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AN INSTRUMENT FOR CONTINUOUS DEEP-SEA MEASUREMENT OF VELOCITY OF SOUND, TEMPERATURE, AND PRESSURE

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ABSTRACT. An electronic instrument for the continuous and concurrent measurement in the ocean of velocity of sound, temperature, and pressure has been designed and tested to depths in excess of 2,000 meters. This 70-pound transistorized instrument contains three sections: a modified NBS velocimeter for measuring velocity of sound, a Borg-Warner Vibrotron for pressure, and a NOTS thermistor-controlled Wien-bridge oscillator for temperature. Outputs from the three sections are frequency-modulated signals, mixed for single-conductor cable transmission to the surface. Velocity of sound is transmitted in the band 2,775-3,225 cps, temperature in the band 5,000-8,000 cps, and pressure in the band 9,712-11,288 cps. Accuracy of measurement is sound velocity 0.3 m/sec, temperature 0.02°C, and pressure 1% in selected ranges of 0-1,000 and 0-2,000 psi.

U.S. NAVAL ORDNANCE TEST STATION

China Lake, California

9 May 1961

U. S. NAVAL ORDNANCE TEST STATION

AN ACTIVITY OF THE BUREAU OF NAVAL WEAPONS

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Technical Director

FOREWORD

This report describes an instrument, developed at the U. S. Naval Ordnance Test Station, for the continuous and concurrent measurement of velocity of sound, temperature, and pressure at any ocean depth.

The work was completed under the Bureau of Weapons Task Assignment R360FR106-2161-R01101001.

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INTRODUCTION

A sound-velocity, temperature, and pressure (SVTP) instrument was built during 1958-1960 at the U. S. Naval Ordnance Test Station (NOTS) to satisfy the need for a continuous-reading instrument for the concurrent measurement and data transmission of three of the oceanic parameters (see Fig. 1).

The NOTS-SVTP instrument contains three sections, permitting the simultaneous measurement of velocity of sound, temperature, and pressure as the instrument is moved through the water. The velocimeter developed by Greenspan and Tschiegg of the National Bureau of Standards (NBS) and slightly modified by NOTS is the velocity of sound section (Ref. 1). The temperature section is a thermistor-controlled Wien-bridge oscillator developed at NOTS (Ref. 2), and the pressure section is the Vibrotron of Borg-Warner Controls, Santa Ana, California. The accuracy of measurement for the NOTS-SVTP instrument is velocity of sound 0.3 m/sec, temperature 0.02°C, and pressure 1% in selected ranges. The basic design of the instrument will permit its use in all ocean depths.

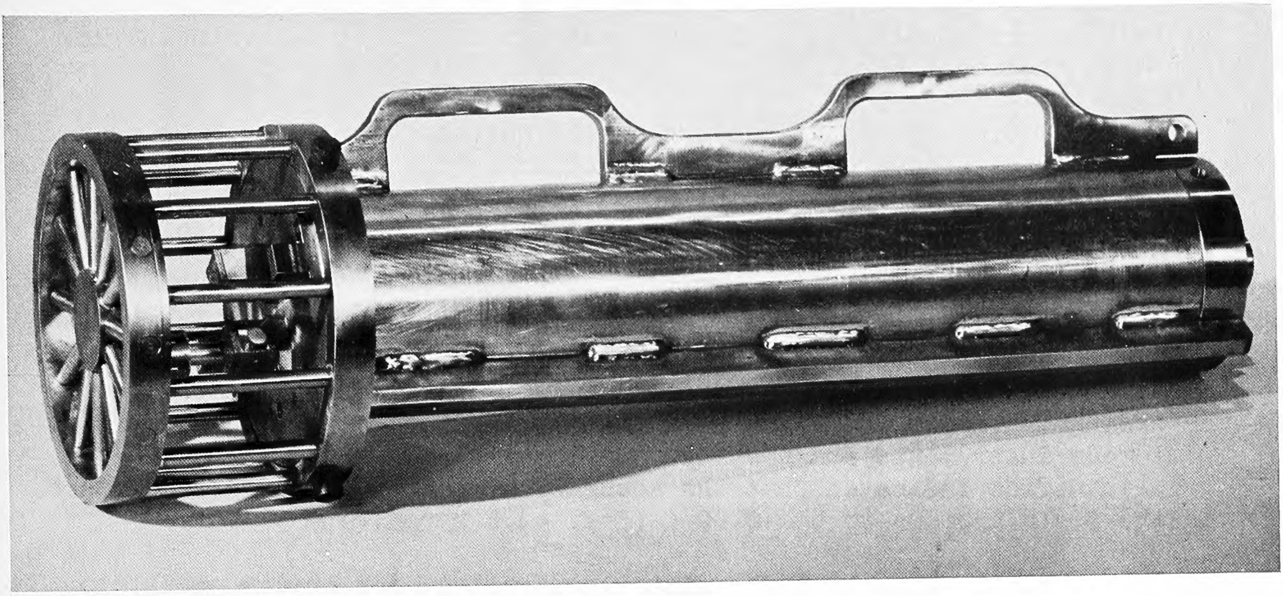


FIG. 1. NOTS-SVTP Instrument.

The data are continuously transmitted as frequency-modulated signals over the supporting cable, and the three measured parameters can be displayed and recorded for detailed examination. The recorded frequency-modulated data can be readily assessed by machine data reduction techniques.

Velocity of Sound. The velocity-of-sound meter is used to examine the variations in sound velocity as a function of depth in the ocean, and it provides data of greater accuracy than the bathythermograph. The bathythermograph has been of unquestioned value in providing information on the thermal structure of the ocean, in studying underwater sound transmission, and in making sonar predictions. However, the bathythermograph does not yield sound-velocity values directly nor does it provide immediate data readout.

The hydrographic method of sound-velocity determination is also an indirect method requiring measurement in situ of temperature, pressure, and salinity. It does not provide either continuous or immediate readings of the velocity of sound.

From 1950 to 1954 and under the Office of Naval Research sponsorship, five experimental underwater velocity-of-sound meters were developed by Springer, Cook, the University of Michigan, and the National Bureau of Standards. Two of these meters employed phase-measuring techniques, two employed the pulse-feedback principle, and one was a resonant-cavity type. Between 1954 and 1956, all five meters were reviewed by the U. S. Navy Underwater Sound Laboratory and the meters with the pulse-feedback principle were considered to be the best for measuring the velocity of sound in the ocean (Ref. 3).

In 1957 Greenspan and Tschiegg of the National Bureau of Standards reported on a "sing-around" velocity measuring technique that seemed most promising for use as a continuous reading instrument for all depths in the ocean (Ref. 1). Consequently, it was decided that this circuitry should be incorporated in a NOTS field instrument that would also measure pressure and temperature.

Temperature. Most observations of sea-water temperature at depths greater than 300 meters have been made with reversing thermometers. Reversing thermometers, first used in 1874, have been improved until well-made instruments are now accurate to within 0.01°C. The Hydrographic Office indicates that the accuracy of the reversing thermometers in the field appears to be ±0.02°C (Ref. 4).

The recently developed thermistor-controlled Wien-bridge oscillator at NOTS has produced a temperature accuracy of 0.02°C, and it was selected for use in the SVTP instrument (Ref. 2).

Pressure. Depth measurements in the ocean can be made by observing the effect of pressure on a pair of reversing thermometers, one protected and the other unprotected from pressure (Ref. 5). A great advantage of this method is its accuracy, but a serious disadvantage is that only point-depth readings are provided. The thermometers can only be read by visual inspection at the surface and only one reading taken for each depth point. The probable error of depths obtained by the unprotected thermometer is about ±5 meters for depths of less than 1,000 meters, and about 0.5% of the wire depth for depths greater than 1,000 meters (Ref. 5).

Other methods of reading pressure to determine ocean depth are as follows: spring-loaded bellows, Bourdon tube (a hollow spring), electrical strain gage, variable-reluctance gage, diaphragm-actuated electrical potentiometer, vibrating-wire transducer, and more recently the solid-state pressure sensitive gage. All may yield a variable voltage, current, or frequency as a function of pressure, and consequently are suitable for use in a continuous depth-reading meter. Accuracy of about 1% may be attained by each of these methods. The vibrating wire transducer was selected for the NOTS-SVTP instrument because of its accuracy, frequency-modulated output, and repeatability and simplicity of its associated circuitry.

Pressure readings in the ocean by the SVTP instrument yield continuous readings within 1% of the range of the Vibrotron used (available in ranges from 100 to 10,000 psi). The resulting error is slightly greater than the 0.5% of protected-unprotected reversing thermometer pairs.

DESCRIPTION

Figure 2 is a block diagram of the NOTS-SVTP instrument. The outputs of the velocity-of-sound, temperature, and pressure oscillators are summed and amplified to drive the cable.

The individual circuits and packaging of the instrument are described in the following sections.

SOUND-VELOCITY OSCILLATOR

Figure 3 is a diagram of the transistorized sound-velocity circuit used in the SVTP instrument. The circuit is essentially that designed by NBS with minor modifications (Ref. 1 and 6). It has been described as a "sing around" or "an ultrasonic delay line that synchronizes a relaxation oscillator," i.e., the circuit consists of a free-running

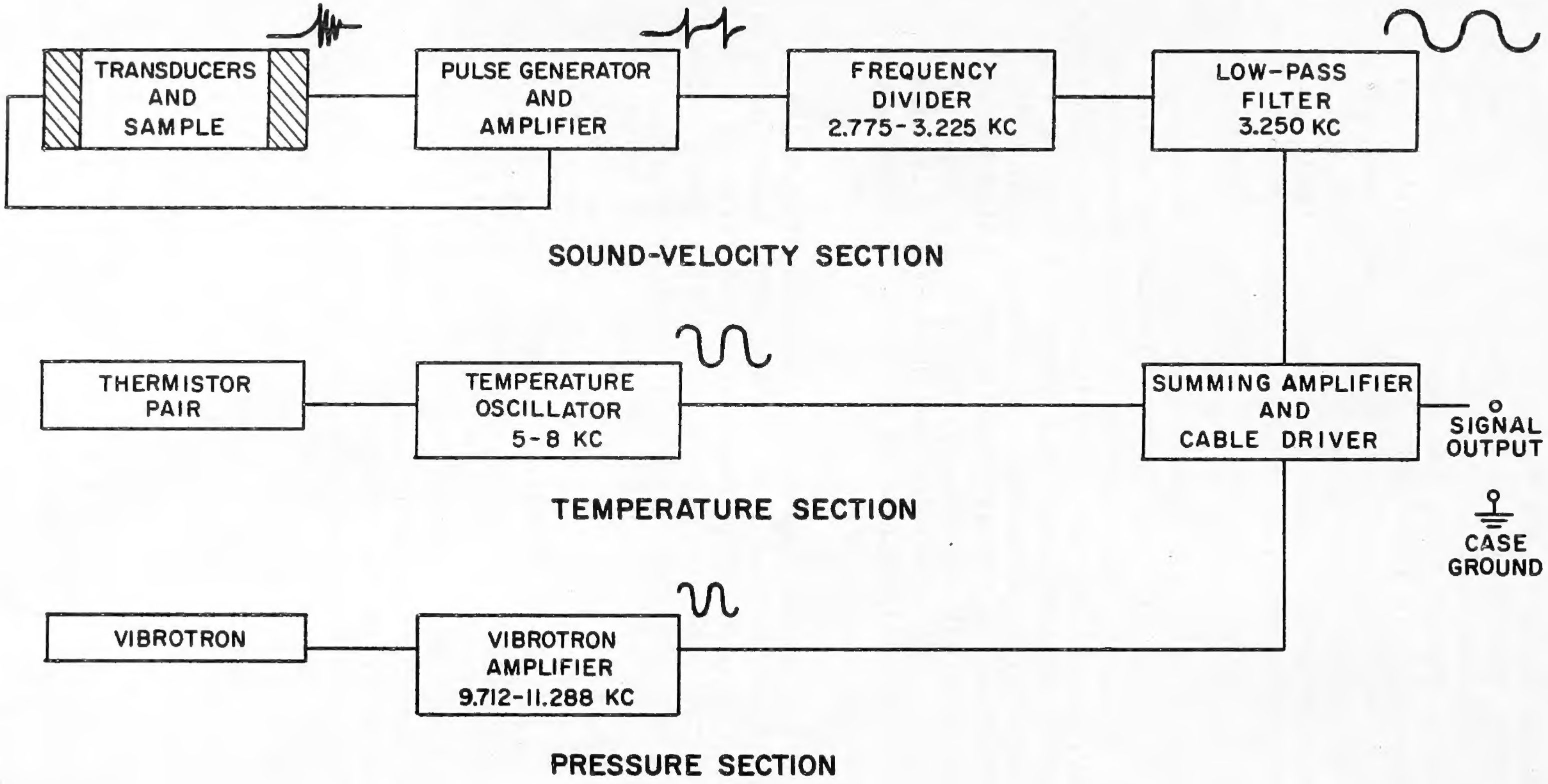
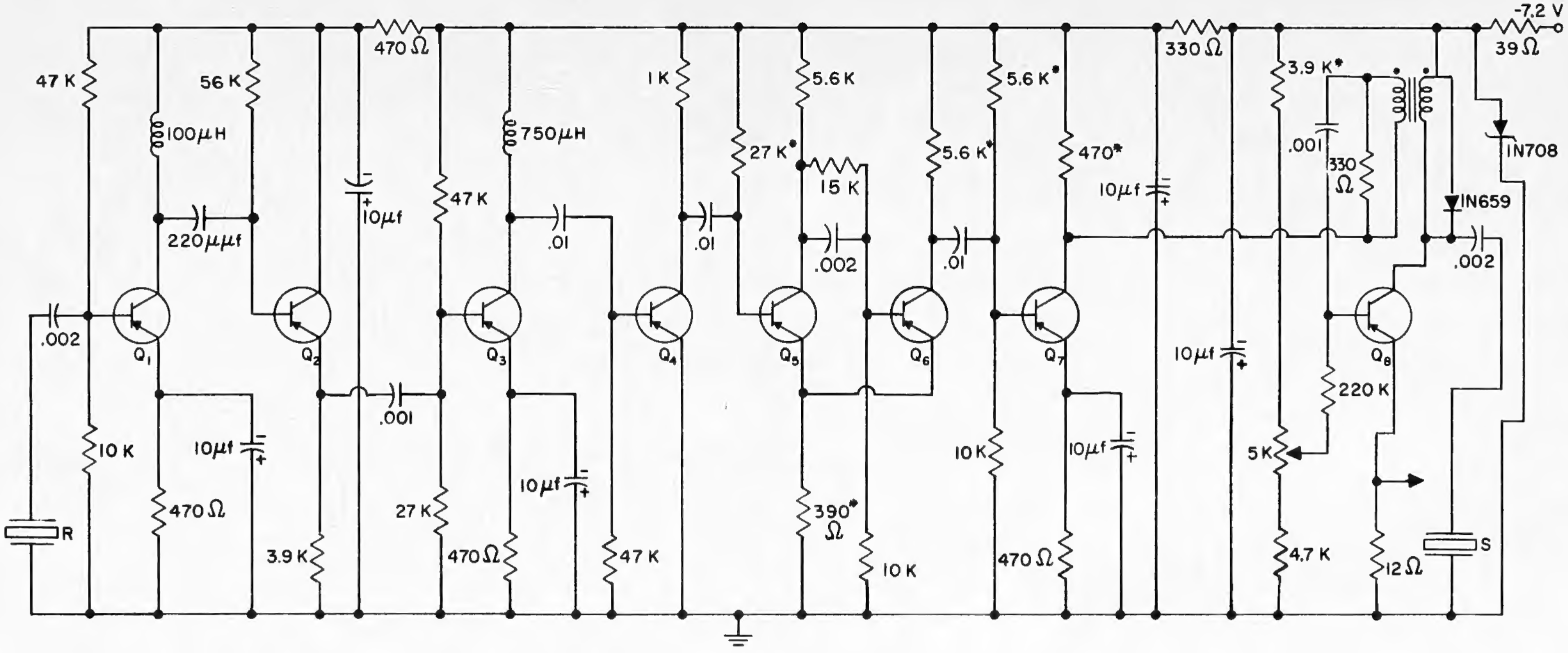


FIG. 2. Block Diagram of NOTS-SVTP Instrument.



Q₁ = AMPLIFIER
Q₂ = EMITTER FOLLOWER
Q₃ = AMPLIFIER
Q₄ = DETECTOR
Q₅ = SCHMITT TRIGGER
Q₆ = SCHMITT TRIGGER
Q₇ = BLOCKING OSCILLATOR DRIVER
Q₈ = BLOCKING OSCILLATOR
* VALUE DEPENDS UPON SOUND PATH

FIG. 3. Sound-Velocity Circuit.

blocking oscillator that is connected to a sending transducer. The resulting sound pulse is reflected twice to reduce errors due to water motion, and then picked up on a receiving transducer that is the input for a high-gain pulse-shaping amplifier (Fig. 4). The amplifier retriggers the blocking oscillator, and a repetition frequency results, which is higher than the free-running rate. Thus the water path acts as the delay line where the variation in sound velocity through the water changes the delay and hence the "sing-around" frequency. The frequency also depends on the path length and the circuit delays. The configuration of the path length makes it impossible to measure this length to any desired degree of accuracy. Also, because of selective attenuation the received pulse rises slowly in comparison with the sent pulse; hence, an unknown time delay is introduced during which the received pulse is below the noise level.

Consequently, the instrument must be calibrated in a liquid for which the velocity of sound is known accurately, and the liquid must be similar to that in which the instrument will be used. Thus, if the instrument is to be used in sea water, it may be calibrated in distilled water in which the sound velocity is known as a function of temperature. Two recent determinations of the velocity of sound in distilled water have been published by Greenspan-Tschiegg and Wilson (Ref. 7 and 8). Both determinations used similar methods. However, over the temperature range of 0-30°C, there is a difference of 0.26 m/sec in spite of claims of 0.05 m/sec and 0.093 m/sec maximum errors.

The free-running frequency of the blocking oscillator is about 5 kilocycles. A "sing-around" frequency of about 6 kilocycles is achieved by increasing the path length to 24.7 cm. Negative pulses are developed across a 12-ohm resistor in the emitter lead of the blocking oscillator to switch an Eccles-Jordan circuit. This circuit produces square waves and divides the frequency in half (3 kilocycles). This frequency (3 kilocycles) is in the center of Telemetry Band 8. A small Band 8 low-pass filter is used to transmit a sine-wave output.

The sound-velocity circuit may shift in frequency due to the input triggering on a precursor. To prevent shifting, NBS has found that the sending crystal should be polarized with the inner electrode made negative, and the receiving crystal should be reversed with the inner or small electrode made positive. Also adjustment of the reflectors is made with the transmitters disconnected from the rest of the circuit, and the output of the amplifier is observed on an oscilloscope. This procedure is repeated until it can be seen that there is enough signal to saturate the amplifier and yet enough attenuation to remove unwanted reflections. The first signal must be clean with no precursor.

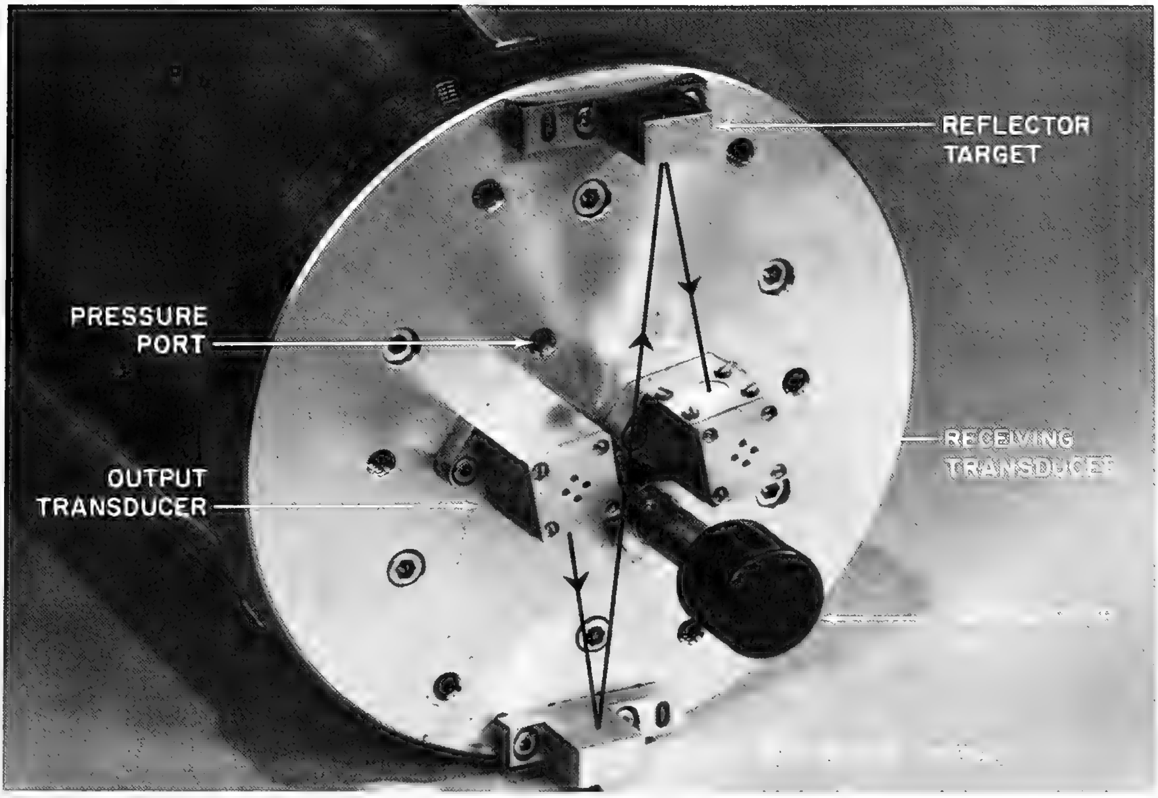


FIG. 4. End Plate With Reflected Sound Pulse.

TEMPERATURE OSCILLATOR

A transistorized-thermistor controlled Wien-bridge oscillator was developed at this Station (Ref. 2). The circuit diagram as used in the SVTP instrument is shown in Fig. 5.

Wien Bridge. In the Wien-bridge oscillator, the input is in phase with the output at the balance frequency, f_o. However, the output of a balanced bridge is zero at $f = f_o$, and hence $\beta = 0$ and $A\beta = 0$ at $f = f_o$

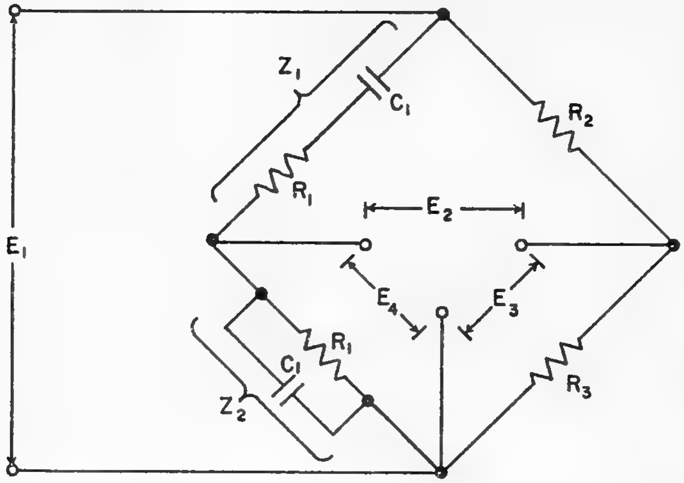
where

$\beta = E_f/E_o$, the ratio of feedback voltage to output voltage

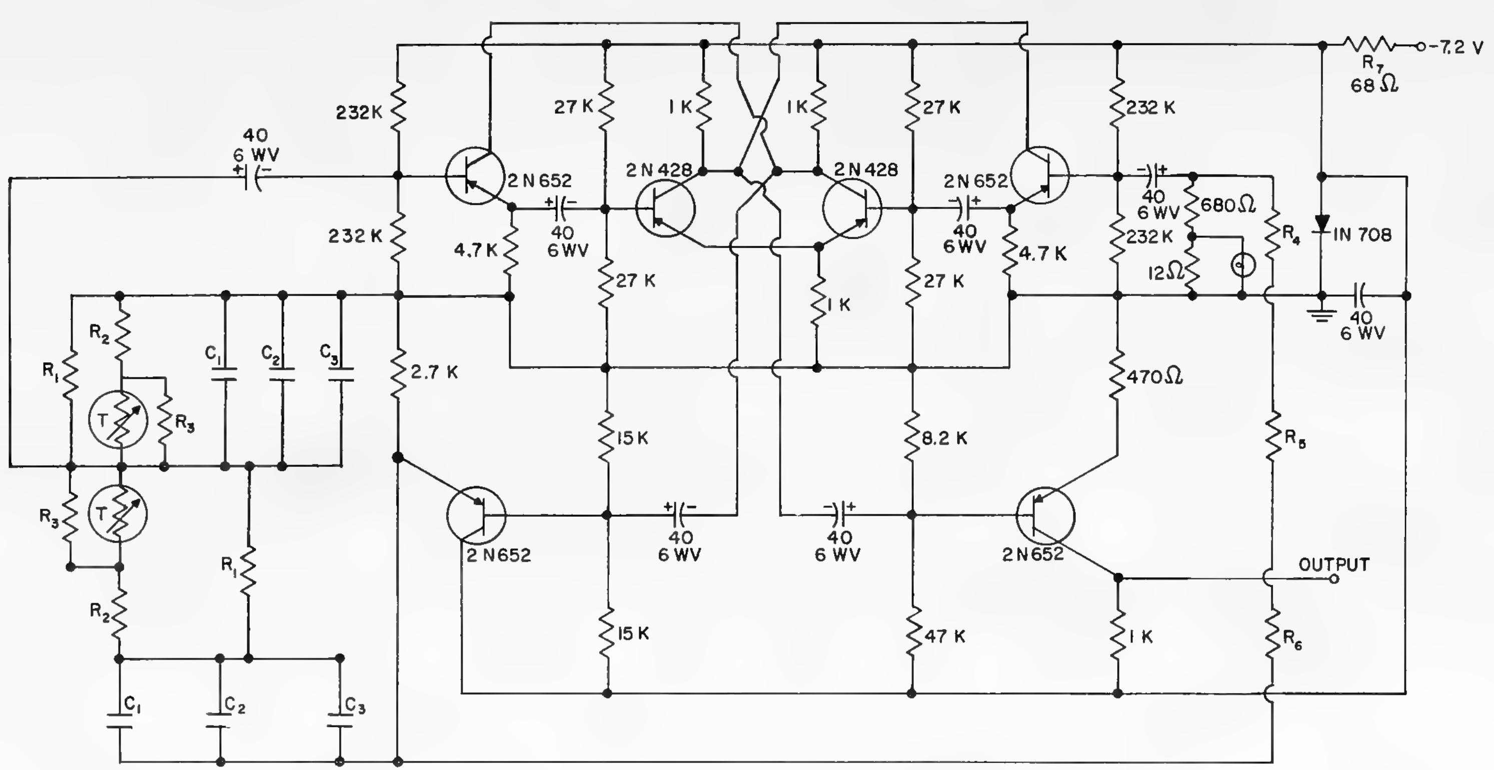
$A = E_o/E_i$, ratio of output voltage to input voltage, or forward voltage gain without feedback

The Barkhausen criterion for an oscillator requires at $A\beta \geq 1$. Therefore, the bridge must be unbalanced but in such a way that the phase shift remains zero.

Consider the Wien bridge in the following diagram:



E_1 and E_2 are the input and output voltage respectively of the bridge.



R$_1$ = 17,667Ω, DEPENDENT ON THERMISTOR AND OSCILLATOR CURVES

R$_2$ = 1,541Ω, DEPENDENT ON SAME AS R$_1$

R$_3$ = 18,000Ω, DEPENDENT ON SAME AS R$_1$

R$_4$ = 100Ω CARBON-DEPOSITED, DEPENDENT ON OSCILLATOR TEMPERATURE COEFFICIENT

R$_5$ = 400Ω BALCO OR α +0.005 OHMS/OHM/°C, DEPENDENT ON SAME AS R$_4$

R$_6$ = 1,500Ω CARBON-DEPOSITED, DEPENDENT ON SAME AS R$_4$

R$_7$ ADJUSTS FOR ZENER DIODE

C$_1$ = 0.0082μf CORNING GLASS

C$_2$ AND C$_3$ = 780μμf, NEGATIVE TEMPERATURE COEFFICIENT, GOULTON INDUSTRIES M750

T = VECO AX 1246 THERMISTORS MATCHED TO WITHIN 98% AT 25°C

∝ = GE NO. 328 LIGHT BULB

FIG. 5. Temperature Oscillator Circuit.

Also $E_2 = E_4 - E_3$

where

$$E_3 = E_1 \frac{R_3}{R_2 + R_3} \quad \text{and } E_3 \text{ is in phase with } E_1$$

$$E_4 = E_1 \frac{Z_2}{Z_1 + Z_2} \quad \text{and at the balance frequency } E_4 \text{ is in phase with } E_1$$

where

$$Z_1 = R_1 - \frac{j}{2\pi f C_1}$$

$$\frac{1}{Z_2} = \frac{1}{R_1} + j2\pi f C_1$$

at the balance frequency $f_o = \frac{1}{2\pi R_1 C_1}$

and

$$Z_1 = (1 - j)R_1$$

$$Z_2 = \frac{(1 - j)R_1}{2}$$

hence $E_4 = \frac{1}{3} E_1$ at $f = f_o$

If a null is desired, R_2 must equal $2R_3$ so that $E_2 = E_4 - E_3 = 0$. However, if the bridge is to be used as the feedback network for an oscillator, the magnitude of β must not be zero although the phase shift must be kept at zero. The preceding may be done by taking the ratio of $R_3/(R_2 + R_3)$ smaller than 1/3, i.e., let

$$\frac{E_3}{E_1} = \frac{R_3}{R_2 + R_3} = \frac{1}{3} - \frac{1}{\sigma}$$

where σ is larger than 3.

At $f = f_o$ and $\beta = 1/\sigma$, the condition $A\beta = 1$ may be realized by making $A = \sigma$.

As shown in the preceding, the impedance of the bridge as seen from output and input varies as a function of R. Therefore, in order to operate the oscillator over a wide frequency range, it is necessary to include amplitude stabilization. Stabilization is achieved by including a tungsten filament light bulb as a part of resistor R_3. Thus when E_1 increases, R_3 also increases, and $A\beta$ is kept more nearly constant.

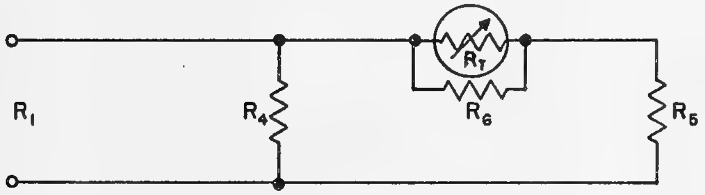
To operate the oscillator over a temperature range from 0 to 30°C, R_2 must have a small positive temperature coefficient of resistance to maintain amplitude stability. The value of this resistance and its coefficient are determined by substituting a resistance-substitution box (0.1%, if available) for R_2 and adjusting it for oscillation and sinusoidal wave form. The temperature coefficient of resistance is found by temperature cycling the oscillator and noting the change in resistance over the range 0-30°C. Enough positive temperature coefficient wire such as Balco (Wilbur Driver Co., Newark, N. J.) is wound noninductively on two 1/10-watt, 1% carbon-deposited resistors to overcome the negative temperature coefficient of these resistors and supply the extra positive coefficient needed to stabilize the amplitude.

To obtain frequency stability of the oscillator with temperature, capacitance C_1 must remain constant. Stability is achieved by paralleling capacitors that have a positive temperature coefficient with capacitors having a negative coefficient. The combination used has enabled the oscillator to be temperature cycled from 0-30°C with a frequency change of less than 1 cps ($\Delta 1\text{cps} = \Delta 0.01^{\circ}\text{C}$).

Temperature stability is further improved by use of a differential amplifier, and by temperature cycling from -60 to 60°C for 8 hours before R_2 is determined. The cycling "ages" the components, and minimizes changes with time in their characteristics.

To avoid phase shifts through the amplifier other than in multiples of 2π, large coupling capacitors are used.

Aged thermistors are used for the temperature sensing elements. The resistance curve of a thermistor with temperature approximates the resistance curve of a Wien-bridge oscillator with frequency. The thermistor curve can be matched to the oscillator curve with a three-point match to achieve maximum linearity with the following network:



where R_1 is given by

$$\frac{1}{R_1} = \frac{1}{R_4} + \frac{1}{R_5 + \frac{R_T R_6}{R_T + R_6}}$$

R_1 and R_T may be determined for three points and R_4, R_5, R_6 computed. A program for the solution on a IBM 709 computer is given in the Appendix. Maximum variation from the best straight line 5-20°C of ±0.02°C has been achieved. R_T should be approximately 1,000 ohms at 25°C.

The specifications for the temperature oscillator are as follows:

Temperature range: 0-30°C

Frequency range: 5,000-8,000 cps

Sensitivity: 0.01°C/cps

Accuracy: 0.02°C

Linearity: maximum variation from best straight line;
5-20°C, ±0.02°C; 0-30°C, ±0.2°C

Power requirement: 7.2 volts at 25 milliamperes

Output voltage: 1.0 volts RMS at $Z \cong 1{,}000$ ohms

PRESSURE OSCILLATOR

The Vibrotron of Borg-Warner Controls, Santa Ana, California, is used for pressure measurements in the SVTP instrument. Pressure is sensed by displacement of a diaphragm that in turn produces a change in tension, and hence, in frequency of a vibrating wire. The advantages of the transducer are that it has a direct frequency output and requires just a simple oscillator to sustain the forced vibrations. The disadvantages are the temperature drift, long-term frequency instability, and inherent nonlinearity. The frequency of a vibrating wire is given by the formula

$$f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

where f is frequency, L is length, T is tension, and μ is mass per unit length.

The nonlinearity is due to the fact that the frequency varies as the square root of the tension. For a frequency deviation of 13%, the linearity can be held to within 3% if the tension deviates about 22%.

Figure 6 shows the oscillator that induces vibrations in the wire. The potentiometer in the feedback loop is adjusted for each Vibrotron, and the thermistor in the loop improves temperature-amplitude stability. The circuit operates on 24 volts and draws 4 milliamperes.

The specifications for the Vibrotron are:

Repeatability: short term, 0.25%

Linearity: within ±3% of a straight line between end points

Temperature sensitivity: ±0.1% of bandwidth per °C change of zero frequency

SUMMING AMPLIFIER

The amplifier shown in Fig. 7 combines and amplifies the sound-velocity, temperature, and pressure signals so they may be transmitted as a mixed frequency signal over the single-conductor cable. The individual signal levels are adjusted by the 50,000-ohm potentiometers. The complementary-symmetry push-pull amplifier can furnish 6 volts, peak-to-peak into an impedance of 50 ohms.

MECHANICAL PACKAGING

The pressure case of the SVTP instrument is made of 304 stainless steel tubing, 18 inches in length, 3-inch inside diameter, and 3/4-inch wall thickness. The end caps are 1-inch thick and have O-ring seals. Sound-velocity, temperature, and pressure sensors are mounted with O-ring seals in the lower cap. A bulkhead-type 2-conductor electrical-signal output plug (No. X8104-57 of the Joy Manufacturing Co., St. Louis, Mo.) is compression mounted in the upper cap.

The case has a computed static pressure crushing strength of 75,000 psi. All components of the SVTP instrument including transducers have been pressure tested to 10,000 psi with no evidence of leaks. The present output plug limits operation to oceanic pressures less than 10,000 psi, and a higher pressure output plug should be used for pressures above 5,000 psi.

To permit recharging of the 7.2- and 24-volt nickel-cadmium batteries without their removal from the case, gravity-actuated mercury switches have been installed that disconnect the batteries from the electronic

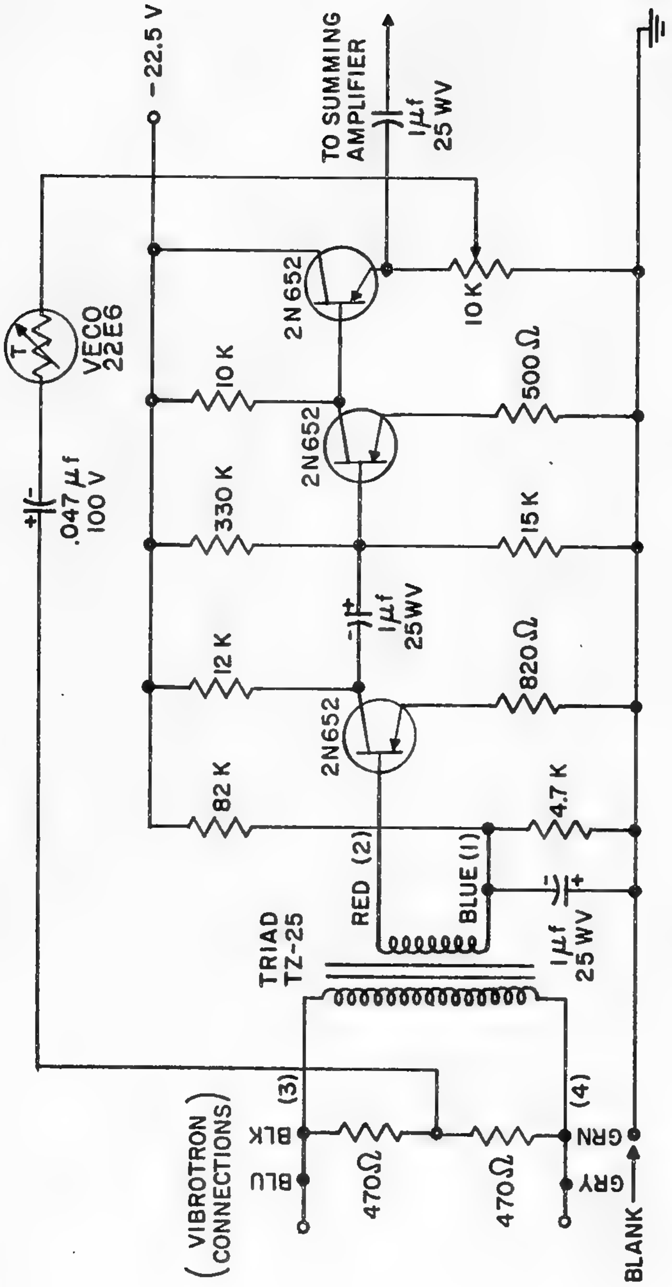


FIG. 6. Pressure Oscillator Circuit.

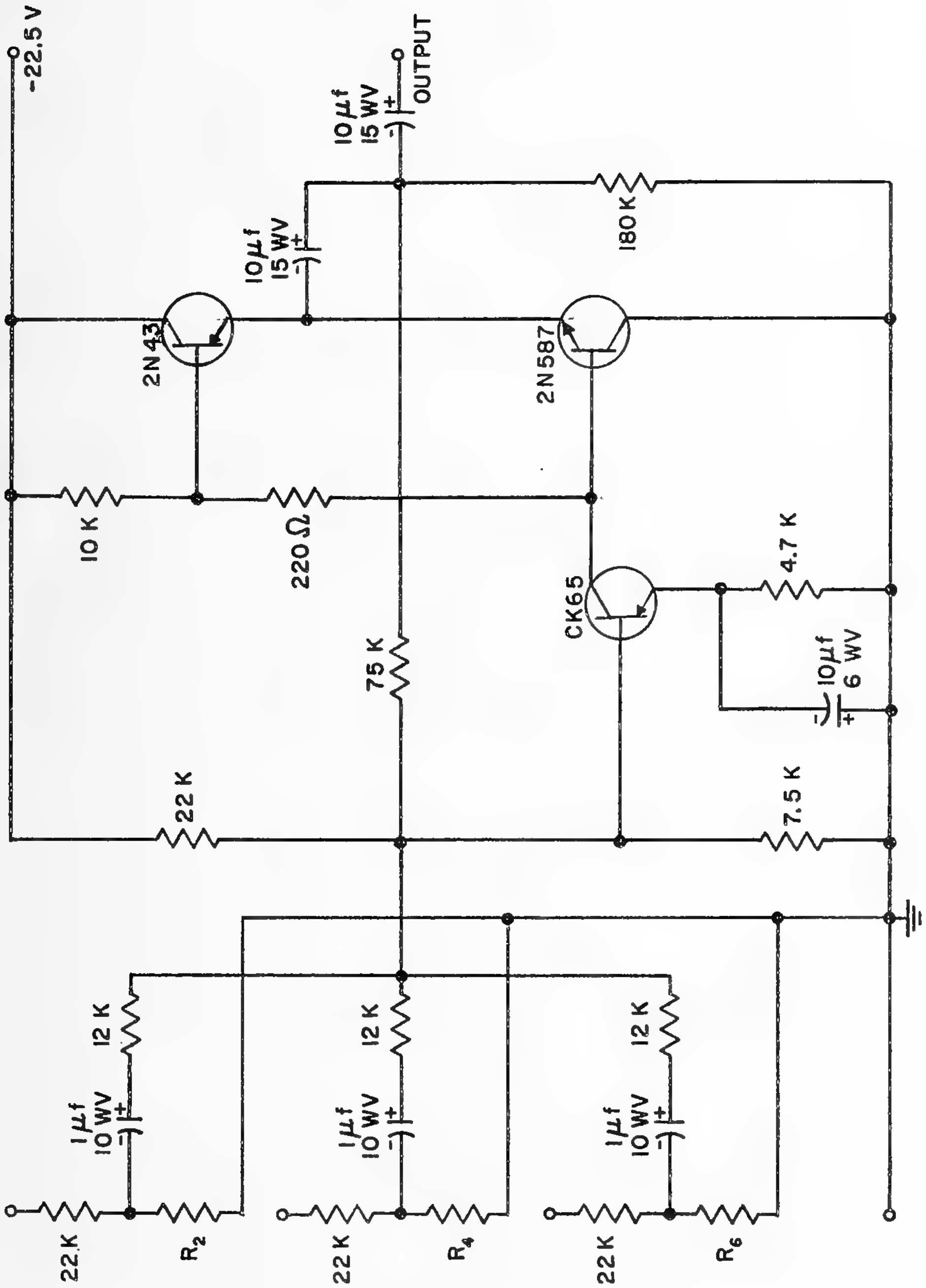


FIG. 7. Summing Amplifier Circuit. R_2, R_4, and R_6 are adjusted to obtain equal signal voltages from sound-velocity, temperature, and pressure circuits.

circuits when the instrument is in the horizontal position. In this position, the batteries are connected to the two pins of the output plug in the pressure case so that charging current can be applied. When the instrument is in the vertical position, the batteries are switched to the electronic circuits and the instrument is operable.

Figure 8 shows the internal construction of the instrument. An inner shell, attached to the lower plate, supports the electronic circuits, wiring, and batteries, and permits the instrument to be calibrated and tested with the pressure case removed.

SHIPBOARD INSTALLATION

Winch and Cable. The winch used with the SVTP instrument handles approximately 6,000 feet of 0.189-inch diameter, single-conductor polyethylene covered steel cable. The inner conductor of the cable is terminated electrically at the winch in a slip-ring commutator. The 6,000 feet of cable weighs 139.8 pounds in air, but because of buoyancy it weighs only 65.1 pounds in sea water. The cable has 47 strands of 30-gage and one strand of 28-gage steel wire, which are sealed with silicone paste and covered with DFD-6015 polyethylene. The breaking strength is 900 pounds. The direct-current resistance is approximately 28.3 ohms per 1,000 feet, and capacitance to sea water about 0.05 microfarads per 1,000 feet. When the cable is on the winch, it has an inductance of 310 millihenries. With this winch and cable, the instrument can be lowered at a maximum rate of about 5 ft/sec and raised at about 3 ft/sec.

Signals from the instrument are attenuated by resistance, capacitance, and inductance in the cable and winch. With 6,000 feet of the cable described above on the drum, resistance is approximately 170 ohms. The cable acts like a coaxial cable when in sea water, and therefore, has an attenuation (Ref. 9):

$$\alpha = \sqrt{\frac{\omega CR}{2}}$$

where α is the attenuation in nepers per unit length, and C and R are capacitance and resistance per unit length.

The greatest attenuation occurs at the greatest depth. At a frequency of 9.8 kilocycles, the value α becomes 0.23 nepers per 1,000 feet or a voltage attenuation of 2.0 decibels per 1,000 feet. When all the cable is wound on the drum, the capacitance to sea water is small, but inductance reaches 310 millihenries.

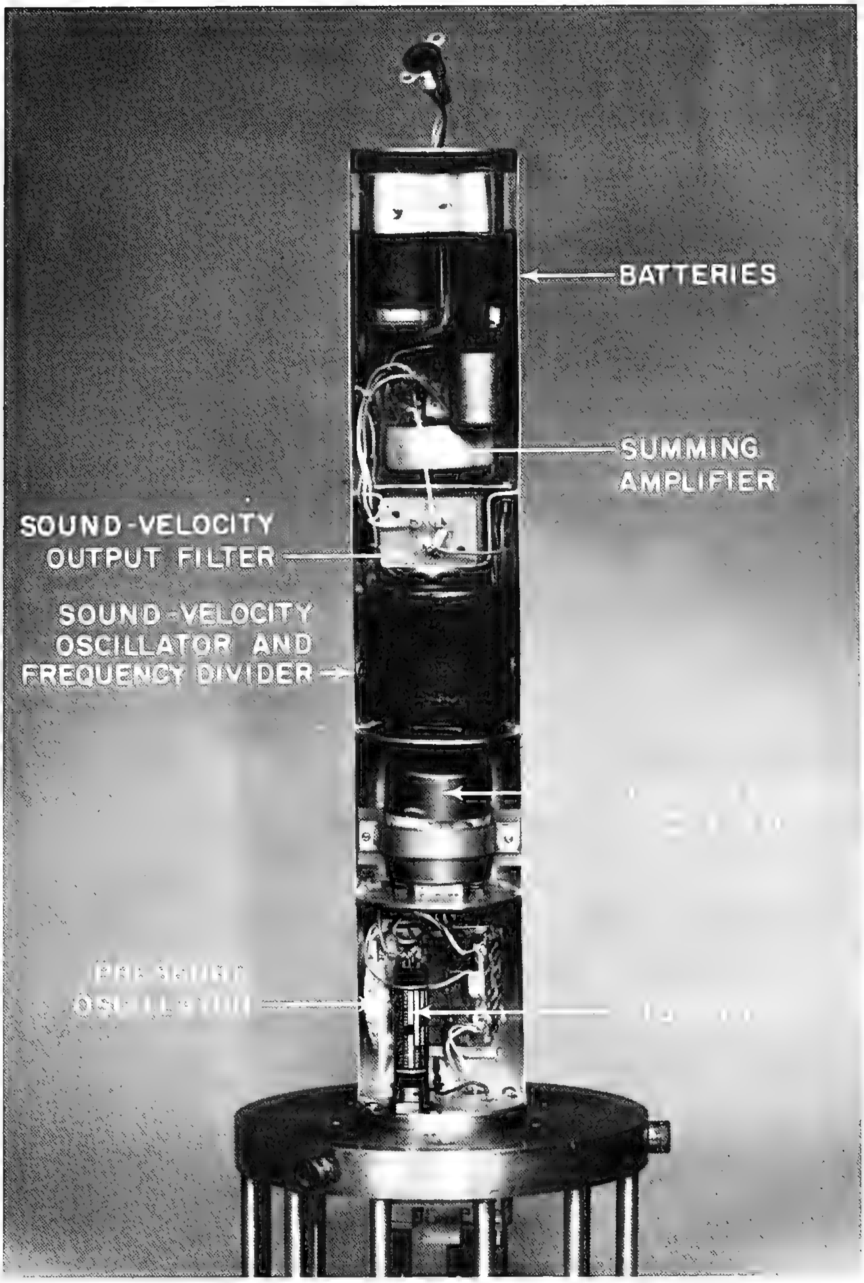


FIG. 8. Internal Construction of NOTS-SVTP Instrument.

It can be seen that amplification must be available to overcome attenuation introduced by the cable and winch. As longer lengths of cable are used, signal-to-noise ratios and signal-amplitude variations with cable length should be carefully considered.

Readout Equipment. The electrical signals transmitted over the cable are amplified, separated into their correct frequency ranges by band-pass filters, and recorded as shown in Fig. 9.

The electrical signal return path is provided by the conductivity of the sea water. The received signals, after band-pass filtering, can be read on one or more digital counters, can be discriminated and recorded on X-Y plotters, or recorded on a magnetic tape recorder for playback and analysis. All three methods have been used with the SVTP instrument. When the magnetic recording method is used, frequency errors are introduced into the recorded data of a magnitude dependent upon the tape speed accuracy of the magnetic recorder. To make possible correct interpretation of the frequency data thus recorded, it is necessary to playback concurrently a stable, reference frequency recorded at the time the instrument data are recorded. From such recorded data on magnetic tape, X-Y plots of sound velocity versus depth and temperature versus depth can be produced. Digital computer tapes can also be produced to give corrected values of sound velocity, temperature, and depth.

Field Use. Since August 1959, the SVTP instrument has been used by NOTS on several cruises in the area of San Clemente Island off the coast of southern California. Figures 10 and 11 show a pair of typical, simultaneously recorded sound velocity and temperature versus depth profiles obtained.

A report on the data collected on these cruises is now in preparation.

CONCLUSIONS AND RECOMMENDATIONS

The NOTS-SVTP instrument is a useful oceanographic research tool whose potentialities have not been fully explored. Its advantages are sensitivity; concurrent measurement of sound velocity, temperature, and pressure; visual display of information; and adaptability to modern data processing methods.

A model should be developed that could be operated in medium depths of the ocean while the ship is underway. Also a free sinking and free returning model with self-contained recording should be investigated for use in great ocean depths.

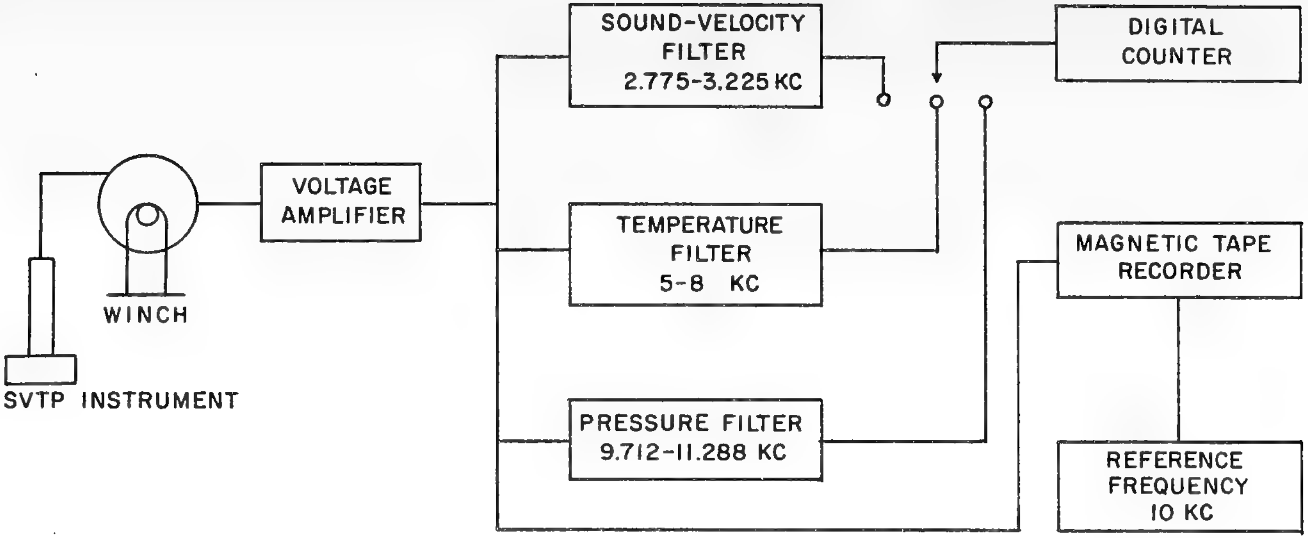
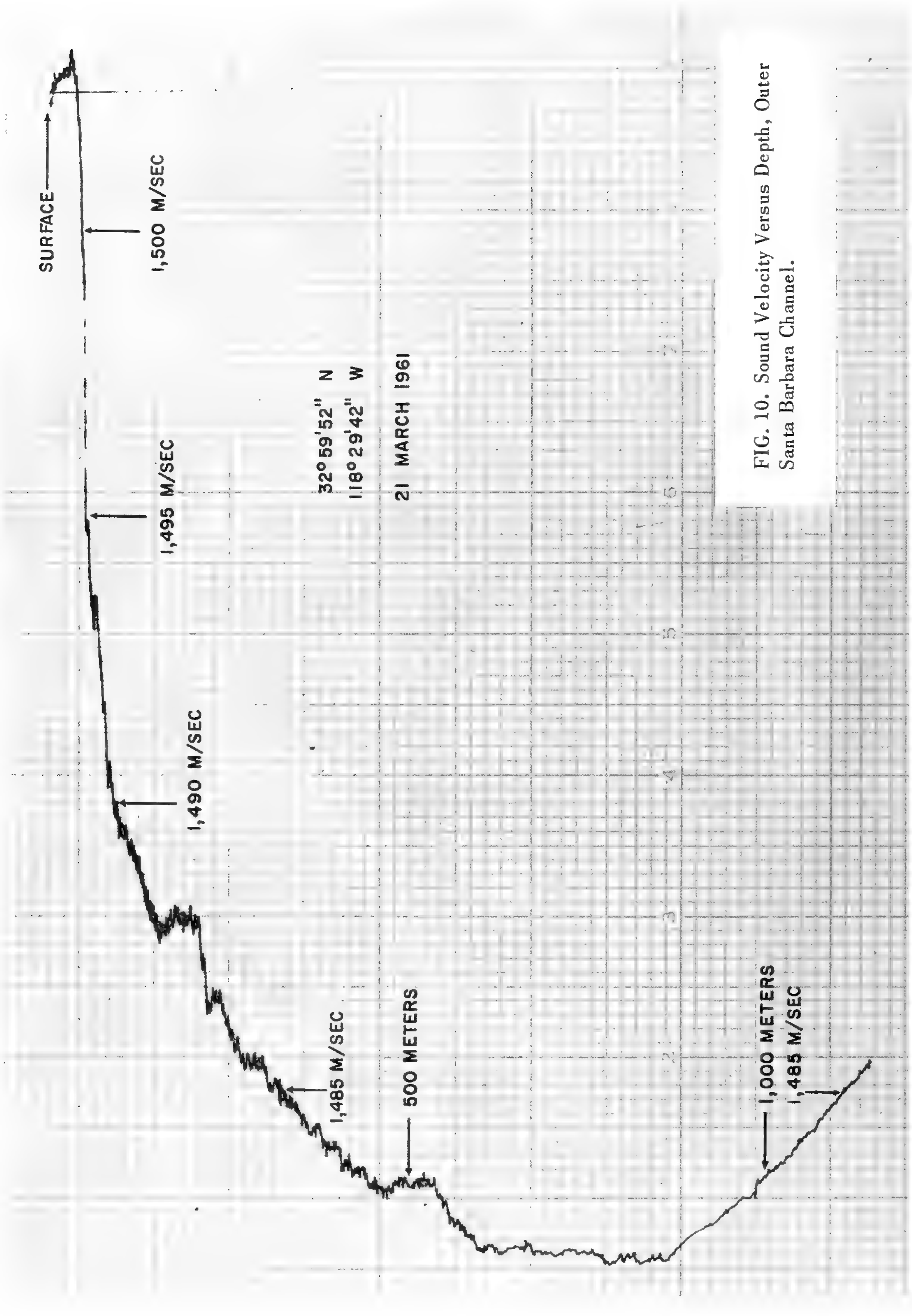
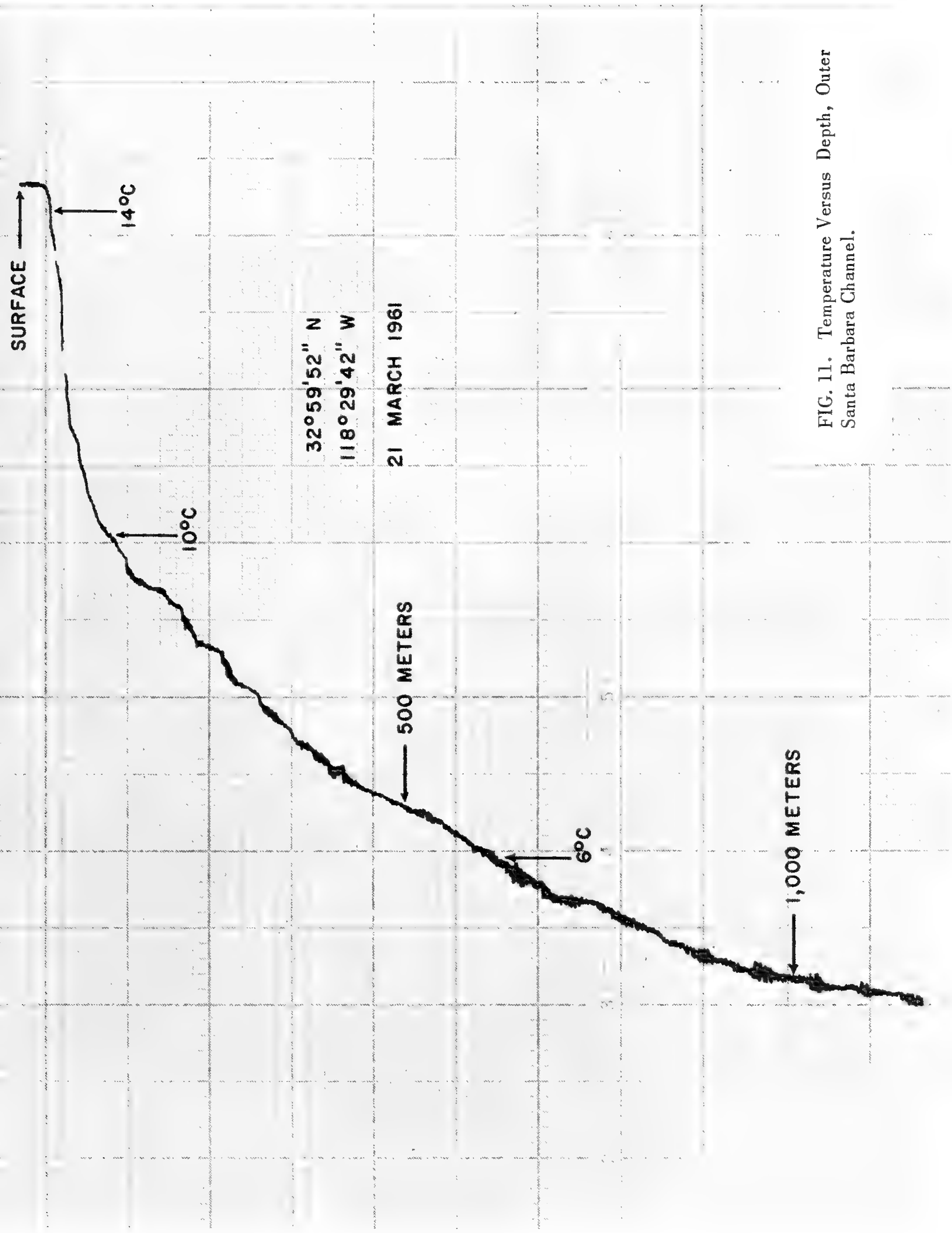


FIG. 9. Layout of Shipboard Readout Equipment.



32°59'52" N
118°29'42" W
21 MARCH 1961

FIG. 10. Sound Velocity Versus Depth, Outer Santa Barbara Channel.



32°59'52" N
118°29'42" W

21 MARCH 1961

FIG. 11. Temperature Versus Depth, Outer Santa Barbara Channel.

APPENDIX

PROBLEM NO. 080-07, THREE R's[1]

Purpose

The purpose of this problem is to solve three equations of the following type for R_1, R_2, R_3.

$$\frac{1}{A} = \frac{1}{R_1} + \frac{1}{R_2 + \frac{BR_3}{B+R_3}}$$

$$\frac{1}{C} = \frac{1}{R_1} + \frac{1}{R_2 + \frac{DR_3}{D+R_3}}$$

$$\frac{1}{E} = \frac{1}{R_1} + \frac{1}{R_2 + \frac{FR_3}{F+R_3}}$$

Method

The problem is converted to one of least squares. Equality in the above equations is replaced by difference and the sum of squares is formed. Through the use of subroutine NØ LSQ, the original estimates for R_1, R_2, R_3 are adjusted in an attempt to minimize the sum of squares.[2]

Procedure

To successfully implement the program, an estimate must be made for R_1, R_2, R_3 and something must be known about the accuracy of the estimate. A quantity DR is input to the program and is the basic increment for adjusting R_1, R_2, R_3. DR should be about 10% of the expected accuracy of the estimate. If the results of the first entry of the program are not satisfactorily accurate, re-enter the program using as an estimate for R_1, R_2, R_3 the values that produced the least sum of squares and a DR, which is 10% of the original. For best results scale R_1, R_2, R_3, and DR to avoid making the sum of squares too small.

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[1] This problem was originated by J. R. Lovett and programmed by R. D. Dancey of this Station.

[2] Subroutine NØ LSQ was written by R. S. Gardner of this Station.

The input deck is assembled as follows:

Card Columns	Entry
1. FORTRAN Job Card	
1	*
7-10	FJØB
16-31	08007, J. O., A. J. O. The numbers should be separated with commas and no blanks should appear
33-66	Identification (name, phone number)
68	9
70	0
72	3
2. "XEQ" Card	
1	*
7-9	XEQ
3. Program Deck	
4. "DATA" Card	
1	*
7-10	DATA
5. Data Card	
1-3	Number of iterations (about 15 or 20)
4-6	Maximum number of entries (normally 100)

These two numbers should be blocked to the right with no decimal point punched. The following numbers can appear anywhere in the field but must have a decimal point punched.

7-18	DR
19-30	R_1
31-42	R_2
43-54	R_3

6. Data card. These numbers can appear anywhere in the field but must have a decimal point punched.

1-12	A
13-24	B
25-36	C
37-48	D
49-60	E
61-72	F

The data is output after every iteration in floating point decimal. The output includes the new R_1, R_2, R_3; the three deviations, and the sum of the squares.

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