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TR-121

TECHNICAL REPORT

INSTRUMENTATION AND PROCEDURES
FOR DIGITAL TO ANALOG CONVERSION
OF
SONIC SURFACE SCANNER DATA FOR INPUT
TO AN ANALOG WAVE ANALYZER

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U. S. NAVY HYDROGRAPHIC OFFICE
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A B S T R A C T

Electronic devices and procedures required to convert discrete ocean surface wave height data into a form suitable for input to a wave analyzer are described. Such wave height data, obtained with an inverted echo sounder (Sonic Surface Scanner) mounted on the deck of a submerged, hovering submarine, are recorded on magnetic tape as a sequence of pulse packets. An example of a power spectral estimate of Sonic Surface Scanner wave height data by digital and analog methods is presented to illustrate techniques used at the U. S. Navy Hydrographic Office.

FOREWORD

A series of technical reports, reflecting developmental aspects in the relatively new science of submarine oceanography has been prepared by the Hydrographic Office. Subjects treated in this series include problems associated with measurement of sound propagation, temperature, boat and fluid motions, and surface gravity waves.

This report discusses one solution of a preliminary problem associated with signal conditioning and analysis of recordings of ocean surface wave height data. Such wave height data obtained with an inverted echo sounder (Sonic Surface Scanner) are recorded in discrete form. Power spectral estimates of these data can be obtained with the digital computer facilities at the Hydrographic Office.

In general, it is necessary also to correct the Surface Sonic Scanner transducer time history for effects of submarine motion. The principal submarine motions which tend to distort the transducer time history are pitch and roll angles, heave displacement, and slow depth changes. These motion data are recorded in analog form. Thus, one method of correcting the Sonic Surface Scanner transducer time history, to yield the free surface wave profile, is to utilize analog computer techniques. The resulting corrected analog recordings can then be analyzed with the wave analyzer facilities at the Hydrographic Office.



E. C. STEPHAN
Rear Admiral, U. S. Navy
Hydrographer

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I. INTRODUCTION

An array of nine Sonic Surface Scanner transducers, mounted on several U. S. Navy submarines, is presently being used by the U. S. Navy Hydrographic Office to obtain digital time histories of the height of the sea surface above each transducer. Such time histories are analyzed subsequently to give average energy densities (power spectra) of surface wave heights. The measurement of these spectra is important since a statistical knowledge of parameters related to sea surface height variability is required and because the surface wave motion constitutes the input or "forcing" function to which the submarine responds.

The Sonic Scanner is, in effect, several inverted echo sounders designed to give instantaneous heights of the sea surface above them, measured in a 3° cone. Since the hovering or slowly moving submarine moves in response to the waves at the surface, a correction must be applied to the transducer time history if such data are to be used for power spectral analysis of surface wave heights. The principal submarine motions affecting the transducer time history are heave displacement, pitch angle, and roll angle. Pitch and roll angles are recorded as FM signals on magnetic tape; heave displacement must be obtained from the FM recording of heave acceleration by a double integration.

A preliminary step, however, is to convert the Sonic Scanner transducer time history, which occurs as a sequence of pulse packets, into an equivalent analog signal. In this form, data can be recorded as a varying d.c. voltage on an FM magnetic tape recorder. Further data processing is required to convert tabular listings of such data into punch cards or punch tape for input to a high speed digital computer. The problem of obtaining digital power spectral estimates of Sonic Scanner data is discussed in references 1 and 4.

An analog wave analyzer system is used at the Hydrographic Office to estimate average energy densities of various components of submarine and fluid motions; therefore, it is important to have the Sonic Scanner data in the same analog form, not only for similar calculations of average energy densities on the analog wave analyzer system, but also to provide for estimation of analog cross-spectral densities connecting wave and submarine motions. In addition, it may be feasible to estimate cross-spectral densities of the outputs of various pairs of Sonic Scanner transducers for study of directional wave spectra.

The aspect of the overall problem to be discussed in this report is that of converting Sonic Scanner data, which occur as sequences of pulse packets, into a continuous signal suitably amplified and calibrated for input to the wave analyzer used at the Hydrographic Office.

This report describes the required instrumentation, with an outline of calibration and analysis techniques. An example of a digital power spectral estimate from an actual recording of scanner data when submarine motion was negligible is compared to the result obtained by converting the pulse packets into an analog signal and, subsequently, using the wave analyzer to estimate the spectral density. The agreement in the two methods is good.

II. INSTRUMENTATION

A. Recording and Playback

Sonic Scanner signals are recorded in the field on 2 channels of 14-channel magnetic tape recorder at a tape speed of $1 \frac{7}{8}$ inches per second. One channel records pulse packets; the other channel records the synchronization or "trigger" pulses. Of the other submarine motion variables, only heave displacement, pitch angle, and roll angle appreciably affect the transducer time history*. A complete description of the instrumentation, measurements, and recording procedures of such variables is given in Hydrographic Office Technical Report, TR-91 (reference 9). Locations of the instrumentation on a submarine are shown in Figure 1.

The instrumentation used at present by the Hydrographic Office to obtain surface wave records is the array of Sonic Scanner transducers mounted on the deck of the USS REDFIN (Fig. 1.). In addition, surface wave records have been obtained with an EDO (a standard fathometer) by the USS ARCHERFISH and, on the global circumnavigational cruise, by the USS TRITON. The Sonic Scanner consists of a nine-transducer array mounted on the deck of a submarine. The transducers are directed upward and are essentially inverted echo sounders. Transducers 1 and 2 are 66 feet apart; all others are 33 feet apart (Fig. 1). Each transducer in turn is used to measure distance between itself and the sea surface directly above in a 3° cone. By sequencing from one transducer to the next aft along the deck of the submarine, a wave profile approximately the length of the submarine can be obtained. The complete sequence takes approximately .54 seconds. The Sonic Scanner was designed to provide an accuracy to the nearest foot.

* The actual wave frequencies present in the surface wave motion are not exactly reproduced because the submarine must keep up a speed of 1 or 2 knots to maintain depth and heading. Thus, strictly speaking, such frequencies of encounter should be transformed into the true wave frequencies.

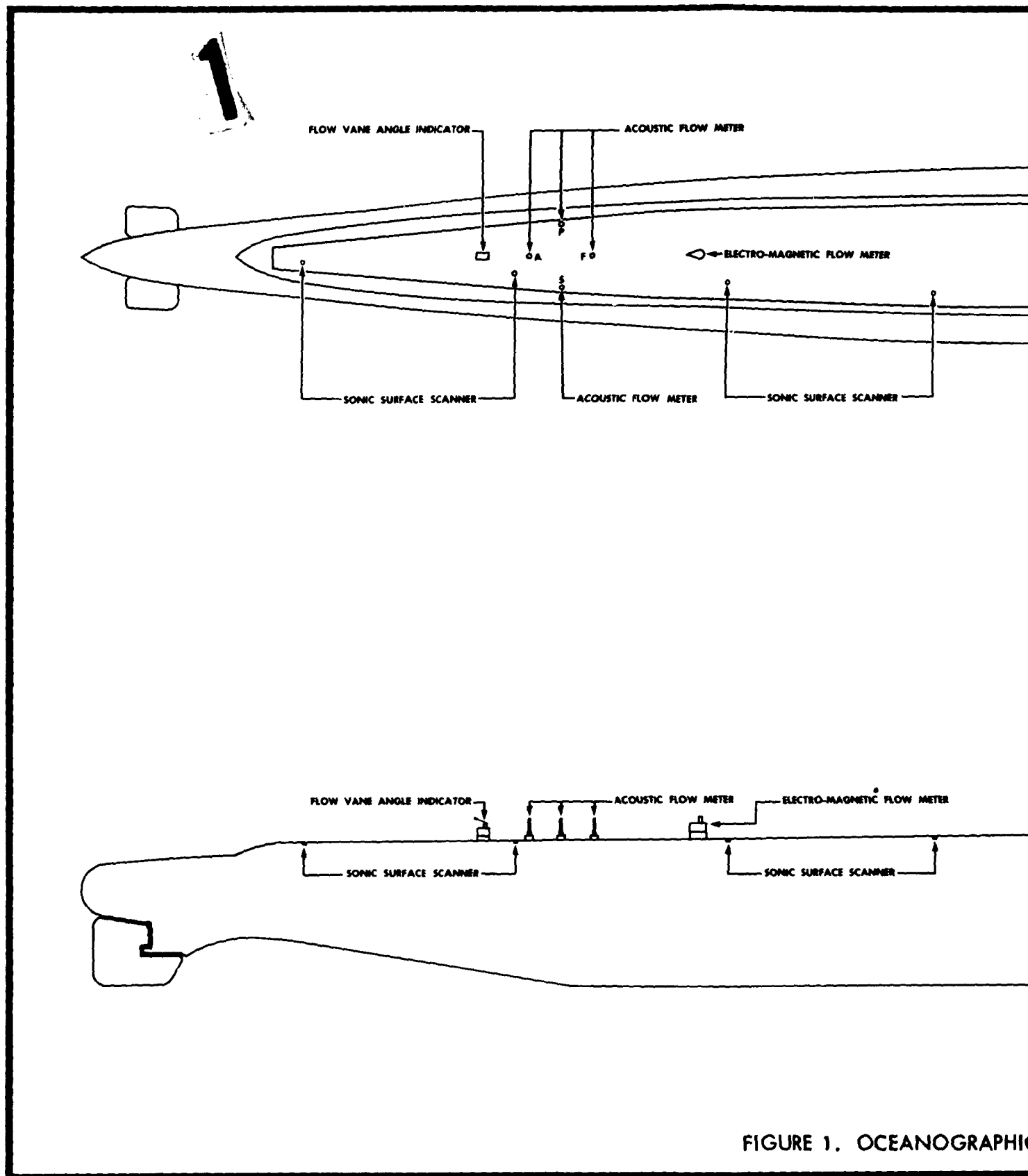
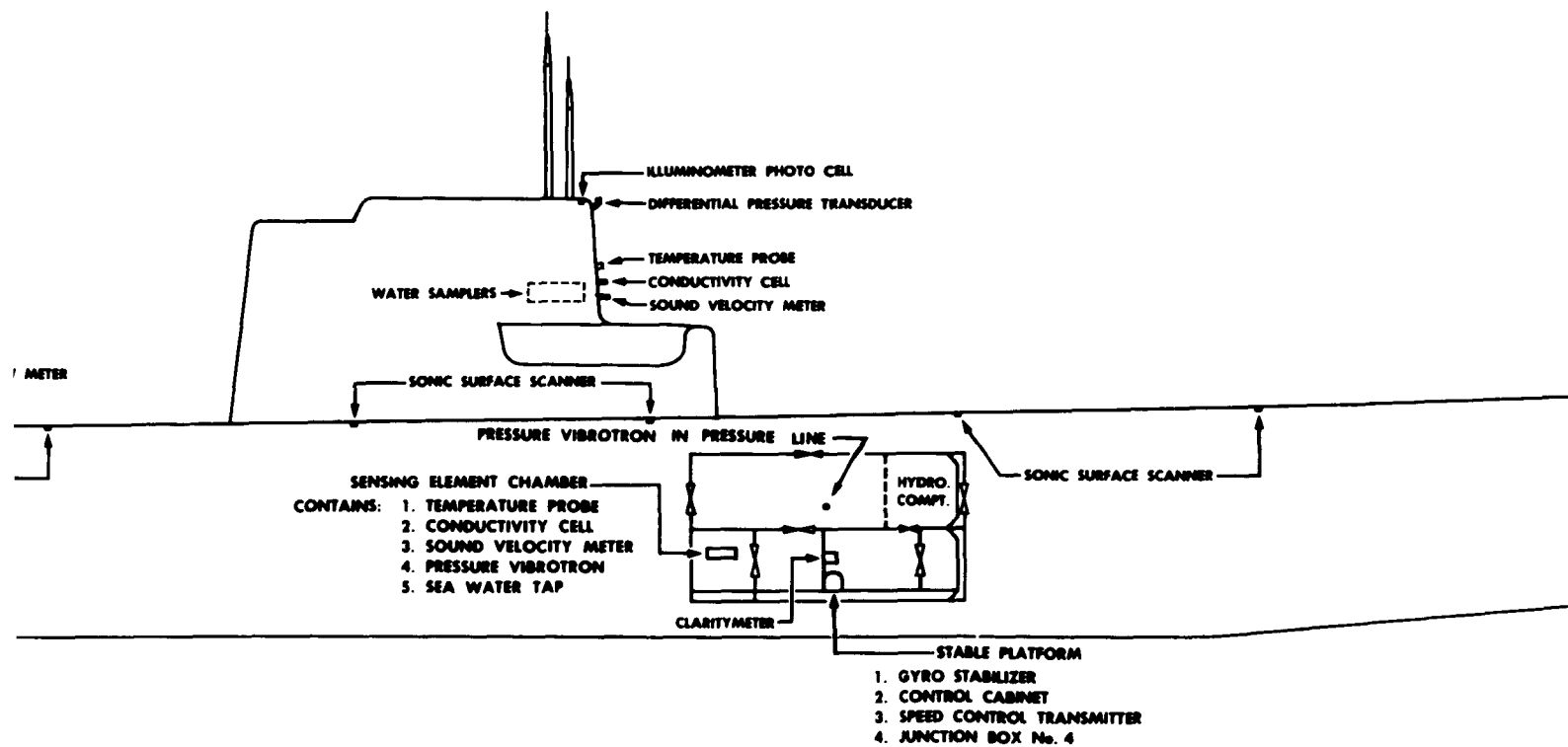
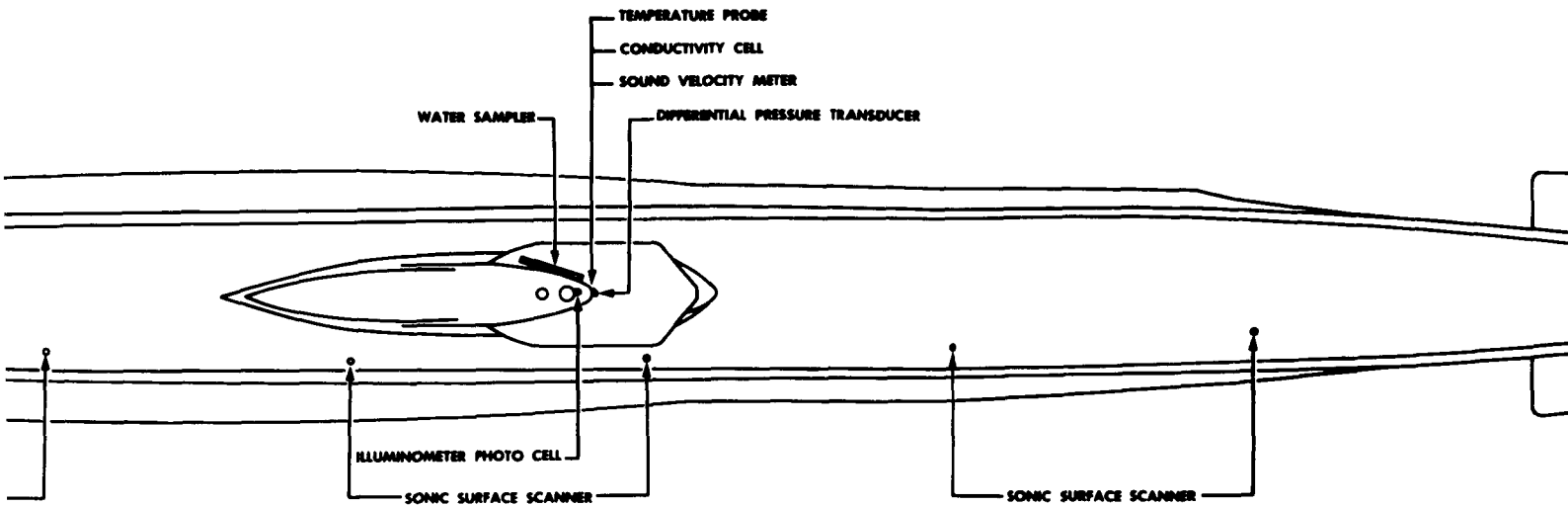
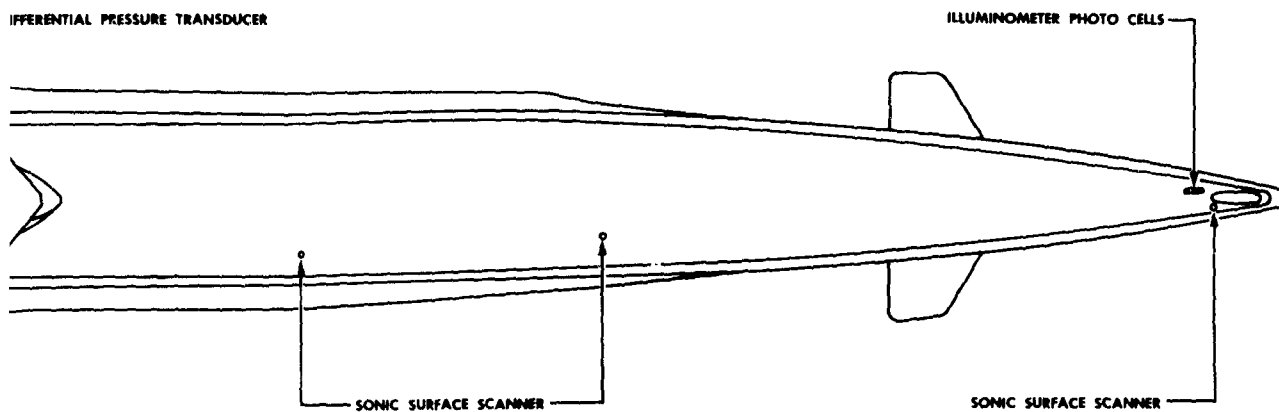


FIGURE 1. OCEANOGRAPHIC



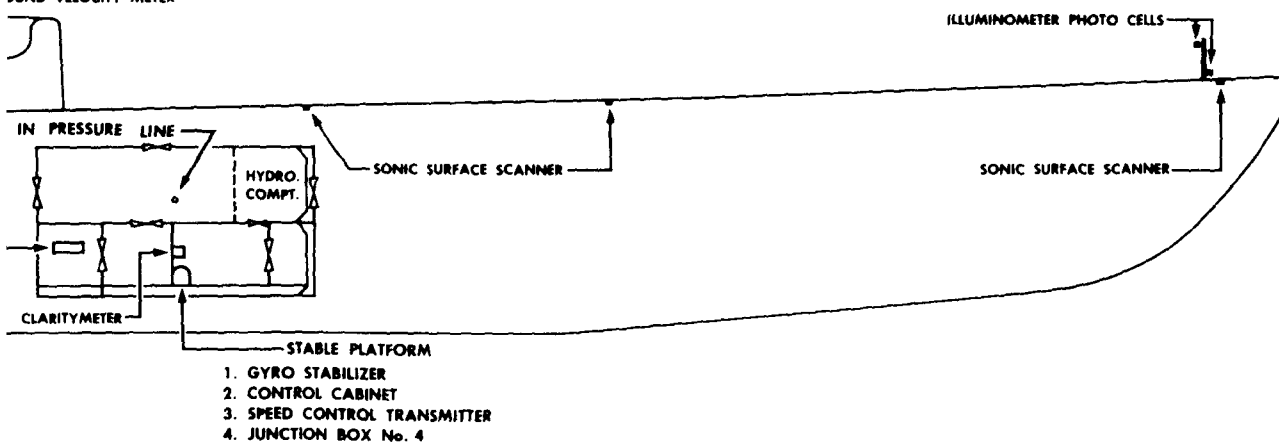
NOGRAPHIC INSTRUMENTATION LOCATIONS, USS REDFIN (SS-272)

TEMPERATURE PROBE
INDUCTIVITY CELL
DUAL VELOCITY METER
DIFFERENTIAL PRESSURE TRANSDUCER



ILLUMINOMETER PHOTO CELL
DIFFERENTIAL PRESSURE TRANSDUCER

TEMPERATURE PROBE
INDUCTIVITY CELL
DUAL VELOCITY METER



USS REDFIN (SS-272)

The outputs of all nine transducers are available, but the primary interest at this stage has been the power spectra of the output of one transducer. A recording from one transducer is, therefore, the instantaneous height of the sea surface above the submarine as a function of time. This is given in terms of the two-way travel time required for a sound wave front to travel from the transducer to the sea surface and return.

Assuming the velocity of sound in ocean waters to be 5000 ft/sec (the resulting error in this assumption is very small), travel time for the sound wave can be expressed:

$$t = \frac{1}{5000} \text{ sec/ft} = 0.2 \text{ millisec./ft.}$$

Since we are concerned with a two-way travel time (the time required for the sound beam to go from the submarine transducer to the sea surface and return), the effect is the same as if the travel time were doubled. Thus, the effective travel time per foot is:

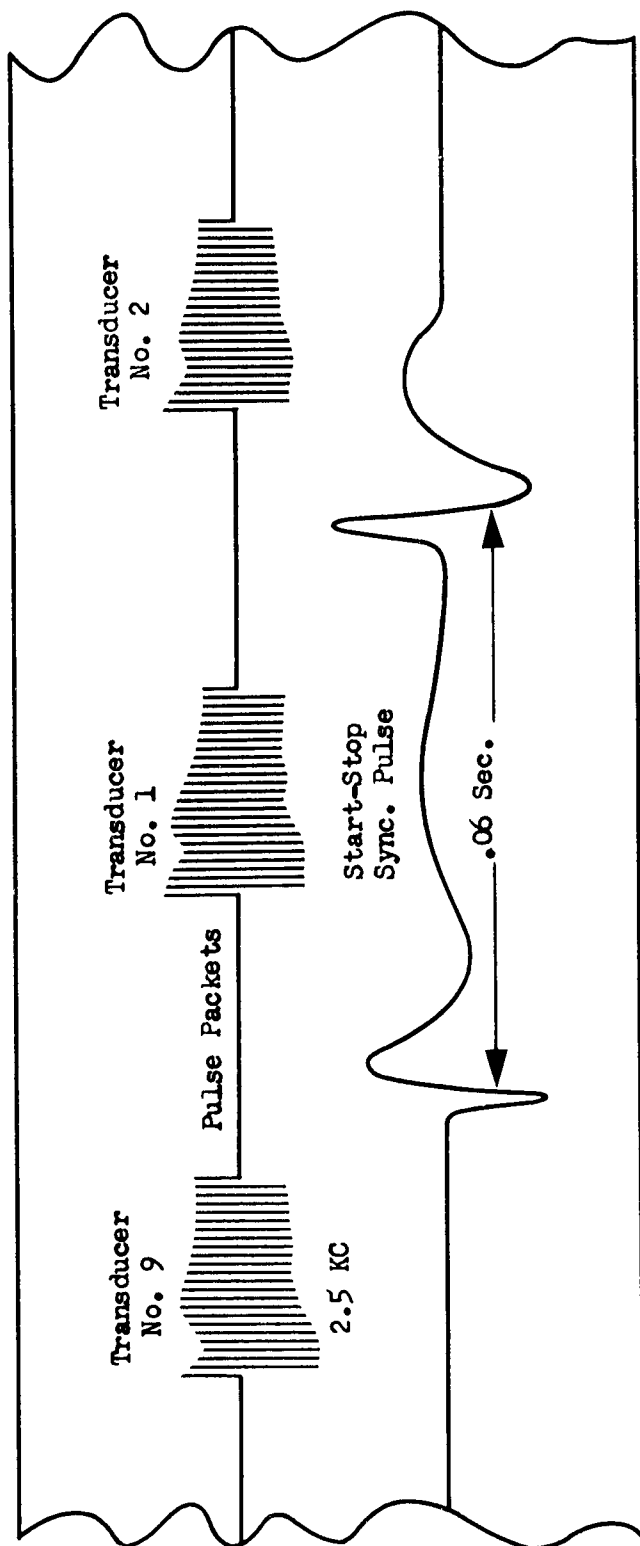
$$t = 0.4 \text{ millisec./ft.}$$

In this way, changes in sea surface height above the submarine are measured in terms of the two-way travel time. These changing values of sea surface height above the submarine are recorded as pulse packets on a Direct Record channel of a magnetic tape recorder. The oscillator signal which forms the pulse packets is a 2.5 kc sine wave. Thus, the number of feet to the sea surface above the transducer is given in terms of the number of oscillations according to:

$$\begin{aligned} d \text{ (feet)} &= N \times (\text{oscillator frequency}) \times (\text{travel time of sound per foot}) \\ &= N \times (2.5 \text{ kc}) \times (0.4 \text{ millisec./ft.}) = N \end{aligned}$$

where N is the number of oscillations which occur during the time the sound wave travels to the sea surface and returns and is numerically equal to the number of feet.

To identify Transducer No. 1, a synchronizing signal is recorded on a separate channel which provides a first trigger pulse with a slightly greater negative excursion and a second trigger pulse with a slightly greater positive excursion, 60 milliseconds later. A typical sequence of pulse packets (including the synchronizing signal provided only for Transducer No. 1) is shown in Figure 2. All other transducers (including No. 1) fire at time intervals of 60 milliseconds for each transducer. The entire sequence of 9 transducers requires 540 milliseconds.



VISICORDER CHART PAPER

FIGURE 2. EXAMPLE OF PULSE PACKETS AND START-STOP SYNCHRONIZING PULSE USED IN SONIC SURFACE SCANNER WAVE HEIGHT MEASURING SYSTEM, U. S. NAVY HYDROGRAPHIC OFFICE.

Assume the oscillation count of the pulse packets recorded for Transducer No. 1 is desired (Fig. 3). The scanner pulse packet signals recorded on one channel of a magnetic tape recorder are fed into the external time base input of the time interval counter and monitored on an oscilloscope. The synchronizing signal from another channel is fed into the start-stop input and also displayed on another scope channel. In order to identify Transducer No. 1.

Numerical values printed out on a digital recorder give changing heights of the sea surface above the transducer. As a check on the quality of the digital printout, a Sanborn Recorder, Model 850, is used to monitor the analog output from the digital recorder. Inasmuch as the printer output is given directly in feet, these values are coded subsequently on punched cards for high speed computations of wave-height spectra on a digital computer. Examples of digital power spectral estimates are presented in references 6 and 7.

If the scanner height data were in analog form suitable for recording on magnetic tape, rapid calculation of surface wave height spectra would be possible on the Hydrographic Office wave analyzer. In addition, it would be extremely desirable to compute cross-spectra of wave and heave, for example, by feeding two random inputs simultaneously into an analog cross-spectrum wave analyzer. The desirability of using the scanner array as a rotating antenna to determine directional wave spectra has been suggested by Professor Walter Munk and described in detail by Macovsky (reference 2).

The instrumentation required to convert the sequence of pulse packets from a particular scanner transducer to an equivalent analog signal with sufficient gain and stability is illustrated in the block diagram in Figure 4. The general procedure for playback, correction, and rerecord is as follows: The pulse packets and synchronization signals, recorded at a magnetic tape speed of $1 \frac{7}{8}$ inches per second, provide the time base for a Hewlett-Packard Model 523 CR Electronic Counter (referred to as: HP Counter). The counter output is fed into the Hewlett-Packard 560A Digital Recorder (referred to as a HP Digital Recorder), which prints out numerical values of the changing height of sea surface (in feet) above the transducer. A relay circuit (shown in Figure 5 and discussed in Part II) eliminates incorrect pulse packet counts, repeating the previous correct count. The HP Digital Recorder also feeds out a balanced staircase voltage which is amplified by a Philbrick P2 Differential Amplifier (shown in Figure 6 and discussed in Part II). The amplified signal is filtered (Fig. 7) and finally recorded on a Precision Instrument Magnetic Tape Recorder and a Sanborn Recorder.

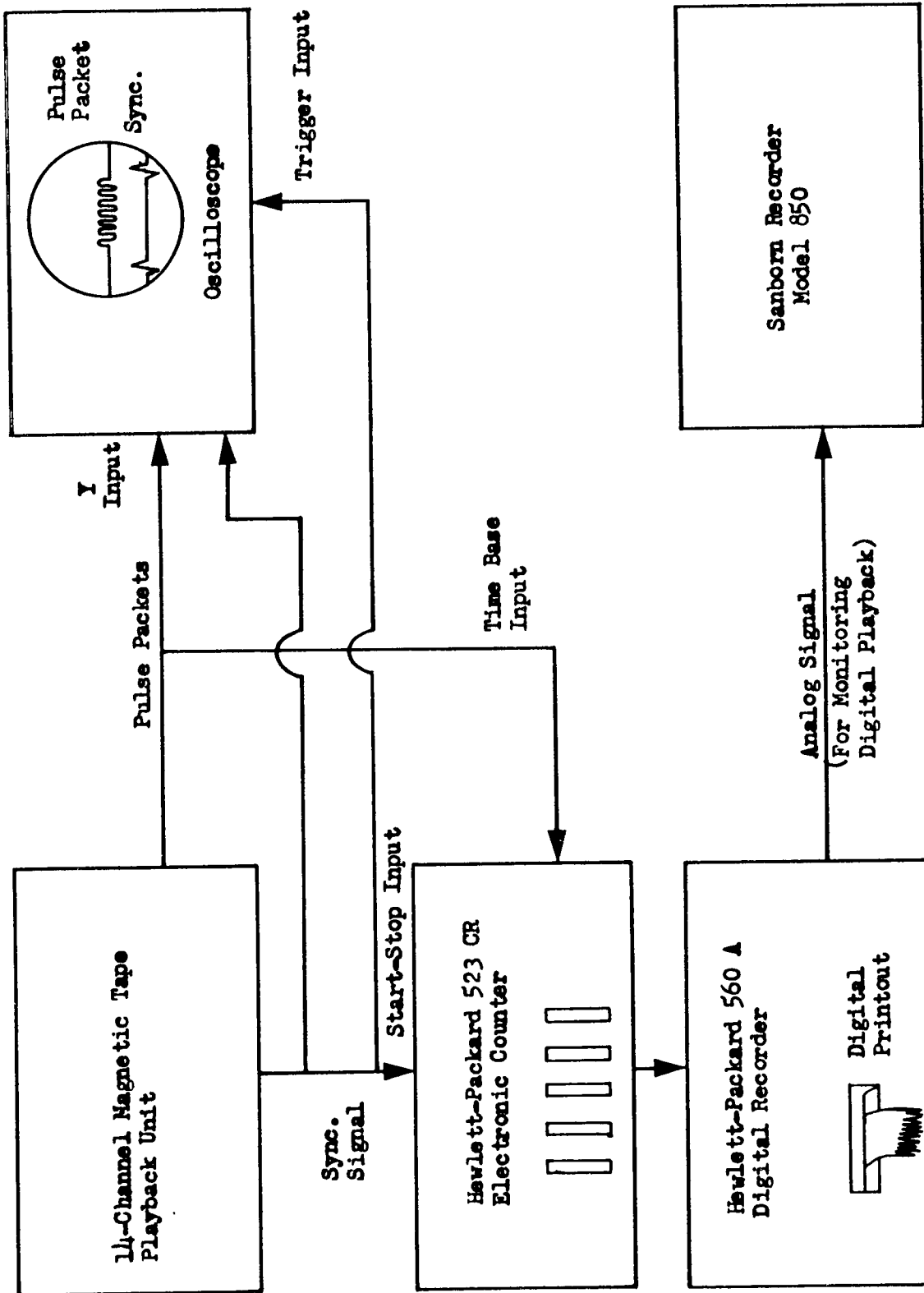


FIGURE 3. BLOCK DIAGRAM OF THE PLAYBACK SYSTEM FOR SONIC SURFACE SCANNER WAVE HEIGHT DATA USED BY U. S. NAVY HYDROGRAPHIC OFFICE.

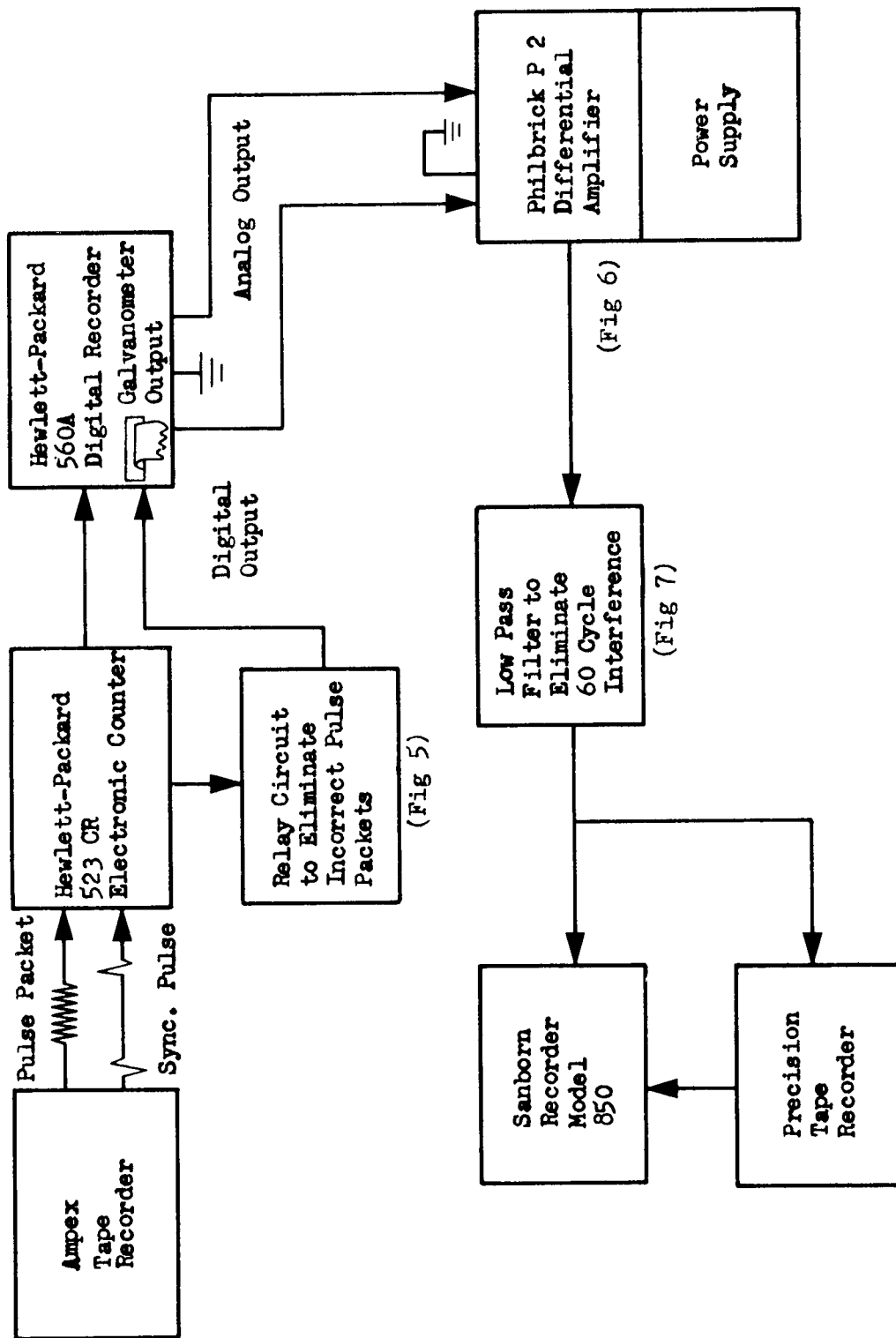


FIGURE 4. BLOCK DIAGRAM OF SYSTEM USED BY U. S. NAVY HYDROGRAPHIC OFFICE TO CONVERT SONIC SURFACE SCANNER PULSE PACKETS INTO AN EQUIVALENT ANALOG SIGNAL.

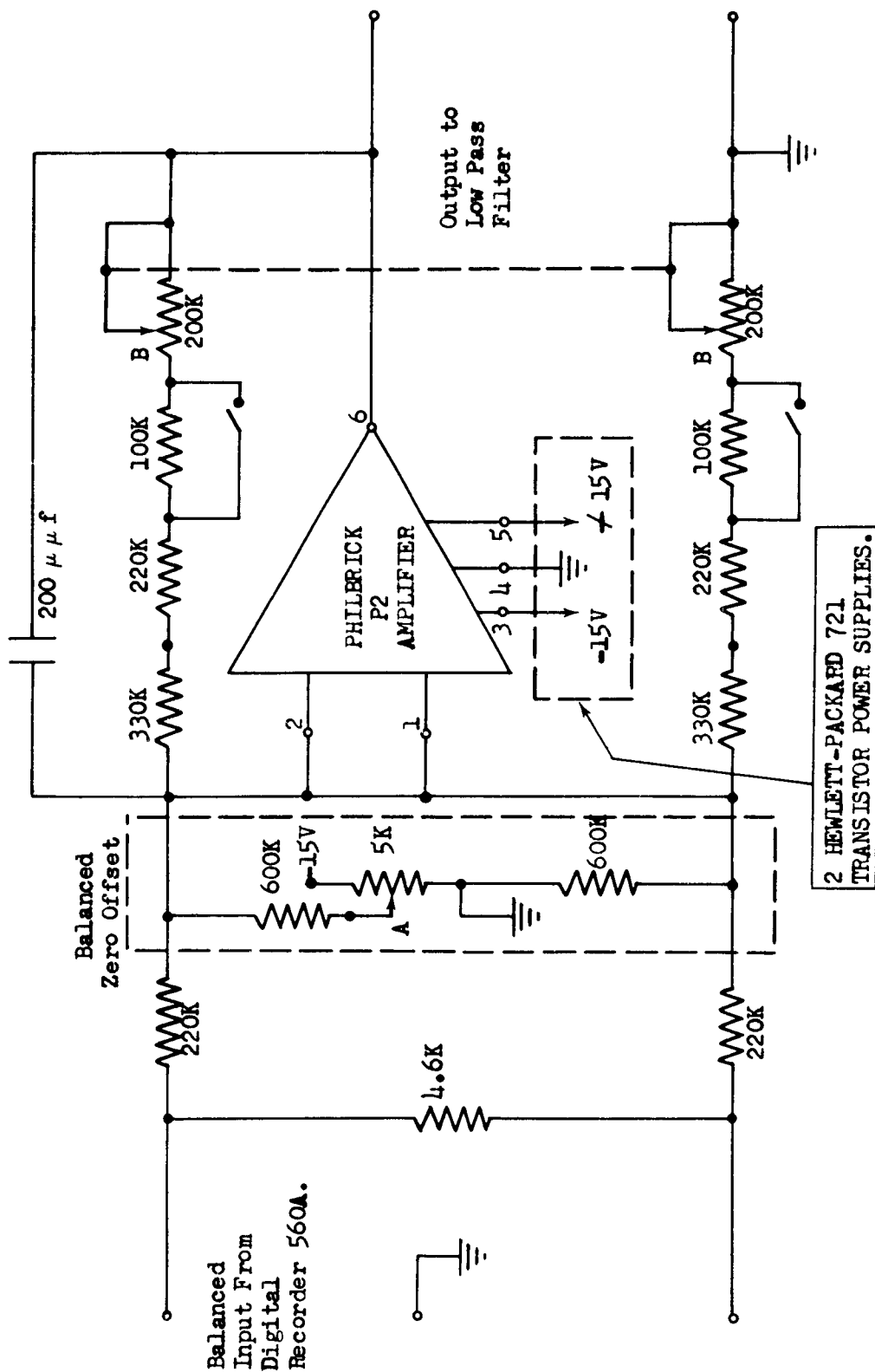


FIGURE 6. D.C. DIFFERENTIAL AMPLIFIER CIRCUIT.

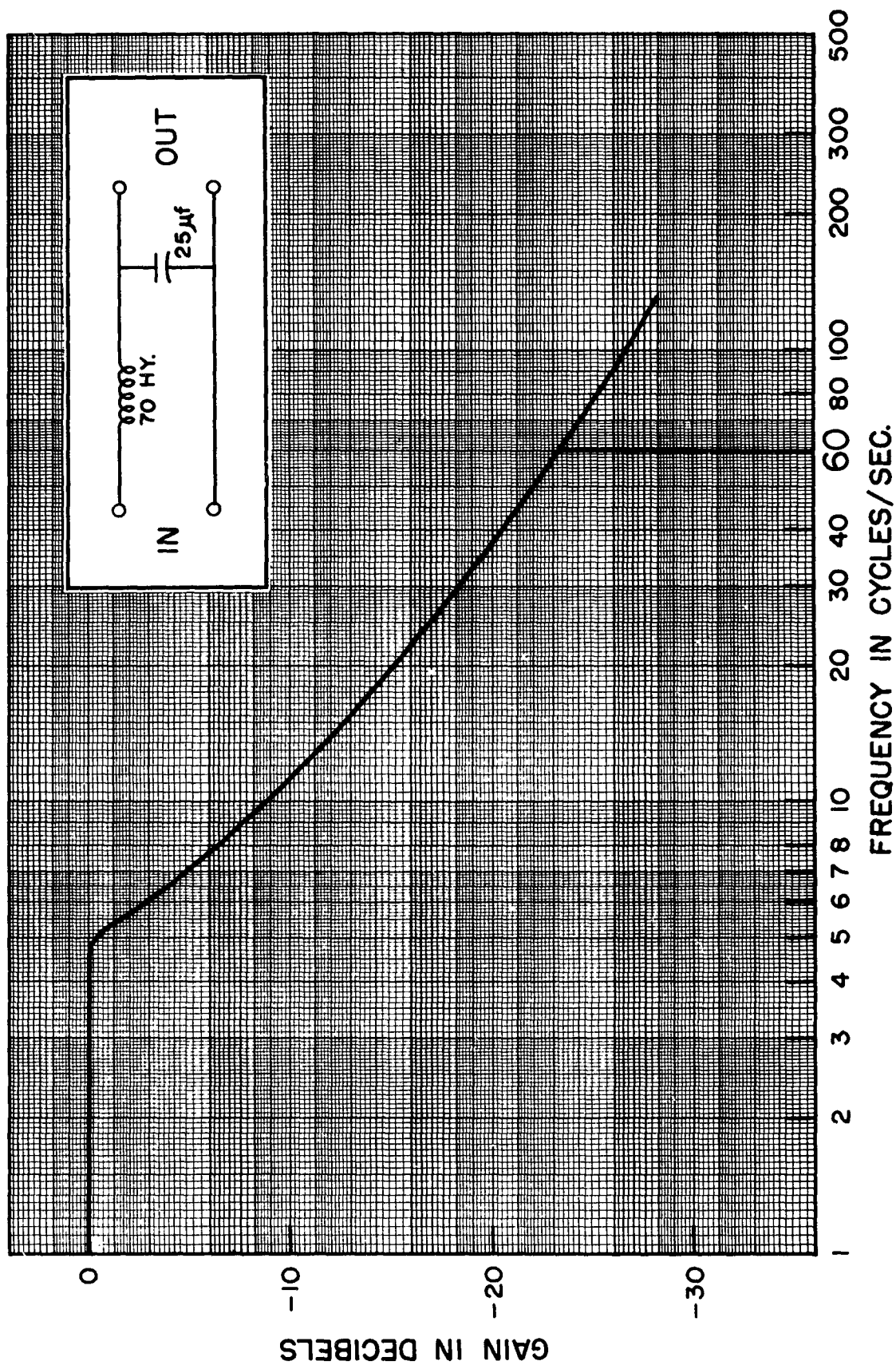


FIGURE 7. FREQUENCY RESPONSE FOR LOW PASS FILTER USED TO ELIMINATE 60-CYCLE INTERFERENCE.

B. Counter Operation

During normal operation, the pulse packet is fed into the "Standard Frequency Counted" inputs. The synchronization pulse is fed into the "Common Start-Stop" inputs. The first trigger pulse opens the gate, and the second trigger pulse closes it. The "Trigger Slope" and "Trigger Level" are adjusted until the counter indicates a pulse packet count which fluctuates above and below the approximate value of the height of mean sea level over the scanner transducer. Such height fluctuations may be thought of as the a.c. component superimposed on a d.c. level, the d.c. level being analogous to the mean depth.

C. Relay Circuit

Occasionally, a return echo is recorded during an operation which is too weak to terminate the pulse packet at its proper time. This results in a pulse packet whose count value (equal to the number of feet of water over the transducer) is far too high, with the result that the pulse packet attains its maximum count. Thus, at a transducer depth of 80 feet, a pulse packet content of 148 cycles (or 148 feet) indicates a weak return echo. Such pulse packets, which are abnormally high with respect to pulse packet variations about the mean depth, will appear at the analog output as a voltage surge with the result that "spikes" will be superimposed on the analog signal. This is extremely undesirable for analog spectrum analysis since such spikes will result in additional perturbations of the spectral values of the random functions of time being analyzed. To block out these undesirable high spikes, a relay circuit as shown in Figure 4, is included to eliminate the incorrect count. The relay circuit (Fig 5) is designed to repeat the last good count, thus keeping the analog output free from excessively abrupt discontinuities. When an abnormally high digital count is registered, the Decade Counter AC-4K (which is a component of the HP Counter) emits a positive pulse. To ensure that this pulse occurs with the proper rise time, it is shaped by passing it through a Squaring Amplifier (T-106). The output pulse of this amplifier triggers the One-Shot-Multivibrator (T-105), which is shunted with a $8\mu\text{f}$ capacitor. The capacitor's function is to extend the output pulse duration of the multivibrator. This duration extension holds the KCP 14 relay activated while the HP Counter is cycling, thus holding the analog output at its previous value.

The above operation is accomplished by direct coupling the multivibrator to the Relay Amplifier (12 AT7WB), which in turn activates the KCP 14 Relay. This action opens contacts 1 and 4 of the above relay, disabling the voltage to the Solenoids L301, L302, etc., in the HP Digital Recorder. This prevents the HP Digital Recorder from changing either its numerical value or analog output. Concurrently, contacts 8 and 11 of the relay, previously closed, are now open, and contact 11 makes connection with an external voltage source, contact 9. This contact has been set to imprint a given number in the sixth column of the printed output of the HP Digital Recorder;

this number thus indicates the occurrence of an abnormally high digital count of the pulse packet. Details and complete circuit diagrams for the 523 CR Electronic Counter and the 560A Digital Recorder are given in "Operating and Service Manuals" prepared by Hewlett-Packard Company, Palo Alto, California. The Squaring Amplifier, T-106, and the One-Shot-Multivibrator, T-105, are described in Catalog No. 859, (Revision B) of Engineered Electronic Company, Santa Ana, California.

D. Amplifier and Filter

The "corrected" sequence of pulse packets is introduced into the HP Digital Recorder which prints out the sequence of numbers giving the sea surface height above the transducer and also feeds out a low level balanced staircase analog output voltage. It is necessary to amplify this analog signal for recording on magnetic tape. This is accomplished with a Philbrick P2 d.c. Differential Amplifier (Fig 6). A balanced output from the HP Digital Recorder is applied across the input terminals of the amplifier. Potentiometer A permits adjustment of the zero reference which can assume arbitrary values, depending on the mean operating depth during a particular recording. Potentiometer B permits adjustment of the amplified output to ensure a gain sufficient to provide ± 1.41 volts, corresponding to an arbitrary wave height variation. Specifications and characteristics of the amplifier are described in GAP/R Technical Bulletin P2, George A. Philbrick Researches, Incorporated. The amplified signal is passed through a low-pass filter to eliminate 60 cycle and higher frequency interference. The low pass filter response curve is shown in Figure 7.

III. RECORDING AND CALIBRATION

The analog output of the random function representative of surface wave height can now be recorded on magnetic tape and a strip-chart recorder. A sample of the analog signal (illustrating a "spike") from a Sanborn Recorder is shown in Figure 8. The lower trace represents the analog output of the HP Digital Recorder, which is fed into the magnetic tape recorder. The upper trace represents the output of the magnetic tape recorder which is rerecorded subsequently for input to a spectrum analyzer. The analog recordings of such random signals are played back at 60 inches per second and rerecorded at $1 \frac{7}{8}$ inches per second to facilitate analysis on the spectrum analyzer. The spectrum analysis procedure used at the Hydrographic Office is outlined briefly in Part IV and is described in detail in reference 7.

The approximate value of mean sea level above the transducer must be known so that peak values of the random signals do not saturate the channels of the magnetic tape recorder. The value of mean depth is available from another channel of the

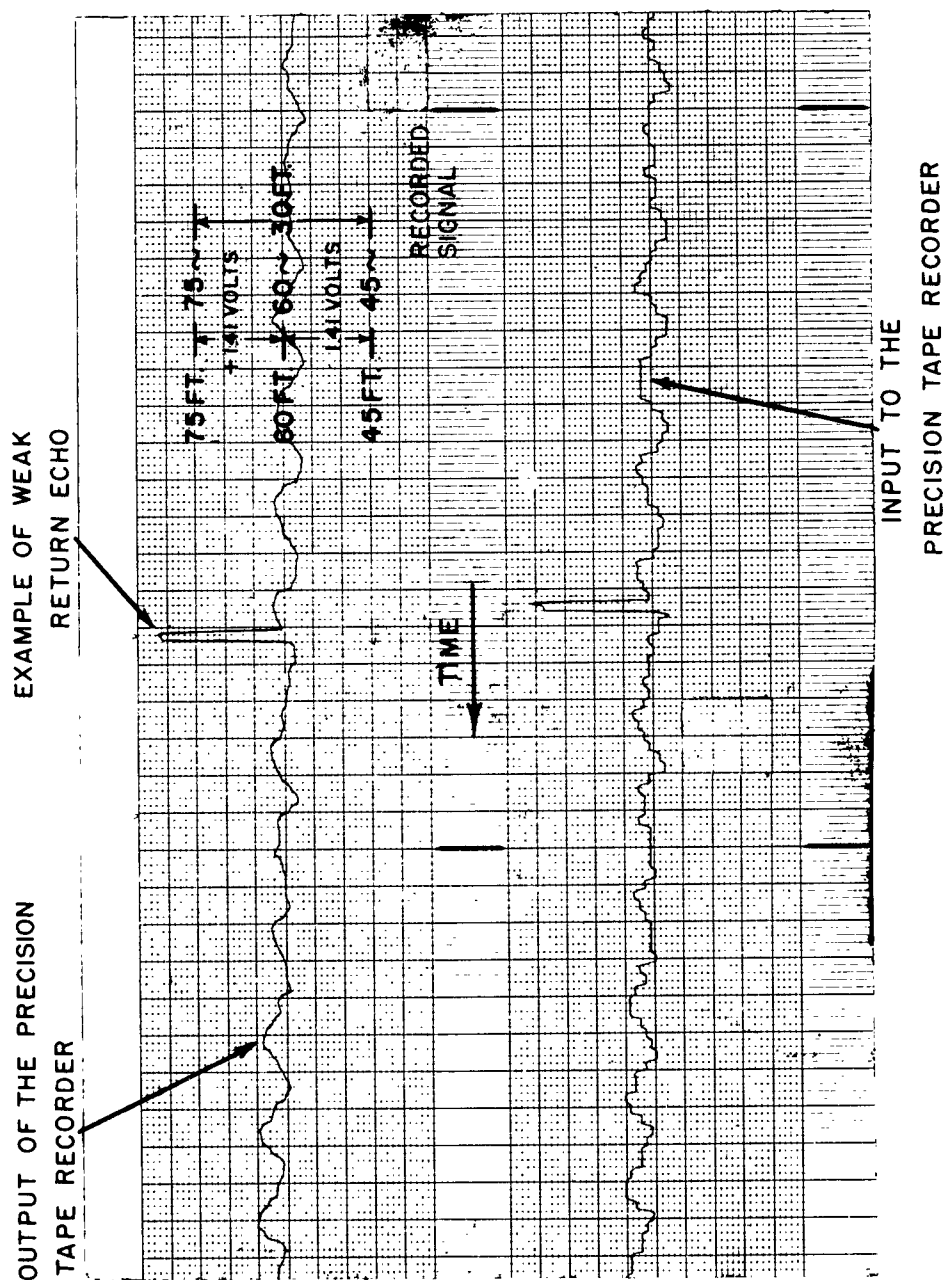


FIGURE 8. EXAMPLE OF SONIC SURFACE SCANNER ANALOG TRACE AND "SPIKE" (WEAK RETURN ECHO) ELIMINATED BY RELAY CIRCUIT.

magnetic tape recording. For example, if mean sea-level distance to the scanner transducer is 60 feet, a 60-cycle signal is fed into the counter, and the amplifier balance is adjusted to read zero d.c. volts at the Precision Instrument Magnetic Tape Recorder input (Fig. 9). The amplifier gain is then adjusted so that 75 cycles per second (75 feet) corresponds to + 1.41 d.c. volts and 45 cycles per second (45 feet) corresponds to - 1.41 d.c. volts. Thus, a 2.82 d.c. voltage range can accommodate a wave height variation of 30 feet. This is illustrated in Figure 9.

To operate the HP Counter to obtain the calibration described above:

1. Apply a sine wave signal from a signal generator into the "Input" terminals. Change the "Function Selector" switch from "Time Interval" (position during normal operation) to the "Frequency" position. (Note: During normal operation, the "Time Unit" is set in the "External" position).
2. Adjust Balanced Zero Offset Potentiometer A (Fig. 6) for a zero d.c. output at a particular center frequency (i.e. 60 cps = 60 feet). Monitor the amplifier output voltage with an oscilloscope.
3. Adjust frequency of signal generator for desired upper frequency limit (i.e. 75 cps = 75 feet).
4. Adjust Potentiometer B (Fig. 6) for + 1.41 volts as indicated on the oscilloscope.
5. Recheck Potentiometer A of Balanced Zero Offset for zero d.c. amplifier output.
6. Recheck Potentiometer B for + 1.41 volts.
7. Adjust signal generator for desired lower frequency limit (i.e. 45 cps = 45 feet). The output voltage should read - 1.41 volts.
8. Repeat steps 5 and 6 if necessary.
9. Check Sanborn Recorder for internal calibration and set pen arm to zero.
10. Disconnect amplifier and apply a d.c. potential of + 1.41 volts to Sanborn Recorder and note position of trace.
11. Repeat above for - 1.41 volts and note position of trace.

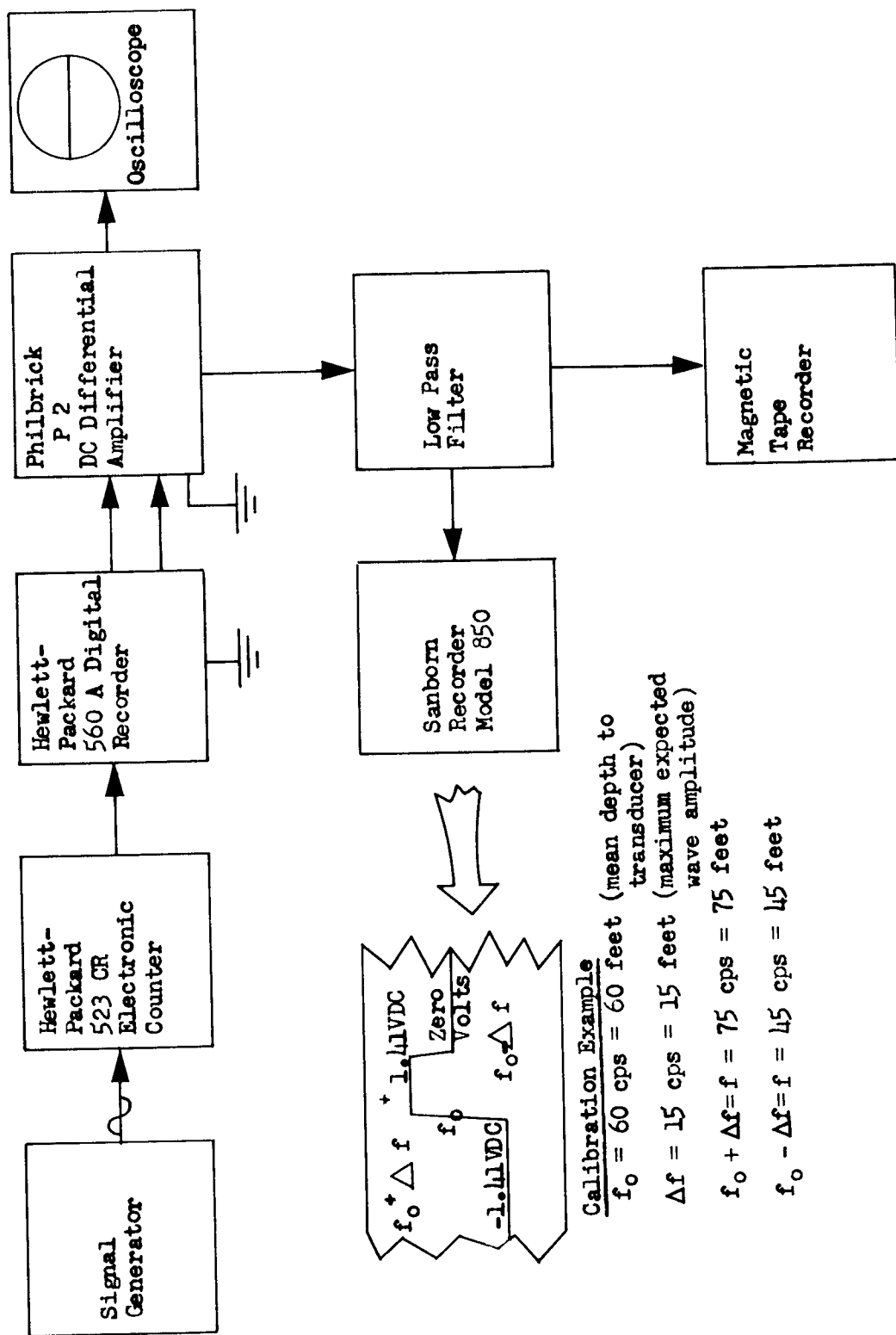


FIGURE 9. BLOCK DIAGRAM OF SYSTEM USED BY U. S. NAVY HYDROGRAPHIC OFFICE TO CALIBRATE DYNAMIC RANGE FOR ANALOG SIGNALS FROM SONIC SURFACE SCANNER DATA.

12. Disconnect d.c. source from Sanborn Recorder and apply output of Philbrick P2 amplifier to Sanborn Recorder.
13. With the signal generator set at 60 cps, the Sanborn Recorder trace should indicate zero d.c. volts. Similarly, with signal generator set at 75 and 45 cps the Sanborn Recorder trace should indicate plus and minus 1.41 volts d.c., respectively.

The analog scanner data recorded in the field on magnetic tape are now conditioned for compressed rerecording. At this stage, these data may serve as an input to the wave analyzer or as input to the various analog computer circuits, where the signal can be corrected for the effect of submarine motion*.

IV. CALCULATION OF SPECTRAL ESTIMATES USING HYDROGRAPHIC OFFICE WAVE ANALYZER

The first step in the analysis of the analog signal is to play the signal back at 60 inches per second and rerecord it at $1 \frac{7}{8}$ inches per second. This results in a compression of $\frac{1}{32}$ the original recorded tape length; the frequency components in the random signal are all increased by a factor of 32. The compressed recording is formed into a continuous loop and threaded into a special loop attachment. A Precision Instrument Tape Recorder is utilized to drive the loop at a speed of 30 inches per second for an additional frequency increase of 16 times and a total frequency increase of $32 \times 16 = 512$ times the original frequencies. Thus, a frequency of 0.10 cycles per second appears on the analyzer as a frequency of 51.2 cycles per second. A bandwidth of 10 to 210 cps was selected for this problem. The reason for analyzing in this frequency range is that the beat frequency analyzers commonly used can easily accommodate frequencies at higher ranges, but can not handle gravity wave frequencies (e.g. 0.03 to 0.3 cycles per second).

The analysis system used at the Hydrographic Office is indicated in the block diagram of Figure 10. Problems associated with filter bandwidths, loop periods, time constants, and frequency scanning rates are discussed in reference 3.

*Corrections for the effect of heave displacement and pitch angle have been applied successfully to the transducer time history with an analog computer by Mr. Gordon Roessler and his associates at the Westinghouse Air Arm Division, Westinghouse Electric Corporation.

Ampex Corp.
Redwood City,
Calif.

11-Channel
Magnetic Tape
Playback Unit

11-Channel
(Transistorized)
Magnetic Tape
Recorder PS2114

Loop
Attachment
(For Loops
1 inch wide)

Precision Instruments Co.
San Carlos, Calif.

Oscillator
TP 626
Analyzer
TP 627
Power
Integrator
TP 633

Technical
Products Co.
Los Angeles,
Calif.

2-Channel
Sanborn
Recorder
Model 850

Average
Energy
Density

Integrated
Spectrum

X-Y Recorder

Moseley Co., Pasadena, Calif.

FIGURE 10. BLOCK DIAGRAM OF THE ANALOG WAVE ANALYSIS SYSTEM USED BY THE SUBMARINE SYSTEMS SECTION, U. S. NAVY HYDROGRAPHIC OFFICE.

V. COMPARISON OF ANALOG TO DIGITAL SPECTRAL ESTIMATES

A. Digital Spectral Estimates

Since the purpose of this report is to show how estimates of analog spectral density can be recovered from a discrete (pulse packet) input, an example was selected in which the transducer time history was not distorted by the motion of the hovering submarine.

Figure 11 illustrates power spectra of wave heights recorded in deepwater about 200 miles east of Cape Hatteras, North Carolina. These spectra were computed by the digital estimation formulae of Tukey (references 1 and 4). The 90-percent confidence intervals are determined by computing the number of degrees of freedom according to:

$$\text{Number of degrees of freedom} = \frac{2 T_n}{m \Delta t}$$

where T_n is the duration of the record in seconds, m is the number of lags, and Δt is the sampling interval in seconds. For example, with $T_n = 1,440$ seconds, $m = 60$, and $\Delta t = .6$ seconds, spectral estimates in Figure 11 are distributed with a chi square distribution with 80 degrees of freedom. The 90-percent confidence intervals can be determined from a table of the chi square distribution. For 80 degrees of freedom, the true spectral density $P_t(f)$ is bounded by the estimated spectral density $P_e(f)$ according to:

$$.78P_e(f) < P_t(f) < 1.27P_e(f)$$

This set of spectra is fairly narrow with periods of maximum spectral energy between 5.5 and 6.5 seconds. Significant wave heights, $\bar{H}_{1/3} = 2.83\sqrt{E}$, where E is the area under the spectra graphs, were found to lie between 5 and 6 feet for these three examples.

During these three runs, roll and pitch angles and heave acceleration were almost negligible, as indicated in Table 1.

LEGEND							
	RUN	DATE NOV 1960	TIME	E (ft ²)	$\bar{H}_{1/3}$	SHIP'S SPEED (kn)	KEEL DEPTH (ft)
————	8-3-2	16	2001 2031	4.18	5.8	1	80
-----	8-3-4	16	2040 2110	3.42	5.2	1	80
oooooo	8-3-7	16	2302 2332	4.85	6.2	1	80

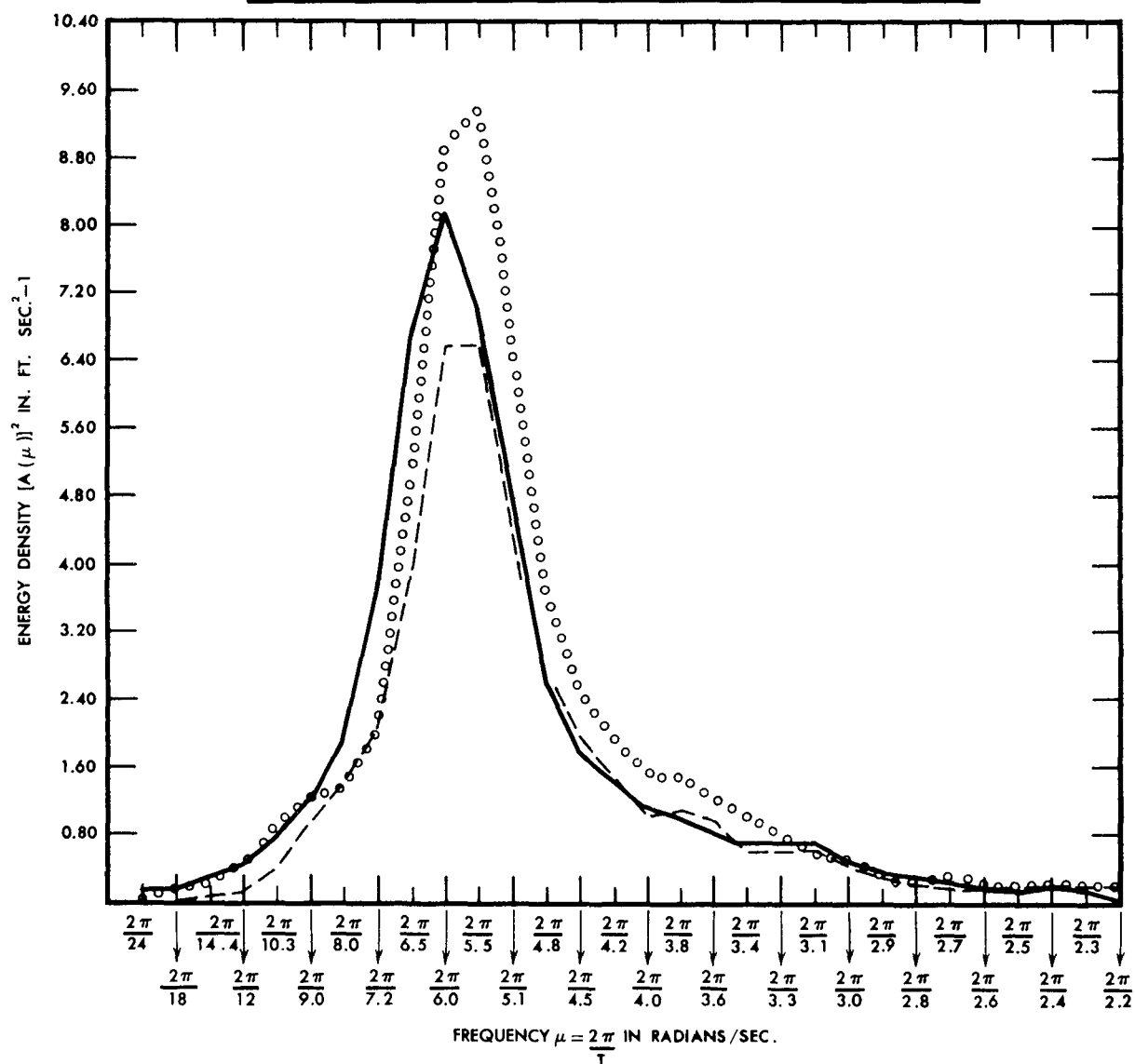


FIGURE 11. POWER SPECTRA OF WAVE HEIGHTS. CRUISE 8, RUN 8-3-2.

TABLE 1. SUMMARY OF SUBMARINE MOTION PARAMETERS
CRUISE 8, RUN 3

Run	Mean Roll Angle (deg)	Mean Pitch Angle (deg)	Mean Heave Acceleration (g's)
8-3-2	.6	.3	Flat Trace
8-3-4	1.2	.2	Flat Trace
8-3-7	1.1	.1	Flat Trace

B. Comparison of Results Derived from Measured Spectra and Hindcasting

Table 2 summarizes significant wave heights and wave period bands derived from measured wave spectra and wave hindcasts by methods of Pierson-Neumann (reference 8). The results obtained by the two methods are compared in Table 2.

TABLE 2. RESULTS DERIVED FROM MEASURED WAVE SPECTRA
COMPARED TO HINDCAST WAVE DATA

Run	Values from Measured Wave Spectra		Values from Hindcast Wave Data	
	Significant Wave Height $\bar{H}_{1/3}$ (ft)	Wave Period Band T-Band (sec)	Significant Wave Height $\bar{H}_{1/3}$ (ft)	Wave Period Band T-Band (sec)
8-3-2	5.8	2.5 - 14.4	5	2.0 - 8.0
8-3-4	5.2	2.5 - 14.4	6	2.0 - 8.0
8-3-7	6.2	2.5 - 14.4	8	2.0 - 8.0

Significant height values compare reasonably well; however, the highest periods from hindcasting are about 8.0 seconds, while the highest periods from the measured spectra are about 14.4 seconds.

C. Example of an Analog Spectral Estimate of Sonic Surface Scanner Data

The three examples of digital wave spectral described above are representative of conditions during negligible submarine motions as evidenced by the low values of the components of motion which can influence the Sonic Scanner recordings. In addition, the good agreement between measured and hindcast wave parameters lends confidence to this method of recording surface wave data.

The first recording in this group, Run 8-3-2, was selected for digital-to-analog conversion. The analog spectrum from Run 8-3-2 is shown in Figure 12. The digital spectrum curve is superimposed as a check on the accuracy of an analog method relative to the digital method. In order to compare two spectral estimates, it is necessary that the same resolution be used in obtaining the two spectra. Since the digital spectrum had 80 degrees of freedom, the filter bandwidth of the analyzer and loop period were chosen to give as close a value to this as possible. Such analog spectral estimates are distributed with a chi square distribution with $2N$ degrees of freedom, where N is the number of elemental bands covered by the filter. If the spectral density is not a fast-changing function of frequency interval equal to the bandwidth of the filter, then N is approximately equal to the effective bandwidth of the filter divided by the elemental bandwidth. The elemental bandwidth is $1/T$, where T is the loop period, and the effective bandwidth used was 16 cycles per second (reference 3). The loop period for this recording was 3 seconds. Thus:

$$\text{Number of degrees of freedom} = 2N = 2 \frac{\text{effective bandwidth}}{\text{elemental bandwidth}} = 2 \frac{16}{1/3} = 96.$$

For 96 degrees of freedom, the 90-percent confidence intervals for analog spectral estimates are given by:

$$.77P_e(f) < P_f(f) < 1.32P_e(f)$$

The agreement between the digital and analog estimates as indicated in Figure 12 is close. The area under the digital spectrum is 4.18 ft^2 , and the area under the analog spectrum is 3.87 ft^2 .

VI. SUMMARY

The instrumentation and equipment discussed in this report are part of the analysis system used by the Submarine Systems Section in the routine preparation and analysis of surface wave height and other random-type data. The assumption that submarine motion had a negligible influence on the recorded data seems valid as evidenced by

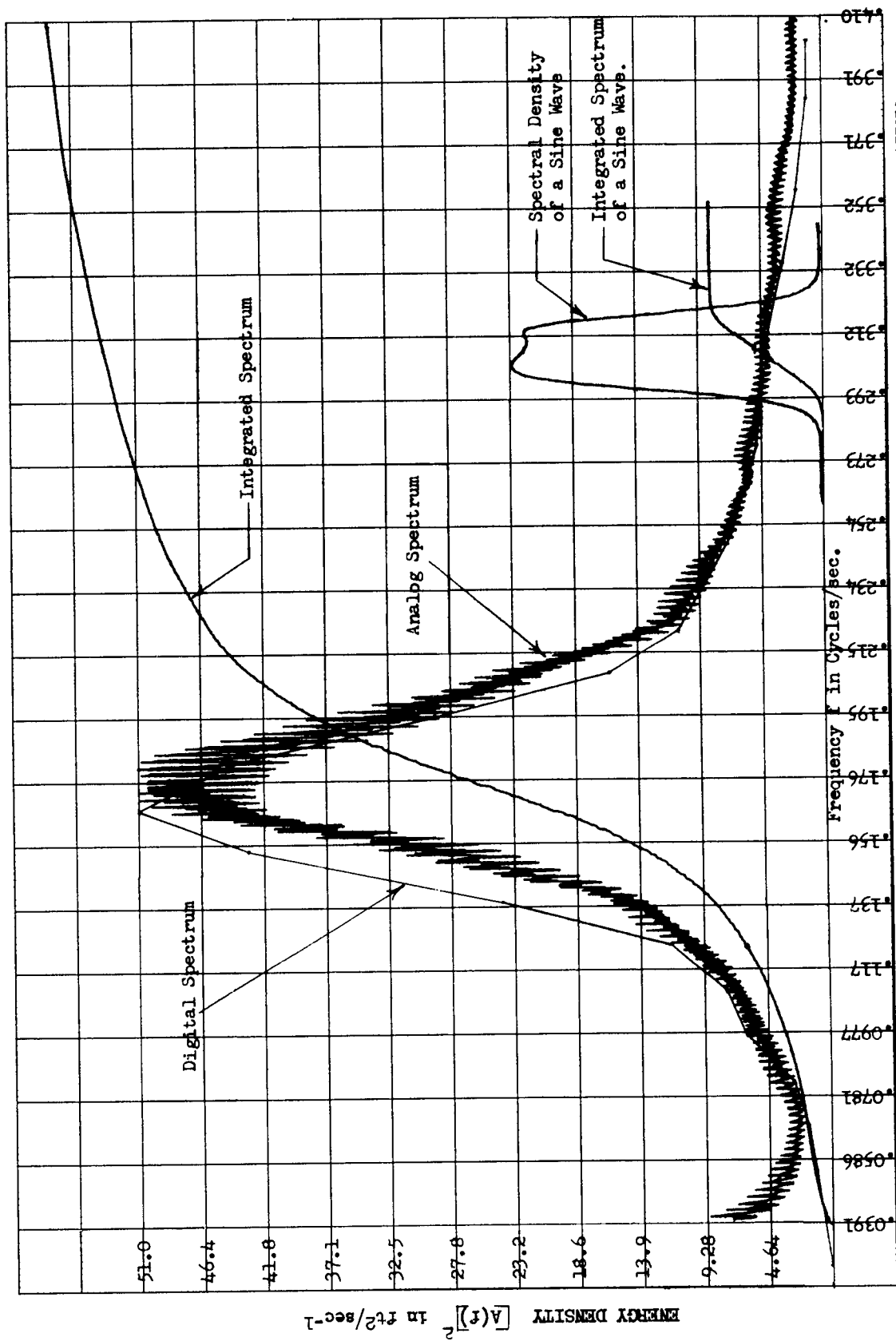


FIGURE 12. POWER SPECTRA OF SURFACE WAVE HEIGHTS, CRUISE 8. ANALOG SPECTRUM OF RUN 8-3-2 WITH DIGITAL SPECTRUM SUPERIMPOSED.

the very low mean values of roll and pitch angles and very small values of heave acceleration.

Although digital spectra can be estimated from the random sequences of pulse packets, it is very desirable to convert wave data into an analog form since an analog wave analyzer permits rapid estimation of power spectra. In addition, cross-spectral densities between pairs of scanner transducers, as estimated by an analog cross-spectrum analyzer, may be an excellent way to estimate directional spectra.

Instrumentation and circuitry are concerned principally with conditioning, amplification, and calibration of the analog signal. The most troublesome problem is associated with proper operation of the relay circuit to eliminate weak return echoes. This is important since the input to wave analyzers must be free of voltage fluctuations exceeding the dynamic range of the magnetic tape recorder.

The sample analog scanner signal whose spectrum was estimated, by both digital and analog methods, was assumed to be corrected for submarine motion. In general, however, such signals will need correction for the effects of heave displacement, pitch angle, and roll angle.

VII. FUTURE INSTRUMENTATION AND ANALYSIS PLANS

A more sophisticated system will replace the present relay arrangement for preventing high and low counts from disturbing recorded results. This system will eliminate both high and low fallacious digital counts.

The problem of correcting for submarine motion may be handled with an analog computer. Such basic operations as summing, scaling, and integration can be performed on the analog inputs representing heave acceleration, pitch angle, and roll angle.

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