an area astern of the escort vessel. This maneuver facilitated penetration of the screen and a simulated torpedo hit was made on the target vessel.

The capability of the Graphic Indicator to distinguish the sonar signature of the one escort vessel from the signature of the other four in the screen was also very important in this simulated attack.

Chesapeake Bay and Potomac River Areas, 6 - 9 November 1950

The primary purpose of these tests was to measure the speed of the vessel over the bottom in shallow water, such as that in the Chesapeake Bay and Potomac River, where depths vary from 20 to 100 feet.

The Graphic Indicator was connected in parallel with the receiving system of the QCT sonar equipment aboard USS E-PCS-1426. In order to obtain a standard of comparison, the time of passage between charted buoys was used to determine absolute speed. Table 6 gives the data for a representative number of runs made in the Chesapeake Bay and Potomac River areas. In addition, a number of runs, made in the Key West area, are included in the Table. Distance measurements made in the Key West runs were taken from navigational charts and checked by radar range measurements. The time and distance speed is compared to the average speed measured by the Graphic Indicator over the same distance and during the same time interval.

Since there were possibilities of slight inaccuracies in distance determinations, a mean deviation was taken for the eleven runs recorded in the table. The mean deviation between the speed as obtained from time and distance and the speed as obtained from the Graphic Indicator was 0.097 knot, indicating an accuracy for these measurements in the order of approximately ± 0.1 knot.

TABLE 6
Speed Data Computed from Navigational Fixes Compared with Speed Data Obtained by Graphic Indicator

Date	Vessel	Area	Distance (Min. Sec.)	Time (Min. Sec.)	Speed (Knots)	
					Computed	GI
11/9/50	E-PCS-1426	Chesapeake Bay Potomac River	2.50	16:33	9.06	9.18
11/9/50	"	"	2.94	19:52	8.88	8.95
11/9/50	"	"	2.70	17:33	9.23	9.00
11/9/50	"	"	1.64	11:32	8.53	8.54
11/9/50	"	"	2.80	19:24	8.66	8.73
11/8/50	"	"	1.95	10:14	11.44	11.31
11/8/50	"	"	1.95	11:35	10.10	10.20
11/7/50	"	"	1.95	11:35	10.10	10.27
5/31/51	USS Amberjack (SS522)	Key West	2.88	11:20	15.25	15.37
2/27/51	USS Robinson (EDE220)	Key West	2.88	11:47	14.67	14.63
2/28/51	"	"	2.88	11:38	14.86	14.87

Several other observations of interest were: When E-PCS-1426 was allowed to drift in the current, the vessel's movements were determined to within 0.2 knot and the direction to within 10°. This determination was by training the ship's transducer through 360°, plotting the magnitude of drift along each bearing. From this plot, it was observed that the vessel presented the maximum opening range rate along a particular bearing 180° from the bearing for maximum closing range rate. Magnitudes of drift were measured as low as 0.1, 0.2, or 0.3 knot. Another interesting observation that emphasizes the sensitivity of the Graphic Indicator was made when the speed of the vessel was changed, that is, when the propeller turn count was changed abruptly. The vessel gradually approached the assigned speed but upon reaching that speed, it over-shot slightly by 0.1 to 0.4 knot, then gradually returned to the speed for which the turn count was set. The over-shoot observed was attributed to the change of ship's dynamic characteristics as her acceleration decreased.

Key West, Florida, 20 November - 9 December 1950

A series of qualitative tests were made with the Graphic Indicator in the Key West area in cooperation with vessels of the UTU (Underway Training Unit) and USS SARSFIELD. Attack runs made by UTU vessels in the course of normal training procedure were monitored in these tests.

Analysis of the presentation observed on the Graphic Indicator during these runs revealed that three apparent targets are present when echo ranging on a submarine. One of the possible targets, as shown in Figure 59, is the hull of the submarine. A second possible target is the dynamic wake or thrust area immediately aft of the submarine's propellers. The third target is the static wake further aft in the medium. The occurence of the latter two targets is a function of the submarine's speed, depth, and aspect. For example, when the attack was made from the quarter, as shown in Figure 59, and the submarine's velocity was sufficient to generate an appreciable wake, it was observed on the Graphic Indicator that the hull presented a velocity and phase character directly related to the vessel's speed, aspect, and its reflecting qualities. The second target, the thrust area, presented a different velocity or range rate from that of the hull. The direction of thrust was opposite to that of the submarine. Its phase character was also different from that of the hull because of the irregular boundaries of the reflecting area. The third observed target, the static wake, produced an energy return showing a range rate identical to that of the volume reverberations. The phase character was also identical to that of the volume reverberations. Whether or not the dynamic wake could be observed depended upon the speed of the submarine, and on its bearing, aspect, and range. However, the stabilized wake was observed in nearly all instances.

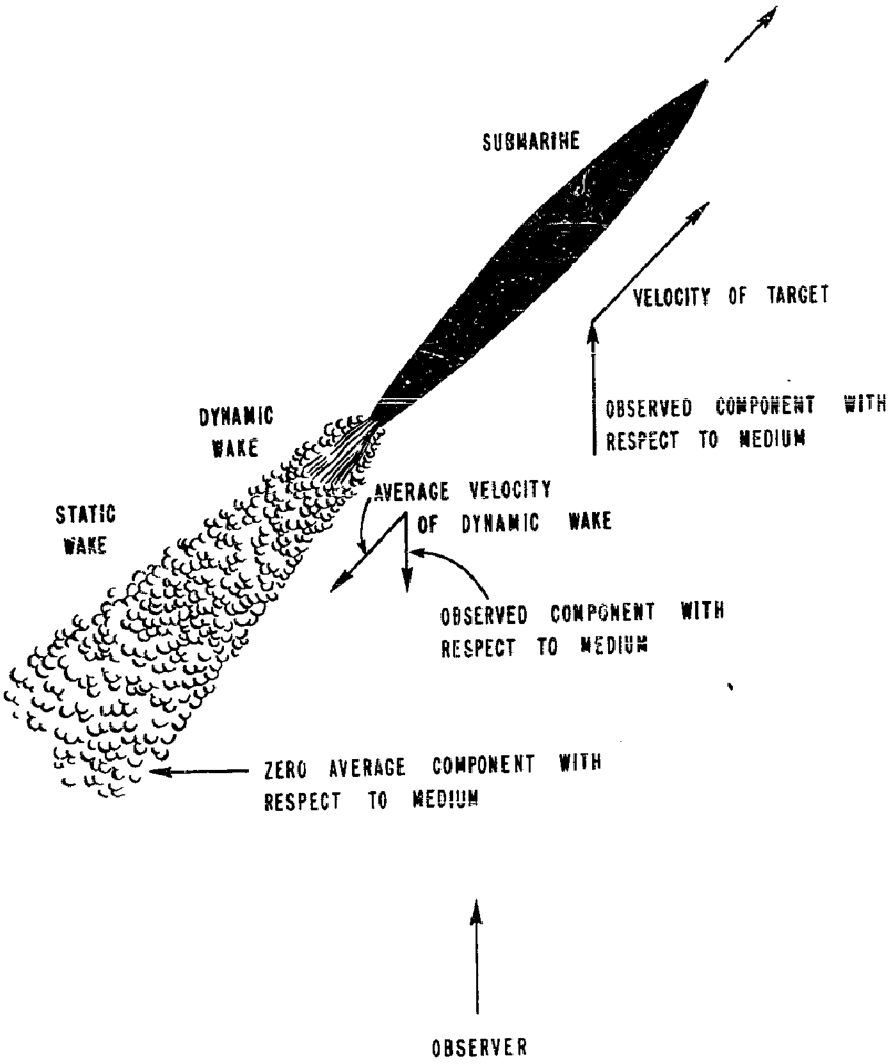


Figure 59 - Velocity components of sonar targets

During these runs it was observed that many of the initial conventional sonar detections were made on the static wake rather than on the target's hull. This occurred when the bearing of the target's wake from the searching ASW vessel was not perpendicular to the direction of the existing current. For example, if the search was made with or against the current, the static wake showed a doppler with respect to the bottom reverberations. This doppler was clearly distinguishable over the audio system and easily mistaken for a doppler produced by the hull of the submarine. The doppler produced by the motion of the static wake with respect to the bottom was identical to the doppler produced by velocity of the current in the direction of propagation. Since the currents in the Key West area were as high as 3 to 4 knots, this condition was prevalent.

During quarter attacks with conventional sonar, the transducer was frequently trained on the static wake during the early portion of the run and in the last few seconds of the attack the transducer was trained on the dynamic wake. It is obvious that this procedure resulted in false bearing and range information.

Since, with standard sonar systems, the operator tends to select the target presenting the maximum energy return, it is obvious that such a system is not at all times selecting the true target. If the hull of the submarine is located only in the last few moments before contact is lost, the fire control information is inaccurate since its accuracy depends on the history of a number of pings.

Additional runs were made aboard USS SARSFIELD in which operations conducted by SurAsDevDet were monitored with the Graphic Indicator. Information obtained during operations confirmed that obtained aboard UTU vessels.

One day was allocated to submarine evasion tactics. This operation included USS SEA CAT (AGS-399) and a destroyer making ASW training runs on the submarine. A series of 16 runs were made; on the first 8 runs, the submarine maintained a constant course, speed, and depth with no evasion. The second 8 runs were made with the submarine operating with full evasion permissible. During the first 8 runs, the range rate was observed on the Sonar Graphic Indicator in the submarine and a plot kept of range rate versus time. These plots resembled those which will be shown in Figures 60, 62, and 64. It was noted in these plots that during the closing the surface vessel always came to an approximately constant closing range rate, and maintained it, until passing overhead. Knowing that the attacking destroyer was equipped with QHB sonar equipment and the integrated sonar system, it was decided to attempt to evade the destroyer by preventing the range rate from coming to a constant value. It was apparent that by preventing the range rate from remaining at a constant value for any appreciable period of time that the computers aboard the destroyer would be unable to solve the fire control problem. Therefore, during the second 8 runs or the evasion runs, the submarine's Conning Officer maneuvered the submarine to prevent the range rate from becoming constant. By combining the range rate versus time plot and bearing information from the JT operator, the Conning Officer was able to evade the destroyer in 7 of the 8 runs. On the seventh run the Conning Officer decided to maneuver the submarine as nearly as possible into a direct hit. This he was able to do, and the charge was detonated directly above the submarine.

Key West, Florida, 20 February - 1 March 1951

The fourth series of tests at Key West was conducted as an assist project (Project Bu/S172/A16-3, Task Six) with Commander, Surface Antisubmarine Development Detachment.

The Graphic Indicator was evaluated as an instrument for prosubmarine and antisubmarine warfare in the following applications:

(a) Measuring, under simulated attack, range rate in an ASW vessel.

(b) Measuring relative range rate in a submarine under simulated search and attack conditions.

(c) Classifying of submarine targets under simulated ASW attack.

(d) Determining, in the submarine, the type of course run by an echo-ranging ASW vessel (zig-zag, constant helm, etc.).

The vessels participating were: 1) USS WILKE (EDD800) 20, 21, 23, and 26 February 1951, 2) USS ROBINSON (EDE220) 27, 28 February 1951, 3) USS GUAVINA (SSO362) 23 February 1951, 4) USS SEA CAT (AGS399) 26, 27, 28 February, and 1 March, 1951. Sonar equipments utilized were the QHB in WILKE, the QGB in ROBINSON, and WFA in GUAVINA and in SEA CAT.

Attack Runs - The major maneuver used in these tests was a normal, simulated depth charge attack by an ASW vessel on a submarine. The initial range at zero time of each run was 1000 yards or greater. Data recorded at 30-second intervals included course, speed (pit-log), and relative bearing (sonar) from each vessel. Range rate from the Graphic Indicators was recorded at 2- to 15-second intervals in both the submarine and ASW vessel, and range rate from the standard range recorder at 15-second intervals. A DRT plot, kept by the ASW vessel, included both own-ship's track and that of the submarine as determined from ship's sonar data.

The accuracy of the attack was determined by the usual procedure of dropping a hand grenade, followed by a dye marker at the calculated time of detonation of the simulated depth charge. At the same time, a slug of air was released from the submarine to mark its position. Dye and slug locations were obtained by visual observation from the bridge of the surface vessel and recorded on the DRT plot with an arrow to indicate the course of the attacking vessel.

A total of 46 runs was made with the submarine at 100-ft keel depth. Eighteen of these runs were made with the submarine holding a steady course, depth, and speed, and 28 were made with the submarine taking evasive action.

The conning information for all but two of the attacks was supplied by the ship's standard sonar equipment and independent observations were made with the Graphic Indicator. Two attacks were made from information furnished by the Graphic Indicator.

A composite plot of the range rate versus time, obtained from the sonar range recorder and a Graphic Indicator in the ASW vessel and a Graphic Indicator in the submarine, was made to determine the ability of the Graphic Indicator to measure and track range rate. The range rate obtained from the Graphic Indicator in the submarine was relative, unless the reference oscillator coincided in frequency with the transmitted pulse of the ASW vessel at a zero range rate condition. The relative range rate data was converted to an absolute range rate basis. This conversion resulted in a vertical shift of the curve but no change of shape. The direction and magnitude of this shift are shown in Table 7.

Representative curves of data from runs in which the submarine was on a steady course and speed are shown in Figures 60, 62, and 64.

TABLE 7
Direction and Magnitude of Shift of Relative Range Rate Curves

Fig. No.	Run No.	Magnitude of Shift (knots)	Direction Moved
60	2 (2/27/51)	0	---
62	3 (2/27/51)	1.2	Opening
64	2 (2/28/51)	0.8	Closing
66	8 (2/28/51)	1.0	Closing
68	9 (2/28/51)	1.2	Closing
70	11 (2/28/51)	0.6	Opening
72	5 (2/28/51)	2.0	Closing
74	1 (3/1/51)	2.0	Opening
76	2 (3/1/51)	3.0	Opening
78	3 (3/1/51)	4.0	Opening

The relative range rate (Figure 60) from the submarine was measured continuously with the Graphic Indicator throughout the total run even when the surface vessel passed overhead and the range rate went from closing to opening. The submarine was able to measure relative range rate regardless of whether the respective transducers were trained directly toward each other or away from each other. This ability of the submarine to maintain contact and measure relative range rate was typical of all runs.

The agreement between the data from the Graphic Indicator in the submarine and the ASW vessel was consistent. The range rate data from the sonar range recorder agreed with that from the Graphic Indicators only in the latter portion of the approach when the range rate had maintained a constant value for an appreciable time. This improvement in the accuracy of the range recorder with time for a constant range rate condition is inherent, since a large number of points in a straight line makes the alignment of the cursor easier for the operator. The characteristic of the range-recorder data to fluctuate was observed in the majority of the runs.

Figure 61 is the dead reconning trace (DRT) and sonar plot for the run. In the analysis of the data, an attempt was made to utilize the DRT and sonar plot for a further comparison of range rate. This was unsuccessful because of the wide variations in the range and bearing measurements. These variations are most clearly evident in runs with the submarine holding a constant course and speed.

Figure 62 illustrates the ability of the Graphic Indicator to produce more reliable range rate information than the tactical range recorder. This is seen between six and seven minutes run time, just as the ASW vessel was beginning to pass over the submarine. Figure 63 is the DRT and sonar plot for this run.

Figure 64, similar to the two preceding illustrations, is another example of range rate versus time obtained from a submarine holding steady course and speed. In this run, the air slug came to the surface approximately 20 yards from the dye marker. Figure 65 is the accompanying DRT and sonar plot.

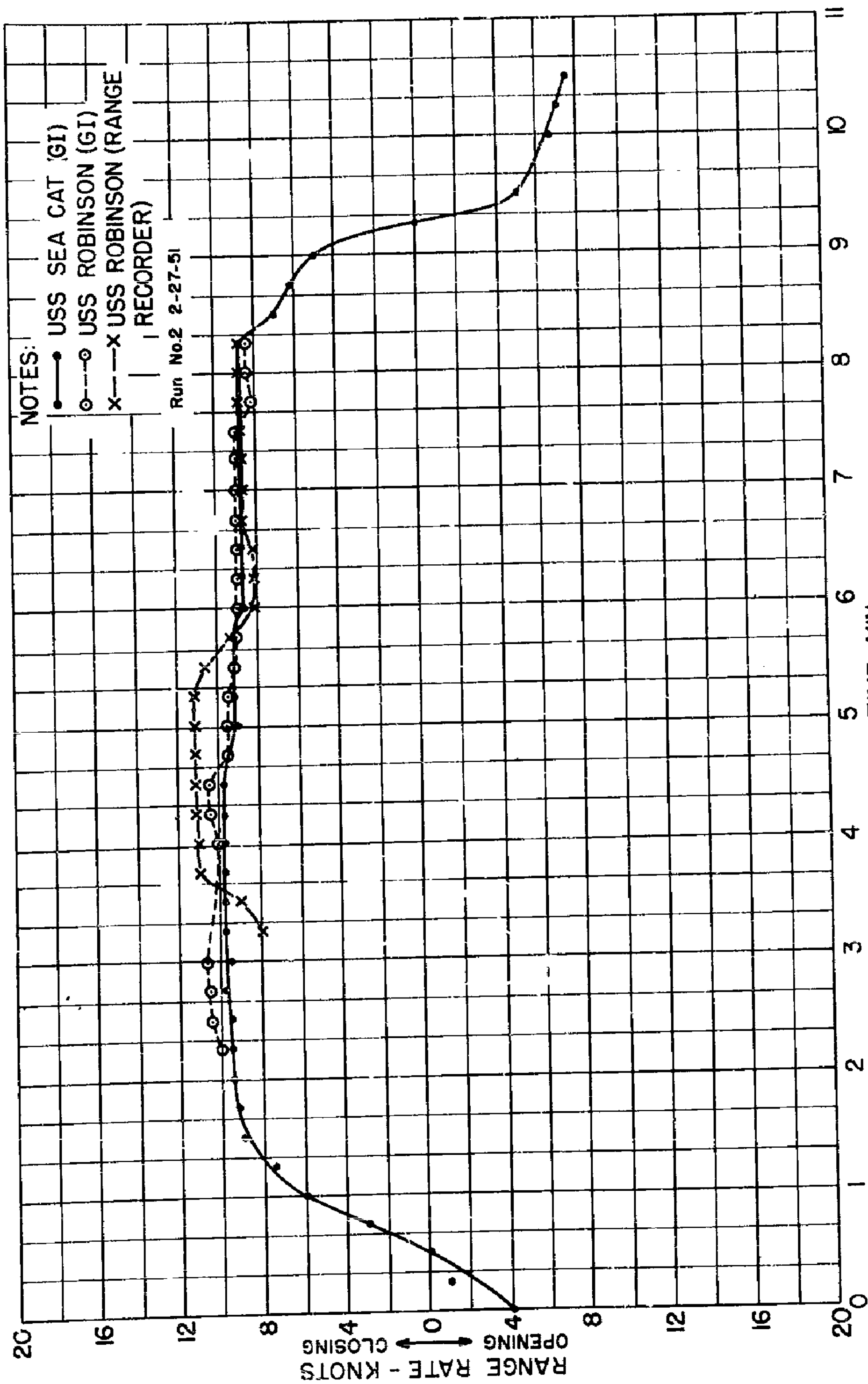
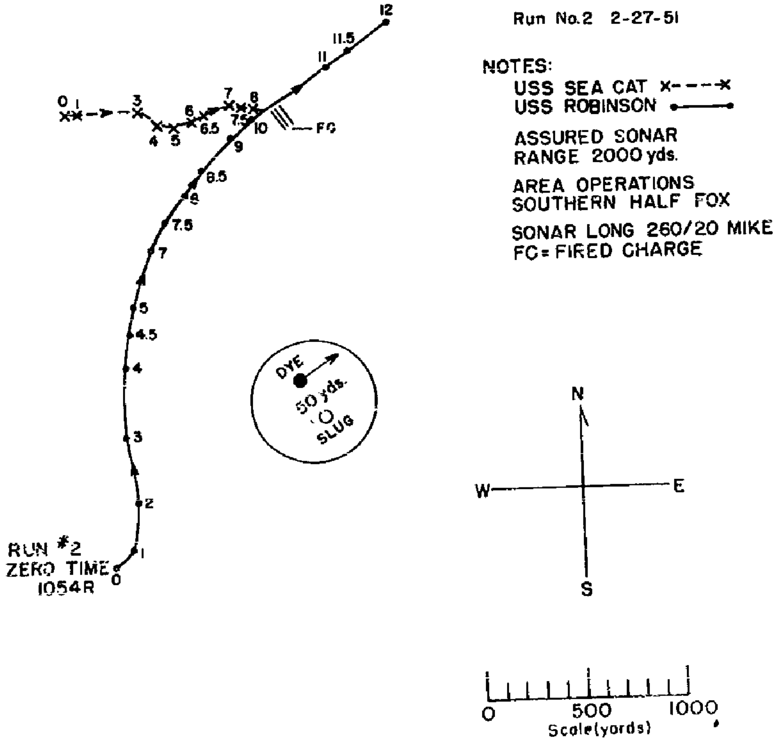


Figure 60 - Attack run, range rate versus time

The following series of illustrations are examples of runs in which the submarine changed both course and speed. In Figure 66, the less steep slope of the range-rate curves, as the surface vessel passed over the submarine, indicates that in this run the surface vessel did not pass directly above the target but a considerable distance to one side. In addition to the degree of slope of the range-rate curves, the fact that the sonar in the surface vessel was able to track the target continuously, as illustrated, indicated the magnitude of the miss. Figure 67 is the associated DRT trace and sonar plot.

The above range-rate curves demonstrate the advantage of the Graphic Indicator method of measuring range rate when the target is maneuvering.

Figure 68 is another example of the range rate versus time plot of an attack run with the submarine maneuvering. In this figure, the range rate just prior to the lost-contact point, decreases in the two curves from the Graphic Indicators, whereas the range rate from the range recorder shows an increased closing rate at this point. From the record of the submarine's course and speed, it is known that, at this point in the run, the submarine made a turn away from the surface vessel and increased speed at approximately two minutes run time. A turn away from the attacking vessel produced a decreasing closing range rate as verified from both curves by the Graphic Indicators. On the other hand, the range recorder gave an increasing closing range rate. This is explained by the manner in which a submarine turns, by pivoting about a point forward of the conning tower, so that the stern area presents an increased closing range rate and the wake area an even greater closing range rate. Since the submarine increased speed at this time, the wake was increased and the energy returning from the wake increased likewise. Thus by this interpretation, the range recorder presents an increased closing range rate, true for the wake, that is interpreted as a turn toward the attacking vessel when the turn is actually away from the attacking vessel. This explanation is further strengthened by the magnitude of the miss. The air slug released by the submarine came to the surface approximately 300 yards from the dye marker. Figure 69 is the corresponding DRT trace and sonar plot for this run.



Run No. 2 2-27-51

NOTES:
USS SEA CAT x---x
USS ROBINSON •——•
ASSURED SONAR RANGE 2000 yds.
AREA OPERATIONS SOUTHERN HALF FOX
SONAR LONG 260/20 MIKE
FC = FIRED CHARGE

Figure 61 - Attack run, DRT

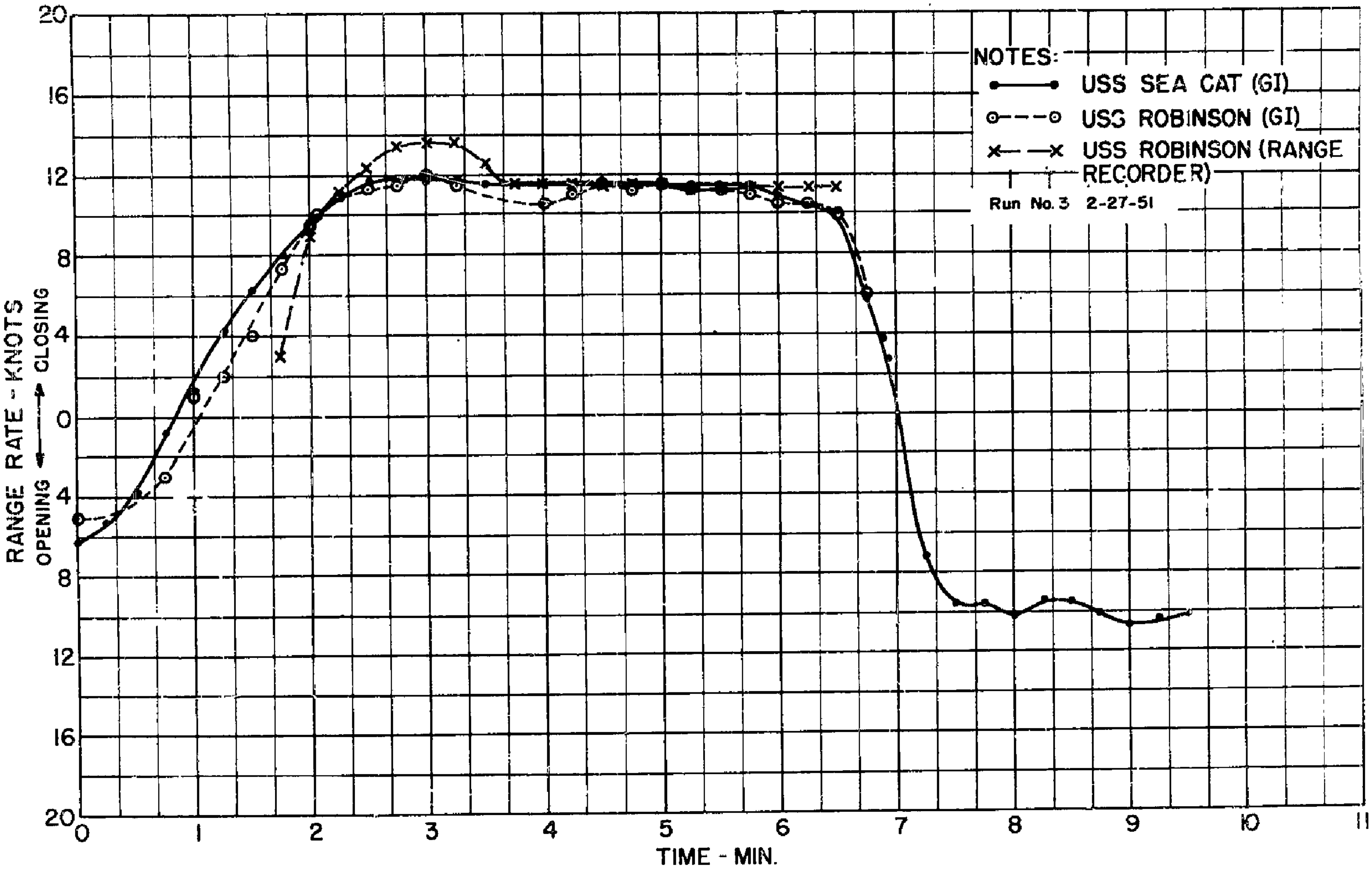


Figure 62 - Attack run, range rate versus time

This run is an excellent example of the classification capabilities of the Graphic Indicator in distinguishing between the hull and the wake of a submarine target. It also demonstrates the ability of the Graphic Indicator to track changes in range rate of a maneuvering target.

In two of the runs during these tests, the information from the Graphic Indicator in the attacking surface vessel was used in conning the vessel in the attack. Figure 70 is the range rate versus time plot for one of these runs. The significant feature is the steepness of the slope of the range-rate curve as the surface vessel passes close over the target. The accuracy of the hit was verified by the fact that the air slug released by the submarine came to the surface approximately 5 yards from the dye marker. The range rate from the range recorder in this run was not recorded. The associated DRT and sonar plot is seen in Figure 71.

The submarine curve (solid line and dots in Figure 72) is typical in illustrating the relative range rate versus time pattern of a searching ASW vessel before gaining contact. It shows that the relative range rate varies in a nonuniform manner with time, as the surface vessel proceeds in the search plan.

Figure 72 also illustrates one of the means of placing the relative range rate received by the submarine on an absolute basis. For example, if this curve were received by the submarine without a zero range-rate reference, that is, shifted up or down from the zero range rate axis, an absolute reference could be set by drawing a mean in the curve and

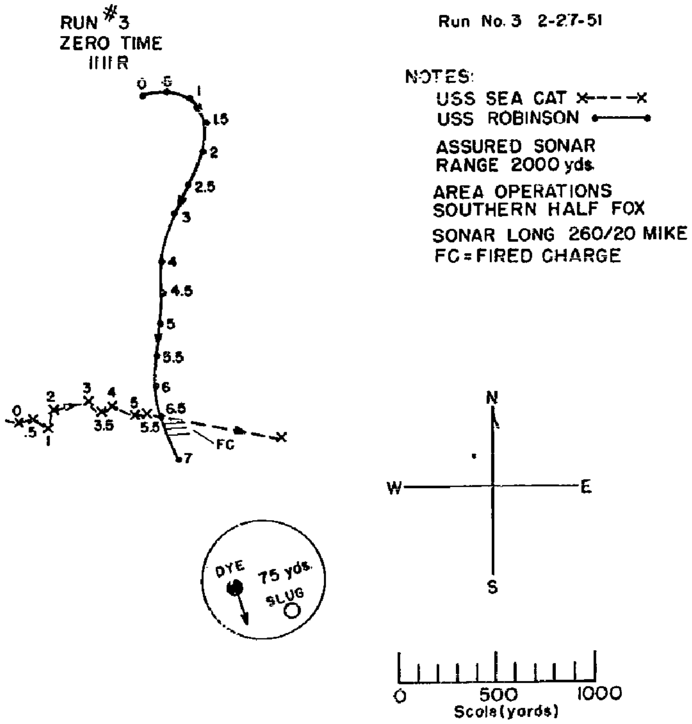


Figure 63 - Attack run, DRT

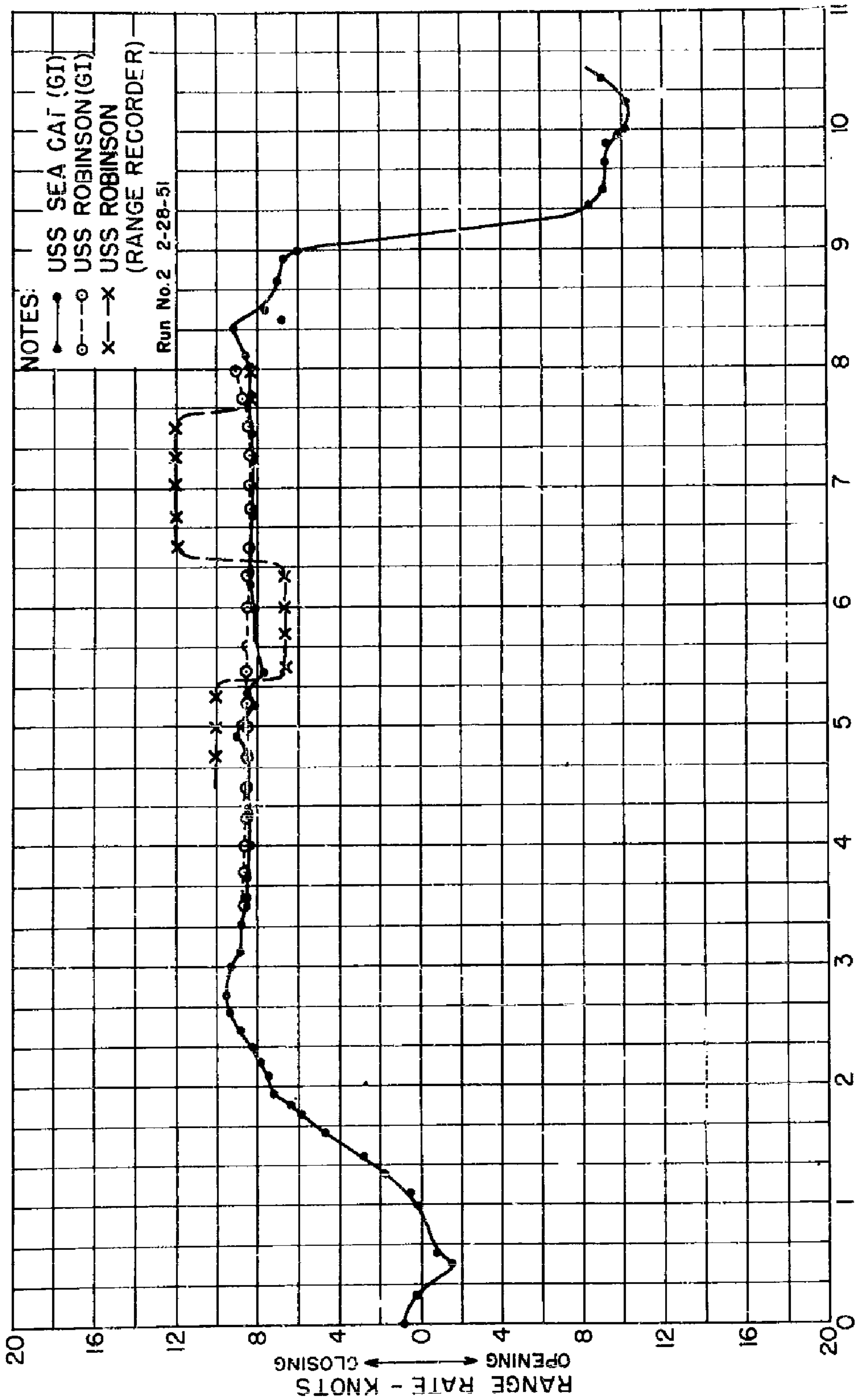


Figure 64 - Attack run, range rate versus time

correcting the reading of the instrument to this mean. This can be done since a vessel maneuvering in a detectable area has to present an equal amount of opening and closing range rate or move out of the area. The accuracy of achieving this type of reference is estimated to be of the order of ± 1 knot.

During this run, the ship's sonar equipment never had an assured contact on the target. Thus the range recorder was unable to obtain a range-rate measurement. This is illustrated in the accompanying DRT plot, Figure 73. As the training operator searched the area, the searchlight transducer was trained through the position occupied by the target. Throughout this search, the operator of the Graphic Indicator in ROBINSON was able to detect the target and measure the range rate as illustrated by the points represented by small circles in Figure 72. At these points, the Graphic Indicator operator called the contact and measured range rate, but the sonar operator was unable to observe any indication of the target.

The agreement between the curve obtained by the Graphic Indicator in the submarine and the points obtained in the surface vessel was so consistent that the contacts were definite.

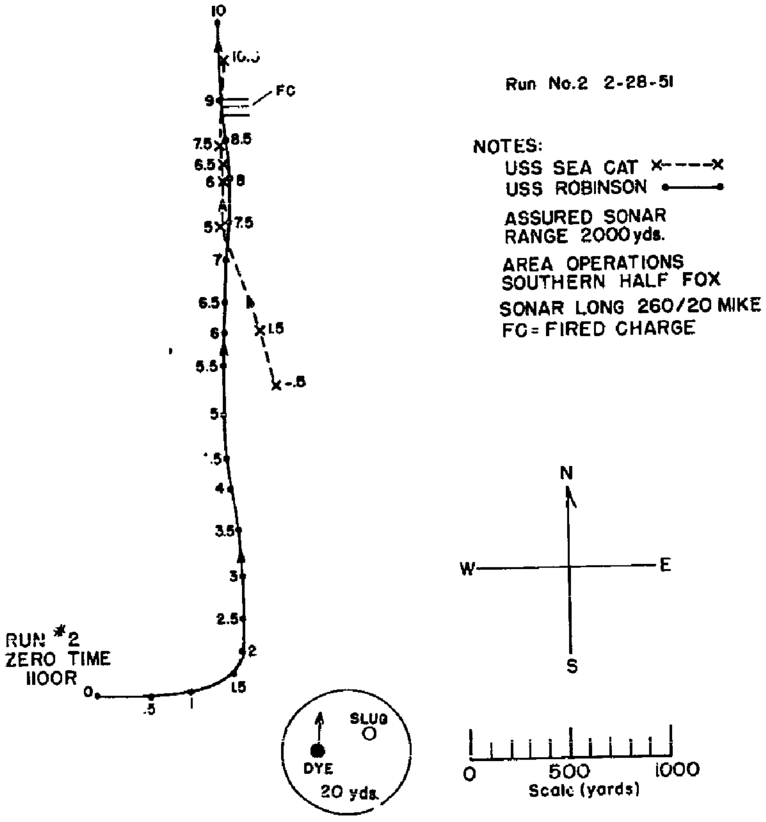


Figure 65 - Attack run, DRT

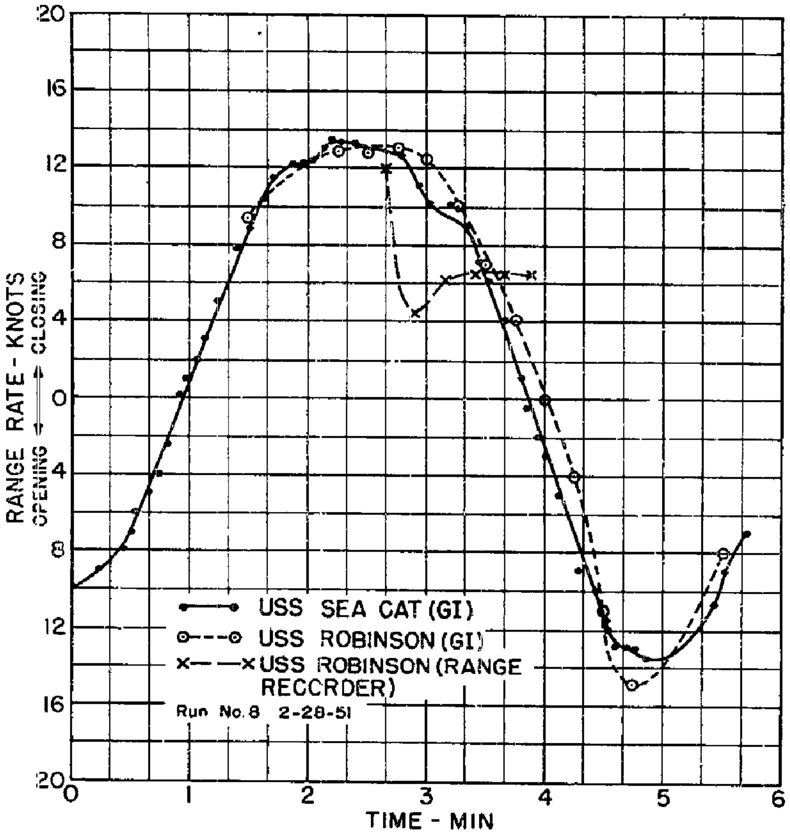


Figure 66 - Attack run, range rate versus time

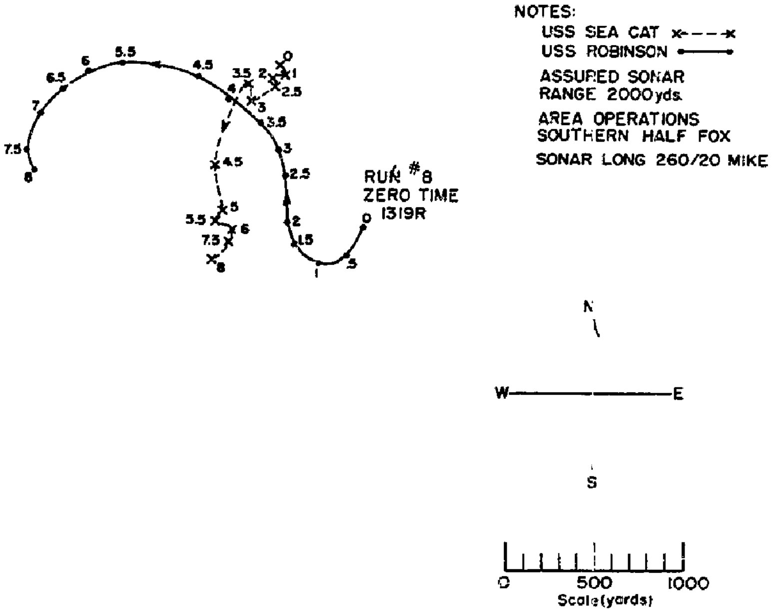


Figure 67 - Attack run, DRT

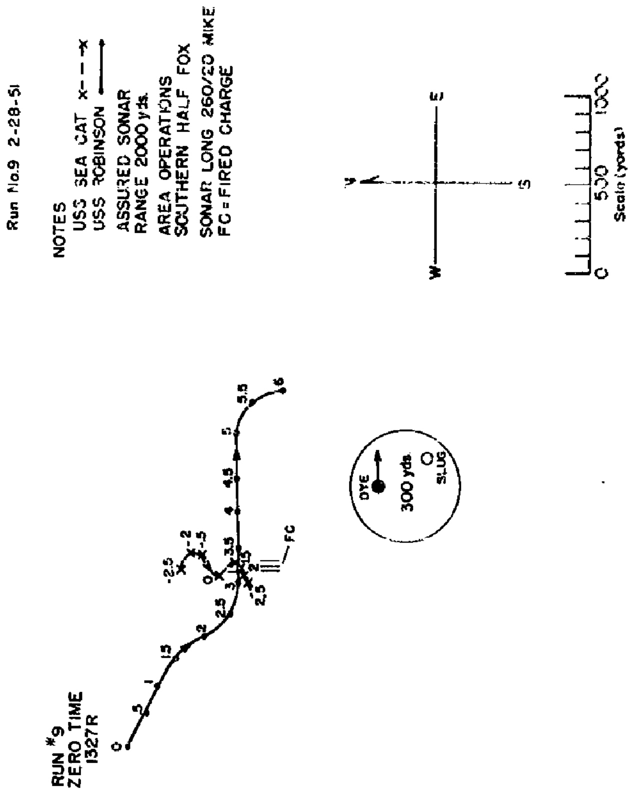


Figure 69 - Attack run, DRT

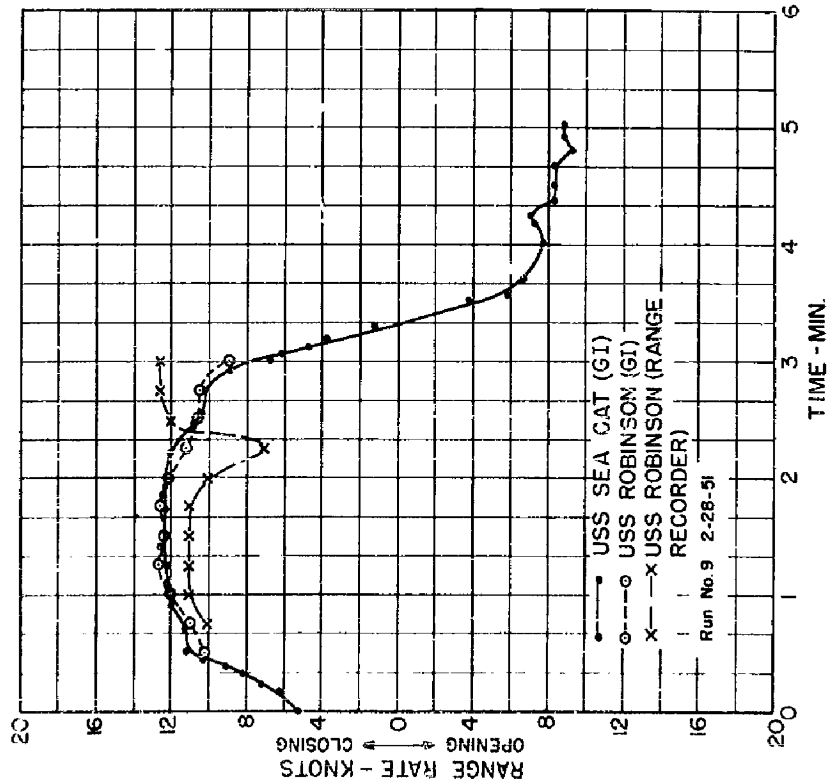


Figure 68 - Attack run, range rate versus time

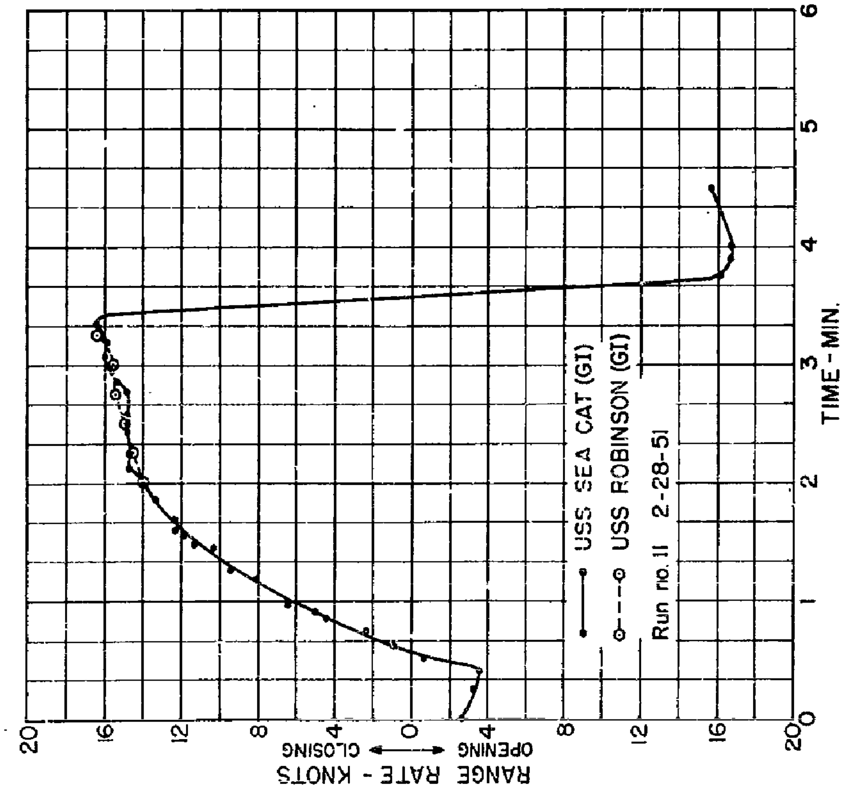


Figure 70 - Attack run, range rate versus time

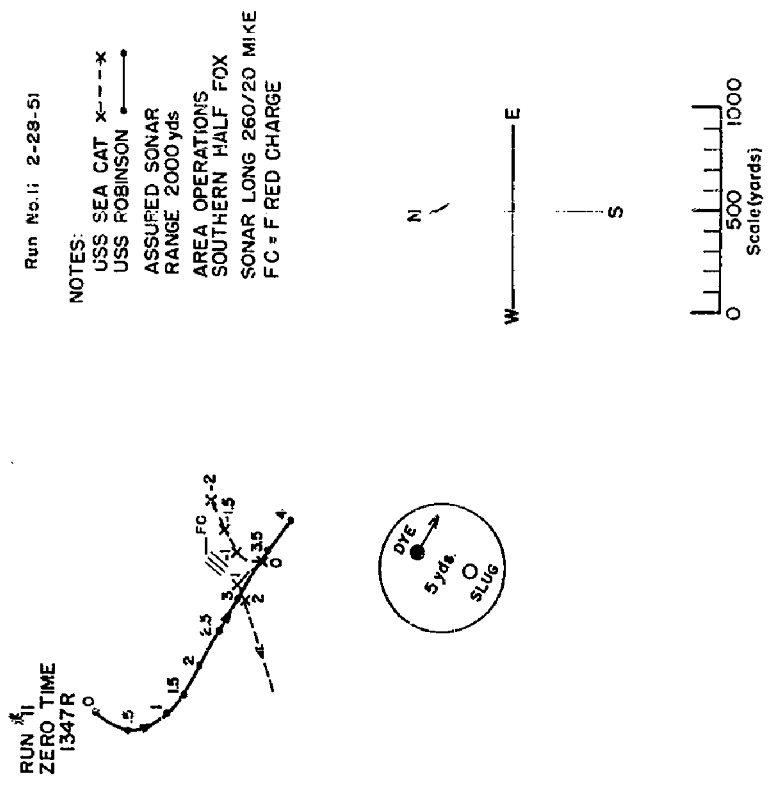


Figure 71 - Attack run, DRT

These tests and illustrations demonstrate the ability of the Graphic Indicator, when used in simulated ASW attack conditions:

a) to track accurately and to measure the relative range rate of an echo-ranging vessel from a passively listening submarine,

b) to classify the target as hull or wake in an ASW attack by differentiating between the hull and the wake echoes because of the differing instantaneous range rates or phase character,

c) to track accurately and to measure range rate and changes of range rate of a maneuvering submarine target in an ASW attack, and

d) to detect a submarine target and measure its range rate when standard sonar equipment did not do so.

Determination of Type of Course Run by an Echo-Ranging Surface Vessel by Passively Observing its Relative Range Rate in a Submarine – Runs were made with a surface vessel and a submarine running parallel courses and passing abeam as demonstrated by the DRT and sonar track from the surface vessel in Figure 75. In the first run, Figure 74, the surface vessel ran a zigzag course as illustrated in the third curve of the figure, a plot of the vessel's course versus time. The submarine's course is plotted in the first curve shown in this figure. The range rate curve obtained in the submarine clearly shows each change in course and is very similar to the course curve from the surface vessel. Plotted on this curve are the values of range rate (circles) measured by the Graphic Indicator in the echo-ranging vessel which show agreement with those obtained by the Graphic Indicator aboard the submarine. The range rate from the range recorder was not recorded during this run. In Figure 75, the plot of the submarine's course by sonar is in poor agreement with that of the course versus time plot from the submarine's gyro shown in Figure 74. This is attributed to the inability of the sonar to measure accurately range and bearing.

The plot in Figure 76 is similar to that in Figure 74 with the exception that the surface vessel was attempting to run a "constant helm" course instead of a "zigzag" course. The submarine's course is not plotted in this Figure, but is maintained at a constant value similar to that shown in Figure 74. In this run, the range rate from the range recorder in the surface vessel was plotted (crosses) along with that from the Graphic Indicators in the surface vessel and the submarine,respectively,in order that a comparison could be made. Note the fine-structured changes in the ship's course, as indicated by the passive range-rate curve. An example is the dip in the curve after a run time of a little past 18 minutes. This fine structure is typical and can be correlated with factors such as pitch and roll of the surface vessel, correction of course by the helmsman in the surface vessel, and other small variations and ship's movement that produce the change in range rate. The DRT for this run is shown in Figure 77.

A run was made (Figure 78) similar to that in Figure 76, except that the surface vessel ran a constant course while the submarine ran a varying course as seen in the DRT (Figure 79), and in the course versus time curve (Figure 78). Since the speeds were lower in this run than in previous runs, the variations in range rates were not as great.

As in the previous run, the range rate from the Graphic Indicator in the submarine and surface vessel from the range recorder were compared with time.

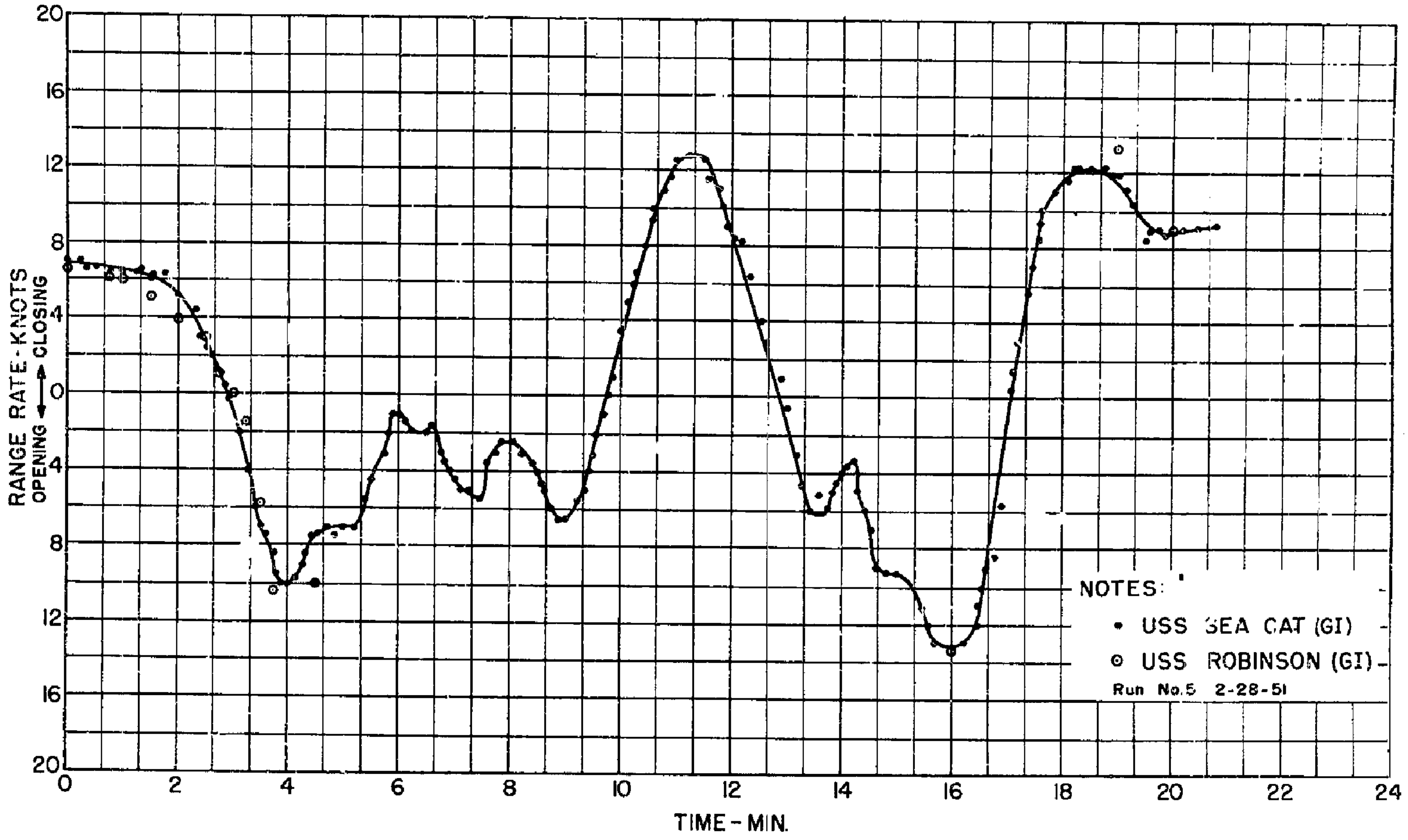


Figure 72 - Search, range rate versus time

The change in range rate with change in course was observed as in the previous run. However, the most significant observation in this run is the inaccuracy of the range rate data from the range recorder. The scatter of points on the range-rate curves in this run is greatly increased over that of the previous run. In the previous run, Figure 76, the target is on a steady course and speed as opposed to Figure 78 in which the situation is reversed with the target on a varying course and the surface vessel on a constant course. In the first condition, the target has essentially a constant aspect with time; in the second condition, the aspect is changing as the course changes with time. Note the difference in the spread of range-recorder range-rate points in the case of the target with varying aspect as compared to the constant-aspect target. This increased variation is interpreted to be a result of the inability of the sonar to give accurate range and bearing measurements under these conditions. This data further indicates the inability of the sonar equipment to classify the target properly as to hull and wake. This inability of sonar equipments to measure range and bearing accurately with varying aspect has been observed by the Surface Antisubmarine Development Detachment, Key West, Florida. The findings of this activity are reported in the Operational Development Forces' report, "Evaluation of the AN/SQG-1(XN)," 11 August 1951.

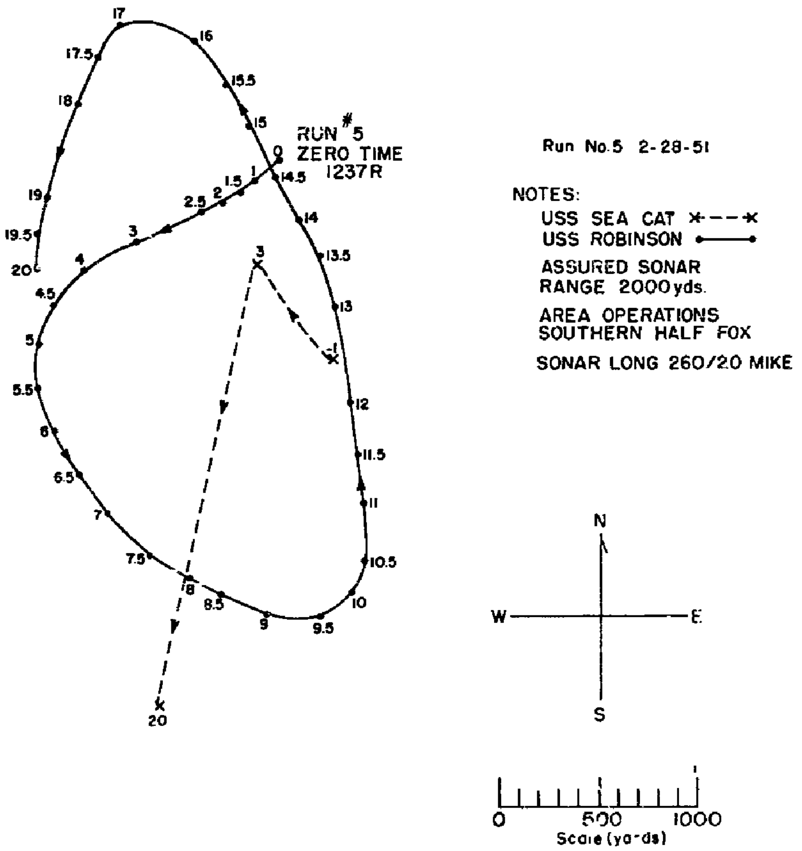


Figure 73 - Search, DRT

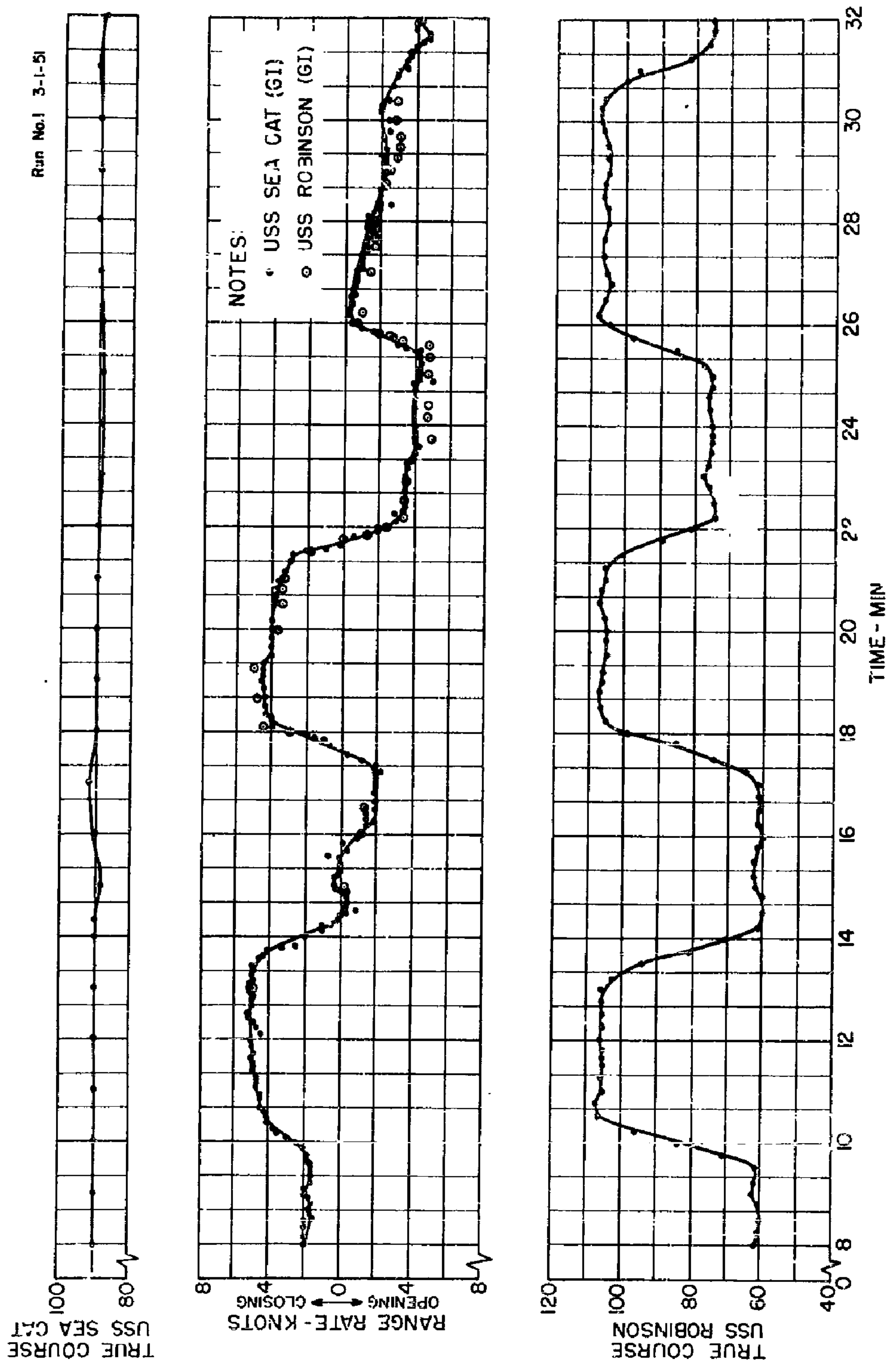


Figure 74 - Course and range rate versus time

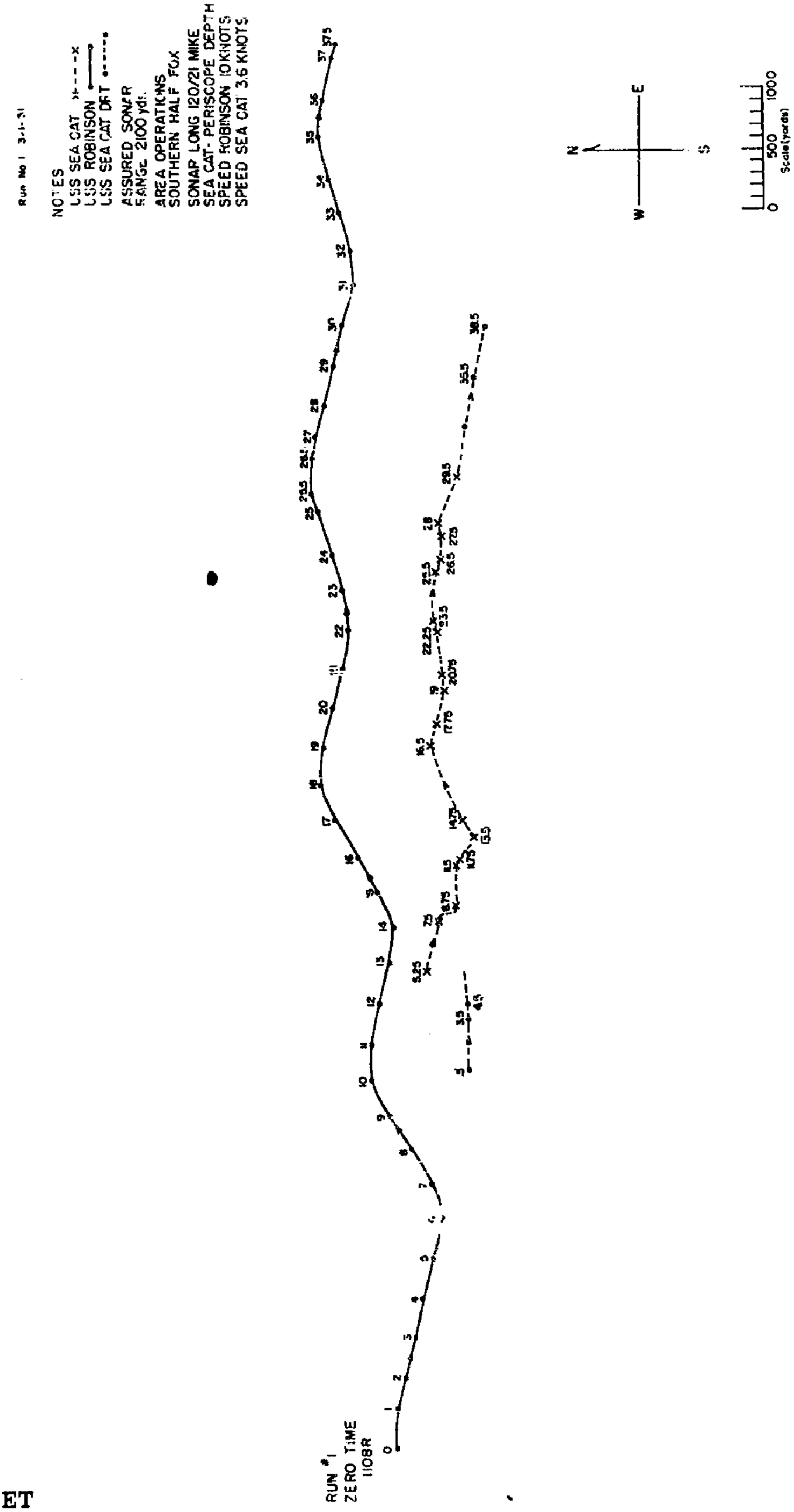


Figure 75 - DRT

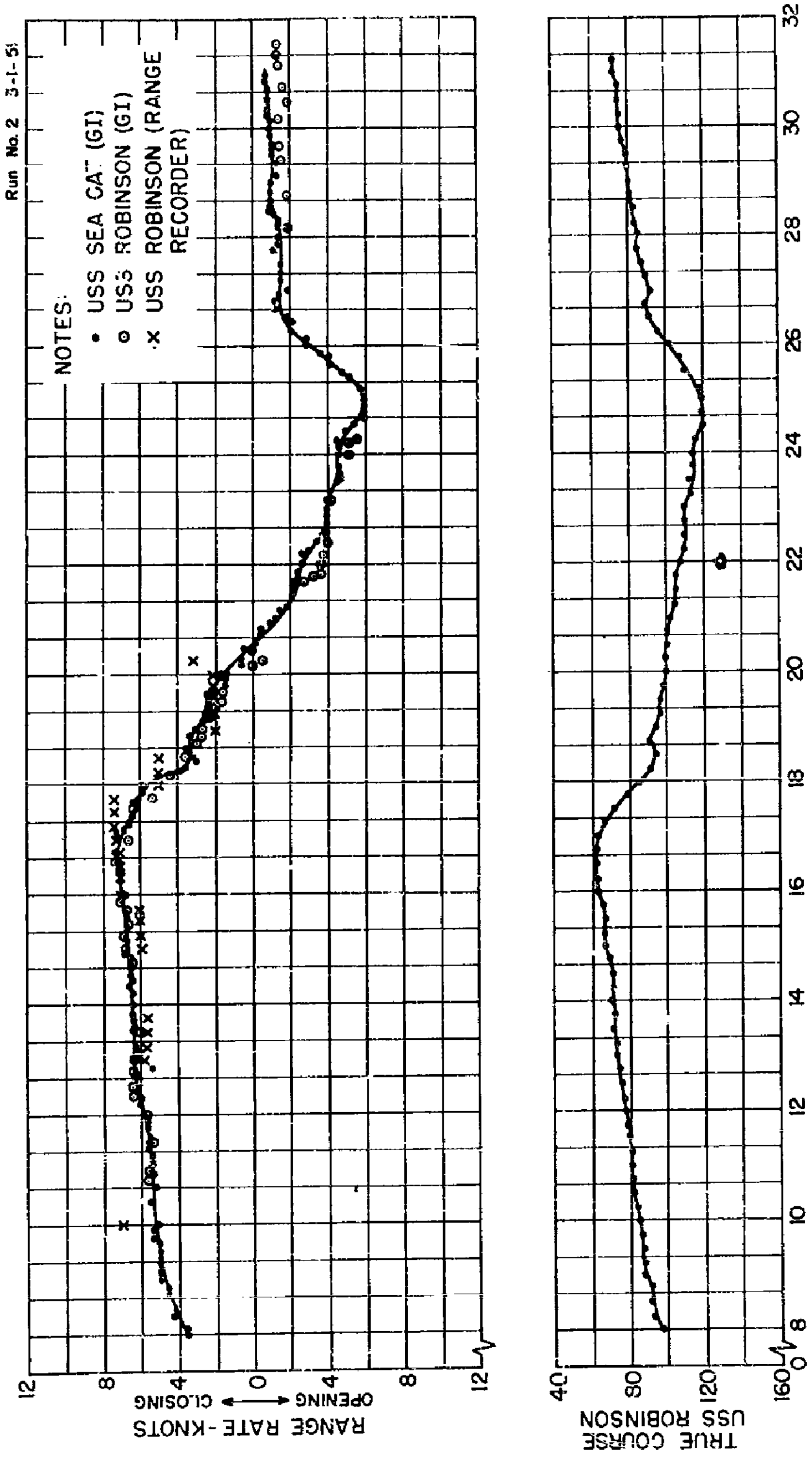


Figure 76 - Course and range rate versus time

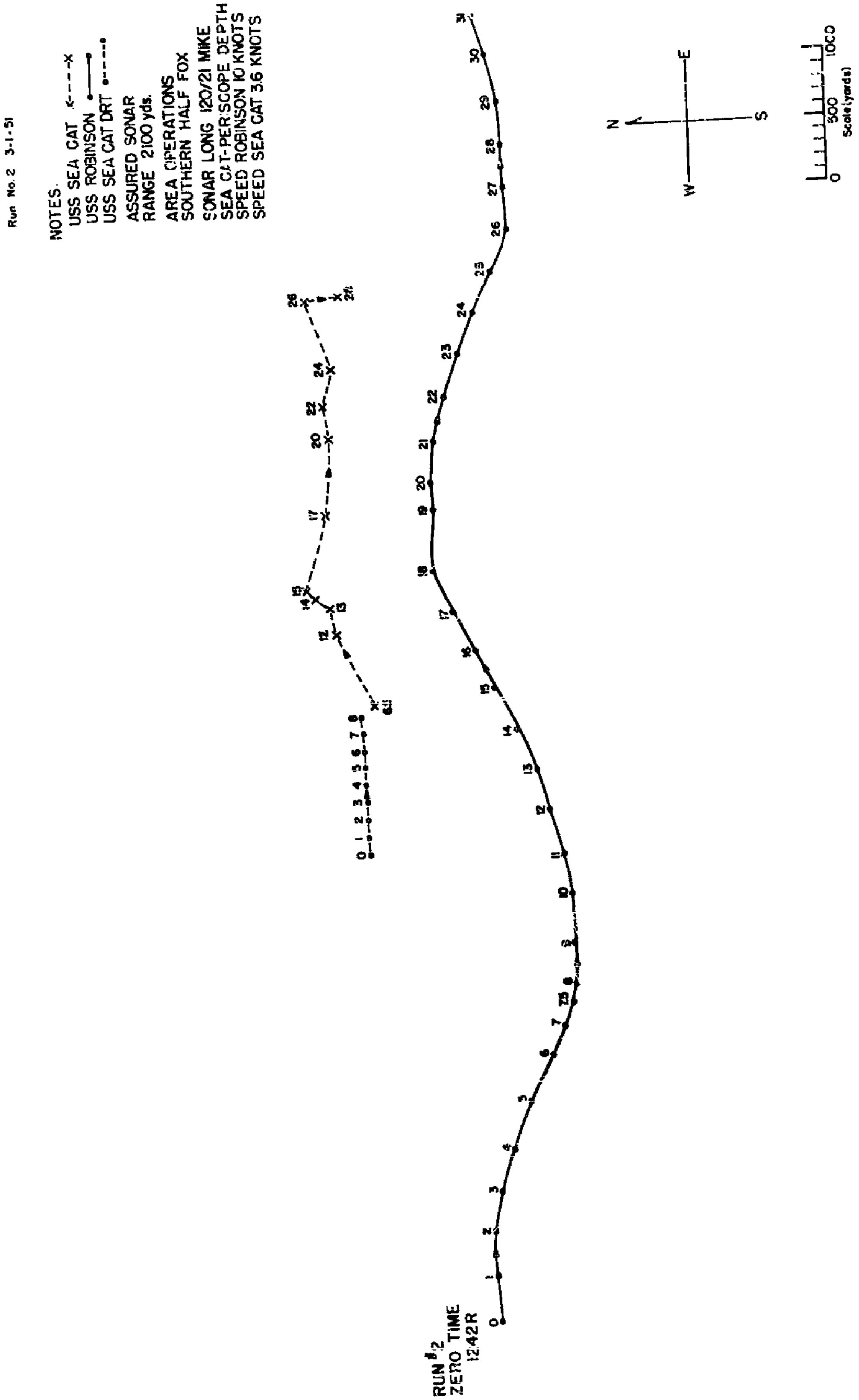


Figure 77 - DRT

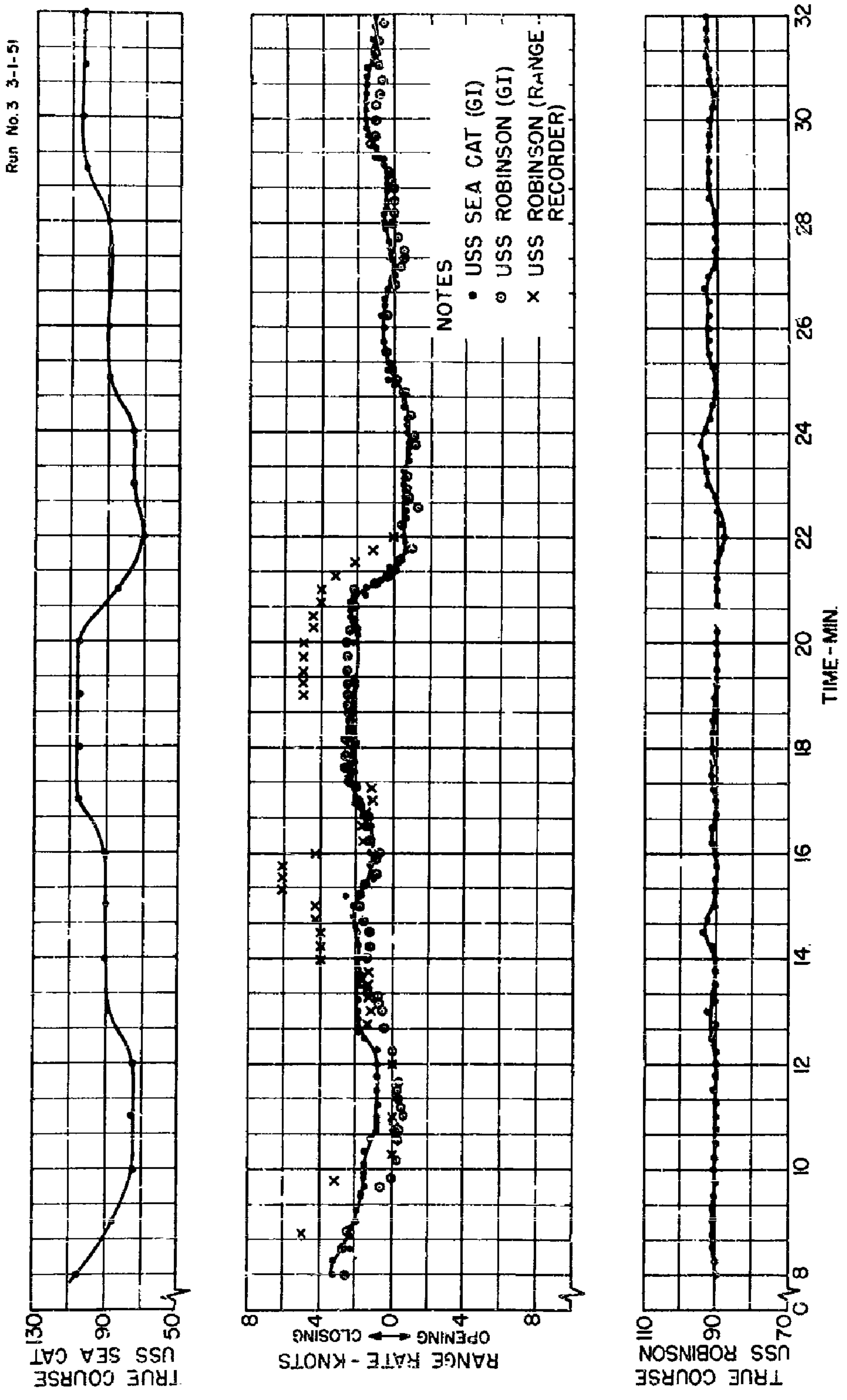


Figure 78 - Course and range rate versus time

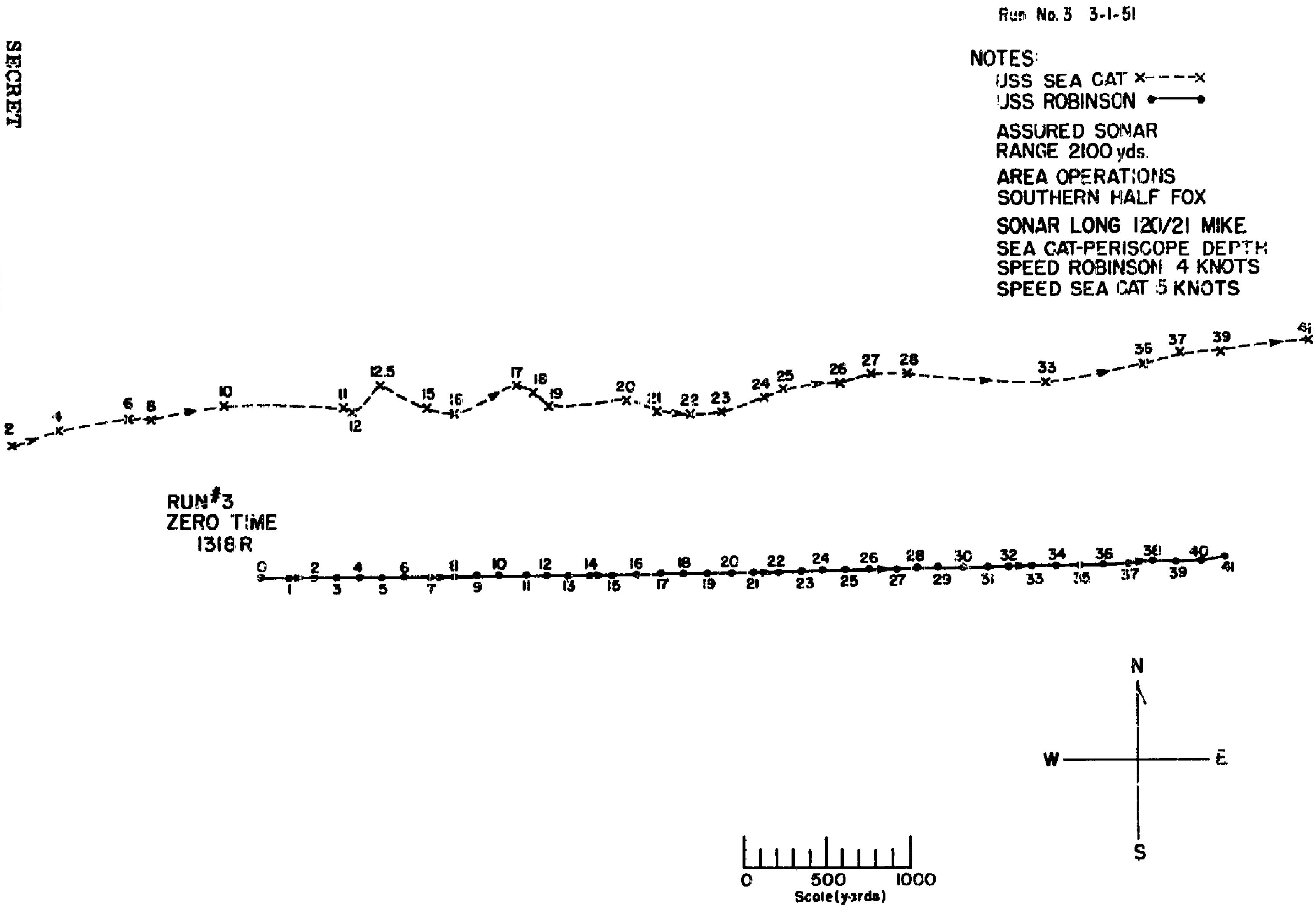


Figure 79 - DRT

It is concluded from this series of runs that the Graphic Indicator has potentiality in aiding a "passive listening" submarine in determining the type of course run by an echo-ranging surface vessel operating in the area. It is also concluded in ASW applications that the Graphic Indicator method of measuring range rate is more accurate than one using the change of range parameter with time, particularly in the case of a varying aspect target.

The Graphic Indicator as a Navigational Aid – A number of test runs were made during the period, 20 Feb. 1951 – 1 Mar. 1951, using the Graphic Indicator as a navigational aid. Results of these runs agreed with previous tests in the measurement of speed through the water and over the bottom, with one exception. When QHB equipment was employed in a vessel operating in relatively shallow water, where the bottom contour had a bold shelf in the vicinity of the vessel, it was found that the selectivity of the listening beam was not sufficient to reject reverberations returning at a bearing outside of the major lobe from along the steep face of the shelf. Therefore, the presentation on the Graphic Indicator contained indications of velocities, not from a single direction, but from many bearings along the shelf. This resulted in the possibility of an error in measurement of ship's speed over the bottom.

This limitation is not found in most operating conditions, but for applications where speed measurement is of prime importance, a searchlight transducer should be used.

New London, Connecticut, 2-3 May 1951

In cooperation with the Submarine Development Group Two, New London, Connecticut, a series of tests were conducted in USS CORSAIR (SS345) and USS HALFBEAK (SS352). The purpose of these tests was to investigate the feasibility of measuring range rate in a single ping employing the Graphic Indicator with associated magnetic-tape recording equipment. The idea involves the utilization of magnetic tape recording in the form of a continuous tape loop on which the transmitted pulse and the returning reverberations and target echo were recorded. The tape recording was then played back to the Graphic Indicator a sufficient number of times to make an accurate range-rate measurement.

This procedure has two advantages: first, memory is supplied in the tape recording; and second, the tape storage enables the data to be played back a sufficient number of times to adjust the reference oscillator to the desired returning signal. This improves the accuracy measurement over that of measuring the slope of the returning echo presentation on the cathode-ray tube. Ten to fifteen seconds are sufficient to secure the range-rate measurement. In addition, own ship's component and target component of the range rate may be obtained.

A high-quality magnetic-tape recorder with provision for loop recording was employed in these tests. Associated with this recording was a frequency translator, which translated the 25-kc frequency to 5 kc for recording and on the playback translated it back to 25 kc for the Graphic Indicator. The Graphic Indicator required no modification from its standard form.

A series of simulated-attack runs were made aboard CORSAIR with HALFBEAK as the target. Magnetic recordings were obtained from which range-rate measurements could be made to an accuracy of approximately ±0.25 knot. The major error involved in the range-rate measurement by this method is produced by the "wow" in the magnetic recording process. It was noted also, that recording enabled a reconstruction of the runs at a later time producing very accurate information as to the movements of both the echo-ranging and the target vessel.

It was concluded from these initial tests that it is entirely feasible to construct a small, compact operational instrument to measure range rate to ±0.25 knot in single-ping operation. It was further concluded that magnetic tape recordings could be extremely useful in obtaining data from field tests for subsequent analysis.

Key West, Florida, 28 May - 1 June 1951

The tests during this period were made in conjunction with the David Taylor Model Basin to measure the speed of a submerged submarine through the water. These speed measurements were used in the Model Basin's program of noise analysis of USS AMBERJACK's (SS522) superstructure as a function of speed through the water. The submarine was operated at 100-foot keel depth with speeds ranging from zero (hovering) to the maximum speed of the submarine. Speed obtained by the Graphic Indicator was compared with propeller-turn-count speed. In obtaining the propeller rpm, the total number of shaft turns in intervals of 1 to 5 minutes was used.

It was found that the Graphic Indicator in measuring speed through the water could discriminate between speeds resulting from less than 0.5 rpm difference in turn count. It was also observed that the submarine was never at a constant speed when operating, as a result of corrections to course and depth. Variations from 0.1 to 0.8 knot were observed when the bow planes, stern planes, and rudder were used. The amount of speed variation was a function of the degree of correction made and the coincidence of correction by the three controlling units. Speed measurements made during these tests were reported (9) by the David Taylor Model Basin.

In addition to measuring speed through the water, measurements were made with the Graphic Indicator of speed over the bottom in the direction of travel and normal to the direction of travel of the submarine. From these measurements the set and drift of the submarine were determined. A DRT plot was kept employing the set and drift measurements by the Graphic Indicator. During the period of submerged operation, the currents varied from 1.5 to 3.5 knots.

With submerged periods of up to nine hours, it was observed upon surfacing on each of the three operating days that the position indicated by the Graphic Indicator DRT coincided with that from navigational fixes within the tolerances of measurement, approximately ± 500 yards.

It is concluded from these observations that the Graphic Indicator has potential value as an aid to submerged submarine navigation.

Key West, Florida, 9-19 July 1951

The tests conducted during this period were divided into three phases. The purpose of the first phase was to obtain high-quality magnetic-tape recordings for analysis and demonstration in the Laboratory, and for use in operator training for the Graphic Indicator.

Magnetic tape recording equipment was used as illustrated in Figure 80. The 25.5-kc sonar signal from the listening channel of the QHBa sonar in USS SARSFIELD was fed through a bandpass amplifier with an essentially constant amplitude output produced by AGC action to a translator which translated this signal from 25.5 to 4.5 kc by mixing with a 30-kc local oscillator and taking the difference component. The 4.5-kc signal was then recorded on an Ampex tape recorder. Precautions were taken to operate the tape's speed at a constant 15" per second by supplying the driving motor with a constant frequency from a tuning-fork oscillator. Additional precautions were taken to minimize "flutter" in the recordings.

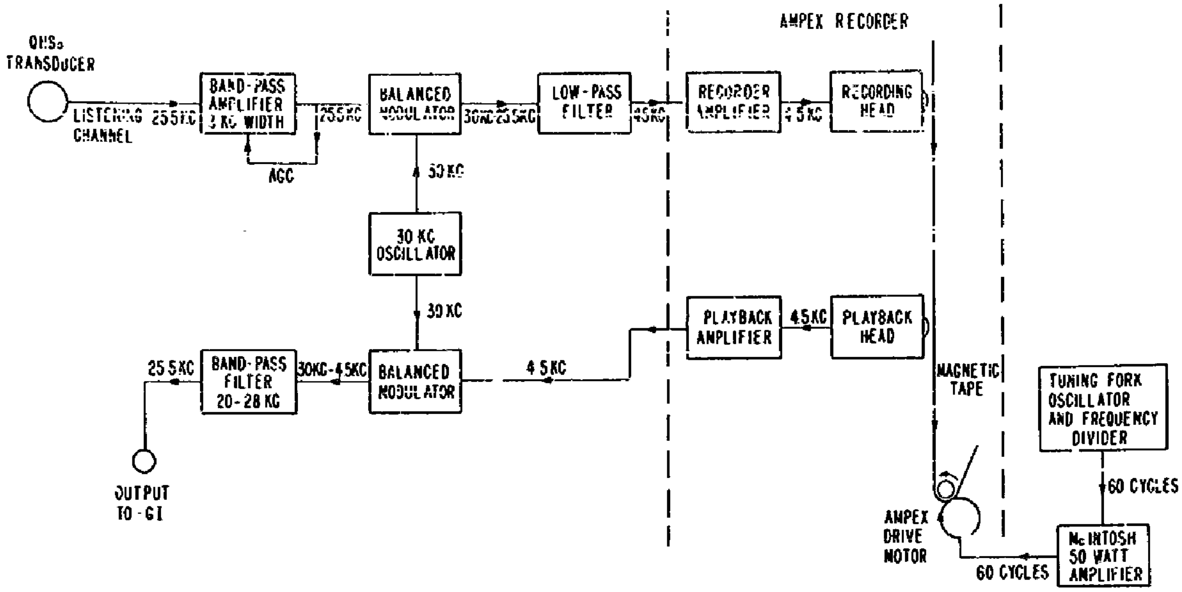


Figure 80 - Recording equipment, block diagram

On playback, the 4.5-kc signal was retranslated to 25.5 kc for presentation by the Graphic Indicator.

A series of recordings were made on 9, 11, and 12 July 1951 aboard USS SARSFIELD, of simulated sonar tracking and attack on submarine targets. These runs included high-speed runs on the target, low-speed tracking runs, and one tracking run with SARSFIELD towing "FXR" equipment.

For illustrative material in this report, photographs were made in the Laboratory on 35-mm film with a strip camera operated at a constant film speed. This was done by removing the horizontal sweep from the Graphic Indicator, and passing the film by the cathode-ray tube presentation in a horizontal direction at the same velocity as the horizontal sweep. The result is a continuous plot of phase, relative to the reference oscillator, versus time or range, in the form of a narrow strip with successive pings following one another in time. The strips were cut at the leading edge of each transmitted pulse and arranged one below the other in sequence.*

Figures 39, 40, 41, 42, and 43 are samples of the presentation of a high-speed attack run by SARSFIELD on USS CLAMAGORE. The pertinent information in this run is described on page 39, of this report.

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* It is to be noted in Figures 81-85 that the slope of the line in the presentation is reversed from that observed in the normal operation of the Graphic Indicator. This occurred because the V-axis plates of the CRT, employed in photographing, were accidently reversed.

An example of low-speed tracking runs is shown in Figure 81. In this run SARSFIELD is echo ranging on CUTLASS. From this figure, it is determined that the ASW vessel is closing through the water in the line of sight of the submarine at a rate of 4.1 knots and that the submarine is opening through the water at the same rate, with the net result of a zero range rate. During the run, the range rate changes with a slight opening range rate at the end of the series of pings shown. One of the most interesting features of this run is the presence of a wake stretching abeam of SARSFIELD. The first part of the wake at a range of approximately 200 yards has a predominate zero range-rate slope. The second portion of the wake in range or time has a closing slope indicating a position forward of abeam. The third portion has an opening slope indicating a position aft of abeam. This wake is not in the beam of the listening channel of the QHBa equipment, but the energy return from the wake is sufficiently high to override the beam selectivity.

While observing this run on the Graphic Indicator, the presentation of the wake portion of the pings gave a pronounced impression of motion in the form of angular rotation of the signal line as the sound returned by the wake came progressively from different bearings.

Center bearing on the hull of the submarine varies from very good in pings, 5, 6, 7, 8, and 9 to very poor in pings 1, 15, 16, 17, and 25. The target range is approximately 1250 yards.

In addition to the range rates through the water indicating a quarter or stern aspect, increased reverberations from the submarine's wake are seen just prior to the hull target in pings 1, 3, and 18.

Figures 82 and 83 are examples of the presentation from another tracking run, illustrating the Graphic Indicator presentation in two conditions. In the first condition, Figure 82, the reference oscillator is made to track the volume reverberations. This results in the presentation of the target as a series of sloping lines. Figure 83 demonstrates the same pings with the target frequency tracked by the reference oscillator. In this run it is noted that there are several pings received from another echo-ranging vessel. These signals are shown as blocks of uniform fine lines in pings 8, 10, 12, 14, 16, 18, and 20. From this illustration it was also determined that the ASW vessel was closing with respect to the water at 14.3 knots, with the submarine also closing with respect to the water at 4.6 knots. This resulted in a total closing range rate of 18.9 knots. This is further evidenced by the decrease of range to the target from 920 yards in ping 1 to 360 yards in ping 25.

An energy return from the wake appears after the hull presentation. Since the target had a bow aspect, a portion of the wake immediately aft of the submarine was shielded, resulting in the appearance of the wake further aft.

Figure 84 illustrates the presentation of a tracking run with an FXR equipment towed by the ASW vessel. The target echo can be readily distinguished and the range rate measured, although the presentation is broken at intervals with high-noise bursts. During this same run the visual displays of the QHB sonar equipment were completely masked by noise. This was true for both the PPI presentation and the range recorder.

During another run, an interesting observation was made when SARSFIELD traversed a wake. The wake completely masked the reverberations and target echo as shown in Figure 85. Further, it affected the transmitted pulse by producing violent phase steps during the length of the pulse. These phase changes were attributed to the effect of the changing acoustic impedance of the wake being reflected back into the transducer and further into the electronic driving system.

It is concluded from these tests that both recording and photographing by this method are valuable in the collection of data and in the analysis of operational sonar conditions. Magnetic recordings are very beneficial as an aid to operator training for the Graphic Indicator equipment

It is further concluded that the Graphic Indicator has potential value in maintaining contact on a target when a countermeasure device such as the FXR equipment is used.

The second phase of this series of tests was conducted in cooperation with the David Taylor Model Basin. The purpose of this phase was to obtain a speed calibration versus the propeller turn count of USS TRUMPETFISH (SS425) with the aid of the Graphic Indicator. This calibration was performed and the results reported (9).

The third phase included preliminary tests of the Graphic Indicator with the 10-kc Long-Range-Search sonar system. The purpose of this test was to make a qualitative comparison between the Graphic Indicator method of receiving and that of the LRS system. During this phase, ranges to approximately 9,000 yards were obtained. The Graphic Indicator was able to detect and measure range rate any time that the target was detected by the LRS system.

It was concluded from the results obtained that the Graphic Indicator was comparable in its capabilities for target detection to the detection and tracking equipment of the 10-kc LRS system and that, in addition, it was capable of measuring range rate accurately.

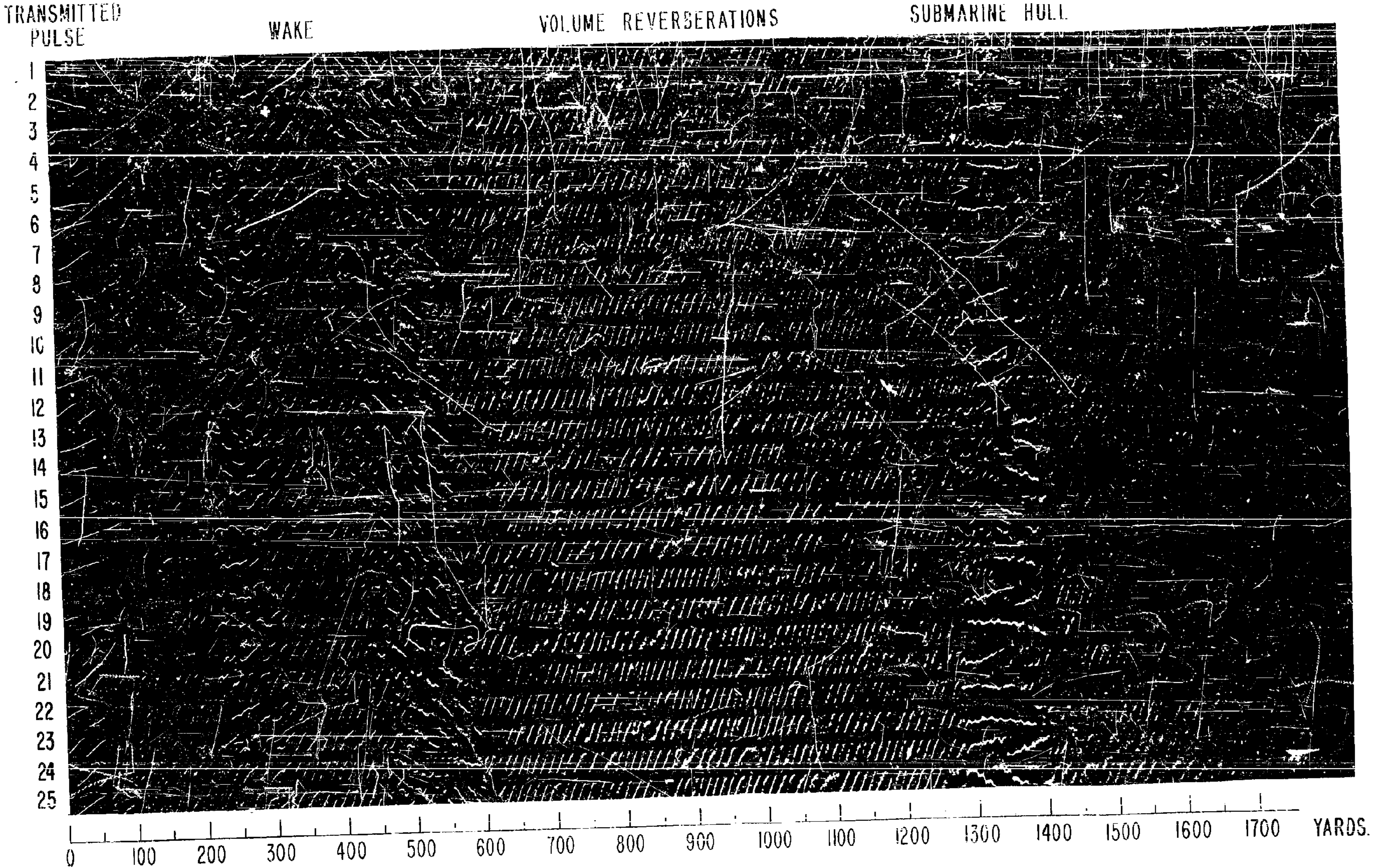

Figure 81 - Ping sequence for tracking run, target horizontal

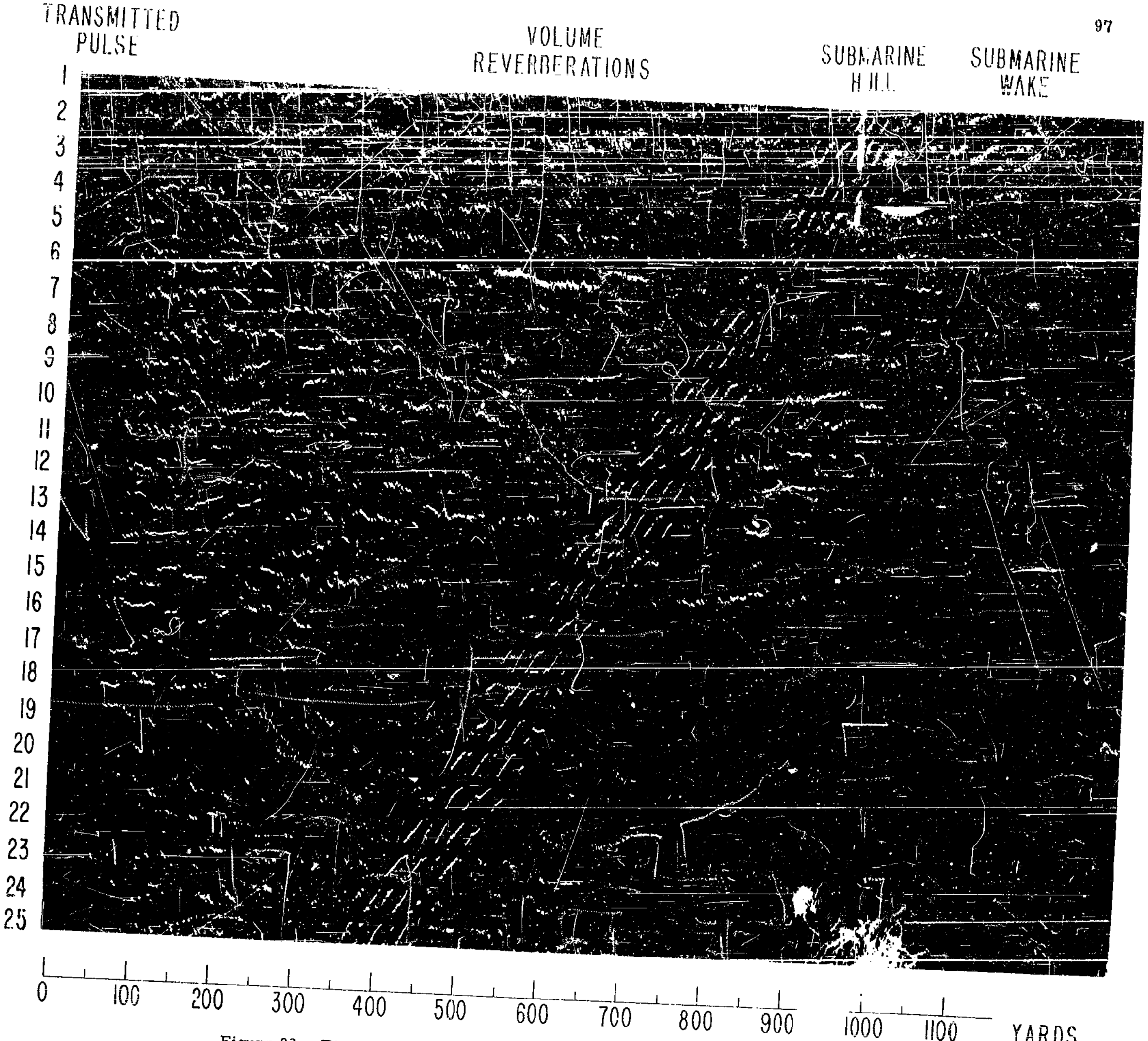

Figure 82 - Ping sequence for attack run, volume reverberations horizontal

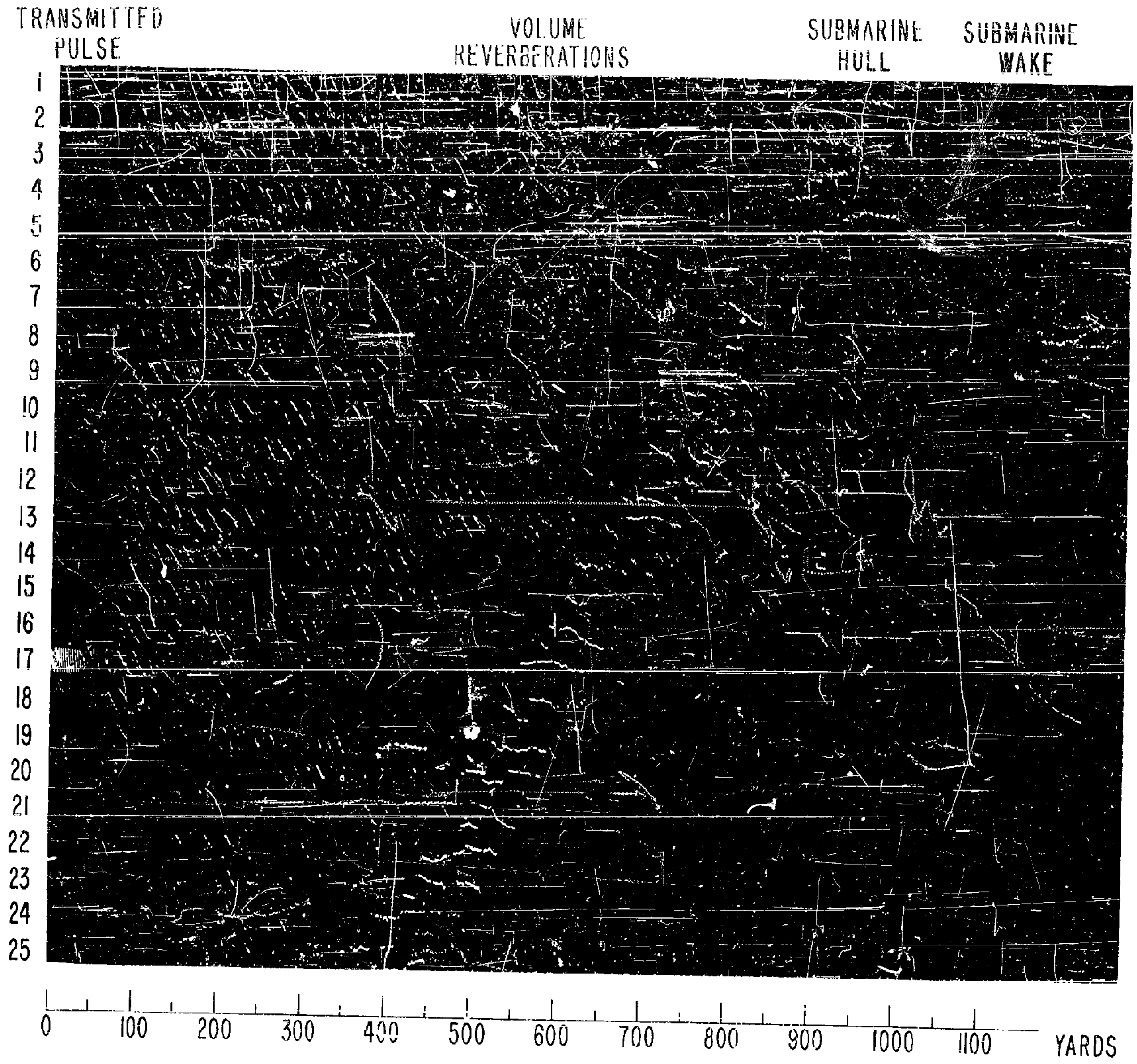

Figure 83 - Ping sequence for attack run, hull echo horizontal

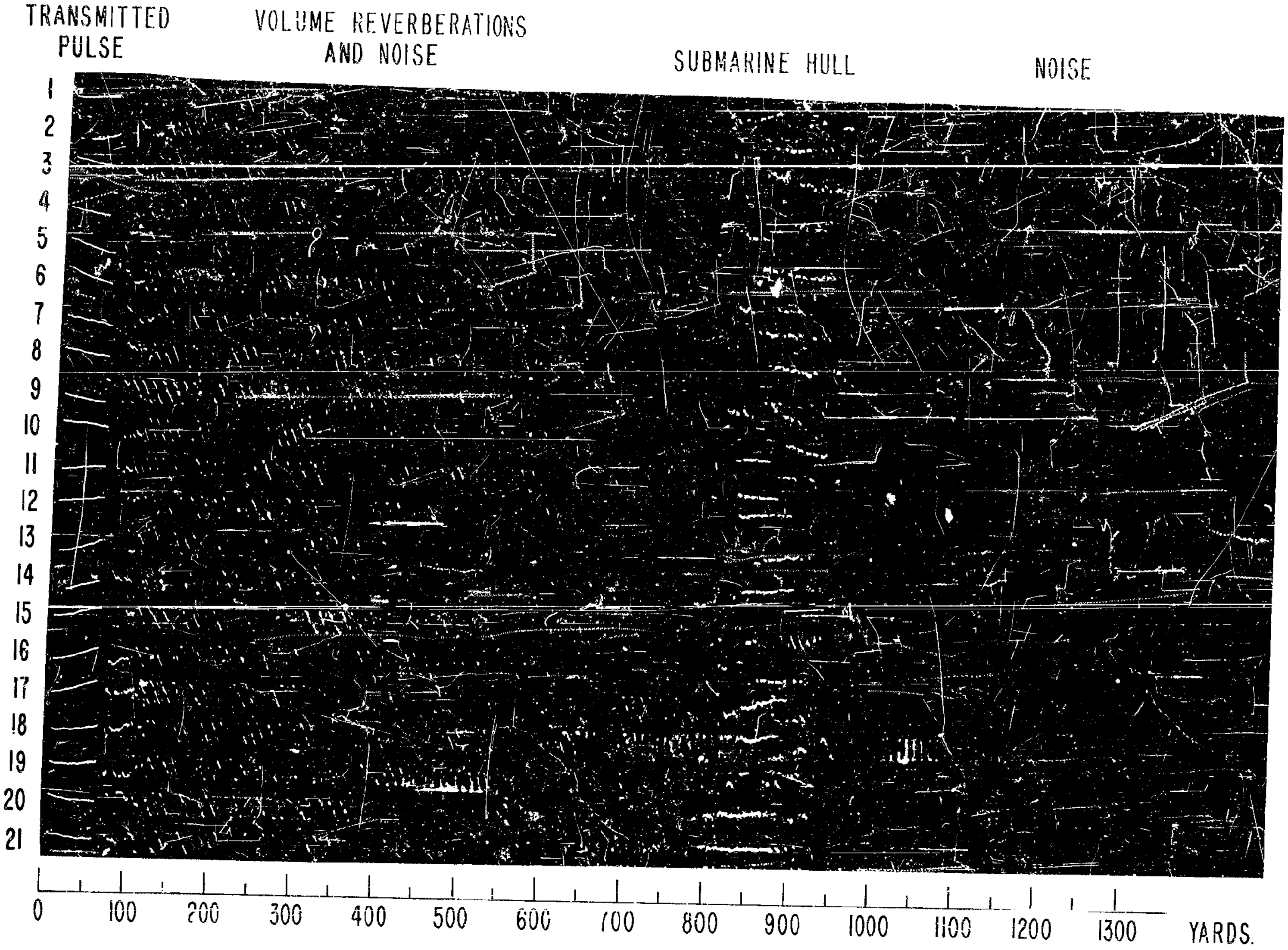

Figure 84 - Tracking run, towed "FXR," hull echo horizontal

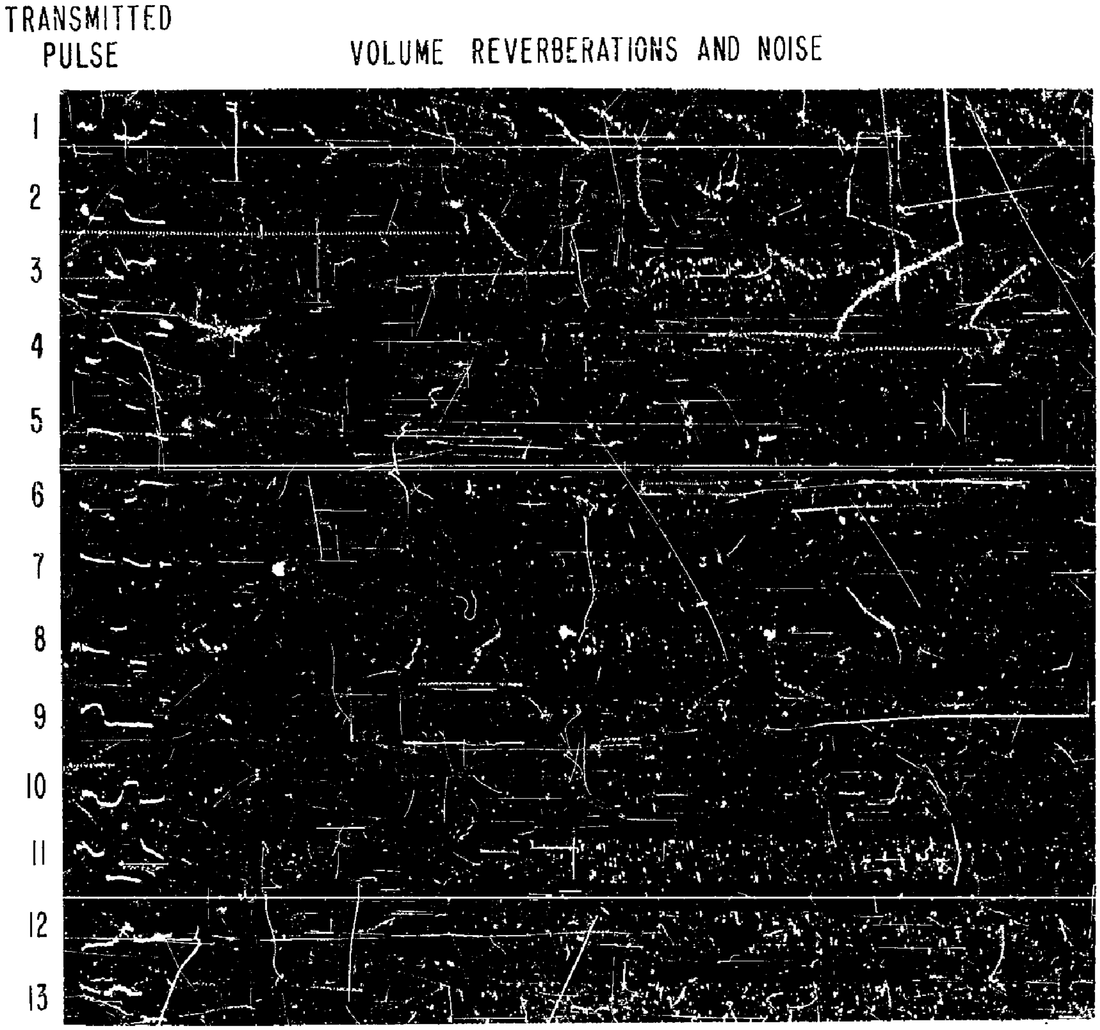

Figure 85 - Echo ranging in a wake

CONCLUSIONS

From results of laboratory and field tests employing the Sonar Graphic Indicator, it is concluded that the method and techniques used in this instrument render it a potentially valuable aid for applications in prosubmarine and antisubmarine warfare and in navigation.

Prosubmarine Applications

(1) Aid to ASW screen penetration
  (a) Determination of changes in the range rate of an echo-ranging vessel,
  (b) Determination of the type of course the echo-ranging vessel is running from a plot of relative range rate versus time,
  (c) Determination of the type of sonar equipment in the ASW vessel (searchlight or scanning) from the presentation of the transmitted pulse and reverberations, and
  (d) Determination of whether the ASW vessel is in a position to make sonar contact by the presentation of the transmitted pulse and reverberations.

(2) Aid in evading attacking ASW vessels by
  (a) - (d) as in (1) above, and
  (e) Determination of the time the attacking vessel begins to lose contact before passing over the submarine.

(3) Aid to passive submarine torpedo fire control by supplying relative motion data and true range rate.

(4) Aid to submarine torpedo attack if used in single-ping echo ranging.

Antisubmarine Applications

(1) Target classification by providing discrimination between a submarine hull, false targets such as wakes, knuckles, reefs, and reverberations, and

(2) Tracking and fire control by supplying accurate range, range rate, and bearing.

Navigational Applications

In navigation, the Sonar Graphic Indicator aids in the determination of ship's speed through the water and over the bottom, set and drift of the vessel, and local water current velocity. These navigational features are equally applicable to submarines and surface vessels.

Other Applications

In addition to the above applications, the instrument is valuable in the analysis of oceanographic conditions, of sound propagation, and of phase and frequency in the laboratory.

The practical results obtained from the techniques and methods employed in the Sonar Graphic Indicator substantiate the philosophy from which they were derived. The processing of the signal for visual display of fundamental signal parameters and their differences is not limited to the field of underwater sound, but has applications to other scientific fields particularly those employing a time-varying series for carrying intelligence.

RECOMMENDATIONS

It is recommended that immediate intensive research and development be undertaken to:

(1) Develop further methods and techniques to process and display the signal, utilizing more efficiently the physiological and psychological properties of the individual, particularly those involving the visual senses.

(2) Employ the method and techniques utilized in the Graphic Indicator in the development of practical equipment for use by the operating forces of the Navy. The primary objectives should be,
  (a) to supply more accurate and valid information for prosubmarine and antisubmarine warfare applications, and
  (b) the simplification of sonar equipments.

(3) Apply the principles employed in the Sonar Graphic Indicator for,
  (a) detection and tracking of targets by long-range, low-frequency listening, using submarine engine, propeller and hull noises,
  (b) area and harbor defense,
  (c) detection, classification, and location of mines for mine countermeasures,
  (d) measurement and analysis of oceanographic currents, and
  (e) navigational purposes with provisions for an entirely automatic system.

ACKNOWLEDGMENTS

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APPENDIX

A Discussion of Some of the Fundamentals of Visual Presentation

The presentation of sonar signal information for visual observation, whether on a cathode-ray-tube screen, on recorder paper, or on a meter, has been secondary in standard sonar systems to the audio presentation, which has been relied upon for initial target detection, for target classification, and for doppler information. The visual presentations have been essentially aids to the aural, providing, for tactical use, geographical plot or a curve of range vs. time or; for the equipment operator, an aid to the correction for a better on-target bearing. In all of these, except the last, practice has been to use for visual presentation essentially the same method of signal processing commonly employed for aural presentation, resulting in the utilization only of the higher energy level existing in a signal. Although for the several specific purposes the intelligence derived from the energy difference alone is adequate, it is insufficient for identifying or disclosing a complex situation wherein the information or signal is the return from a manifold target, such as a submarine and its wakes.

The weakness of present signal treatment is evidenced when the inherent functional differences of the eye and ear are considered. These differences make apparent the superiority of the eye with memory, as compared to the ear, in the analysis of situations of complex nature, provided that the complexity is properly presented to the eye. It is not to be inferred that a visual presentation should necessarily be used to the exclusion of other forms of presentation, for, in many instances, utilization of both the visual and auditory senses results in an enhanced signal perception and recognition. However, the signal must be processed separately for the visual and auditory senses.

This situation was assessed early in an investigation established jointly by the High Polymer Branch of the Chemistry Division and the Transducer Branch of the Sound Division to develop an improved recorder paper for application in the tactical sonar range-recorder. The study of what constituted an ideal recorder paper led to a study of those conditions necessary for optimum signal perception in a graphic presentation. This involved consideration of the manner in which the eye and brain function in seeing, of those factors which constitute attributes (characteristics) of modes of appearance,* and of how the perception of these attributes and of changes in them is governed by reactions learned during the life of the individual.

A brief comparison of the capabilities and functions of the eye and ear established that: (1) the eye can accommodate about 430 times more bits of intelligence per second than the ear (11); (2) the eye can accommodate many sources of information simultaneously when suitable angular displacement between sources is present, whereas the ear

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* The attributes of modes of appearance for a surface are listed by the Optical Society of America (10) as, brightness or lightness, hue, saturation, size, shape, location, flicker, sparkle, transparency, glossiness and luster. In addition, motion can be considered an attribute when cathode-ray-tube presentations are used. This list is added to emphasize that there are many parameters available for exploitation in visual presentation.

functions best with a single source; (3) in accordance with Weber's law of perceptional differences (for a just noticeable difference, $\Delta S/S = C$), the human ear, to perceive a difference, requires a change of 20% in the original loudness, whereas a change of only 1% in brightness can be perceived by the eye (12); (4) the visual senses are sensitive to a larger number of perceptual variables than are the auditory senses.

It was concluded that in the perception and analysis of a complex signal situation, a system designed to tailor the intelligence to as great a degree as possible for visual observation, should yield a higher recognition differential and information rate. A new and different approach to signal display was tried, preserving, so far as possible, in the signal presentation or picture the information inherent in variation of the average signal energy but not at the usual cost of discarding the information in the frequency and phase character within the wave train or trains which constitute the signal.

The following design procedures were, and still are, advocated:

1. Display all signal information in a manner to emphasize the differences and changes of differences between the signal and coexisting distractions or noise.
2. Design visual displays to enhance the ability of the operator to recognize meaningful patterns of many bits of information.
3. Utilize the ability of the operator to scan, analyze, compare, and integrate, from the aggregates of many bits of information without conscious rationalization.

The Sonar Graphic Indicator is an electronic equipment developed to conform to these recommended practices. It presents the signal as a transitory pattern, in a graphic presentation on a cathode-ray-tube screen, for quick perception by the eye of the observer. The structure or form of the pattern as observed transmits through the eyes to the brain the complex signal information which has controlled the pattern formation and makes it perceptibly different from the picture which immediately precedes or follows. Recognition of the signal pattern and the transmission of the complex information of course require previous experience or training of the observer.

This signal display system is based essentially on a phase comparison of two frequencies as a function of time. The indicator presents patterns that vary with the change in the periodicity between successive cycles of the received signal over continuous range intervals. The cycle-to-cycle phase of the signal is plotted versus time to form this pattern, at a rate suitable for comprehension by the visual senses and commensurate with the reaction time of the brain. Means for measuring the rate of change of phase between a reference and the signal are incorporated. The phase, frequency and amplitude characteristics of the signal are presented in such a manner that the phase and rates of change of phase are the primary parameters with comparative levels of amplitude or energy treated as secondary parameters.

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UNITED STATES GOVERNMENT

memorandum

7103/120

DATE: 31 October 1996

FROM: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF. (a) FOR DECLASSIFICATION

TO: Code 1221.1

VIA: Code 7100

REF: (a) NRL Confidential Report #4028 by G.F. Asbury, Sr., et al, 6 Aug 1952 (U)
(b) DoD Dir. 5200.10

1. Reference (a) is a report on the theory, implementation and testing of the Sonar Graphic Indicator, a method for measuring the phase of a sonar signal on a cycle-to-cycle basis and displaying it on a cathode ray screen. The phase pattern of the signal is used for classification and for measuring the range rate, via the Doppler shift, and range of the target.

2. The AN/BQA-3 was the practical utilization of this technology. The AN-BQA-3 has not been in service in submarines for at least ten years, this technology being superseded.

→ 3. Reference (a) was declassified by reference (b).

→ 4. Based on the above, it is recommended that reference (a) be declassified with no restrictions.

Burton G. Hurdle
BURTON G. HURDLE
Acoustics Division

CONCUR:

Edward R. Franchi 11/4/96
EDWARD R. FRANCHI Date
Superintendent
Acoustics Division

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Naval Research Lab, Washington, D. C.

SONAR GRAPHIC INDICATOR, by Thomas O. Dixon, George F. Asbury, Jr., Burton G. Hurdle, and others. 6 Aug 52, 113p incl illus, tb. (NRL Rpt 4028)

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DIV: Detection ~~(6)~~ 17
SEC: Acoustic ~~(1)~~ 1

SUBJECT HEADINGS
Sonar equipment
Indicators, Sonar

P'7'

(Copies obtainable from ASTIA-DSC)

✓ Sonar; sound analyzers
[illegible]

[redacted]

SCP-3 Authority: U.S. NRL ltr,
13 June 61

C SCP-3, AUTH: DOD DIR 5200.10, 29 June 60