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ARPA Order No. 292-62, Amendment 1
ARPA Project Code No. 8100

March 15, 1963

ADVANCED OCEAN-BOTTOM SEISMOMETER

SEMI-ANNUAL TECHNICAL REPORT NO. 4

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Contractor: Texas Instruments Incorporated
Date of Contract: March 15, 1961
Contract ~~No~~. AF 19(604)-8368
Contract Expires: June 30, 1963

ACKNOWLEDGMENT

The Seismic Programs Branch of Science Services Division, Texas Instruments Incorporated, wishes to acknowledge the contributions of the following individuals for their assistance in preparing this Semi-Annual Technical Report No. 4 on the development and production of the advanced Ocean-Bottom Seismometer.

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FOREWORD

Means whereby underground nuclear explosions can be detected and identified represent the task of VELA UNIFORM.

Dr. Jack Oliver of Lamont Geological Observatory, other scientists, and members of the Panel on Seismic Improvement have suggested monitoring ocean-bottom seismic signals may prove advantageous in a nuclear detection system. Expanding this premise reveals several potential advantages which lend themselves to three main categories which can exist singly or in combination.

1. Ambient seismic noise on the ocean bottom may be less than on land resulting in an improved signal/noise ratio.

2. An ocean-bottom monitoring system would provide broader geographic coverage.

3. The ocean environment permits use of an additional tool, the pressure transducer.

In this report we describe a compact self-contained unit which has been engineered and developed specifically for items 1, 2 and 3 in their application to the VELA UNIFORM task.

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ABSTRACT

The five advanced ocean-bottom seismic monitoring and recording devices incorporate many features of the prototype units, ~~(Semi-Annual Technical Report No. 1)~~ with improvements suggested through experience, and field testing. In ~~making these improvements we feel we have increased the capability of the units to collect useful data in the intended environment.~~ Major advantages of the new systems are:

1) Capable of operation to 20,000 feet versus 10,000 feet previously;

2) Choice of using a tripod-type base as well as the original pointed nose cone;

3) Addition of an overload circuit which eliminates amplifier shock susceptibility;

4) Increased dynamic range by dual-level recording which provides 72 db over-all versus 36 db previously;

5) Addition of a calibration signal applied to each trace every hour;

6) Simplification of power requirements to one rechargeable 28-volt supply versus multiple supplies in the original units;

7) Simplification of the clock circuitry using a 1600 cps tuning fork in place of the original crystal control;

8) Addition of a manual program selector;

9) FM recording 0.3 inch per second, 270 cycle per second center frequency. This format is compatible with Seismological Observatories equipment;

10) Redesign of the horizontal seismometer spring to overcome the ringing present in the original units.

SPECIFICATIONS OF ADVANCED UNITS

Height (with tail fin and nose assembly)	10 feet 3 inches
Diameter	2 feet
Weight (in air)	1800 pounds approximately
Weight (in water)	1100 pounds approximately
Maximum Operating Depth	20,000 feet
Sensors	3 velocity, 1 pressure
Sensitivity	velocity = 0.1 mμ
	pressure = 2.1 volts/psi
Type of Magnetic Recording	FM-data; digital-time
Continuous Recording Capability	11.1 hours
Other Recording Capability	Manual program selector
Recording Speed	0.3 ips
Number of Recording Channels	14
Integral Field Playback	Scan any channel x 50 speed
Dynamic Range	72 db
Timing Control	1600 cps tuning fork
System Frequency Range	0.8 to 10 cps
Power Requirements	Recording - 8 watts
	Standby - 0.6 watt
Power Supply	10 ampere hour 28 volt battery
Calibration	Each channel pulsed hourly
Drop and Recovery	Cable

SECTION I

INTRODUCTION

Under extension to Contract No. AF 19(604)-8368, Texas Instruments is constructing five advanced marine seismic monitoring and recording devices for measurement of ocean-bottom seismic phenomena.

This Semi-Annual Technical Report No. 4 details work completed under the referenced contract to March 15, 1963. At present, systems capabilities and components have been determined and two units are complete and are being tested on land sites near Dallas. The remaining three units are in final production and assembly and will be ready for field testing by May 1.

Since the period covered by this report has been mainly spent in device construction, we have tried to describe the various instrumental components with respect to their role in over-all systems reliability and capability. The diagrams and photographs in this report provide a useful basic description of the equipment and form the ground work for more detailed operation and maintenance information.

Field testing of the new units has been limited to land stations near Dallas and has not progressed sufficiently for inclusion here. Concurrent with the instrumental phase, field tests using the prototype units have continued. A description of these tests, their objectives and results is the subject of a special report presently being prepared.

SECTION II

SYSTEM COMPONENTS

A. SYSTEM BLOCK DIAGRAM

Functional arrangement of the improved ocean-bottom seismometer is illustrated in block diagram in Figure 1. The device's physical arrangement is shown in Figure 2. A block diagram of the prototype unit, which was described in previous reports, is shown in Figure 3. Comparative features of the prototype unit and the improved model are shown in Figure 4.

The improved device's four transducers are located in the seismometer housing and the electrical package is confined to a spherical watertight container. Electrical interconnection between the sensors and the sphere is made by means of a special watertight cable.

Normally, the signal path through the calibrator circuit to the reactance amplifiers is unaltered. Exception to this is when the clock control injects a calibrate signal into the record.

The reactance amplifier inputs terminate the sensors in their characteristic impedance for maximum power transfer and proper damping. After preamplification in the low-noise, high-gain front end, each signal is split two ways into the high level amplifier section. Separated high and low-gain levels are then fed to the tape recorder and recorded by wideband FM techniques. Time information stored in the block is recorded in digital form.

Power is obtained from a single 28-volt battery source. The system control and remote system control areas switch the battery voltage by manual or programmed command to the clock and the two-phase inverter/regulator. In programmed operation, only the clock is energized at all times. The clock directs the system control to energize the inverter at preselected time intervals to start the recording process.

The two-phase inverter/regulator furnishes 400-cycle, two-phase power for the synchronous motors in the Parsons recorder. It also furnishes all the precision regulated dc voltages required by the system. The recorder control area is the inverter's power switching center where the operator has manual control over the record and playback facilities of the recorder.

B. SENSOR CHARACTERISTICS

1. Seismometers

The ocean-bottom seismometers are of the velocity type and are constructed as moving coil units. Natural undamped frequency is 1 cps and the units are damped at 0.6 critical with a 12,500 ohm load. Open circuit sensitivity is 1000 volts/meter/second, whereas loaded sensitivity is about 450/volts/meter/second (Figure 5). Moving mass weight is 12 pounds. The vertical seismometer will operate up to a tilt angle of 5° and the horizontal to 0.5°. The gimbal mount allows the maximum housing angle to be 15°. The vertical seismometer is 4.5 inches in diameter, 20 inches long and weighs 50 pounds. About 15 pounds of the weight are used in a heavy case to resist high pressure effects. The horizontal is the same diameter as the vertical but is 13.5 inches long and weighs 40 pounds.

2. Pressure Transducer

The pressure transducer, Figure 6, contains 16 Clevite PTZ-4 piezo-electric crystals and operates at a sensitivity of 2.1 volts/psi. Capacitance of this unit is 0.032 microfarad and it has a reactance of 6 megohms at 1 cps so that over the frequency range of interest the impedance is high. The outside diameter is 14.12 inches, height is 3.5 inches and it weighs 75 pounds.

C. SYSTEM ELECTRICAL DESCRIPTION

1. Reactance Amplifier

The theory behind the design of the reactance amplifier was presented in an earlier report, Semi-Annual Technical Report No. 2, April 23, 1962. Description of the amplifier circuits here is limited to new features or changes in circuits and packaging.

The amplifier section of the ocean-bottom seismometer is shown in block diagram in Figure 7. The system is composed of a master pump (oscillator), four reactance preamplifiers, four dual-level, real-frequency amplifiers and an overload control section (see Figure 8).

a. Master Pump

The master pump is a 455 kc oscillator with a distribution system which supplies pump voltages to all four reactance preamplifiers in the system. The new pump is a modified version of the type used in the prototype ocean-bottom seismometers. The prototype design made use of negative feedback to control the amplitude of the pump signal. This resulted in good short-term regulation (very low amplitude variation in the system passband of 1-10 cps) but was not stable over wide temperature ranges. An effort was made to temperature stabilize the prototype pump for use in the new system but this was abandoned in favor of a design not dependent on feedback for amplitude regulation. Long-term amplitude stability is absolutely essential for gain stability of the reactance preamplifier section. Short-term amplitude stability is necessary to insure that extra noise is not injected into the system from the pump. The new design achieves amplitude stability by diode clipping of both positive and negative peaks of the pump signal. This scheme maintains good regulation resulting in excellent long and short-term stability.

b. Reactance Preamplifiers

The preamplifiers used in this system are solid state reactance (or parametric) amplifiers of the same class as those used successfully in the prototype units. The amplifiers' inherent high-input impedance (greater than 15 megohms at the frequencies of interest) allows the use of both pressure transducers and high-impedance (i.e., high sensitivity) seismometers. The pressure transducer employed requires a six megohm minimum load for frequency response down to one cycle/second. Over-all system sensitivity can also be increased by the use of high impedance seismometers. In the practical case, sensitivity can be increased to the point where the minimum detectable signal is limited by the thermal noise generated within the seismometer and not by amplifier noise.

Other features which make the reactance preamplifiers ideal for use in this application are their small size, insensitivity to orientation, low-noise level, and low-power requirements. The low-noise level of less than 0.05 microvolt rms (over the bandpass from 0.8 to 10 cps) makes it ideal for amplifying the low-level outputs from the sensors used. This low-noise level gives an over-all system capability of responding to earth motions as low as 0.1 millimicron. Seismometers used in the ocean-bottom system have an inherent sensitivity of one microvolt per millimicron of earth movement at 1 cps. Figure 9 is a strip chart recording of the high-level amplifier output showing signals of 1 microvolt rms, 0.316 microvolt rms, 0.1 microvolt rms and zero signal applied to the reactance preamplifier input terminal. The low-power requirement, only 262 milliwatts for the eight channel system, is necessary for use in an unattended station such as this.

The reactance preamplifier is composed of a front-end reactance amplifier section and a tuned amplifier - detector section. The tuned amplifier has been completely redesigned in favor of one which requires less power and uses no IF transformers. Tuning is accomplished by small fixed tuned "transfilters" which are antiresonant at the pump (carrier) frequency. These elements, used in the emitter circuits of the two amplifier stages, provide emitter degeneration for all frequencies outside their pass-band. A high degree of local negative feedback is employed in both stages to stabilize the gain against changes in transistor parameters. The first stage is optimized for low-noise performance to preclude the possibility of injecting additional noise on the signal as it is passed through. Recently developed Texas Instruments silicon low-noise transistors are used in the amplifier stages of the tuned amplifier. The preamplifier has an adjustable gain nominally set to 2000 (66 db).

c. High- and Low-Level Amplifiers

The output from the reactance preamplifier is fed to a dual channel real-frequency amplifier. This amplifier has two channels with a fixed 30 db gain separation obtained by giving the high-level section a fixed gain of 40 db and the low-level section a fixed gain of 10 db. Figure 10 is a strip chart recording of the relative amplitude separation between channels. The high-level channel has an amplitude of 5 volts p-p which is the maximum signal handling capability of the recorder. The signal on the low-level channel is clearly discernible when the high-level reaches its maximum recordable amplitude. This provides a smooth transition from high to low-level output with no dead space between.

The real-frequency amplifiers have been completely redesigned. The advantage of the new design is elimination of the requirement for five separate power supply voltages. Only two voltage inputs (+12 volts and -12 volts) are now required. Also, the new amplifier is designed for rapid initial turn-on response so that it can be switched off when not in use. The prototype units required a long stabilization period and consequently were left on continuously. The amplifiers employ heavy negative feedback to obtain good stability. Each section has an open loop gain of approximately 70 db and closed loop gains of 10 and 40 db, respectively, for the low and high channels. Each section is designed for both high-cut and low-cut filtering. The response, along with that of the preamplifier, is chosen to give the over-all amplifier system response shown in Figure 11. Filtering requirements for the FM recording system used are not as critical as those for a digital system and, in order to conserve both space and power, no separate filter as such is included in the new system. Filtering circuits are built in both at the preamplifier and the real-frequency amplifiers to give the over-all characteristic shown in Figure 11.

d. Overload Control Circuits

An overload control circuit has been incorporated into the design of the new amplifier section. This unit automatically restores the preamplifiers to an operating condition in the event the system receives an overload signal (defined as an input exceeding 1.5 millivolts p-p for a period greater than approximately five seconds). In an overload condition, the prototype amplifier remained disabled for the duration of that particular recording interval, but would restore itself to an operating condition when power was cut off and reapplied for the next programmed "on" time. Incorporation of an overload control circuit in the new system insures automatic recovery once the overload signal is removed without the necessity of turning the power off to the preamplifiers. Overload occurs only when the input signal has reached a value 10,000 times the system noise level and is unlikely when the system is in operation unless it is located near the epicenter of a rather large earthquake.

2. Calibration Circuits

Calibration circuits have been incorporated into the new system to provide a periodic check on over-all system performance. These circuits apply a dc voltage to the three seismometers and the pressure transducer upon receipt of a calibrate command pulse from the clock. Once each hour this voltage is applied for a period of two seconds and then removed. The resultant output signal provides a means by which the seismometer and amplifier sensitivity can be measured and also gives an indication of the frequency response of the system. A built-in manual control also allows manual calibration commands to be made. Figure 12 is a strip chart recording of seismometer output and high-level amplifier output for two manual calibrate commands. A 0-60 db calibration switch is provided for each channel for calibration pulses with peak amplitudes corresponding to peak earth motions of from 5 millimicrons to 5 microns in 6 db steps. The dc calibration voltage is supplied from a precision three volt regulated supply with appropriate voltage divider resistors switched in by the calibration switch. Subminiature latching relays are used to supply the dc calibrate signal to the appropriate seismometer or pressure transducer.

3. Power Supply and Control

A block diagram of the power supply and control section of the system is shown in Figure 13. Included are the battery pack, two-phase inverter/regulator, tuning fork oscillator and the system control and recorder control centers.

a. Battery Pack

The battery pack consists of 16 Yardney LR-10 Silvercel units, Figure 14, in series which have a conservatively rated capacity of 10 ampere-hours and are rechargeable. The terminal voltage is 28 ± 4 volts dc during rated operation. The cells are contained in a protective fiberglass package which can be quickly disconnected from the system for recharge. A specially designed constant current battery charger which operates from 115 volts ac line voltage is used to charge the pack. A separate constant voltage output from the charger permits bench operation of the system while simultaneously charging the batteries.

b. System Control

The system control center, Figure 15, employs latching relays to switch the battery power as needed into the system. A circuit breaker in series with the relays protects the batteries from dangerous overloads and a current meter provides visual inspection of the proper operating current level. System control can be executed either by manual or programmed commands.

The system control pushbutton switch functions are: ON, OFF, MANUAL CONTROL, PROGRAM, and clock RESET. The ON/OFF pushbuttons directly control the clock and tuning fork power, and, indirectly, the rest of the system. After the ON button has been pressed, the MANUAL CONTROL can be used to turn on the inverter supply, thus energizing the entire system. In MANUAL CONTROL, the recorder is under manual control from the recorder control center. A red indicator light shows when this mode is in effect. If PROGRAM is commanded, the inverter turns off and the system automatically returns to the record mode under clock control. Clock RESET holds the clock reset until the moment of release. This permits the clock to be synchronized with WWV or an equivalent time standard.

The low-level signal control from the clock is insufficient to drive a latching relay, so relay drivers were designed which consume no standby power, but, when triggered by the clock, furnish a 5-millisecond power pulse to latch the relay to the proper state.

c. Two-Phase Inverter

The two-phase inverter is required to provide accurate 400-cycle synchronous power for the tape recorder motors. To achieve the rigid wow, flutter and absolute speed requirements of this system, the inverter frequency must be stable within 0.01 per cent. Since the two-phase inverter is synchronized by the same time standard that operates the clock, the frequency stability is about two orders of magnitude better than required. The tuning fork operates into a Schmitt trigger at 1600 cps at a known accuracy of approximately 1 part in 10^6 (about 2.6 seconds per month). The single phase Schmitt output is fed to a complementary symmetry flip-flop which splits the phase into two 800-cycle outputs, 180 degrees out of phase. These two outputs drive two other complementary flip-flops at 400 cycles, 90 degrees out of phase. The direction of rotation of the recorder synchronous motors is determined by the phase relationship of the inverter, so it must be the same each time the inverter is energized. To "lock" the phase relationship, conditional steering is used in the 400-cycle stages; i.e., the output of each flip-flop is cross-gated to the opposite-phase input so that the change-of-state sequence is always in the same order. The two phase flip-flop outputs are coupled through impedance-matching transformers to the power driver stages of two toroid power transformers. Two-phase synchronous power is delivered to the motors by means of two transistor bridges. The bridges are conservatively designed to handle as much as 30 watts load so that even the locked rotor power demand of the motors can be safely handled. The remaining secondary windings on the transformers are used to step the primary voltage up or down as necessary for rectification and dc regulation.

d. DC Regulators

The regulated dc supplies of ±12 and ±3 volts must be maintained within ±0.1 per cent under extremes of operating temperature, battery voltage fluctuations of ±14 per cent and load changes. The voltage requirement is critical since the linearity of the FM voltage-controlled oscillators is a direct function of the quality of the power supply voltage regulation. To achieve temperature stability all the regulators are referred to a precision reference supply. The reference contains a pre-regulated and temperature-compensated constant current generator driving a stack of temperature-stable zener diodes which in turn provide a precision current to a special reference zener. The reference zener characteristics under these conditions are more stable than a standard cell. Low-noise, temperature-stable metal film resistors are used throughout. Each regulator is temperature compensated and potted. In addition, load charges are compensated by a negative output impedance feature in each regulator which samples the load current and changes voltage to equal the variable IR drops in such areas as relay contacts. Tests on these regulators have indicated stability in the order of 0.01 per cent for operating extremes.

Some typical power consumption figures for the power supply are:

	Battery Voltage	Current Milliamps	Power Watts
Clock and Fork	24V	25	0.60
(System not recording in	28V	27	0.75
programmed operation)	32V	30	0.96
Two-Phase Inverter	24V	22	0.53
(No bridges, no regulators and	28V	27	0.75
not including clock and fork)	32V	29.5	0.95
Total Power Supply	24V	215	5.1
(No system load)	28V	245	6.8
	32V	275	8.8
Total Power Supply	24V	332	8.0
(System recording in programmed	28V	410	11.5
operation)	32V	505	16.0

<u>Conversion Efficiency</u>	24V	35.2%	
(No load to record load)	28V	40.3%	Power Conversion
	32V	45.5%	

NOTE: Much higher conversion efficiency is obtained for no load to full load conditions.

Assuming the maximum recording time of 11.1 hours, the unit has sufficient battery capability to operate over a 10-day period.

e. Recorder Control

The recorder control center, Figure 15, contains latching relays, steering logic and manually operated pushbuttons. The manual commands are: START, STOP, RECORD, FAST FORWARD, REWIND and OVER-RIDE. The functions, except the OVER-RIDE command, are self-explanatory. The negator spring system in the recorder requires that end-of-tape sensors be used to prevent the tape from running off the reels during operation. When a reel of tape has been completely recorded, the record end-of-tape sensor stops the recorder, then causes the system to shut off. When the operator desires to rewind the tape, the OVER-RIDE must be depressed; any command other than REWIND is ignored as long as the sensor strip is present. At the rewind end-of-tape, the recorder will stop, but without stopping the system. Again, it will ignore any command except RECORD or FAST FORWARD (i.e., a proper command) while the end-of-tape sensor is present.

4. Clock

The clock, Figure 16, provides the timing requirements for the system. It is composed of two sections, the Clock Output and Control and the Clock Programmer. Four basic plug-in modules were designed for the clock: (1) a binary count flip-flop (BCFF); (2) a shift register flip-flop (SRFF); (3) an emitter-follower (EF); and (4) an inverter amplifier (AMP). Various combinations of these basic modules plus a small amount of external circuitry forms the entire clock. Like modules may be innerchanged during trouble-shooting procedures. The clock requires only 750 milliwatts of power, but it is reliable and stable at environmental extremes.

The Clock Output and Control section, Figure 17, counts down the 1600 cps from the fork-controlled Schmitt trigger to a basic 30-second rate and provides all logic functions necessary for operation of the clock. The count-down process is not a straight binary count. Three count-by-ten and one count-by-three stages provide the desired 30-second rate to the Clock Programmer. In the Programmer, the count is straight binary code.

The Clock Programmer, Figure 18, provides the 12-bit binary coded time storage (about 34 hour capacity). Every 30 seconds during recording time, the real-time information in the binary counters is sampled by the shift register modules and shifted serially back to the clock output section. From there the time information is transferred to the tape recorder at a 100 pulse-per-second clock rate. The real-time and the 100 pps data are both recorded digitally by the write amplifiers. The combined technique provides binary coded time data in 30-second binary increments but with 10 millisecond (100 pps) resolution.

Two programmer switches select the desired recording turn-on and turn-off intervals. Normally, the program is set to delay the turn-on time by a few hours while the system is being lowered to the ocean floor, then the system is programmed on, allowed to record 11 hours of data (which automatically shuts the system off) and the system is retrieved. It can, however, be programmed for several days operation. The clock will simply store time data to full capacity, then reset and continue without error.

5. Tape Recorder

The tape recorder, Figure 19, and recording electronics used in this system are the highest quality available. Performance of this system surpasses most land-based consoles. The recorder was designed and constructed by the Ralph M. Parsons Co. of Pasadena, California, in accordance with Texas Instruments specifications. It performs all the recording functions required by the system and also contains a quick-look reproduce facility which can be monitored by the operator one channel at a time during FAST FORWARD or REWIND operations.

The FM recording format is such that the data reels may be compatibly reproduced on the same playback system used for standard Experimental Seismological Observatories' recordings. A special real-time decoder will be adapted to the playback system to recover time data.

D. SYSTEM MECHANICAL DESCRIPTION

1. Pressure Considerations

The requirement to increase maximum depth of operation from 10,000 feet to 20,000 feet was such as to surpass the physical capability of the prototype design. In order to keep repackaging effort at a minimum, it was decided that the system configuration would remain the same, preferably with the same external dimensions. Seismometers would be redesigned only to the extent of making them more producible and would require the same internal case dimensions. A larger seismometer case (i.e., the brute force method would require thicker cylindrical walls) would seriously alter over-all equipment size as increased spacing of seismometers would require a larger diameter housing. Since buckling failure would not occur with the wall thickness being used, the only critical mode of failure was by compression. Higher compressive strength was obtained by use of heat-treated 4130 steel, raising the compressive stress yield point from 55,000 psi to 150,000 psi. End caps were made of aluminum and thickened to resist bending stresses. Test models were run to 10,000 psi (22,500 feet). No failures occurred and subsequent tests on the final design seismometers were made to 12,000 psi (27,000 feet) without failure. By holding the size increase to approximately 1 inch of additional length (end cap increase), the same size 24-inch O. D. seismometer housing was used, although the mounting flange diameter had to be increased to allow entry of the assembly.

The pressure transducer, as originally constructed, was made in a square configuration and sealing problems were encountered. No redesign was considered necessary for the higher pressure requirement but the unit was made round to expedite machining and provide more producible seal joints. A change was also made in the terminal seal to provide a more reliable sealing method. In the previous design, conductive cement was used to effect an electrical contact between the crystals and mounting plate. Initially, this was tried in the new system but difficulty in obtaining a uniform thickness of cement over the entire crystal area caused the crystal to be loaded in bending, resulting in crystal breakage under high pressure. The improved design now depends upon surface contact for continuity.

The instrument hemisphere was originally made of T-1 steel with a yield point of 105,000 psi. Again, buckling was not a problem in going to a higher pressure but a thicker wall was specified because T-1 material was desired and its yield point could not be materially increased. The inside diameter of 15.500 inches was retained and the minimum wall thickness was increased from 0.375 inch to 0.500 inch. Critical pressure based on yield strength is calculated to be 13,800 psi minimum. Critical pressure based on buckling strength is well above this figure. The sphere is of minimum thickness at the poles and thickens toward the equator. The additional thickness is added safety in resisting crushing stresses.

The seismometer housing is filled with a castor oil. Expansion and contraction of the oil caused by temperature and pressure changes must be compensated for by means of an expansion chamber. No change from the older system was made in the expansion chamber, an inner tube, although more care must be taken in measuring the correct amount of oil in the housing to prevent leakage through the housing or over-expansion of the inner tube.

The electrical cable connecting the sphere and seismometer chamber remained unchanged. Its construction is made by molding a neoprene jacket over the insulated and shielded conductors and end fittings carrying the terminations. The end fittings contain an "O" ring for sealing purposes.

2. Ringing of Horizontal Seismometers

In the field tests conducted on the first system a spurious ringing noise was bserved on the horizontal traces. These signals were at a frequency of approximately 4 cps and bloomed whenever a high enough excitation amplitude was provided. Field investigation gave indications that the unit was oscillating about its nose as it impinged on the ocean floor. The noise was considerably reduced by providing a large stable base under the unit. Several good records of actual field events were made.

In the period of new construction, continued 4 cps oscillation "noise" was observed using seismometers alone. Investigation of this phenomena was shifted from package configuration to horizontal seis spring design. A new spring design suspending the seis mass as an inverted pendulum was installed and subsequent tests have shown marked improvement. The springs are shown in Figure 20.

3. Electronic Packaging

Because the method of recording has been changed from digital to FM, the electronic circuits and packaging have been redesigned; however, the volume of the pressure housing has been left unchanged. Since much of the clock circuit is repetitive in nature a modular plug-in unit was made to plug into a mother board, Figure 21, providing interconnections. The mother boards are then held in an aluminum case which plugs into the main chassis.

The battery, made up of 16 Yardney LR-10 Silvercels, is packed in a foam-rubber-lined plastic case, Figure 22. The case is provided with a quick disconnect connector so that the battery may be inserted or removed from the system rapidly. It can also be recharged without removing any cells from the case.

All other sections of the electronic system are more permanently attached to the main chassis. This chassis is made up of a central vertical plate and a circular horizontal plate, Figure 23. The reactance amplifiers and high-level amplifiers are mounted on the top of half the circular plate. The recorder is mounted by brackets to the vertical plate and extends through a cutout in the horizontal plate. The power board is mounted at the recorder and both control and calibration units are mounted on either side. These locations are shown in Figure 24.

Controls for both system and recorder are placed so they can be operated without removing the electronic chassis from the spherical housing. This allows final checkout of the system prior to emplacement. Figure 25 illustrates an over-all view of all the control switches. All gain setting switches are also available.

Portions of the system susceptible to modular construction have been designed as separate packages. The clock sections are the best examples wherein repetitive circuits have been made as plug-in units. Construction steps of two of these are shown in Figure 26. The power supply board also carries modular units constructed as wire lead units. The circuit is contained on two etched boards on which the components are mounted. Various outputs and inputs are brought off the board to one side and the unit potted with these leads free. This construction is shown in Figure 27. The individual modules may then be attached to the main board as shown in Figure 24.

Construction of the reactance amplifiers and high-level amplifiers was made by conventional etched board techniques.

4. Mechanical Packaging

The over-all mechanical packaging configuration has changed only slightly from the prototype units. The electronic package is electrically attached by a single cable to the remainder of the package, Figure 28, and is easily removed. The mechanical package is designed to be placed on the ocean floor by either of two methods: first, by lowering the unit to the bottom and resting it on three pads which provide a wide platform base; second, releasing it by means of a trip mechanism 10-20 feet above the ocean floor to allow penetration of a nose piece into the bottom. Both methods have been tried successfully with the prototype system.

E. FIELD TEST EQUIPMENT

For convenient checkout of equipment in the field, three pieces of field test equipment have been constructed (Figure 29). These are, left to right in the photo, the battery charger, external control box and seismometer checker.

1. Battery Charger

This unit is used to charge the seismic system batteries at a constant current from 0.4 amp to 0.8 amp. It can, at the same time, supply up to one amp to the system at 28 volts. Meter indication of voltage and current are provided. The power ON-OFF switch turns power on to both the eliminator terminals (+28 volts) and the battery charger circuit. When the power is first turned on the red reset lamp should come on, indicating that current is off to the charging circuit. A reset switch is provided to activate the output. If the charger circuit can deliver the current for which it is set (i.e., at a lower voltage than that set by the VOLTAGE CUTOFF ADJUST), then the circuit will remain reset when the button is released.

If input power is lost during the charging cycle the batteries are not discharged through the battery charger. However, meter current will be drawn from the batteries. This current amounts to about 30 milliamps.

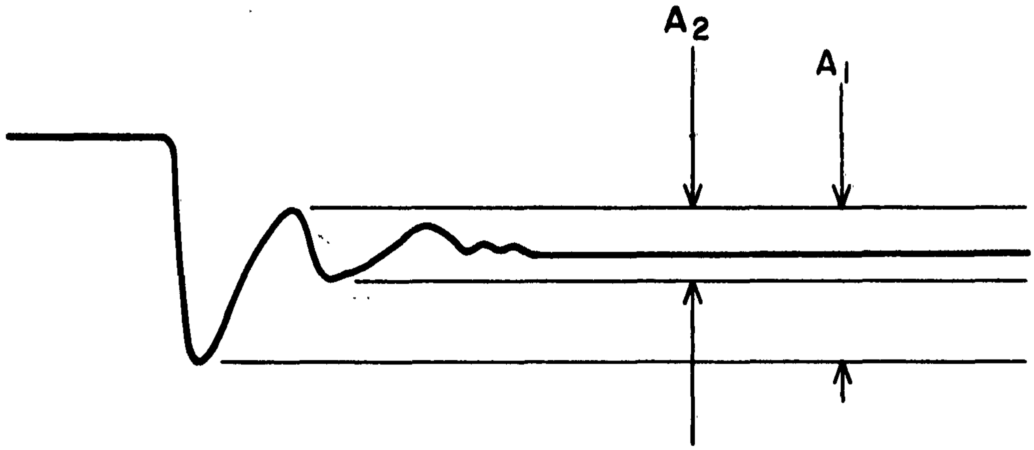
2. External Control Box

The external control box allows the major functions of the internal control unit to be performed when the electronic unit is inaccessible. The ON and OFF push button control the system power which is indicated by a green light. Pushing the reset button places the system in the program mode and resets the clock. The manual record button starts the system recording in the manual mode. This is indicated by a red light.

3. Seismometer Checker

The seismometer checker provides a means of making continuity, shorting, damping and frequency checks on the seismometers. Only shorting checks are made on the pressure transducer. Continuity of the seismometers is checked by setting the left hand switch to CONT. CHECK and the right hand switch to PRESS. Resistance between the red and white test points labeled PRESS. NS, EW, and VERT should be zero for the PRESS position and 13 K ohms for the others. Shorting checks should reveal no continuity between any of these test points and the black GND test point or the system housing.

No load damping is checked on an oscilloscope by means of the DAMPING CHECK switch with the left hand selector switch at DNL (no load damping). The resulting wave shape should show as an exponentially decaying sine wave. To check DL (loaded damping) the selector switch should be at DL and again press the DAMPING CHECK switch. Hold it until the oscillations are damped out. Upon release, the wave shape should produce a ratio A_1/A_2 between 15 and 20, as illustrated below.



Natural frequency checks (FN) are made by means of an oscilloscope and a low-frequency function generator. Power fed to the seismometers by the frequency generator is adjusted in frequency until the scope pattern is a straight line from the lower left to the upper right portion of the screen. The frequency at which this occurs is the natural frequency of the seismometer and it should be between 0.85 and 1.1 cps.

ILLUSTRATIONS

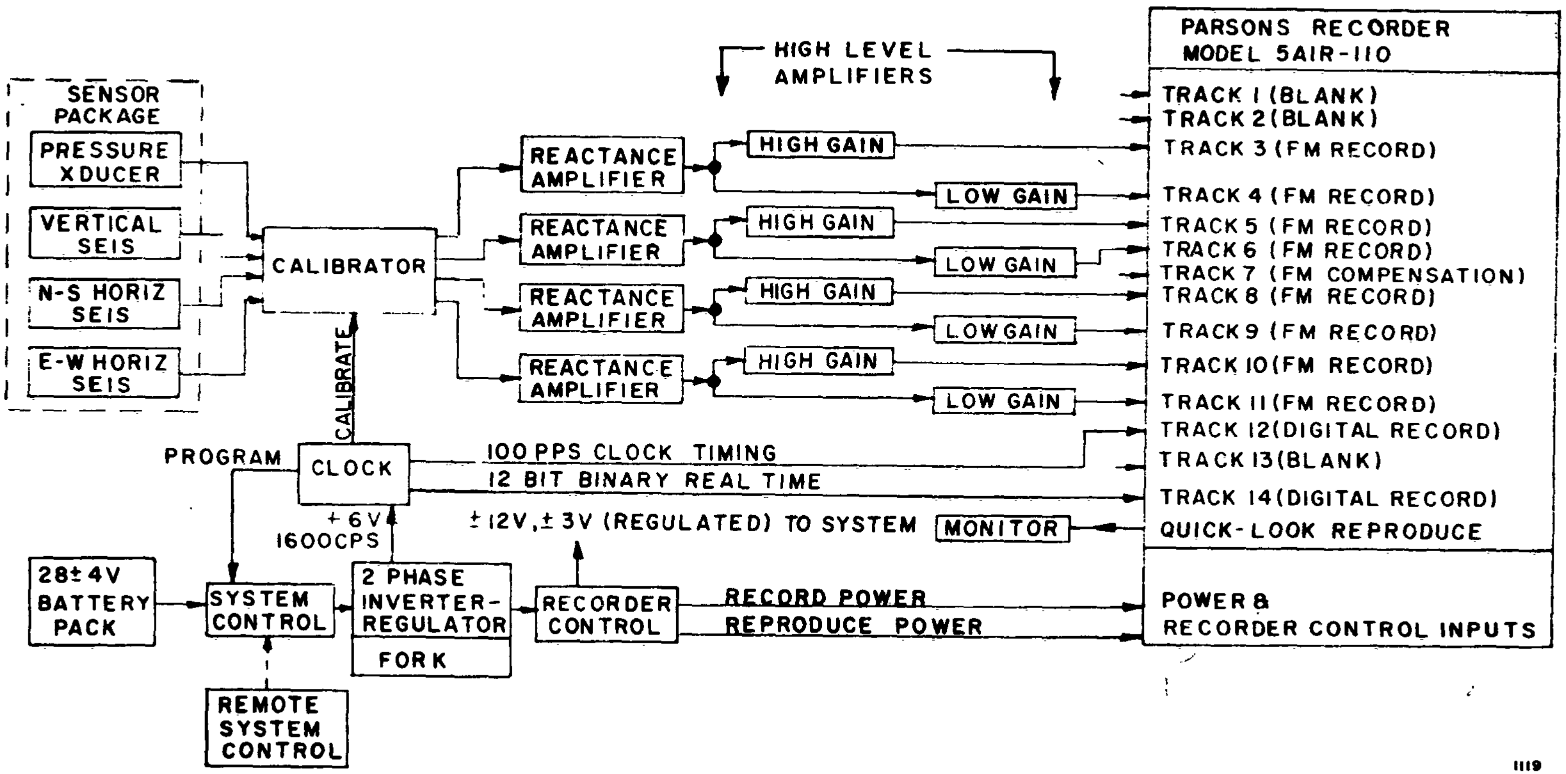


Figure 1. Improved Ocean-Bottom Seismometer System - Block Diagram

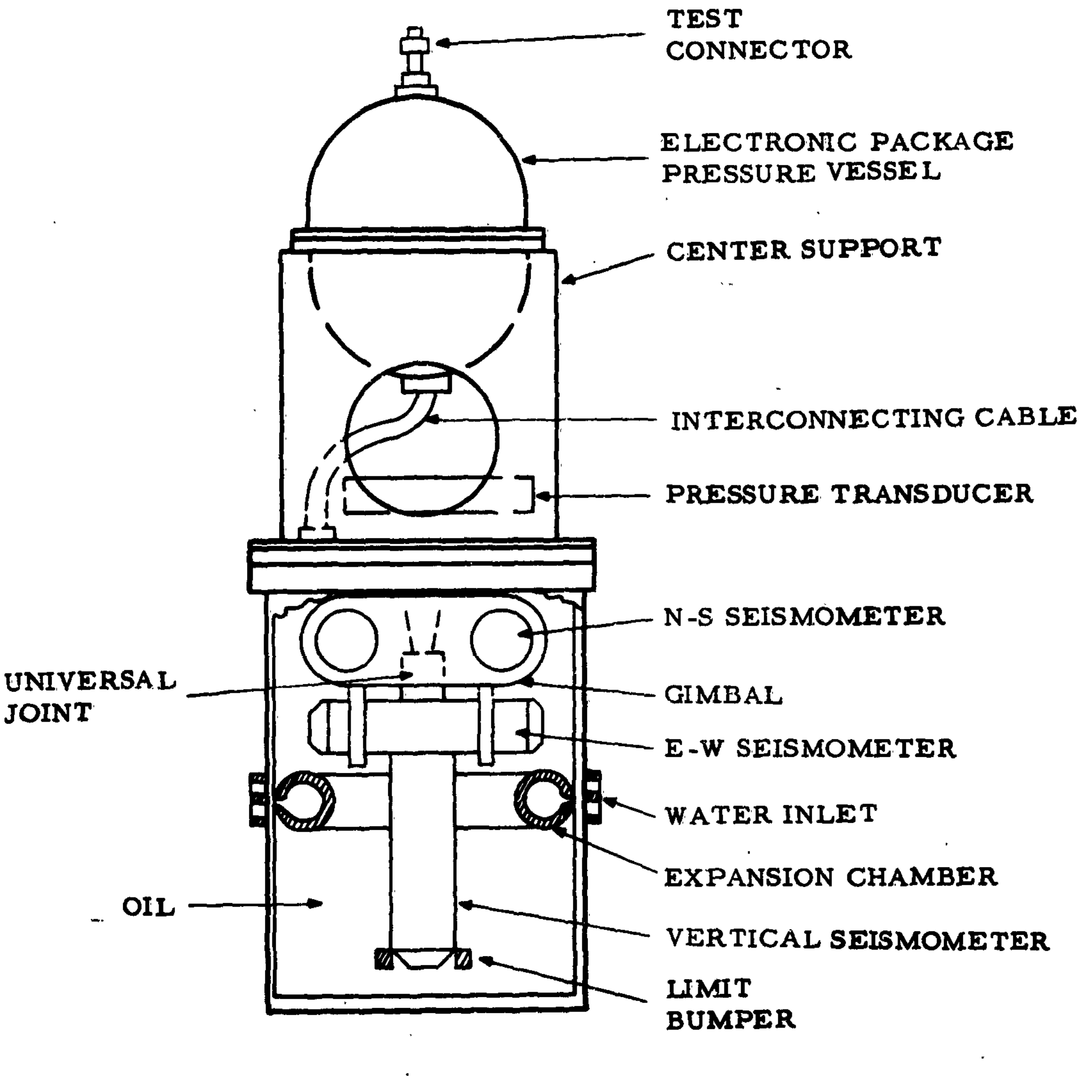


Figure 2. Basic Marine Seismic Package

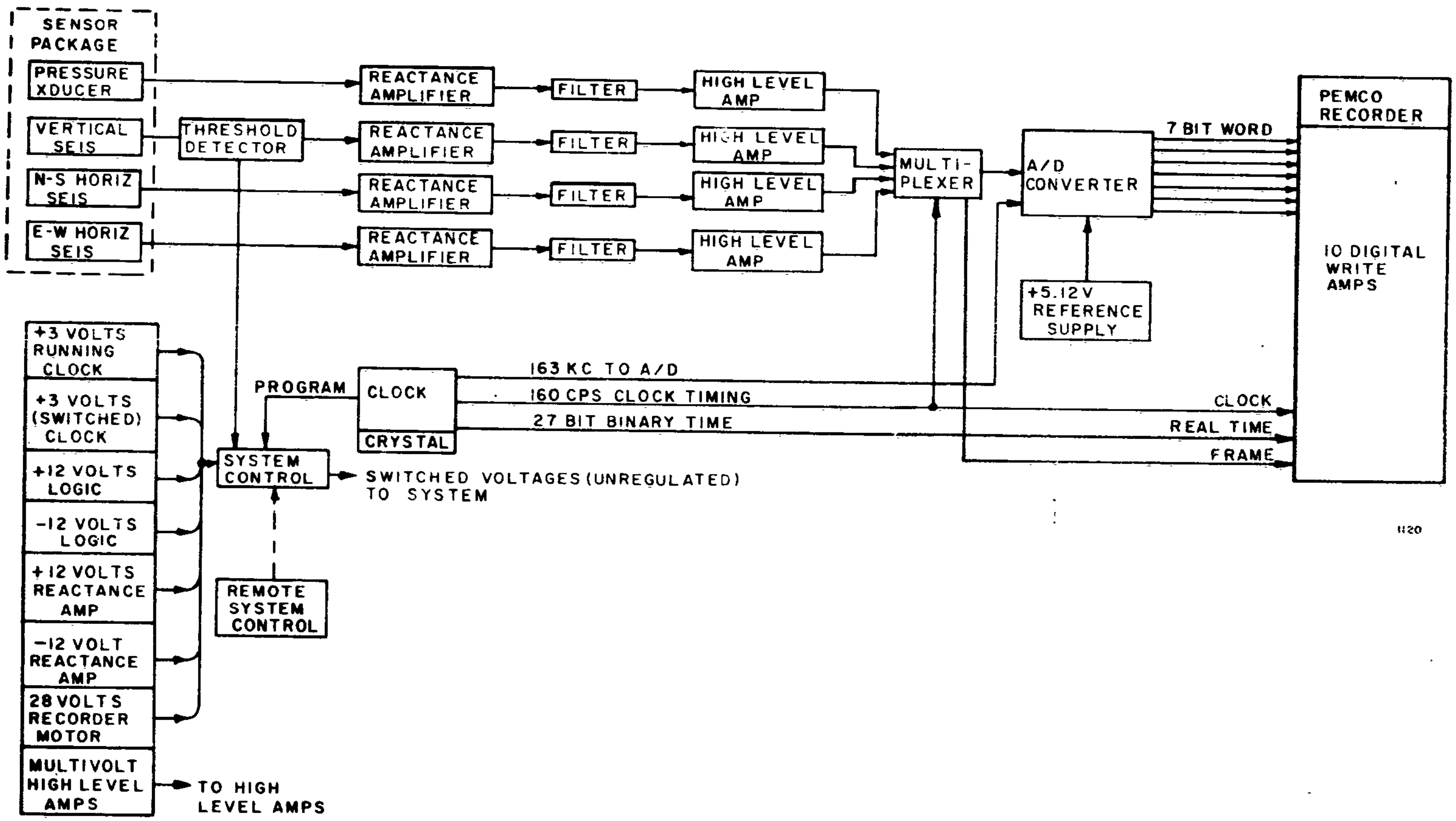


Figure 3. Prototype Ocean-Bottom Seismometer System - Block Diagram

INSTRUMENTATION	PROTOTYPE DIGITAL	IMPROVED FM/DIGITAL
SENSORS	1 PRESSURE TRANSDUCER 1 VERTICAL SEISMOMETER 2 HORIZONTAL SEISMOMETERS	SAME
TAPE RECORDER	PEMCO, 1/2 INCH TAPE, 10 TRACK DIGITAL	PARSONS, 1 INCH TAPE, 14 TRACK FM/DIGITAL
TAPE CAPACITY	800 FT. AT 0.355 IPS	1000 FT AT 0.300 IPS
RECORDING TIME	7.5 HRS.	11.1 HRS
RECORDER CAPACITY	4 DATA CHANNELS 2 TIMING CHANNELS	8 DATA CHANNELS 2 TIMING CHANNELS
RECORDING TECHNIQUE	DIGITAL	FM/DIGITAL
DYNAMIC RANGE	36 DB PER CHANNEL	42 DB PER CHANNEL 72 DB PER SENSOR
RECORDING FREQUENCY RANGE	0.1 TO 10 CPS FLAT 1 1/2 DB	0.1 TO 50 CPS FLAT 1/2 DB
POWER REQUIREMENT	6.3 WATTS	8.0 WATTS
TIMING METHOD	CRYSTAL 163.8400 KCPS	FORK 1600.00 CPS
MAX. OPER. DEPTH	10,000 FEET	20,000 FT.

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Figure 4. Comparative Features of Ocean-Bottom Seismometer

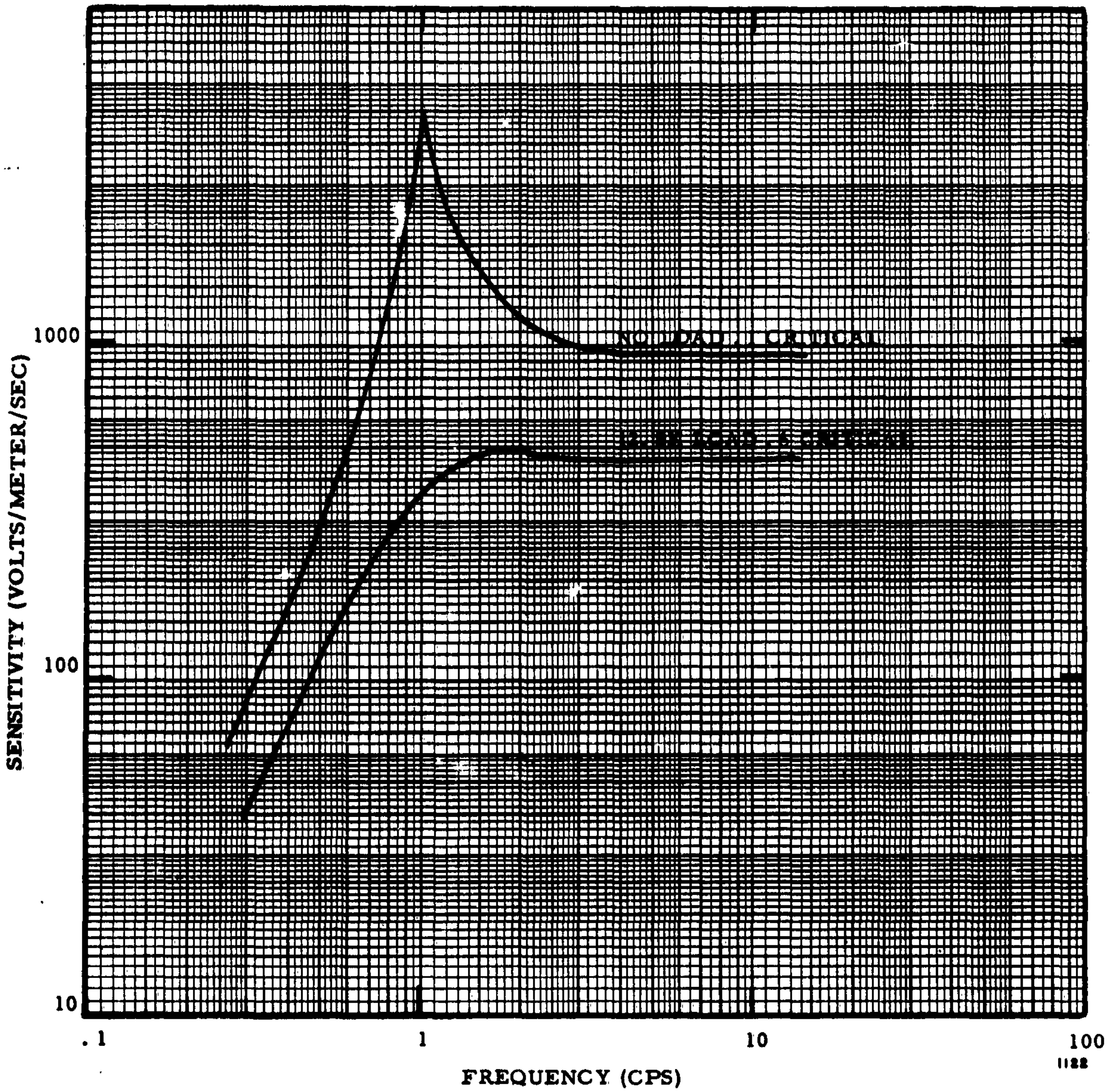


Figure 5. Response of Vertical Seismometer as Determined by Response to an Impulse

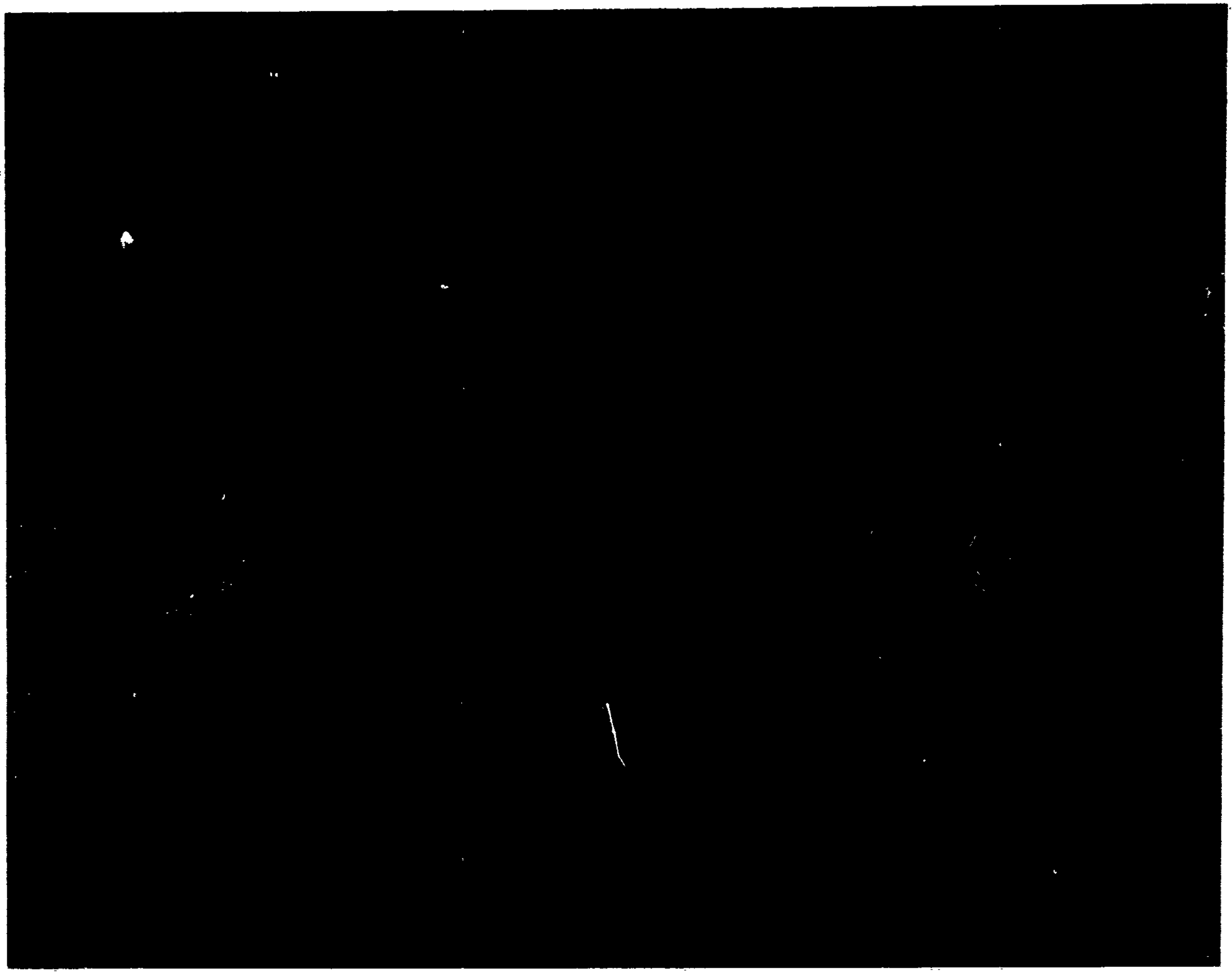


Figure 6. The Pressure Transducer

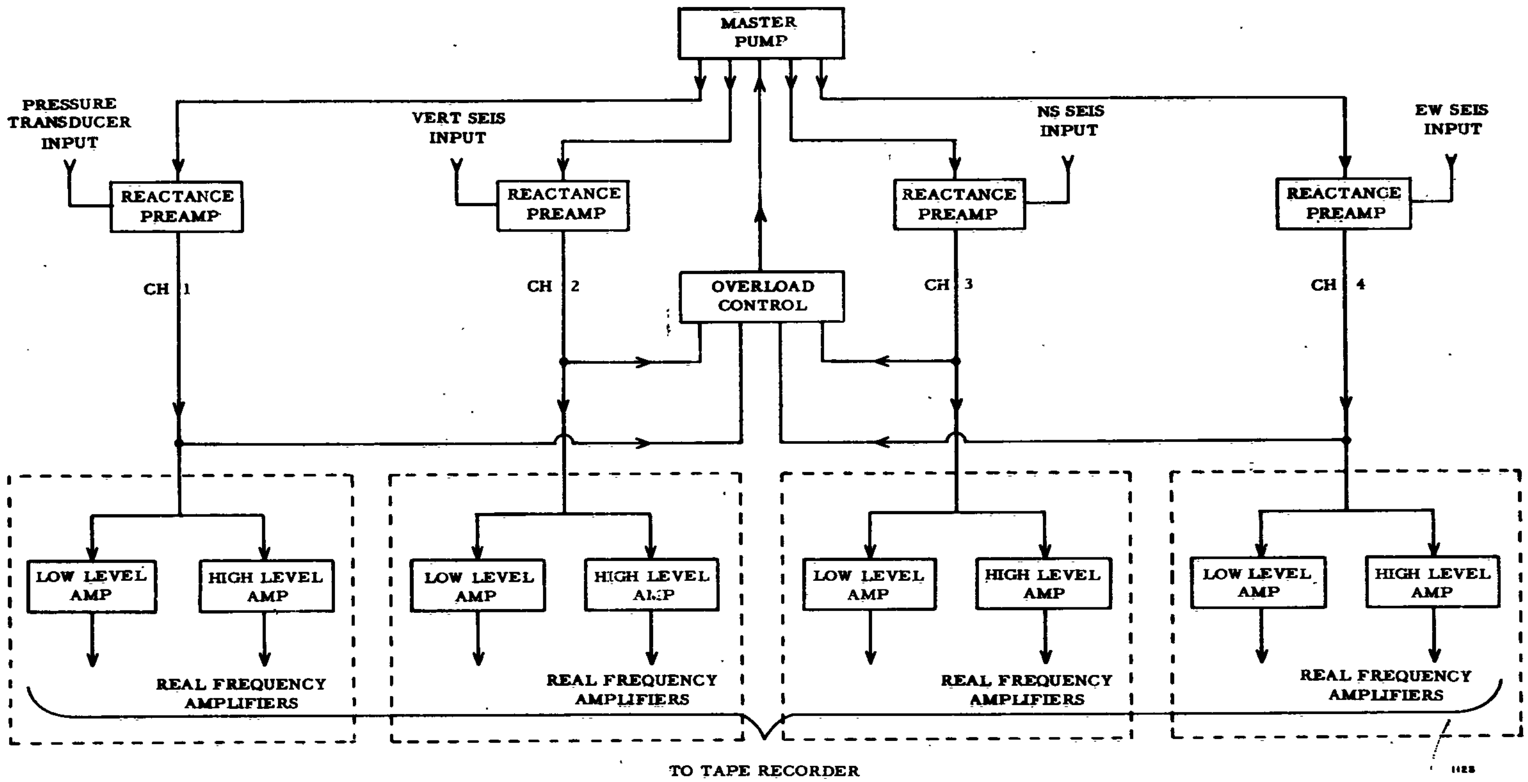


Figure 7. Block Diagram, Amplifier Section of Ocean-Bottom Seismometer

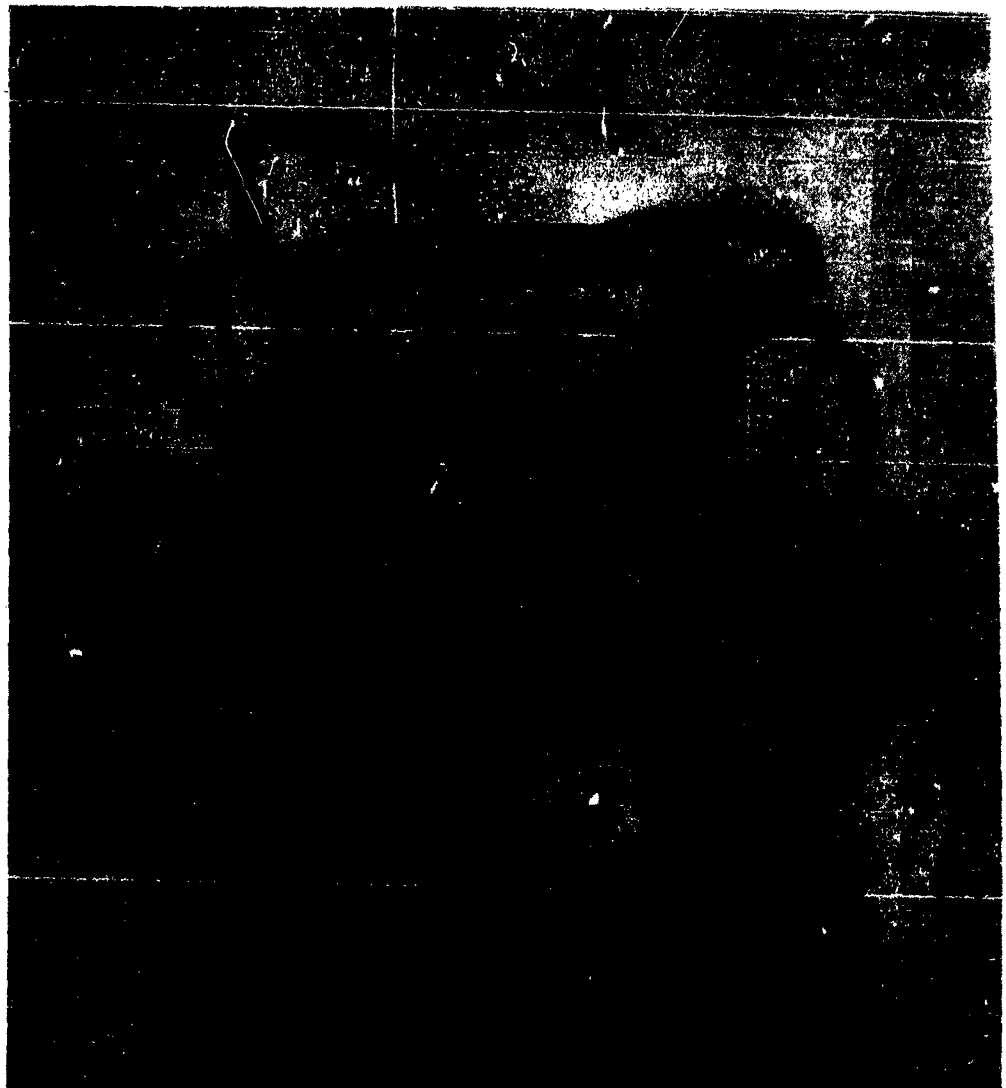


Figure 8. Photograph of Amplifier Section of Ocean-Bottom Seismometer

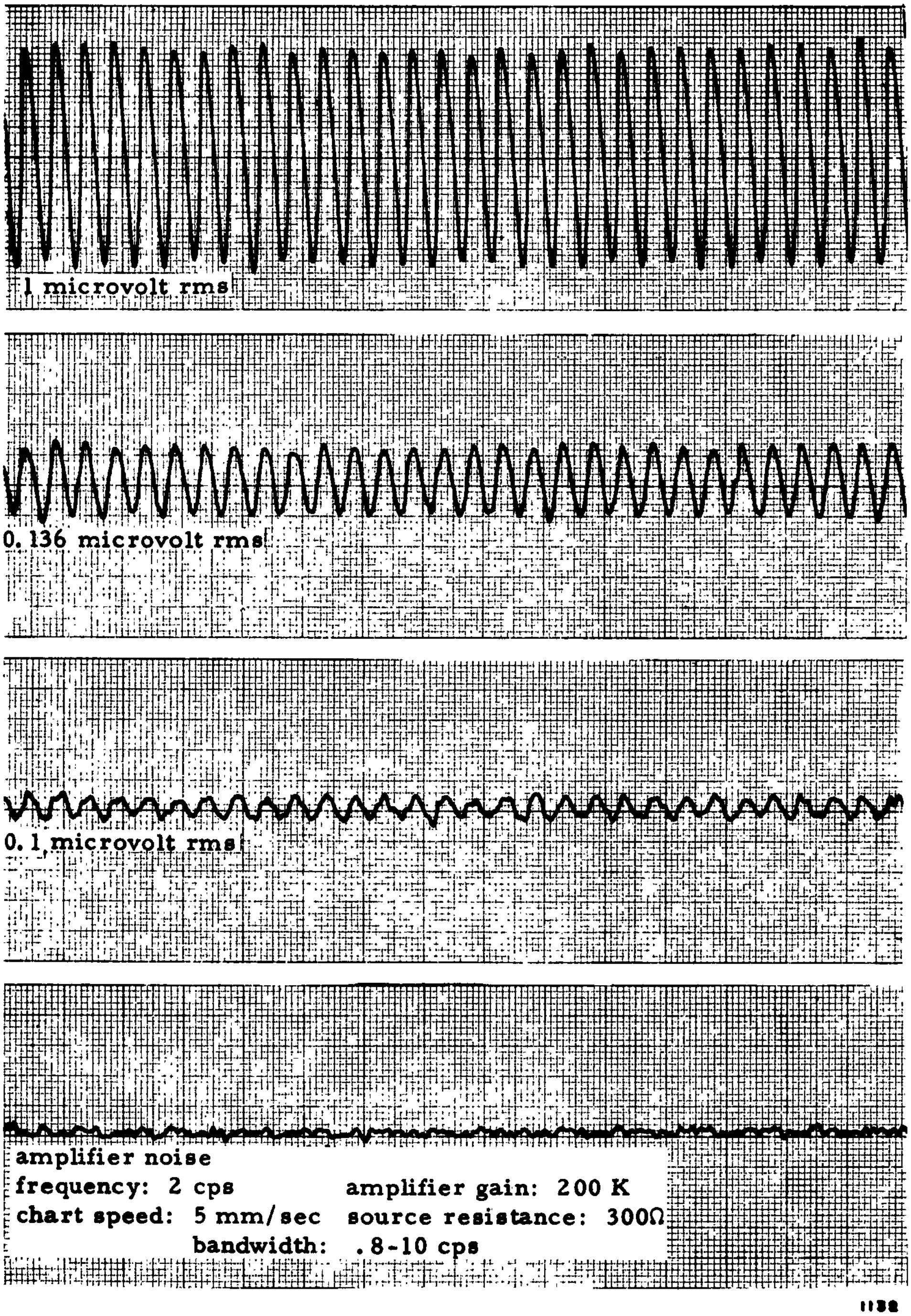


Figure 9. Strip Chart Recording of High-Level Amplifier Output

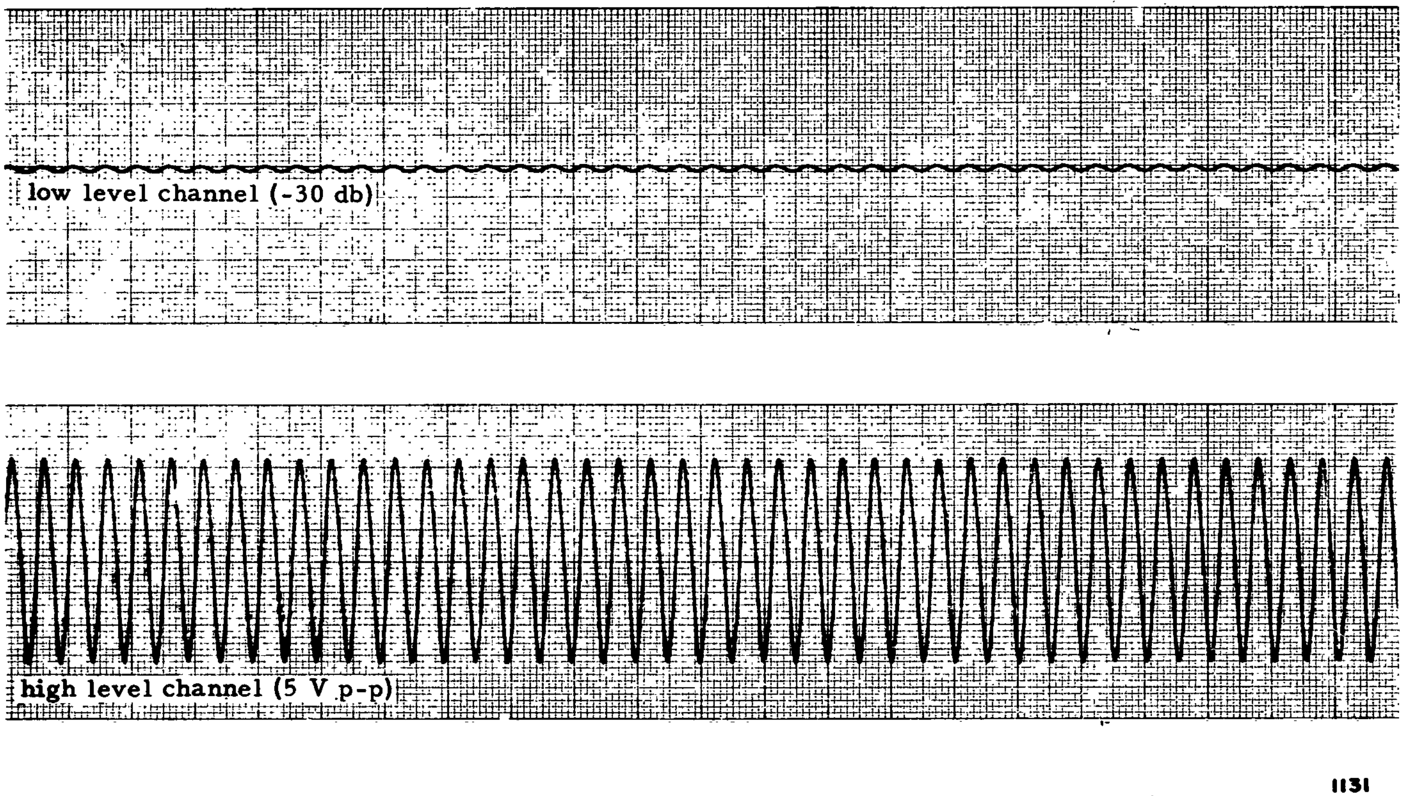


Figure 10. Strip Chart Recording of Relative Amplitude Separation Between Channels

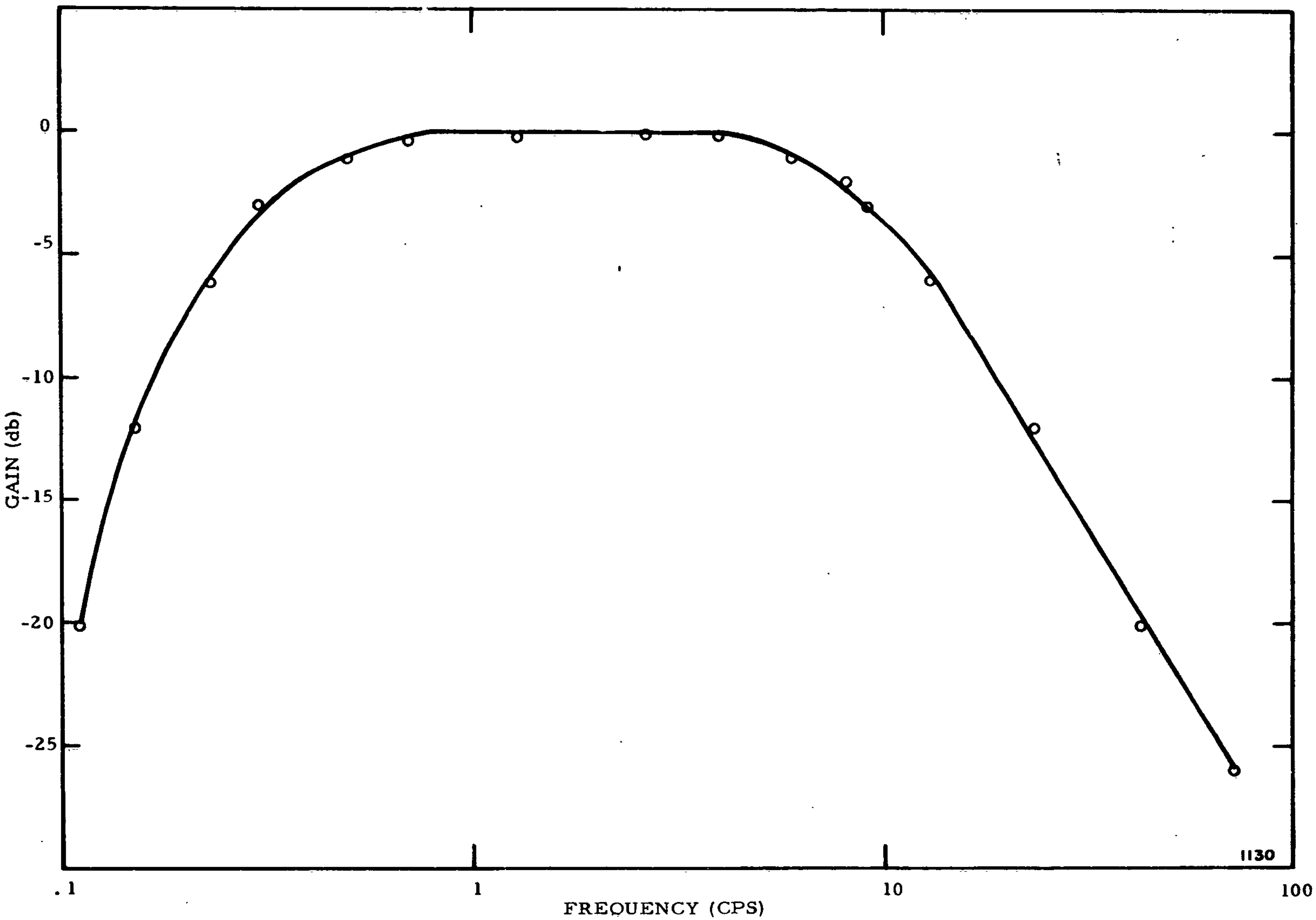


Figure 11. Over-All Amplifier Section Response

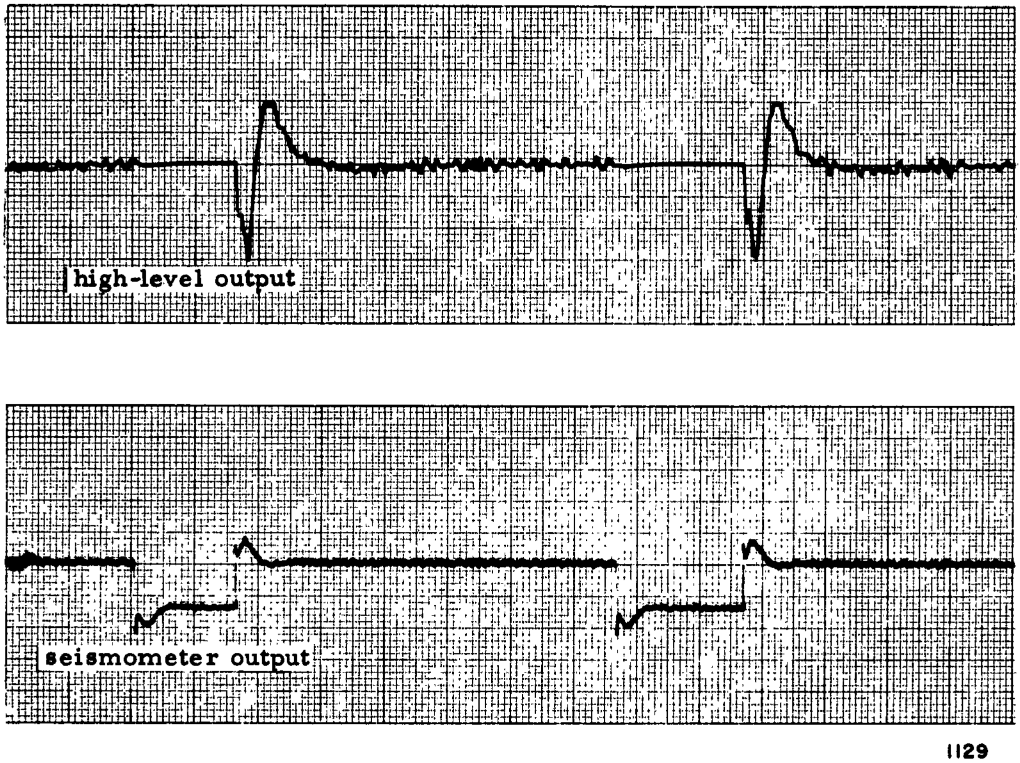
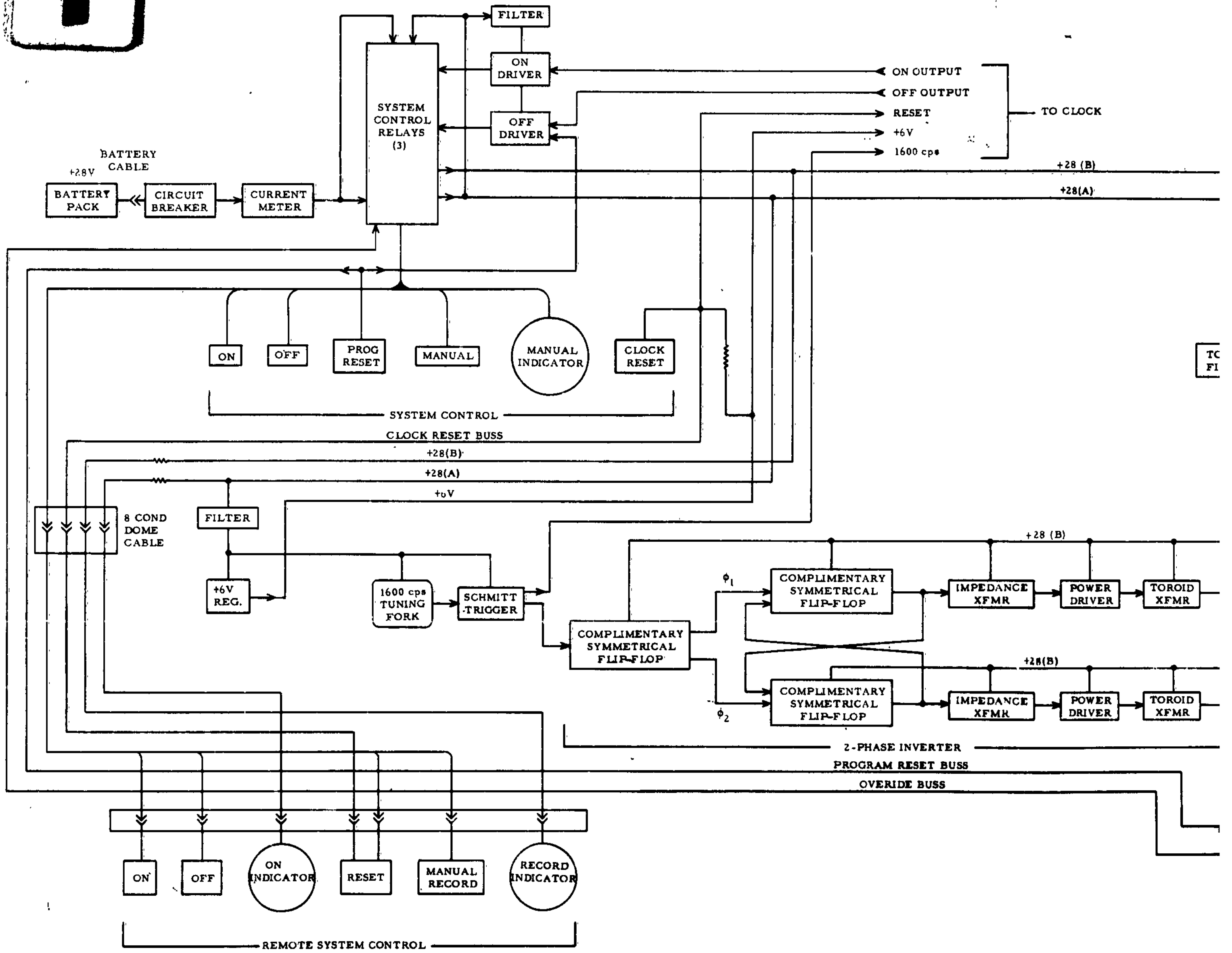


Figure 12. Strip Chart Recording of Seismometer Output and High-Level Amplifier Output for Two Manual Calibrate Commands

1



FILTER
ON DRIVER
OFF DRIVER
SYSTEM CONTROL RELAYS (3)
ON OUTPUT
OFF OUTPUT
RESET
+6V
1600 cps
TO CLOCK
+28 (B)
+28(A)
BATTERY CABLE
+28V
BATTERY PACK
CIRCUIT BREAKER
CURRENT METER
ON
OFF
PROG RESET
MANUAL
MANUAL INDICATOR
CLOCK RESET
SYSTEM CONTROL
CLOCK RESET BUSS
+28(B)
+28(A)
+6V
8 COND DOME CABLE
FILTER
+6V REG.
1600 cps TUNING FORK
SCHMITT TRIGGER
COMPLIMENTARY SYMMETRICAL FLIP-FLOP
+28 (B)
COMPLIMENTARY SYMMETRICAL FLIP-FLOP
IMPEDANCE XFMR
POWER DRIVER
TOROID XFMR
+28(B)
COMPLIMENTARY SYMMETRICAL FLIP-FLOP
IMPEDANCE XFMR
POWER DRIVER
TOROID XFMR
2-PHASE INVERTER
PROGRAM RESET BUSS
OVERIDE BUSS
ON
OFF
ON INDICATOR
RESET
MANUAL RECORD
RECORD INDICATOR
REMOTE SYSTEM CONTROL

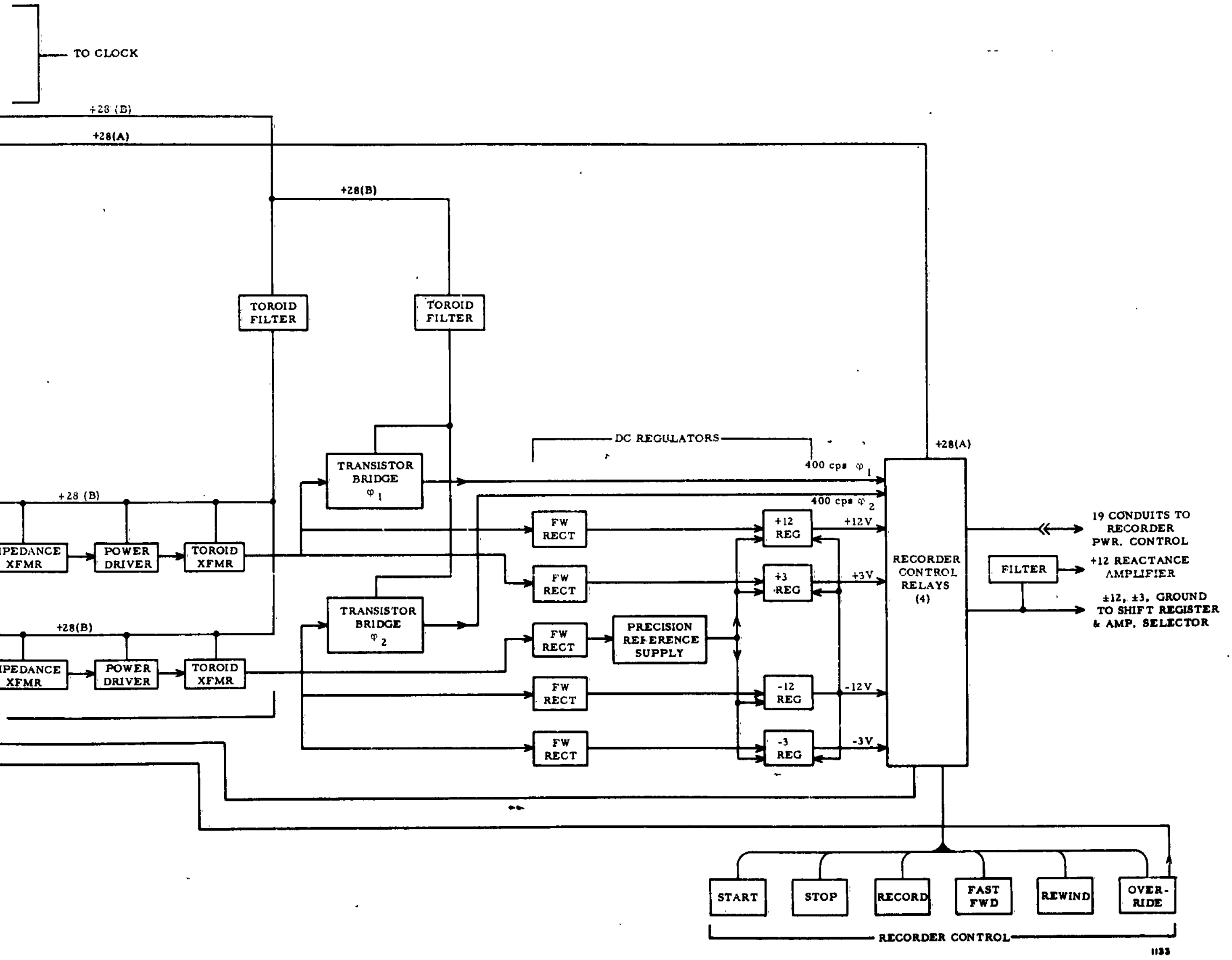


Figure 13. Block Diagram of Power Supply and Control Section of Ocean-Bottom Seismometer

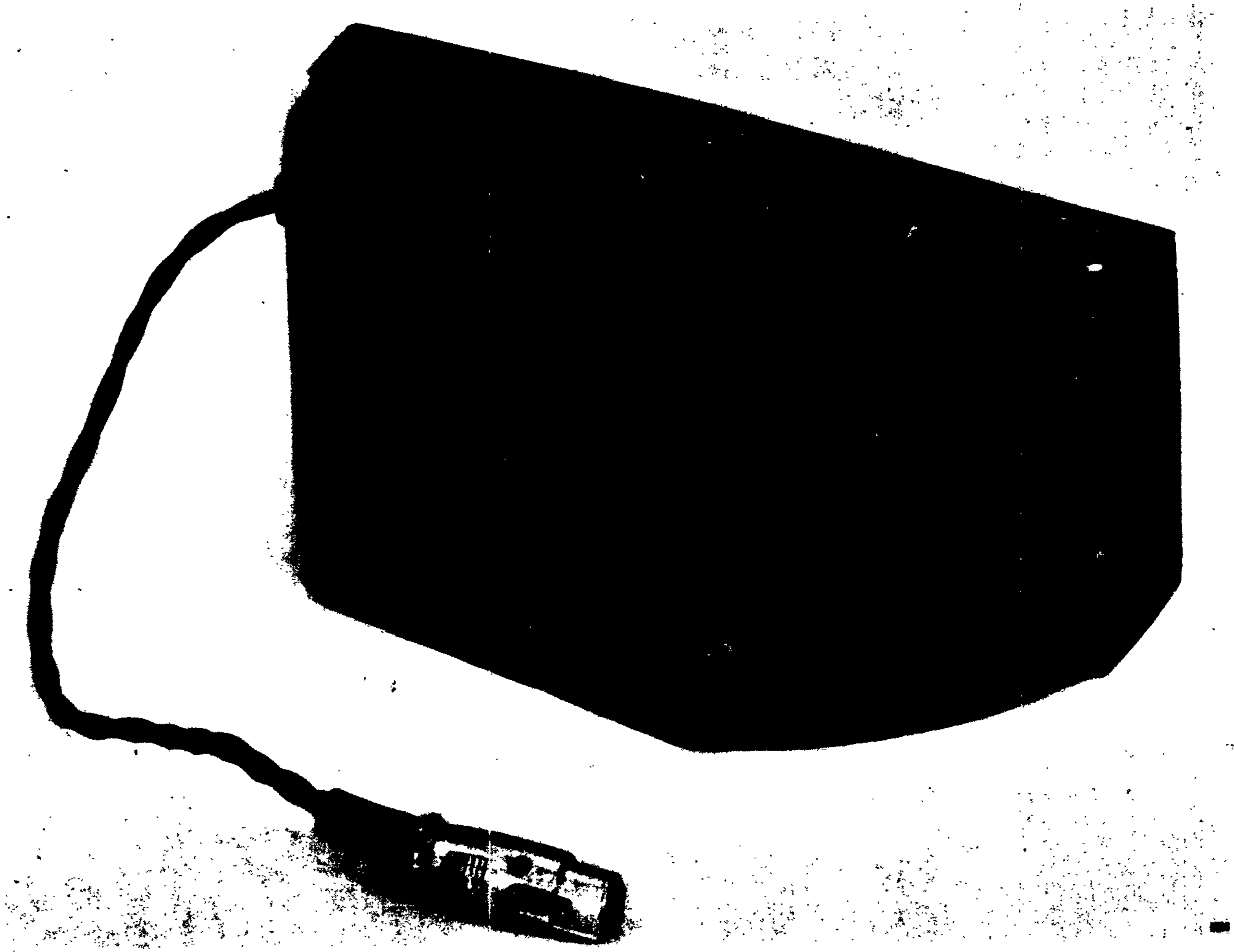


Figure 14. Battery Pack

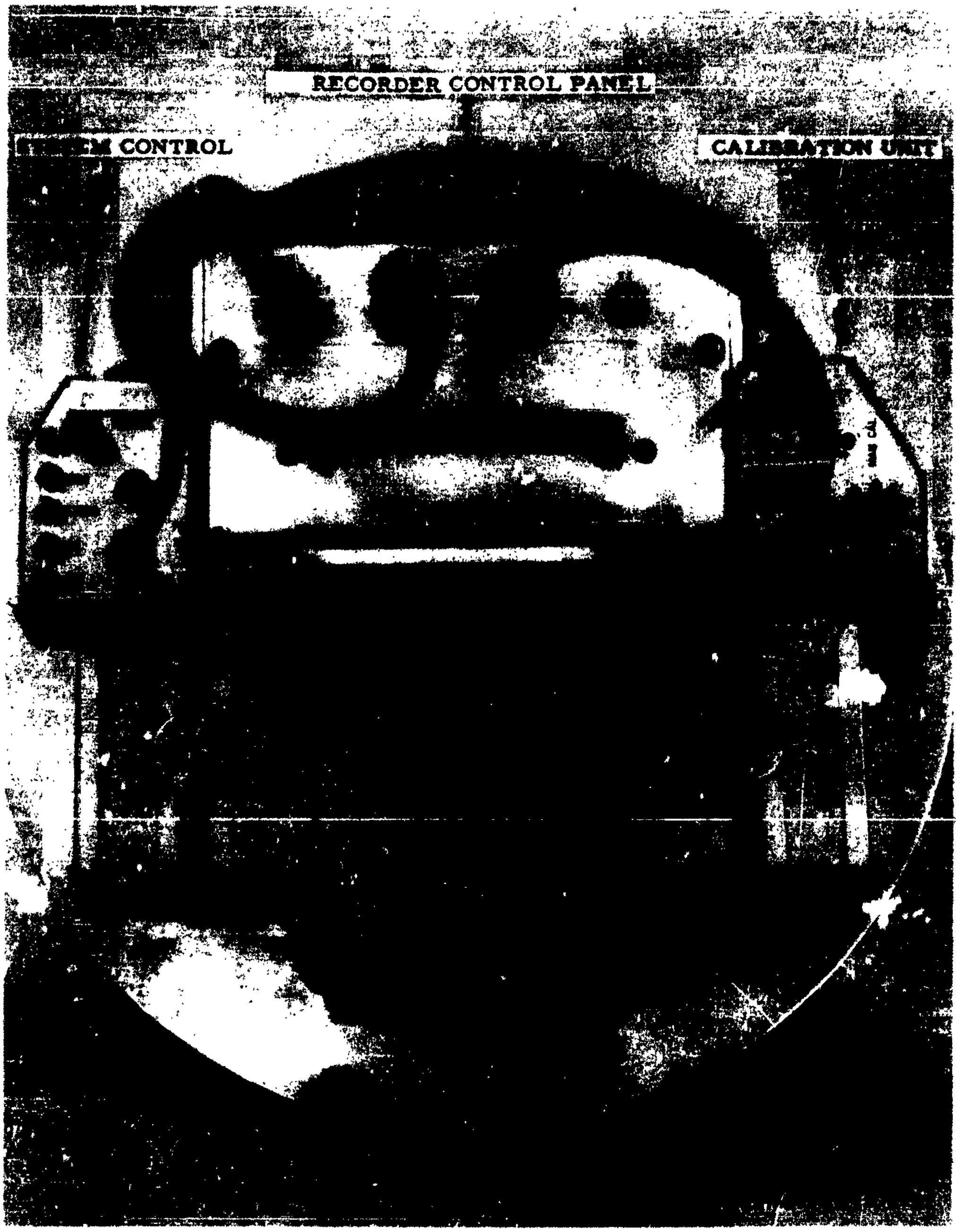


Figure 15. System Control, Calibration Unit, Recorder Control Panel

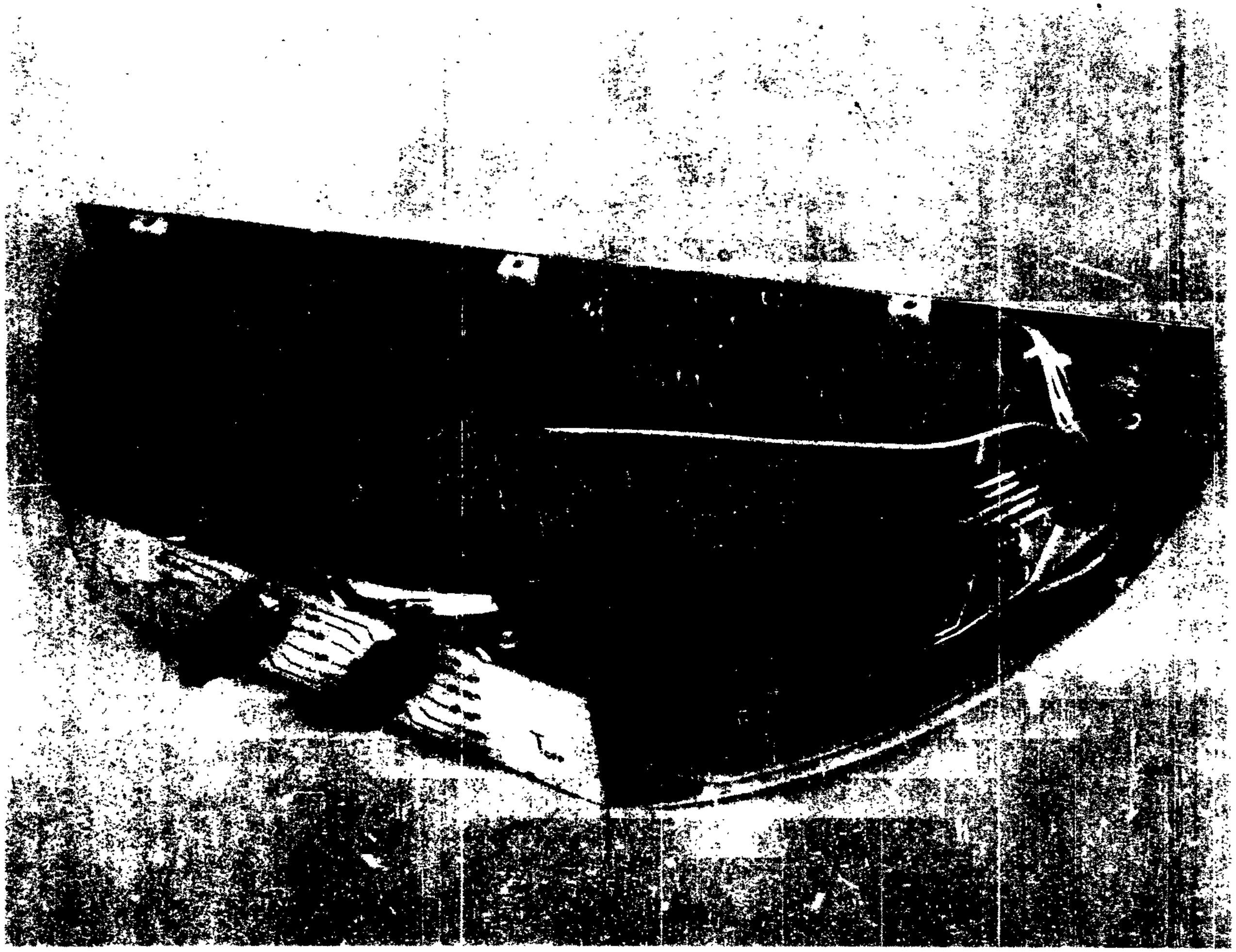


Figure 16. The Clock

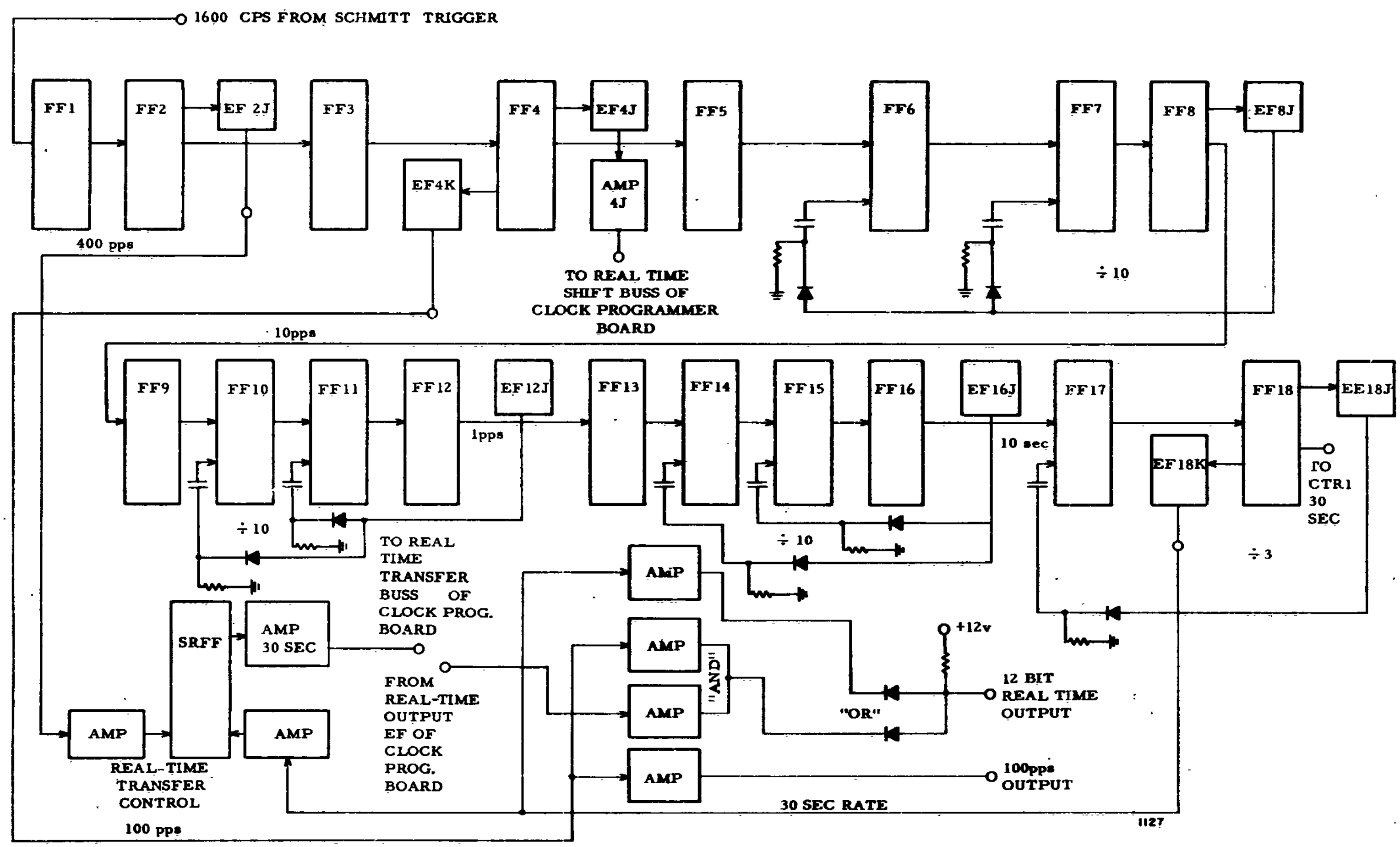


Figure 17. Clock Output and Control - Modular Block Diagram

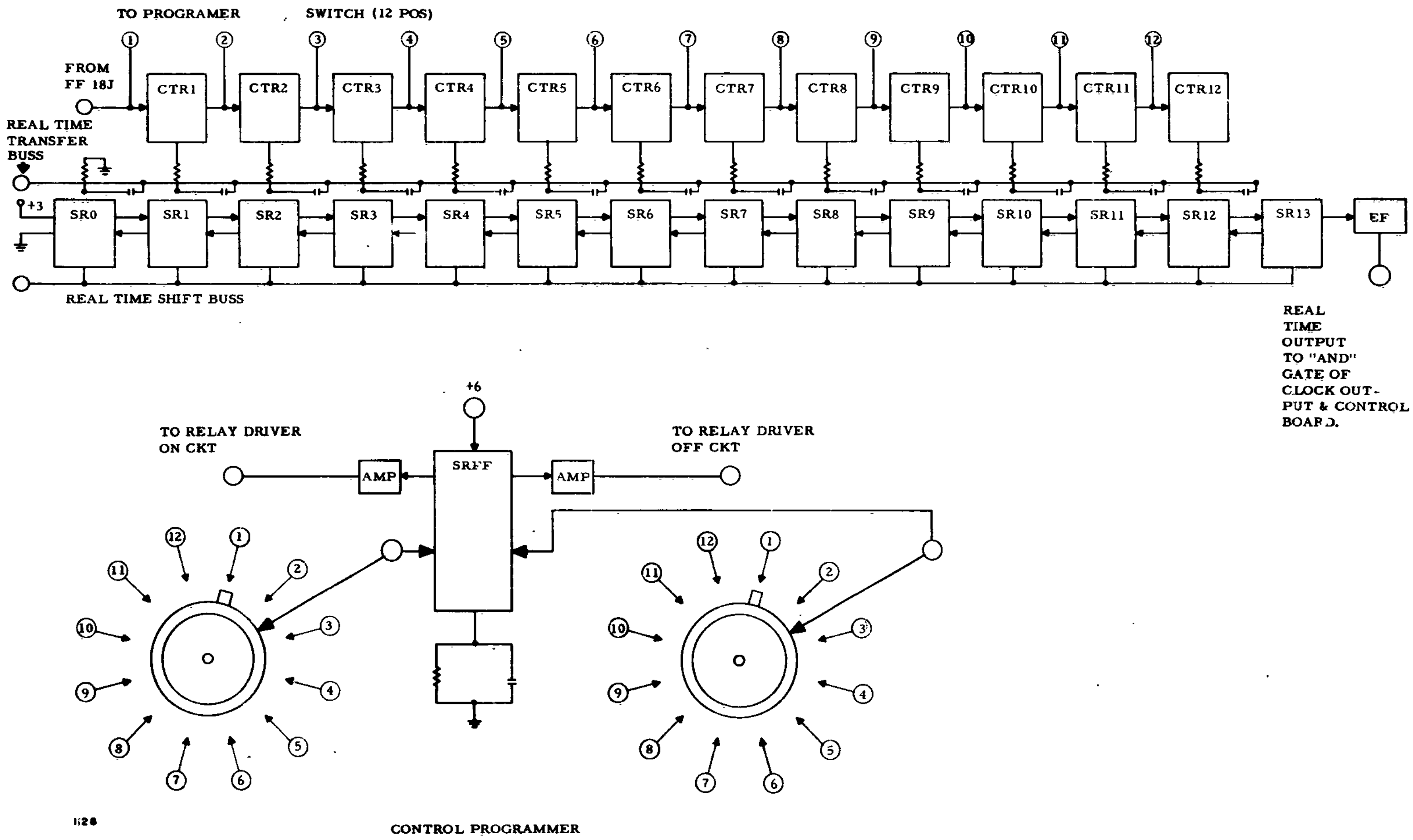


Figure 18. Clock Programmer - Modular Block Diagram

Figure 21. Modular Plug-In Unit

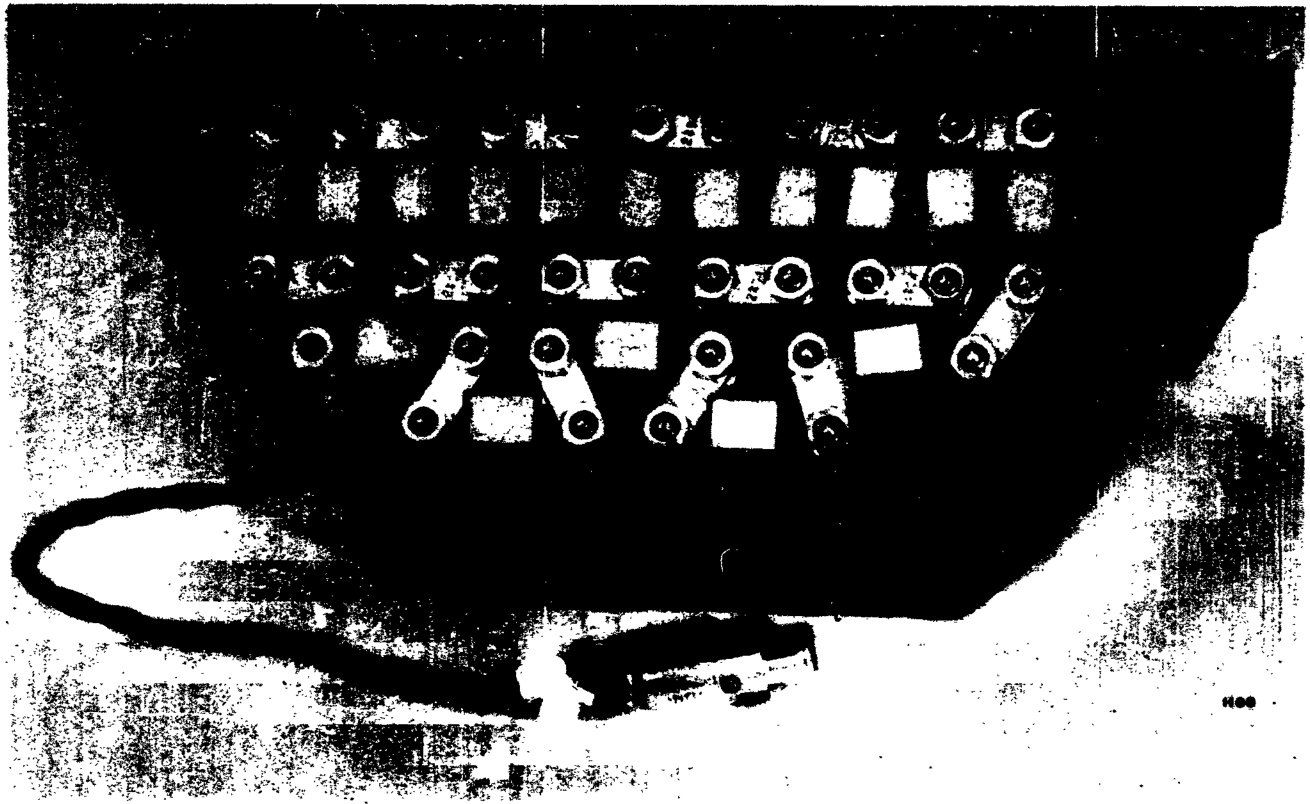


Figure 22. Ocean-Bottom Seismometer Battery Unit
(16 Yardney LR-10 Silvercels)

Figure 23. Main Chassis for Electronic Packaging

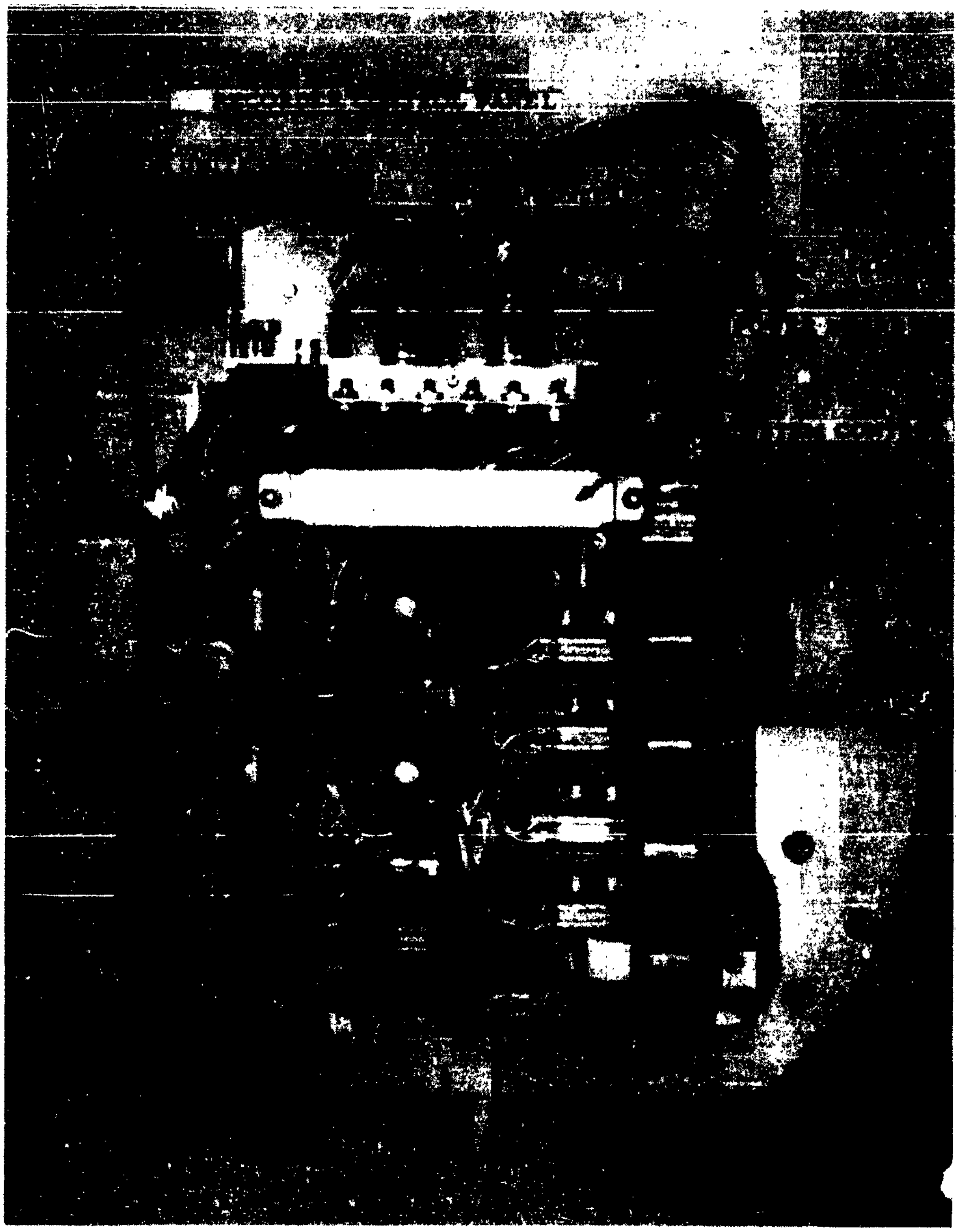


Figure 24. Calibration Unit, System Control, Power Board, Recorder Control Panel

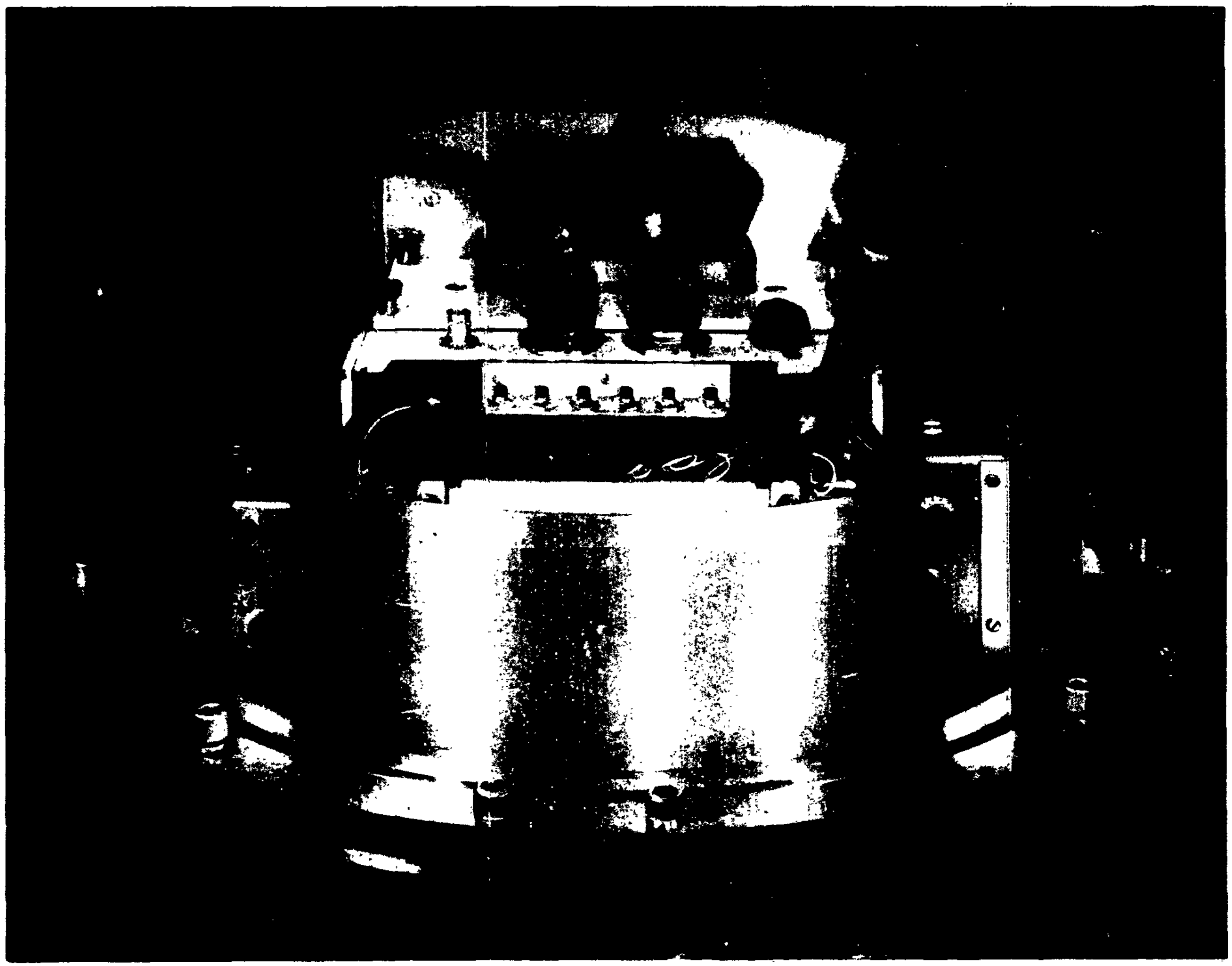


Figure 25. Over-All View of All Control Switches

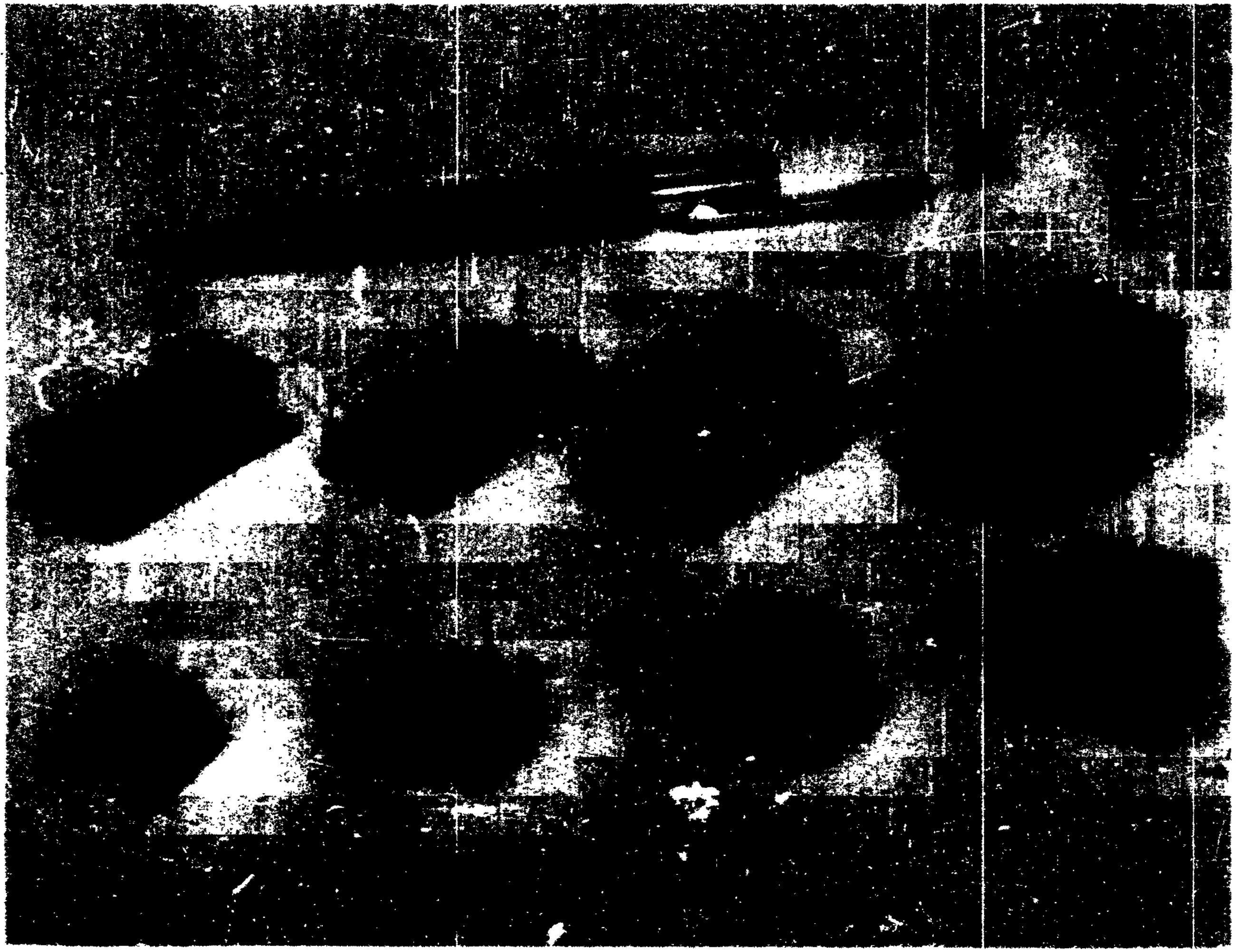


Figure 26. Construction Steps of Modular Units for Clock Section

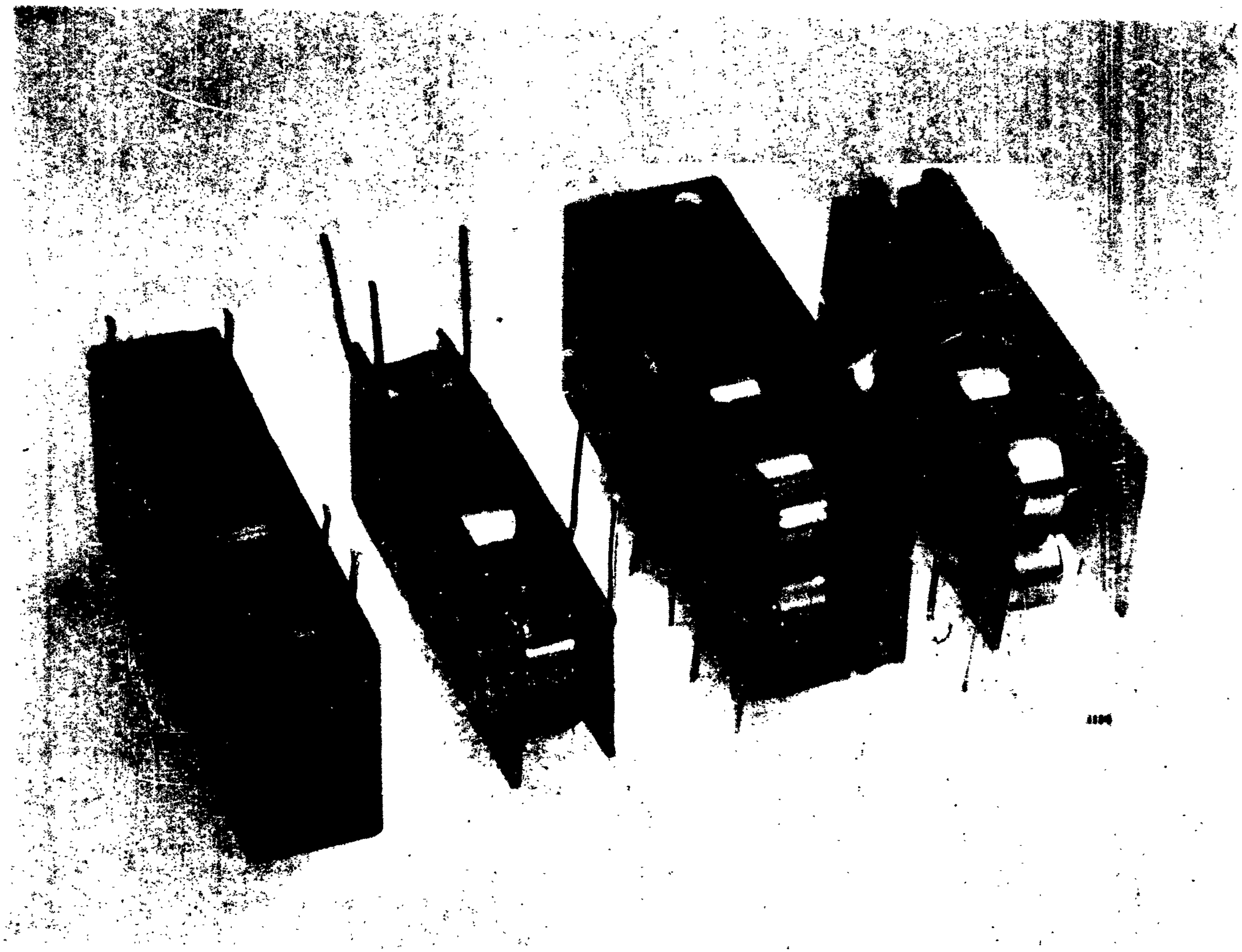


Figure 27. Power Supply Board Modular Units

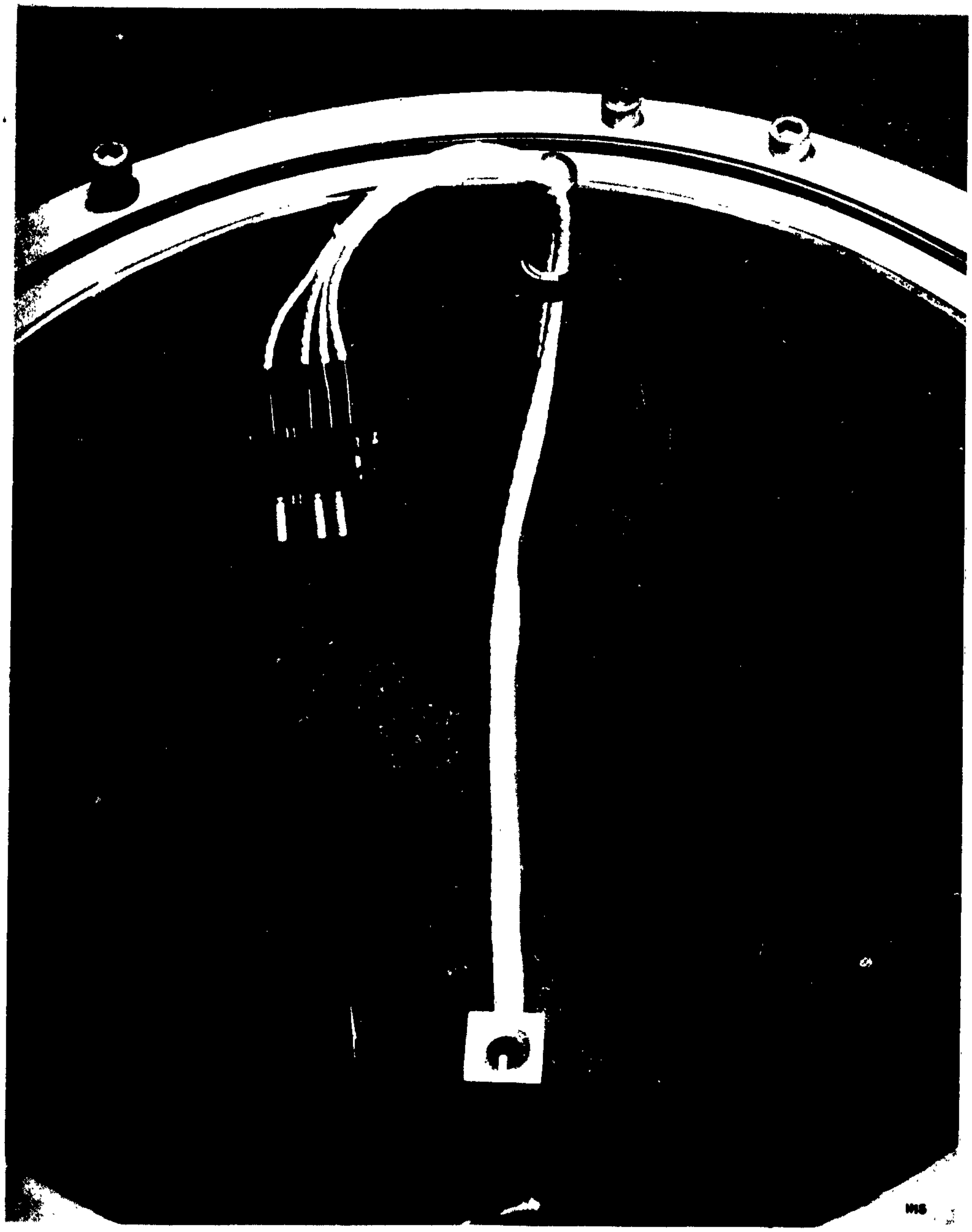


Figure 28. Cable Connection to Electronic Package

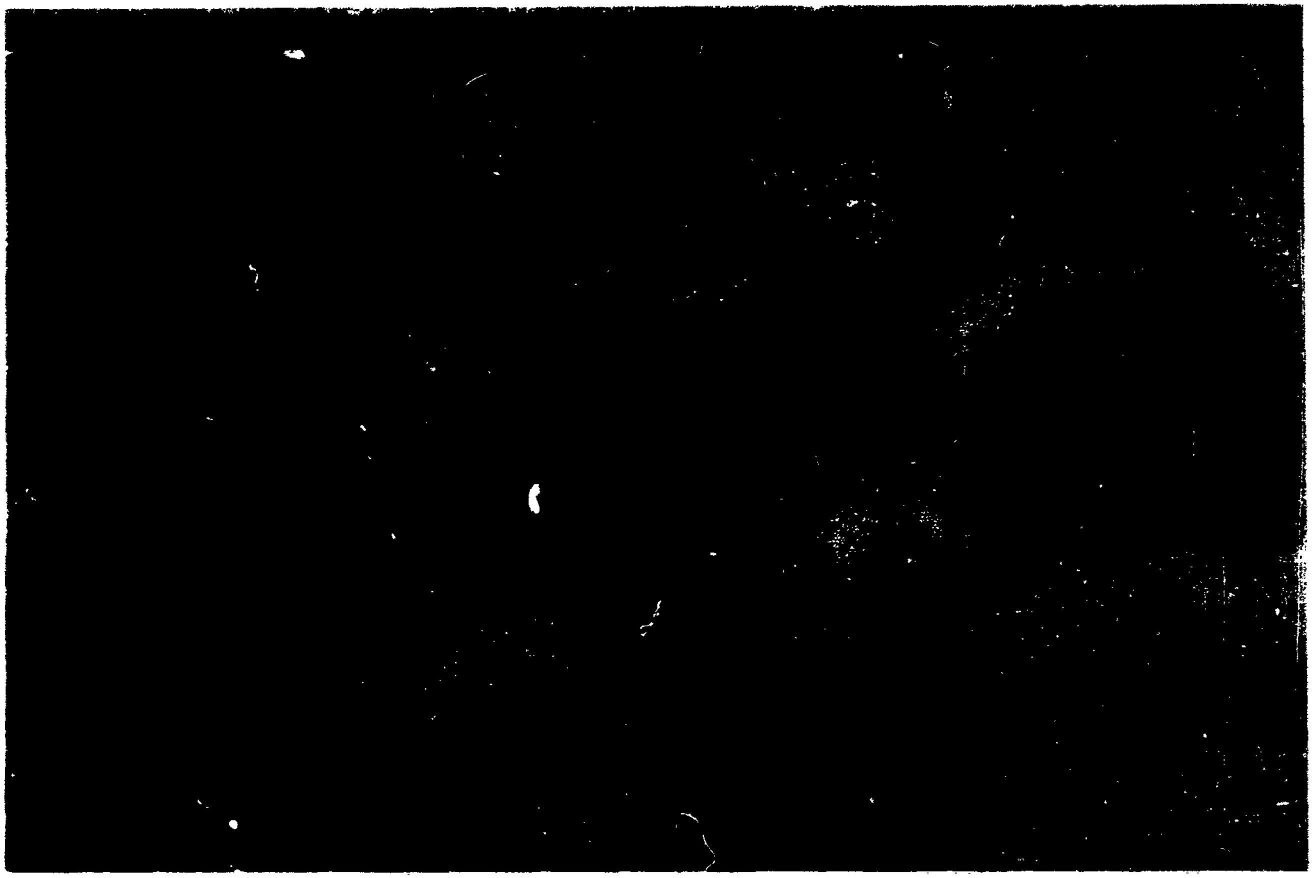


Figure 29. Field Test Equipment for Ocean-Bottom Seismometer (Battery Charger, External Control Box, Seismometer Checker, left to right)