

5. *New DSDP (Deep Sea Drilling Project) Downhole Temperature Probe Utilizing IC RAM (Memory) Elements.*

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Summary

A new device for heat flow measurements in DSDP (Deep Sea Drilling Project) holes has been constructed and used successfully during DSDP Leg 60. The device is a digital self-recording instrument, utilizing CMOS RAM (Complimentary Metal Oxide Semiconductor Random Access Memory). The device, therefore, requires no mechanical parts for recording. This made the instrument particularly suitable for use under severe mechanical handling during DSDP-type operations. A bead type thermistor sensor is attached to the device housed in a pressure case which is lowered in the hole by a wire. The IC memorizing temperature recording system employed in our probe appears to be useful for a variety of data recording purposes.

1. Introduction

Measurement of heat flow through the earth's crust is one of the major objectives of the geophysical field survey. There are essentially two ways to determine the geothermal gradient. The first one is to measure the geothermal gradient down along a drill hole deep into the earth's crust by lowering a temperature probe. Usually the temperatures are read by a thermometer at the wellhead. This method is utilized mainly for measurements on land. The second method is to measure the geothermal gradient of the topmost part of the ocean floor by means of self-recording probe which is normally only a few meters long.

DSDP holes have provided a new opportunity for measuring the geothermal gradient down to greater depths in the oceanic areas. For this purpose a self-recording temperature probe was developed by Von Herzen and Erickson (ERICKSON, 1973) at an early stage of DSDP. The Von Herzen-Erickson probe was successfully used during several legs of the cruise of the Glomar Challenger (*e.g.* ERICKSON *et al.*, 1975; HYNDMAN *et al.*, 1976). Since, however, the operation of DSDP downhole temperature measurement requires that the probe be forced into the undrilled part of the bottom, the probe has to stand severe mechanical shocks. It was reported that the Von Herzen-Erickson probe often suffered from mechanical troubles caused by shocks inevitable for the DSDP-mode of operation. For DSDP Leg 60, the authors have developed a new heat flow probe. It was hoped that the probe be as rugged as possible. To meet this requirement, we decided to construct a recording system that needs no mechanical device by utilizing an integrated circuit memory. Since the electric power consumption has to be kept minimal, we chose to use CMOS RAM commonly used in a microprocessor type electronic computer.

2. Outline of the measuring and retrieving systems

Essentially, the whole system consists of two components. The first one is a set of solid state digital memories (CMOS RAM) which memorize the digitized temperature values with an electric power dissipation small enough to be supplied by a set of small dry battery cells. This part, called the Daughter, goes to the sea bottom. The second component, the Parent which stays aboard the vessel, is a data-retrieving circuit combined with a digital panel display.

The temperature sensor is a bead-type thermistor molded in a water-tight teflon sheath. The Daughter, *i.e.* the measuring and recording system except for the thermistor, is packed in a water-tight pressure-resistive vessel and lowered by a wire into the drill hole. The thermistor mounted in a nose piece is pushed into the undrilled sediment.

The recorded digital data is transferred to a set of integrated digital memory circuits of the retrieval system, the Parent, right after the recovery of the Daughter on deck. The transferred data is stored and kept in the latter memory network as long as the back-up battery cells run (over 48 hours). The retrieval circuit can easily be modified to be connected with an external electronic computer for further data processing.

3. Temperature measurements with a thermistor

Relation between the resistance R of a thermistor versus absolute temperature T is given by:

$$R = R_0 \exp B \left(\frac{1}{T} - \frac{1}{T_0} \right) \quad (1)$$

where R_0 and B are resistance (R_0) of a thermistor at a certain temperature (T_0) and a characteristic specific constant of the given thermistor, respectively.

For example, in case where $T_0 = 273$ K, $R_0 = 30$ K Ω and $B = 3500$ K, one obtains

$$R = 0.08 \exp (3500/T) \quad (2)$$

and:

$$\frac{\Delta R}{R} = -\frac{B}{T^2} \Delta T = -0.04 \Delta T \quad \text{at } T = 273 \text{ K} \quad (3)$$

where ΔR and ΔT are infinitesimal intervals of R and T , respectively. The relation (3) denotes that the resistance of the thermistor decreases by 4% through a rise in temperature of 1°C at 273 K.

The accuracy of measurement is estimated based upon the formula (3):

$$|\Delta T| = \frac{T^2}{B} \left| \frac{\Delta R}{R} \right| \quad (4)$$

Suppose that the temperature ranges from zero to 25°C and correspondingly R ranges from 30 K Ω to 10 K Ω . Then the change in T at around 25°C ($R = 10$ K Ω) is given as:

$$|\Delta T| = 25 \times \left| \frac{\Delta R}{R} \right| \quad (5)$$

In the electronics system of a low dissipative electric power such as the one used in the present device, the accuracy of the analogue circuit is limited normally to 0.1%. Therefore, the accuracy in the measurement of $\Delta R/R$ being also 0.1%, the maximum error in ΔT ($\Delta T_{\text{err} \cdot \text{max}}$) turns out to be:

$$\Delta T_{\text{err} \cdot \text{max}} = 0.025^\circ \text{C}$$

The resolution of the minimum number (the lowest figure) of the digital display of the data retrieval system should be less than the accuracy in R , *i.e.* the maximum error in $|\Delta R|$. It is set at 10 Ω for the present design.

4. Recording circuit (Daughter)

The present system measures the resistance of the thermistor sensor (between zero and 40 k Ω) with a resolving power of 10 Ω , and a total number of 128 data items are recorded either every one or two minutes (presettable). When a 1 minute mode is selected, the recording system runs for 128 minutes. After completion of recording, the stored data is transferred to the memory installed in the data retrieval system (Parent) through an auxiliary connecting wire. The transfer is accomplished within 250 msec. The stored data in the memory of the Daughter is still preserved until the next measurement is initiated, or the power supply is cut off. Previous data is all automatically cleared and set to zero by turning on the start switch of the recorder.

A set of six manganese D-cells are used for the main power supply of the Daughter. All the electronic elements of the recording system except for the thermistor sensor are contained in a transparent acrylic pipe 60 mm in diameter and 400 mm in length.

5. Data retrieving circuit (Parent)

The temperature data transferred from the recording circuit is displayed on light emitting diodes (LED) with decimal numerals. The order of the displayed data coincides with that of the sampled temperature data. Two modes of display can be selected. In the first, data is recalled and flashed on the display every ca. 1 second in the same order as data sampling and the procedure is repeated until it is stopped manually. In the second, data is recalled successively by snapping a toggle switch. In addition to these normal modes, there is a high-speed mode with which the recall rate can be increased to 16 times per second. The initial address (in the memory area) is accessible at any time by using an address counter reset switch.

The stored data in the retrieval network of the Parent is eliminated automatically when the transfer of new data is initiated. Otherwise, the stored data is preserved intact.

Power supply is obtained either by a set of six D-cells, an external DC power source or a commercial AC (100-117 volts) power supply line.

6. Details of the recording mode

For operational procedures and electronic circuits of the system, reference will be made to Figs. 1, 2, A-1, A-2, A-3, A-4 and the technical catalogues (Motorola Company, 1976). Figs. A-1~A-4 are found in the

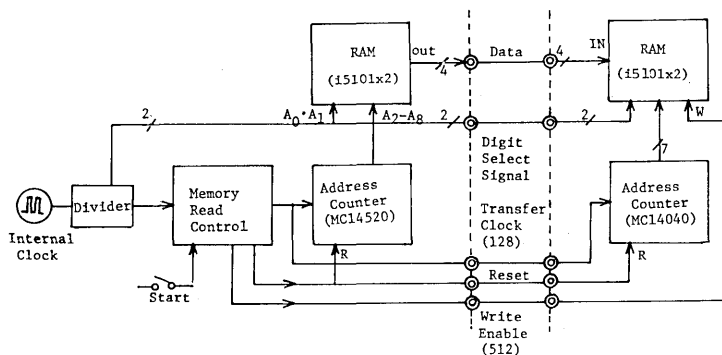
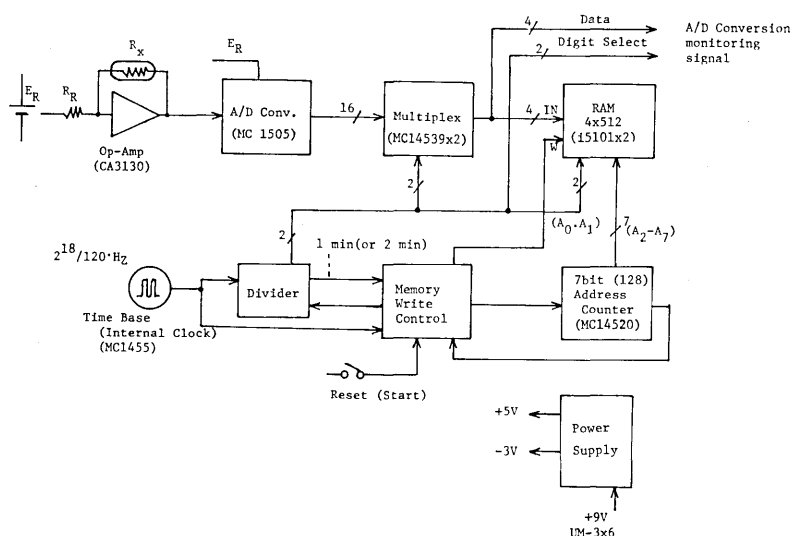


Fig. 1. Block diagram showing the functions of electronic circuits in the recording system (Daughter Instrument).

Appendix of this paper, showing the details of circuitry that are not fully explained in the text.

Resistance Rx (Fig. 1a) of the temperature sensor (thermistor; 0-40 K Ω) is converted to DC voltage output (0-2.0 volts) through the Resistance to Voltage converter consisting of an operational amplifier CA 3130 (RCA). The DC output is converted to a 4-digit Binary-Coded-Decimal (BCD) number (0000-4000) which is the resistance value of the thermistor in units of 10 Ω . The Analogue to Digital (A/D) converter combined with a comparator MC1505 is of dual-slope integration type and carries an accuracy of conversion 0.05%. All digital integrated circuits around the A/D converter are composed of CMOS

integrated circuits. Conversion time is less than 40 msec. Two CMOS RAM's (Intel 5101) with a parallel 4-line Input/Output capable of storing 1 kilobit are used as memory integrated circuits. Each 4-digit BCD data word occupies 16 bits, therefore, a total number of 128 ($=2 \text{ kilobit}/16$) data can be stored in the whole memory area. More memories can be installed if needed.

The measurements and data storing are initiated by turning a start switch on. The counter in the timing circuit and the 7 bit address counter, which assigns appropriate addresses to incoming data, are cleared (reset) at the same time. Following this reset process, successive 512 pulses of a 2 KHz repetition rate are sent out as the address-counting signals. A 4-lined multiplexer connected to the RAM input lines gives only a zero signal at this stage and, therefore, all the RAM cells carry zero's, *i.e.* they are all cleared. All these processes are completed within 250 msec after switching the measuring mode to start. Immediately after the reset procedure, the first digitized signal is sent to the RAM and stored there.

4-digit BCD data coming out of 16 lines of the A/D converter in a parallel fashion is divided into four groups according to the order of the figure of BCD. Four sets of the numeric data are sent successively starting from the lowest figure of the decimal digit. Every one (or two) minute a status signal of ready-to-store-data is sent out to check whether the A/D conversion is over. When it is in the ready state, a status signal of move-to-memory is sent to the address counter to add one step increment. Then the binary outputs of the A/D converter, are sent successively to the memory area. Therefore, for storing one set of data, the address of the memory has to be increased by four steps. The least two bits (A_0 and A_1) of the address counter are utilized to select and pick up one of the four sets of A/D converted 16 bit data. The higher bits (A_2 to A_3) are used to identify and allocate the address. After 128 cycles, the memory area is filled up and the storage process does not continue and all the data obtained and stored so far are preserved, *i.e.* the measuring and memory circuit is locked.

Electric power of +5 DC volts is supplied from a set of six AA-cells and the voltage is regulated by a simple three-terminal positive voltage regulator MC78L05. A negative DC source (-3.0 volts) for analogue amplifiers is obtained by rectifying an internal 2KHz clock signal. Total amount of electric power dissipation is about 200 mW with a DC current of 22 mA.

7. Transfer mode

Transfer of the data from the measuring device (Daughter) to

the retrieval storage area of the Parent is accomplished by connecting them by an auxiliary cable and keeping all the mode switches in the transfer position (Fig. 1, b). The process is initiated by turning on the start switch of the Daughter device. At first the counter in the timing circuit and the address counters in both the measuring and retrieving circuits are cleared and then the transfer of data begins from the lowest address of the stored memory. The data consists of four sets of 4-lined BCD signals which are transferred one after another starting from the least significant four bits of the 16 bit data. This procedure is repeated for 128 cycles and as a result 512 sets of four-bit data (equivalent to 128 BCD 4-digit decimal data) are transferred.

All signals controlling the transfer process are sent out from the measuring circuit (Daughter) to the retrieval circuit (Parent). They are composed of the following:

1. Signal to reset the address counters of both the measuring and retrieving devices.
2. 512 pulses to transfer all the data stored in the memories of the measuring circuit to the corresponding identical memory address of the retrieving circuit.
3. One fourth of the above 512 pulses are used to identify the figure of the four-bit BCD output from the 16 bit signal. They are synchronized to the status signal "ready-to-write" and are repeated every round of four pulses.
4. 128 pulses, generated of every fourth pulse of the original 512 pulses, are to stimulate transferring the 16 bit BCD data. They also identify and allocate addresses of the memory area through the 7 bit binary-coded address counter.

As a result the state of the address counter of the measuring device is always kept identical with that of the retrieving device when both devices are connected by placing the snap switches in the same transfer mode position.

There is another combination of mode switches in the measuring and retrieving devices for checking, monitoring and adjusting the measuring device. When the measuring and retrieving devices are connected by an auxiliary wire, and used with the measuring mode in the measuring device and with the transfer mode in the retrieving device, the digitized data of the A/D converter of the measuring device are continuously transferred. One item of data is transferred every 40 msec and shown directly on the LED display of the retrieving device.

8. Retrieval mode

This mode (Fig. 2) is designed to display the data transferred to the memory in such a way that the resistance of the thermistor is given in decimal numerals in units of 10Ω (*i.e.* 0000-4000) along with the order of measurements (000-127).

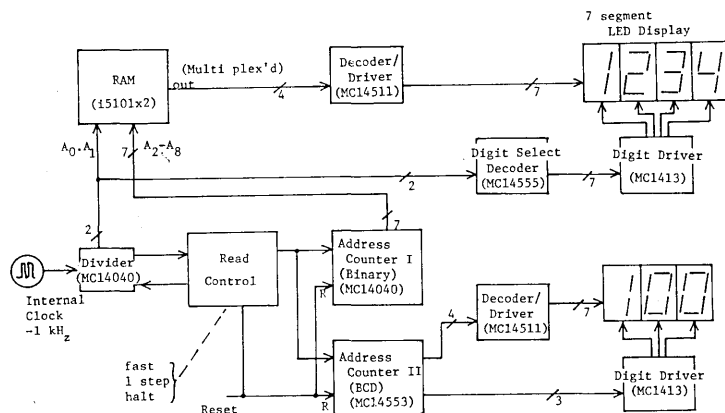


Fig. 2. Block diagram showing the functions of electronic circuits in the retrieving system (Parent Instrument).

First, the address counter has to be reset right after the completion of transferring data. Two types of address counters (I and II) are installed: one is a purely binary coded counter (7-bit) which is used to spot the location of the assigned data memory and the other is a BCD output counter which is used to display the number of measurements on the front panel of the retrieving device (the Parent). The latter counter is automatically reset to zero by the former one when one cycle of the 7 bit binary counting is completed (*i.e.*, when 128 is reached).

As for the display of data, a set of LED are driven in a dynamic fashion. The internal clock pulses (1 KHz) are divided down by four in order to obtain a two bit binary signal for identifying one of the four LED displays (displays for data and the address of measurement are connected to address counter I and II, respectively). Signals assigning the memory address are increased every 1 sec and the dynamic scanning signals for the display are repeated about 1000 times per second. Therefore the four-line output data from the memory is repeatedly sent to the display circuit one after another keeping the LED display bright. The data thus reformed is led to the segment decoder to be rearranged in the form of legible decimal numbers. The same principle is applied to the display of the number of measurements.

Several modes of shifting the data allocation are prepared. "Automatic shift" mode gives a display of data with an increment of the address number every second. "One shot" mode is to be manually operated and gives an increment of the data address every snapping of a toggle switch. "Address reset" mode causes the reading-out process to repeat from the beginning when the switch is

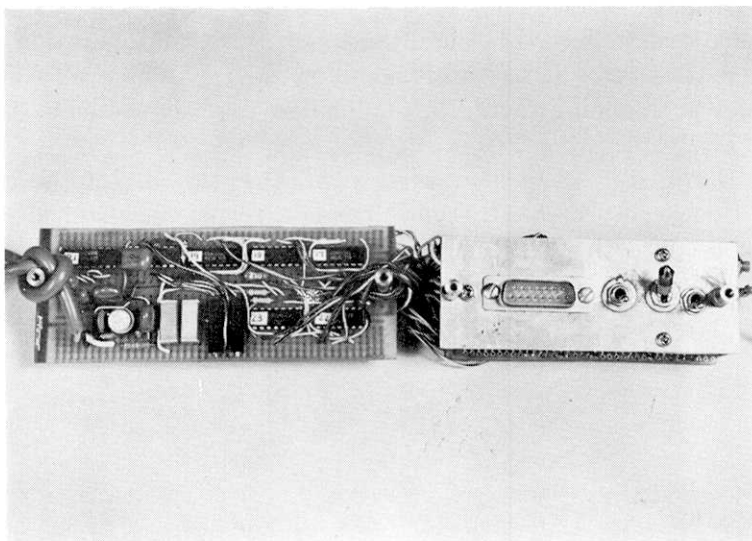


Fig. 3a. Photograph of the recording device (Daughter Instrument) to be packed in an acrylite pipe.

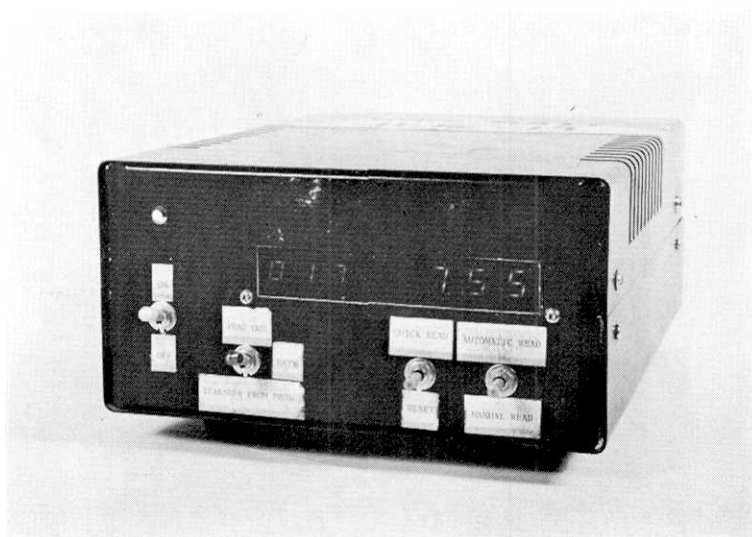


Fig. 3b. Photograph of the retrieving device (Parent Instrument).

snapped. "Rapid shift" mode is used to skip unnecessary addresses quickly with the increment rate of the address in 16 steps per second.

9. Pressure case and probe

The Daughter Instrument is packed in an acrylite pipe and housed in a stainless steel case with water-tight end plugs. For use on the Glomar Challenger, it was designed that the temperature measurement could be made simultaneously with the operation of the existing Barnes-type pore-water sampling device, which also required the sampler-probe being forced into undrilled part of sediment through the drill bit.

The thermistor bead is placed near the tip of the nose piece. The bead is well-protected from direct external mechanical contact but is exposed to the external pressure. Leads from the thermistor

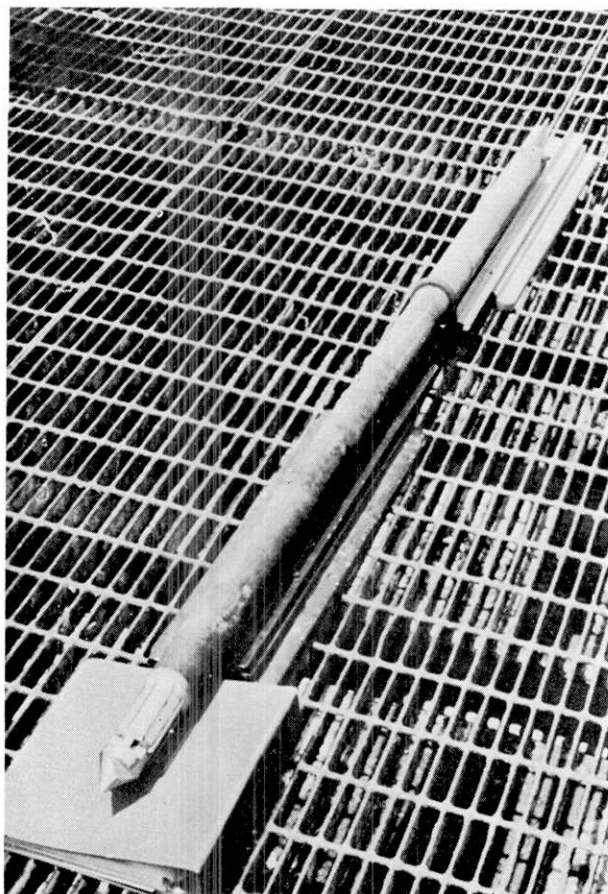


Fig. 4. Daughter Instrument in the ready-to-go state.

sensor are taken through the bulkhead into a pressure-water tight container same as the size of the core barrel (Fig. 4). This system is lowered by the sandline through the hole and latched into the bottom-hole assembly with the 10 inch nose sticking out of the drill bit.

This new heat flow probe was successfully used in DSDP Leg 60 for the first time. More detail of actual measurement will be described elsewhere (Uyeda and Horai, 1980). The instrument has also been in continuous use for later DSDP legs.

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References

- ERICKSON, A. J., 1973. Initial report on downhole temperature and shipboard thermal conductivity measurements, Leg. 19, in Initial Reports of the Deep Sea Drilling Project, vol. 19, 643-646, U. S. Government Printing Office, Washington, D. C.
- ERICKSON, A. J., R. P. Von HERZEN, J. G. SCLATER, R. W. GIRDLER, B. V. MARSHALL and R. HYNDMAN, 1975. Geothermal Measurements in Deep Sea Drill Holes, *J. Geophys. Res.*, **80**, 2515-2528.
- HYNDMAN, R., R. P. Von HERZEN, ERICKSON, A. J. and JOLIVET, J., 1976. Heat flow measurements in deep crustal holes on the Mid-Atlantic Ridge, *J. Geophys. Res.*, **81**, 4053-4060.
- Motorola Semiconductor Products Inc., Semiconductor Data Library, vol. 5. CMOS, vol. 6, Linear I/C's.
- UYEDA, S. and K. HORAI, 1980. Heat flow measurements in DSDP Leg. 60, (in press) Initial Reports of Deep Sea Drilling Project, vol. 60, U.S. Government Printing Office, Washington, D.C.

5. サーミスタ及び半導体メモリを用いた記録システム とその深海掘削孔内での温度測定への応用

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最近わが国も参加している国際深海掘削計画 (IPOD) による掘削孔の中で海底地温勾配を求めることは、海洋底地学にとって重要である。従来、米国において用いられてきた方式は故障が多く実用性

に乏しいきらいがあるので、全く新しい方式を開発した。この方式ではデータの記録はすべて IC メモリによるので、機械的可動部分は一切用いない。このため故障は全くおこらず、DSDP 第 60 次航海 (マリアナ) において成功裡に使用された。この装置は以後の航海においてもひきつづき利用され、成果をあげている。

本システムは地中 (海洋底) で無人の状態でも自動的に温度を測定、記録する小型低消費電力の「測定装置」と、記録されたデータを地上 (船上) で再生する「再生装置」の 2 つの装置より成る。地中で得るデータはサーミスタの電気抵抗で、それをデジタル信号に変換して、半導体メモリに記録する。温度への変換は地上での換算による。

サーミスタの抵抗値は $10 \sim 40 \text{ k}\Omega$ を 10Ω の分解能で測定する。これは $0^\circ\text{C} \sim 25^\circ\text{C}$ 程度の温度に対応する抵抗値をカバーしている。測定は 1 分または 2 分間隔で 128 時点の測定記録を行なう。即ち、測定間隔を 1 分に設定した場合には、機器を船上から海中に投下し、引き上げるまで約 2 時間の測定、記録が可能である。

測定、記録の終了後、「測定装置」と「再生装置」をケーブルで接続し、短時間で「測定装置」内メモリに記憶されたデータを再生装置内メモリに転送する。「測定装置」内メモリに記憶されたデータは次の測定の開始までは保存されている。電源には乾電池を用いている。「測定装置」全体つまり電子回路部分、電池、スイッチ、コネクタなどサーミスタを除くすべては $60 \times 400 \text{ mm}$ のアクリル製の筒に収容されており、これはさらに鋼製の耐圧容器に収められる。耐圧容器は、サーミスタを含む先端部とともに、コアパレルと連結され、ワイヤにより、掘削孔の中を降下し、孔底においてドリルビットにラチェットにより固定される。測定にあたっては、先端部は未掘削の堆積物中に強制的に押込まれて約 20 分間保持される。測定後は逆の手続きで揚収される。

「再生装置」では「測定装置」より転送されたデータ (抵抗値) を各測定点 (測定時刻) 毎に 0 から 127 で示される測定順位とともに発光ダイオードで 10 進表示する。表示するデータの測定順位の指定 (進め方) として、次の 2 種の方法が用いられる。① 低速で自動的に進む。② 1 測定順位ずつスナップスイッチにより進める。他に「早送り」及び「リセット」(測定順位を 0 に戻す) がある。「再生装置」内メモリに記憶されたデータは次の新しいデータが転送されるまで保存される。電源は内蔵の乾電池、外部 DC、外部 AC の 3 種が使用可能である。

Appendix

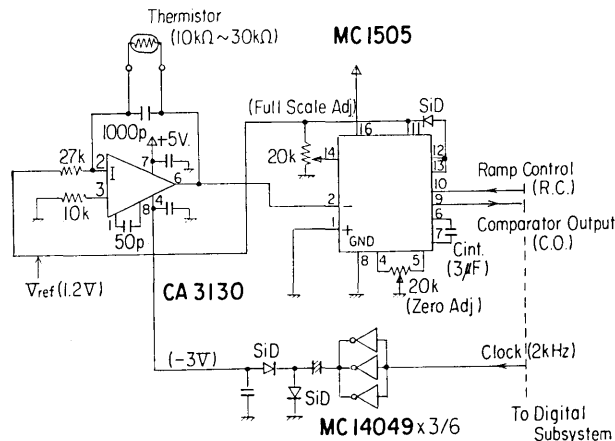


Fig. A-1. Measuring Instrument (1)
-Analog subsystem.

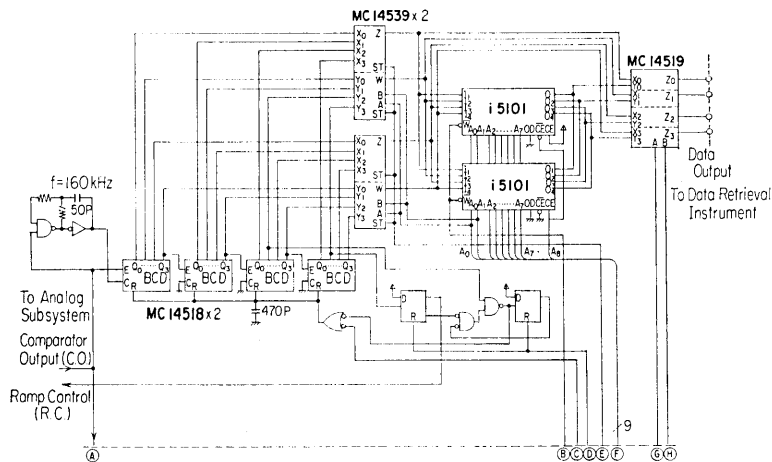


Fig. A-2. Measuring Instrument (2)

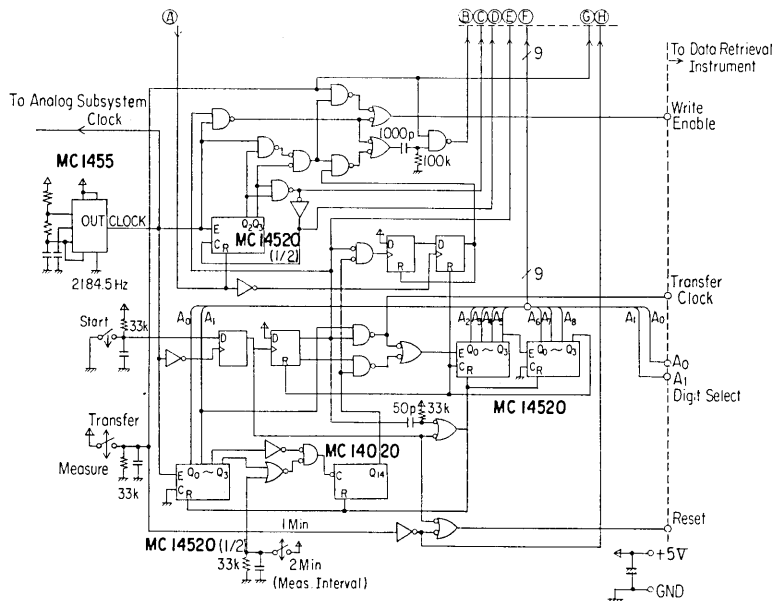


Fig. A-3. Measuring Instrument (3)

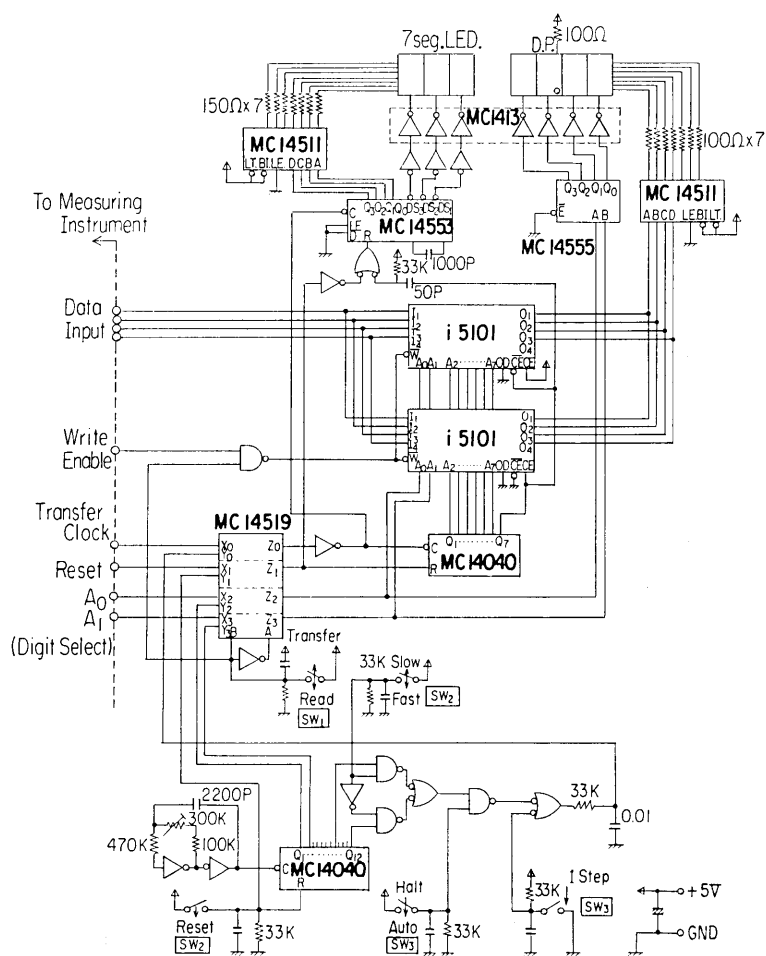


Fig. A-4. Data retrieval Instrument