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Electronic Thermal Sensor and Landsat Data Collection Platform Technology

By

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

THERMAL SURVEILLANCE OF ACTIVE VOLCANOES USING THE LANDSAT-1 DATA COLLECTION SYSTEM

Part 5: Electronic thermal sensor and Data Collection Platform technology

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16. Abstract

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Refinements in the temperature-monitoring system designed and operated in experiment SR 251 included a backup system consisting of a multipoint temperature scanner, a servo mechanism and an analog-to-digital recorder. Improvements were made in temperature-probe design and in construction of corrosion-resistant seals by use of a hydrofluoric-acid-etching technique.

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ABSTRACT

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5.1.0 Introduction

The purpose of Part 5 of this final report on thermal monitoring of selected volcanic areas is to present, in one place, a brief review of the Data Collection Platform and electronic thermal-sensing-system technology. Related topics such as the electronic interfacing between the sensing system and the DCP, and a very brief description of the comprehensive Data Collection System are also presented. The specific components of the sensing systems for the five DCP's used at volcanic sites are tabulated. For temperature data obtained and scientific interpretations, including heat flow data, the reader is referred to Parts 1-4.

It should be mentioned here that the electronic thermal sensing systems (including the electronic interfacing with the DCP's) were designed and built as prototypes specifically as part of and for this experiment, Landsat-1 SR 251, by U.S. Geological Survey laboratories at the Gulf Coast Hydroscience Center, Bay St. Louis, Mississippi. It is hoped that the systems technology presented here will be of use to future investigators who need temperature-monitoring systems of this type.

The authors acknowledge and thank Tom Kollar, U.S. Geological Survey, for the important contributions he made to the laboratory assembly and field installation of the equipment described in this report.

5.2.0 Landsat-1 Data Collection System

The Landsat-1 Data Collection System is designed to transmit samples of data from various types of sensors deployed on the earth's surface to a central collection point by means of a satellite radio relay (figure 1.6, Part 1). It consists of a number of data formatter and transmitter units, called Data Collection Platforms (DCP), which accept and transmit sensor data to the satellite, which in turn retransmits the data at a different frequency to receiving stations at Goldstone, California and Greenbelt, Maryland. The data are transmitted from the receiving stations by land lines to Goddard Space Flight Center where they are screened for quality, converted to specified computer format, and distributed to the Principal Investigators in the Landsat experiment program.

Data is relayed through the system when the spacecraft is in view of the DCP and the collection (receiving) station simultaneously (figure 1.7, Part 1). Since the DCP was designed to transmit one data sample each three minutes, this mutual visibility must theoretically exist for at least three minutes to insure that one transmission is successfully relayed. The original system analysis and specifications were overly conservative, and predicted a coverage area of the conterminous United States, southern Canada, Mexico, and nearby Atlantic, Pacific, and Caribbean locations. The actual coverage is considerably greater than specifications. The extended coverage results primarily from a DCP transmitter output power increase of twice the nominal power in manufactured units, the addition of a fast transmitter repetition rate, and the overly conservative prelaunch system analysis. Performance data reported in Part 1 of this report indicate that successful collection of data can occur from DCP's located within 5,000 km of either NASA collection station, provided that appropriate steps are taken during installation of the transmitter unit at the experiment site to ensure maximum possibility of transmission to the satellite.

The performance goal for the Data Collection System is to provide at least one correct message within any twelve-hour period from each of as many as 1,000 Data Collection Platforms distributed in and around the continental United States. The probability of a failure to achieve the above is less than five percent and the probability that an erroneous message will be falsely accepted as being correct is less than one percent (figure 5.a).

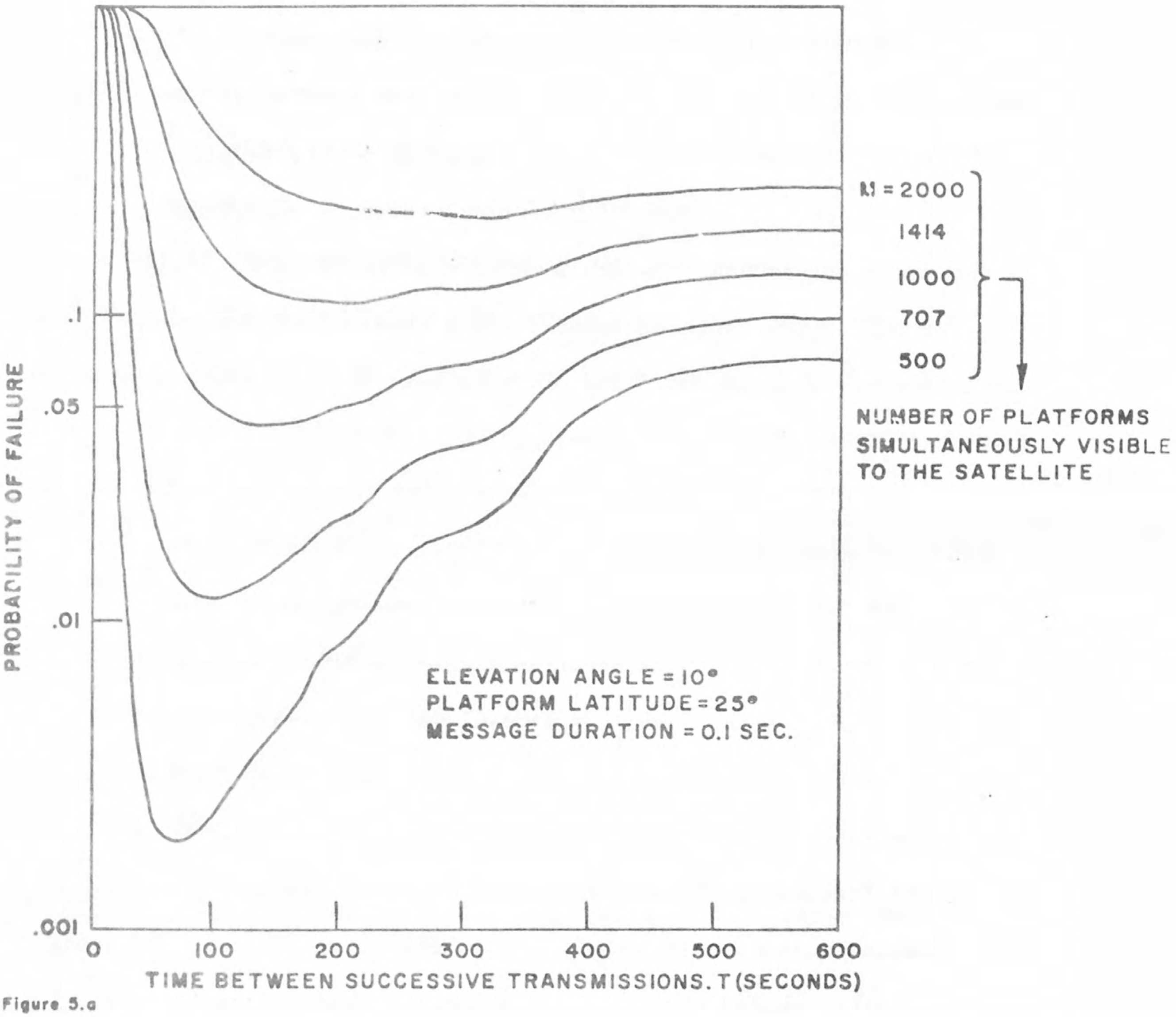


Figure 5.a--Probability of DCP transmission failure due to mutual interference and limited satellite visibility.

5.3.0 Data Collection Platforms (DCP)

The Data Collection Platform capabilities include the possibility of using as many as 8 sensor inputs. Each sensor input is converted to an 8-bit code word, giving 256 possible values with a 0.2 percent peak error. A convolutional coder expands each word to 16 bits. The coded sensor data are transmitted at a nominal 5-watt level.

The decoder at the receiving terminal corrects occasional transmission errors and provides a measure of confidence.

The DCP systems were engineered for a theoretical 6-month maintenance-free operation. The DCP sets were designed for operation from small 24-V batteries or solar cells.

5.3.1 Physical description

The DCP is a small aluminum box about 3500 cm^3 in volume 20 cm x 15 cm x 10 cm. Data input is through multipin connectors on the front panel. Front panel toggle switches are used to select the data input format and also to determine the transmission-repetition rate. The repetition rate the user selects is either a 90- or 180-second frequency; the selection depends on geographic location. The transmitter is on only 68 ms out of every period. Radio-frequency output power is routed through a front panel miniature coaxial connector and ten feet of coaxial cable to a crossed dipole antenna with a 117-cm diameter aluminum ground plane. Total weight of the original antennas is about 8.2 kg. Rain or snow on the antenna was expected to have little or no effect on its performance.

5.3.2 Power requirements

Power requirements for the DCP are 24 V nominal DC with 3 A peak current required. There are two curves (figures 5.b and 5.c) which show the performance of dry cells versus temperature and battery capacity versus temperature for lead-acid and dry-cell batteries. Four NEDA-type 907 six-V batteries (4 kg ea.) were expected to be sufficient for most operational cases. However, where prolonged low temperatures (below -12°C) were expected, the use of two 12-V lead-acid batteries was planned. In the -12°C to -24°C range, dry cells were used in parallel. Below -24°C it is necessary either to go to lead acid or some other special forms of power such as catalytic generators. A set of dry-cell batteries was expected to give at least six months' operation at 24°C and three months at -7°C. A set of small (40 A-Hr) 12-V lead-acid batteries was expected to give about three months' operation at -35°C. The average power consumption (see table below) of the DCP is about 30 milliwatts (mw) with a 180-second transmitting cycle and about 60 mw with a 90-sec cycle.

The system power demands are as follows:

Element	Average Current Drain Milliamp	Volts	Yearly Power
DCP	1.5	27	12 A-Hr
Signal conditioner	.05	±13.5	.5 A-Hr

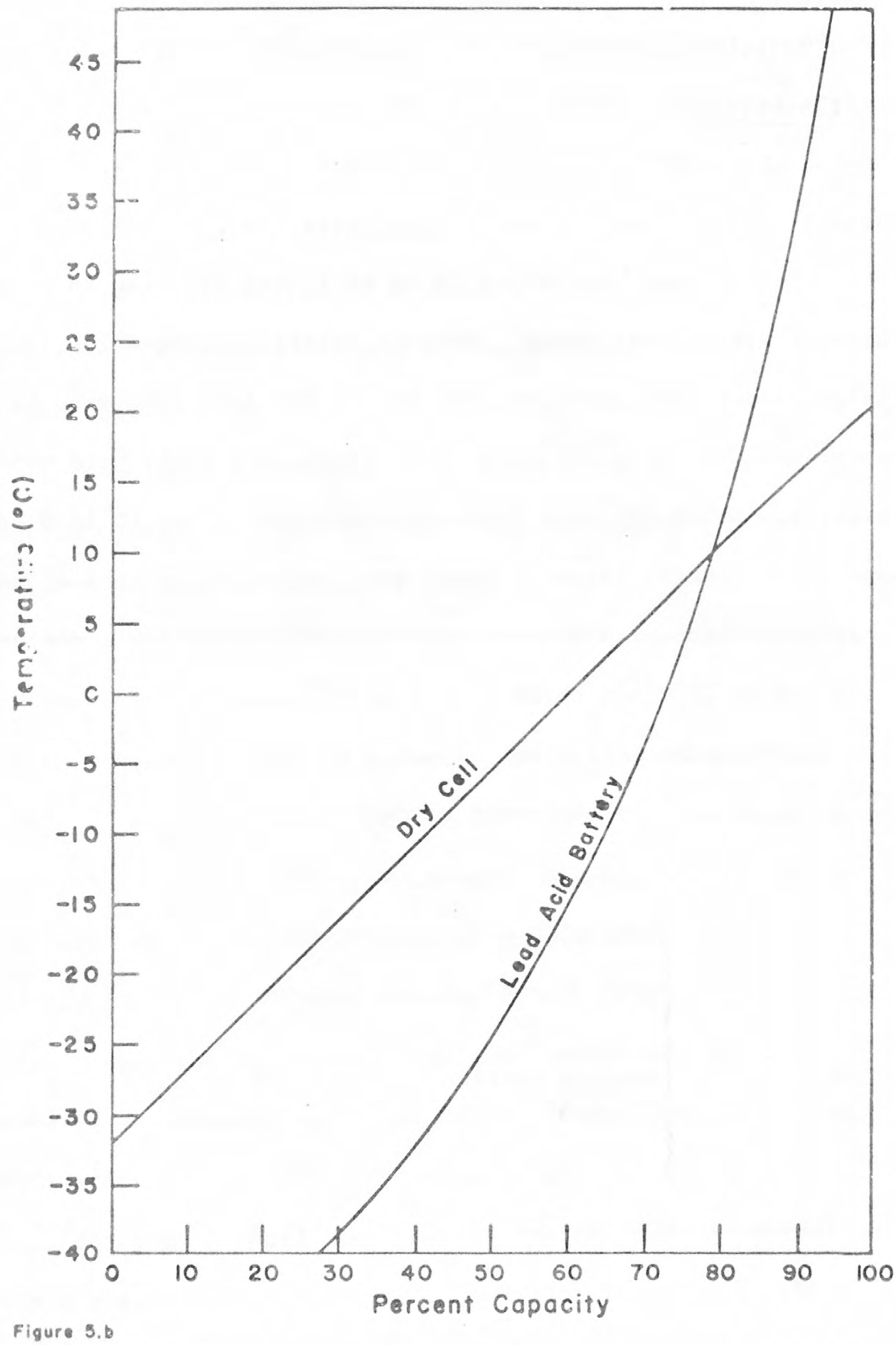


Figure 5.b--Capacity of dry cells and lead-acid batteries vs. Temperature.

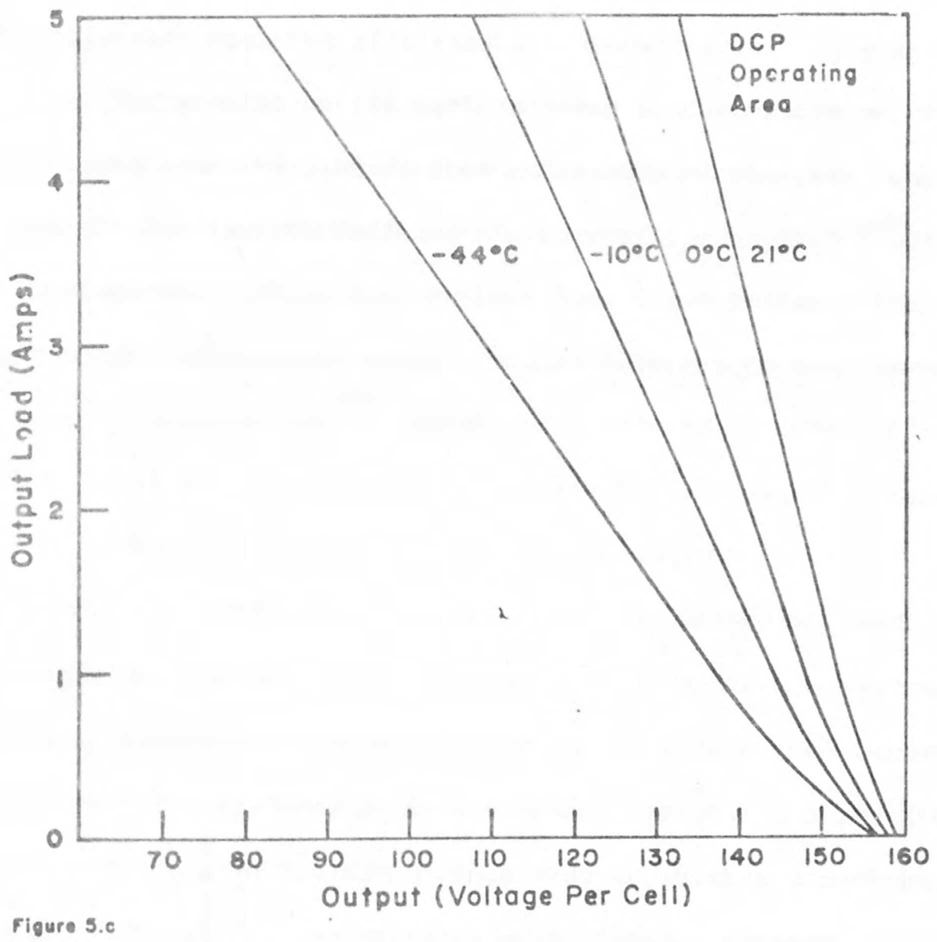


Figure 5.c--Loaded dry cell voltage output vs. temperature.

Eveready[1] alkaline primary batteries rated at 13.5 volts and 10 A-Hr capacity were ultimately selected for experiment SR 251 because of their satisfactory energy/weight ratio and cold weather performance. These units performed well over the test period.

5.3.3 Data input format

Three types of data formats are available for each channel. Each channel may be accessed in a parallel digital, serial digital, or analog mode. The mode is chosen for each channel by front panel three-position switches. Although the parallel digital mode is useful in working with analog shaft position input to digital recorders, analog inputs were more useful in the volcano-temperature monitoring experiment in interfacing with thermistors, potentiometers, or any other change of resistance or voltage-type probes.

5.3.4 Input circuitry

Figure 5.d shows the input circuitry for the parallel digital and analog inputs. The analog input circuitry consists of an array of 8 MOS switches, one for each channel, working into a non-inverting buffer amplifier. A diode at the input to the buffer amplifier prevents negative-going signals from entering the analog to digital converter circuitry. Minimum transducer output impedance to give rated accuracy of 1 percent is given as 10K ohms shunted by 1000 pico farads. Full scale input voltage is plus five volts. Digital input

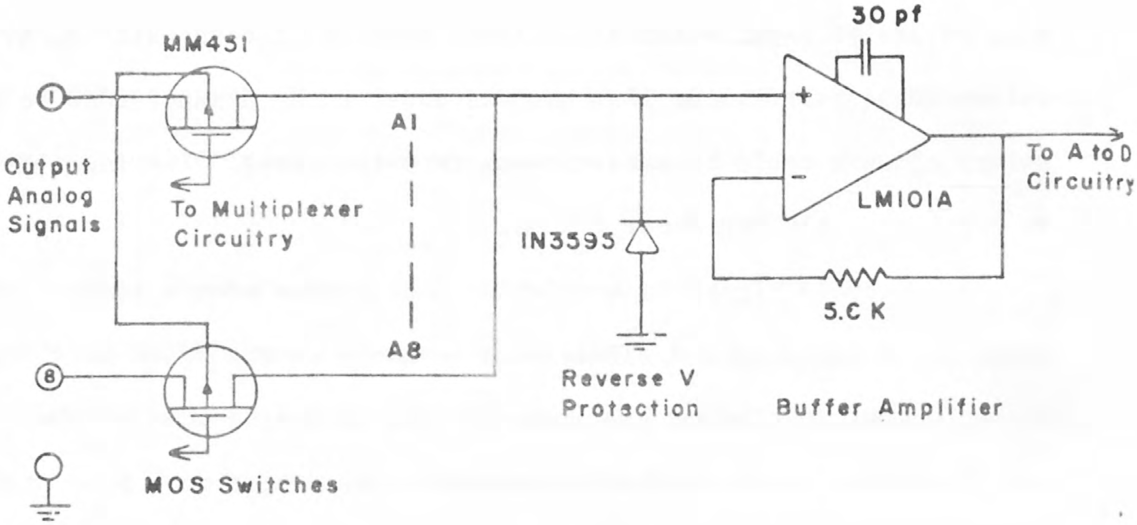
[1] The use of manufacturers' names or brand names in the report does not imply endorsement by the U.S. Geological Survey.

circuitry consists of an array of eight Texas Instruments SN54151 multiplexer packages which give eight channels of eight bits each. A pullup resistor of about 10K ohms was added to each input lead so a switch closure could be used to work into the gates. The input device is capable of sinking about 1.5 ma.

An in-cycle signal is available to determine when a transmitting sequence is taking place. This gate is known as the "data gate" and has an output on-time period corresponding to the on time of the platform which is about 68 milliseconds. The output gate is a standard TTL gate as shown in figure 5.e. This gate is very useful in programming transducers and other readout devices into an active state during the transmitting period.

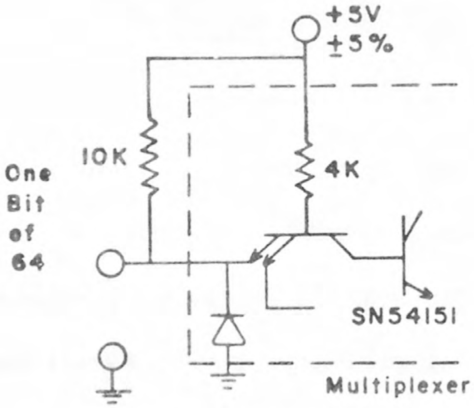
5.3.5 Data storage

The previously described input schemes permit direct input of data to the DCP which means that a 12-hour data-sampling period (equivalent to one satellite overpass) is available. Several schemes may be employed to decrease this sampling period; however, even though the data-sampling period may be decreased, the data will still only be available each 12 hours. One such scheme would be to periodically store data in a cyclic pattern in a memory device so that at any given DCP sample time the 64 bits stored could represent many hours of data. For example, four sets of 16-bit data could represent a sampling period of every three hours, or eight sets of 8-bit data could represent a 1.5-hour sampling period. Figure 5.f shows a block diagram



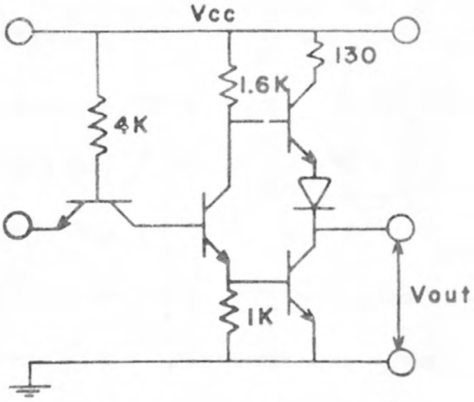
Analog Input Circuitry

Figure 5.d



Digital Input Circuitry

Figure 5.d (con't)



Signal	Vmax	Vmin
0	0.4	0.0
1	5.5	2.4

Data Gate

Figure 5.e

Figure 5.d--DCP input circuits. Figure 5.e--Data gate.

of functions needed to accomplish this task. RCA COS/MOS integrated logic was used because battery operation was planned. This type of logic consumes about 10 micro watts of power per medium-scale integration package. Therefore a great deal of data-handling circuitry may be used for a small amount of power. The flow of data in a sequential data storage goes in the following manner: data are periodically punched on an ADR, and following every punch cycle or after any integral number of punch cycles, the 16 bits of data from the recorder are shifted up one channel. Data in channel four (assuming a four-channel system) would be shifted out. This procedure allows the data in the register to represent the most current data. An A to D converter is shown dotted which could be used in conjunction with an ADR or separately if analog data are being obtained and a punched paper-tape record is not desired. An A to D converter would only be on during the sampling period to save power. Also, the register updating cycle could be inhibited during the DCP's transmitting cycle. An alternate data-storage scheme which would decrease sampling time would be to store all significant bits of the first data set, then record a series of fewer, less significant bits more often. The number of bits stored in a small data segment would depend on the frequency of sampling and the anticipated maximum rate of change of the variable. This is not a sequential type storage and all bits must be reset at once when the register is full.

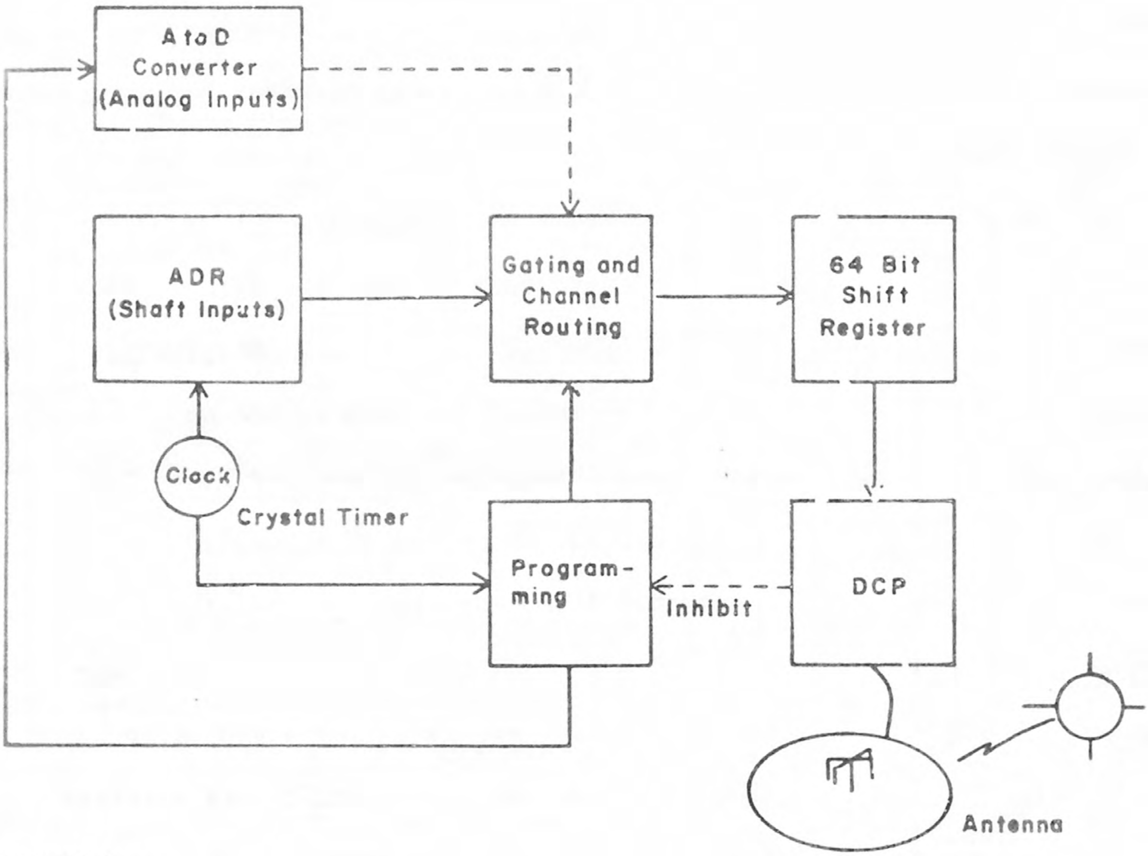


Figure 5.f

Figure 5.f--Sequential data storage.

5.4.0 Electronic Thermal Sensing System for Volcano-Temperature Monitoring

5.4.1 Thermal sensors

The objective of the geothermal instrumentation is to measure and transmit over Landsat DCS geothermal temperatures as many as eight parameters at 5 different sites in the northwest U.S. and Iceland. Figure 5.v shows five different measurement requirements. These are ground surface and ground depth (to 1 meter), water, fumarole vapor, and ambient air temperatures.

The Landsat DATA Collection Platform (DCP) inputs are capable of accepting either analog or digital inputs. The method selected for Experiment SR 251, the simplest and least expensive method, was to work into the analog inputs. However, the thermistor inputs were scaled and shifted to the specified working voltages of the DCP. The following discusses the choice of thermistors, interfacing instrumentation, and practical aspects of instrumentation, including cabling, shelter, and antenna mounting.

This description of the instrumentation will proceed from left to right on the block diagram in figure 5.g. The order of discussion is probes, cables, signal conditioners, control and reference voltage circuitry. Later, selection of power system, installation, analyses of failures and subsequent recommendations are discussed.

Table 5.1 gives a selective list of thermistors available from Yellow Springs Instrument Company, their useful range and accuracy.

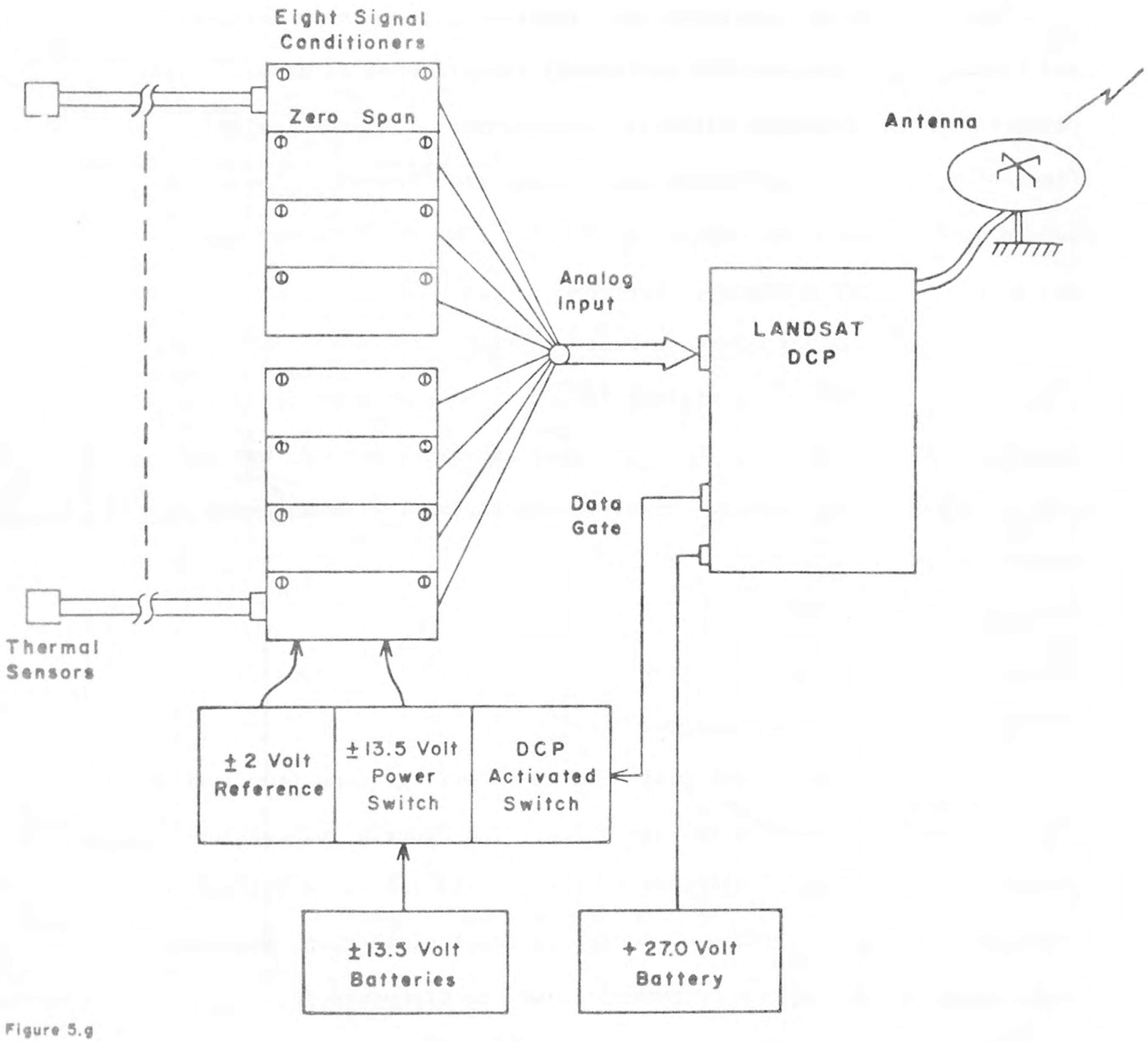


Figure 5.g--Electronic thermal-sensing system block diagram.

YSI Part No.	Range	Accuracy	Curve Shape
44031	$-40^{o}C$ to $100^{o}C$	$\pm .1^{o}C$	Logarithmic
44301	$-80^{o}C$ to $150^{o}C$	$\pm .25^{o}C$	Logarithmic
44201	$0^{o}C$ to $100^{o}C$	$\pm .4^{o}C$	Linear
44202	$-5^{o}C$ to $45^{o}C$	$\pm .25^{o}C$	Linear
44203	$-30^{o}C$ to $50^{o}C$	$\pm .4^{o}C$	Linear
44212	$-50^{o}C$ to $50^{o}C$	$\pm .25^{o}C$	Linear

Table 5.1-Temperature range and accuracy of selected YSI thermistors.

The temperatures to be measured ranged from $-30^{o}C$ to $+150^{o}C$. Maximum accuracy was obtained by limiting the range over which each sensor and signal conditioner were scaled to operate. Geothermal water temperature was measured over a narrow range of $70^{o}C$ to $95^{o}C$. Accuracy was better than $\pm.5^{o}C$. Air temperature was measured from $-40^{o}C$ to $+60^{o}C$ with an accuracy of $\pm 2^{o}C$. Yellow Springs Instruments thermistor composites were selected for use where temperatures above $100^{o}C$ were not anticipated. Platinum resistance elements manufactured by Rosemont Instruments were used for measurements above $100^{o}C$. Figure 5.h shows the construction of each probe type. The geothermal ground probe that was to measure temperatures at 1-meter depth was constructed of 1.9-cm-diameter stainless steel rod with a sharpened point welded to one end. For most of these units, platinum resistance probes were used. Those units constructed using YSI thermistors had a high failure rate. Failures occurred in this type construction when the Dow Corning 310 encapsulant distended either from stress or large temperature changes. This caused separation of the small parts. Later probes used a small printed circuit board with small drops of epoxy cement to hold all components securely in place. Two other probe forms were

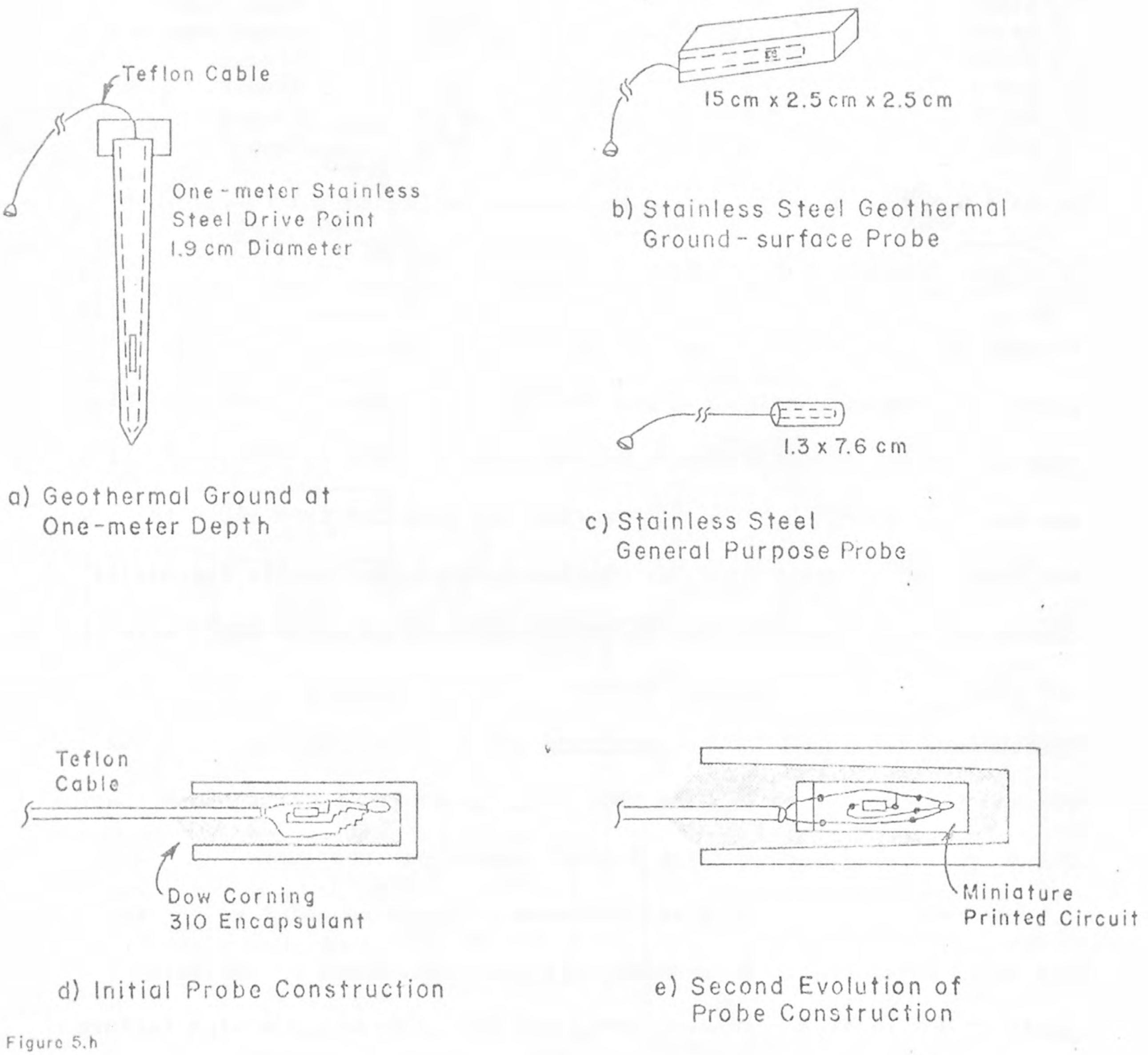


Figure 5.h. Thermistor probes.

constructed as shown in figure 5.h. The ground-surface probe was made using a relatively large stainless steel body so that minor temperature fluctuations would be averaged. The small general purpose probes were used to measure air, fumarole, and water temperature. Figure 5.h also shows the general construction of the probe intervals.

The DCP adds about a one percent error to the range over which it operates. For example, if air temperature is known to range between $-5^{o}C$ and $40^{o}C$, then thermistor number 44203 was selected and an accuracy of about $\pm.8^{o}C$ was expected. The logarithmic-type thermistors cover a wide range but require more computation as a table must be referred to rather than a simple linear equation. A tabulation of variables (table 5.2) with temperature ranges and desired accuracies was used to determine probe selection.

Temperature Variable	Range	Thermistor Number	Thermistor Accuracy	DCP Accuracy	Total Accuracy
Water	$-5^{o}C$ to $+45^{o}C$	44202	$\pm.25^{o}C$	$\pm.5^{o}C$	$\pm.75^{o}C$
Air	$-30^{o}C$ to $+50^{o}C$	44203	$\pm.4^{o}C$	$\pm.8^{o}C$	$\pm1.2^{o}C$
Soil	$-30^{o}C$ to $+50^{o}C$	44203	$\pm.4^{o}C$	$\pm.8^{o}C$	$\pm1.2^{o}C$
Fumarole gas	$-30^{o}C$ to $+150^{o}C$	44301	$\pm.25^{o}C$	$\pm1.8^{o}C$	$\pm2.05^{o}C$
#1 fumarole	$-30^{o}C$ to $+50^{o}C$	44301	$\pm.25^{o}C$	$\pm.9^{o}C$	$\pm1.15^{o}C$
#2 fumarole	$+60^{o}C$ to $+150^{o}C$	44301	$\pm.25^{o}C$	$\pm.9^{o}C$	$\pm1.15^{o}C$

Table 5.2-Relationship between temperature range of selected variables, YSI thermistor type, and accuracy of measurement.

5.4.2 Cabling

The cable selected had to withstand temperature extremes, rocky ground surface, and noxious corrosive fumes. Teflon cable was the only material which could qualify for use in these harsh environments.

A significant initial problem (besides its high cost) was to attain a seal between the teflon cable insulation and the probe encapsulant. After a considerable amount of consultation with the cable companies and some later careful experimentation, a good seal was obtained by etching the few inches of cable to be encapsulated in hot hydrofluoric acid prior to encapsulation.

5.4.3 Signal conditioners

Each probe was interfaced to the DCP with a signal conditioner. Figure 5.i and figure 5.j show the circuitry used for the thermistor and platinum-resistance probes. Both used LM101A solid-state operational amplifiers manufactured by Analog Devices. Zero and span trimpot adjustments for each signal conditioner were mounted on the front panel of each four preamplifier subassemblies. This permitted calibration so that for each scale selected, the top of the scale would give 5.00 volts at the ouput and 0.00 volts at the bottom.

A voltage proportional to temperature was obtained by applying a -2.0-volt reference voltage to a resistance network incorporating the varying thermistor elements. A similar output was obtained from the platinum-resistance element by exciting it with a constant current which caused the voltage output from the first amplifier to be proportional to the resistance of the element. Since platinum resistance only varies ±10 percent of its 25°C value over the temperature range of interest, a differential amplifier was used to eliminate the non-varying proportion of the signal.

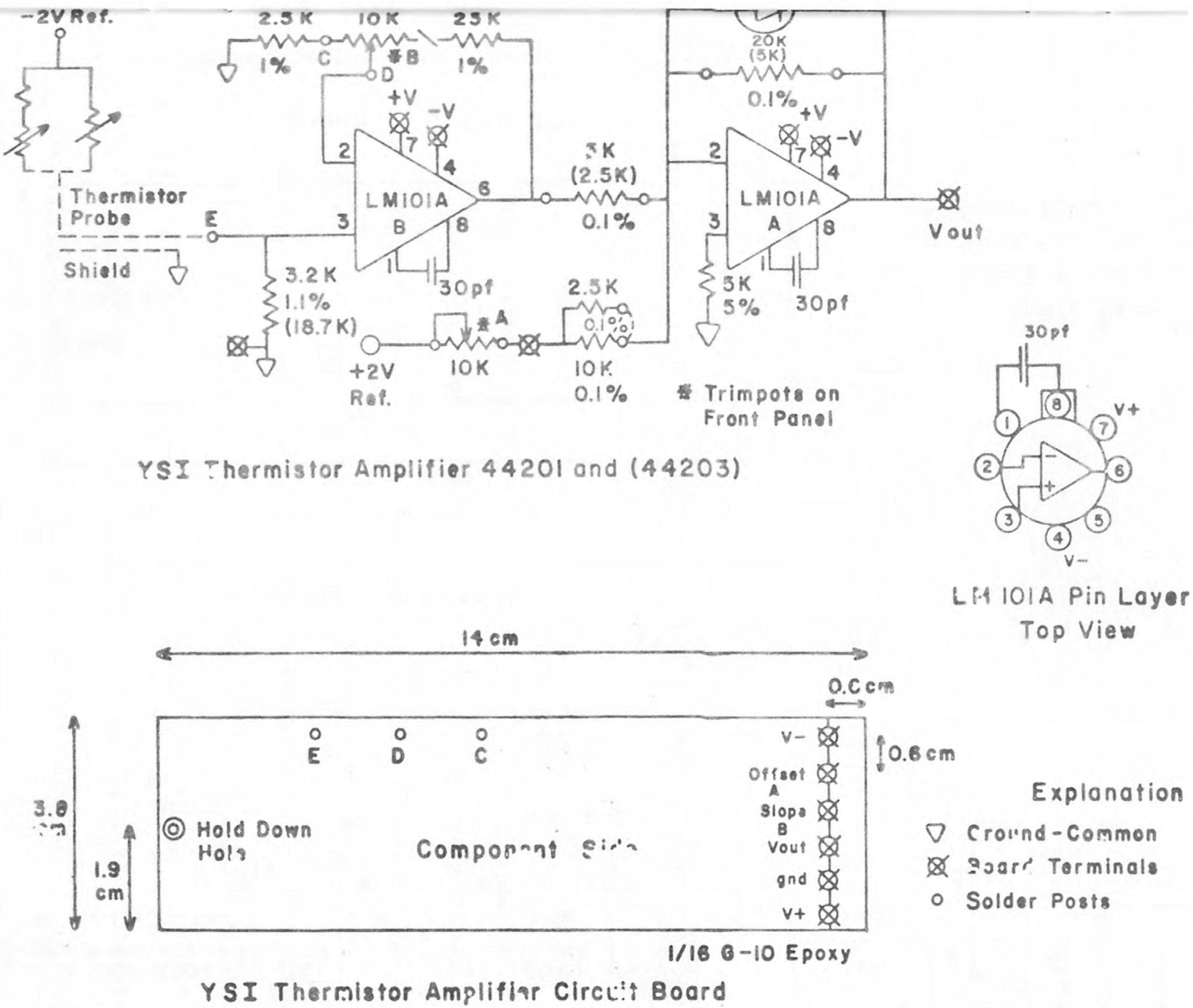


Figure 5.1

Figure 5.i--Thermistor signal conditioner for Landsat-1.

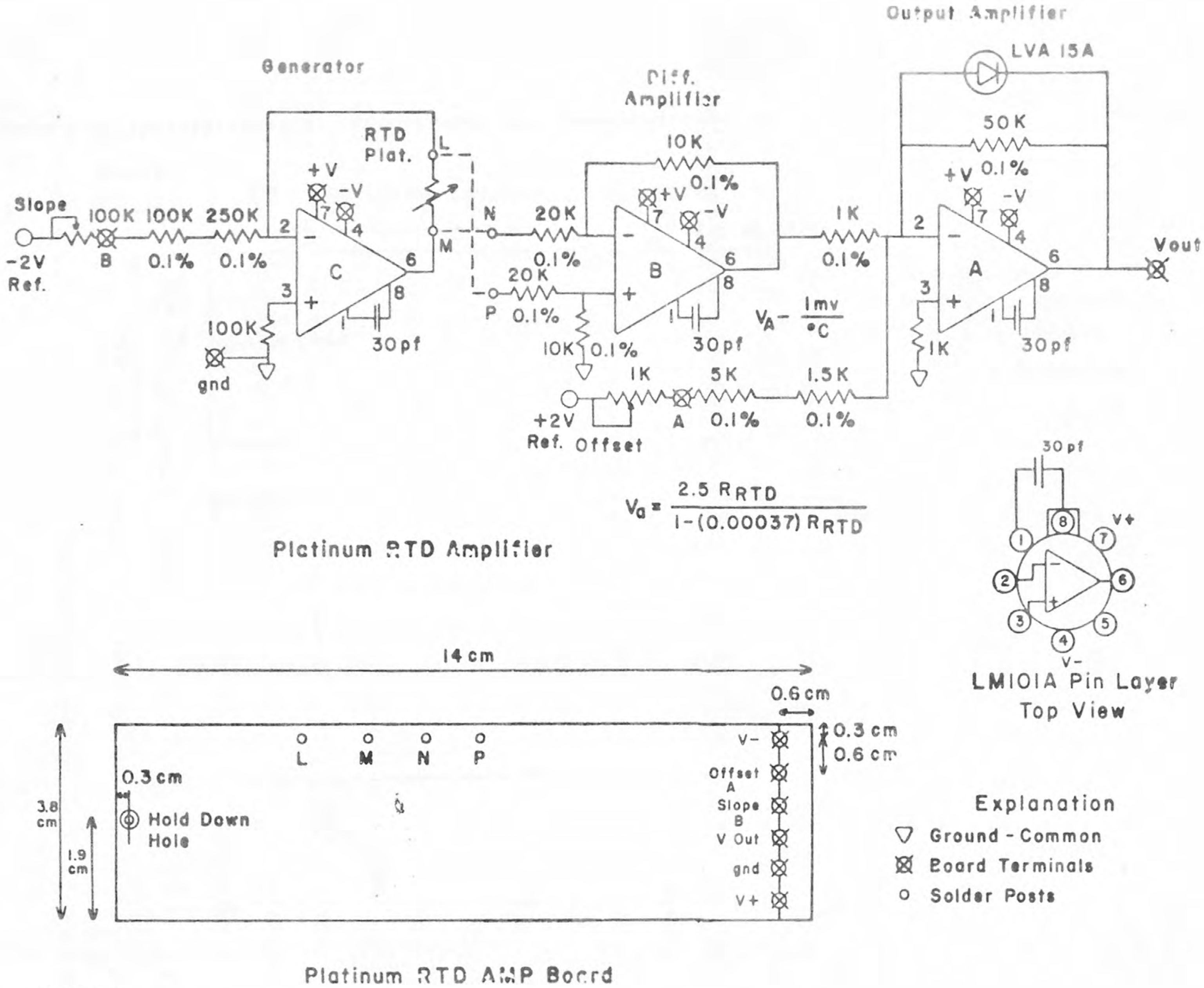


Figure 5.j

Figure 5.j--Platinum resistance elements of signal conditioner.

Each probe and its signal conditioner were calibrated to a pre-selected temperature measurement range to ensure optimum accuracy. Table 5.3 lists these three values for each probe.

Calibration temperature	Probe resistance K ohms	Output voltage
23.4 /	18.83 /	3.17
-10 /	47.857 /	1.50
+40 /	11.422 /	4.00

Table 5.3-Calibration temperature vs. probe resistance and output voltage.

In addition to these laboratory calibration adjustments, an NBS* traceable thermistor probe was used to make spot checks during field installation.

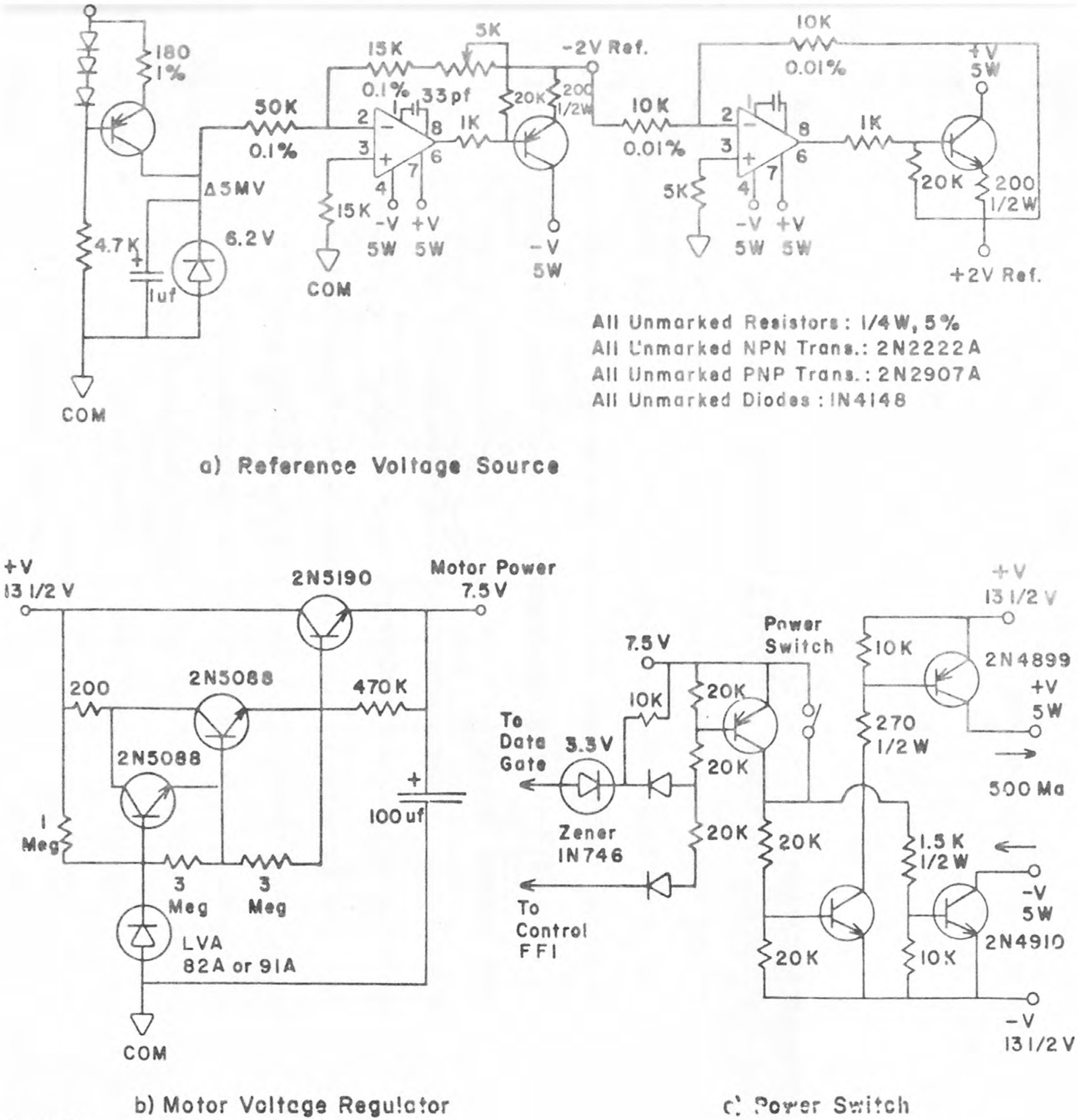
5.4.4 Control and reference voltage circuits

Each signal conditioner required a very stable reference voltage to generate either the thermistor network voltage or platinum constant current. A 6.2-volt reference zener diode provided a voltage which was stable to one part in one thousand over a $-40^{o}C$ to $+60^{o}C$ temperature range. Operational amplifiers with transistor driver provided scaling and power drive so that 2.0 volt and 50 milliamp supply could be distributed to each signal conditioner.

Section b of figure 5.k shows a low-power regulator circuit which continuously supplied 7½ volts to peripheral circuits.

* National Bureau of Standards

Figure 5.k-Control and reference voltage circuits.



a) Reference Voltage Source

b) Motor Voltage Regulator

c) Power Switch

Figure 5.k

Section c shows the circuit of the transistor switches which controlled the switching of battery power to all other circuits. Power was switched "on" whenever the "data gate" signal would switch on. This would occur 40 milliseconds before a manually set DCP transmission and remain on until transmission ceased. Since the data gate was only on 80 milliseconds every 3 minutes, the duty cycle was only .05 percent. Therefore, power consumption was extremely low.

5.4.5 Multipoint temperature scanner

The Multipoint Temperature Scanner (figure 5.1) is intended to provide a paper-punch tape record of as many as ten different channels of temperature record as a backup system for DCP's at the Surtsey, Iceland site, or where DCP's were not available, as at Boiling Springs Lake in the Lassen region, California. The block diagram shows an outline of the functions required to perform this operation.

A brief outline of its operation is as follows: at a prescribed time interval the master clock starts the punch cycle program at channel one. Channel one of the analog multiplexer is turned on, which amplifies, scales, and directs the input signal to the servo mechanism. The servo mechanism in turn positions the shaft input of the paper-tape punch. When the servo reaches a null position the punch program signals the recorder to punch out and the multiplexer to advance to the next channel. This procedure is repeated until all ten channels have been punched out whereupon the system is shut down until the next recording signal is given by the master clock. The paper-tape punch

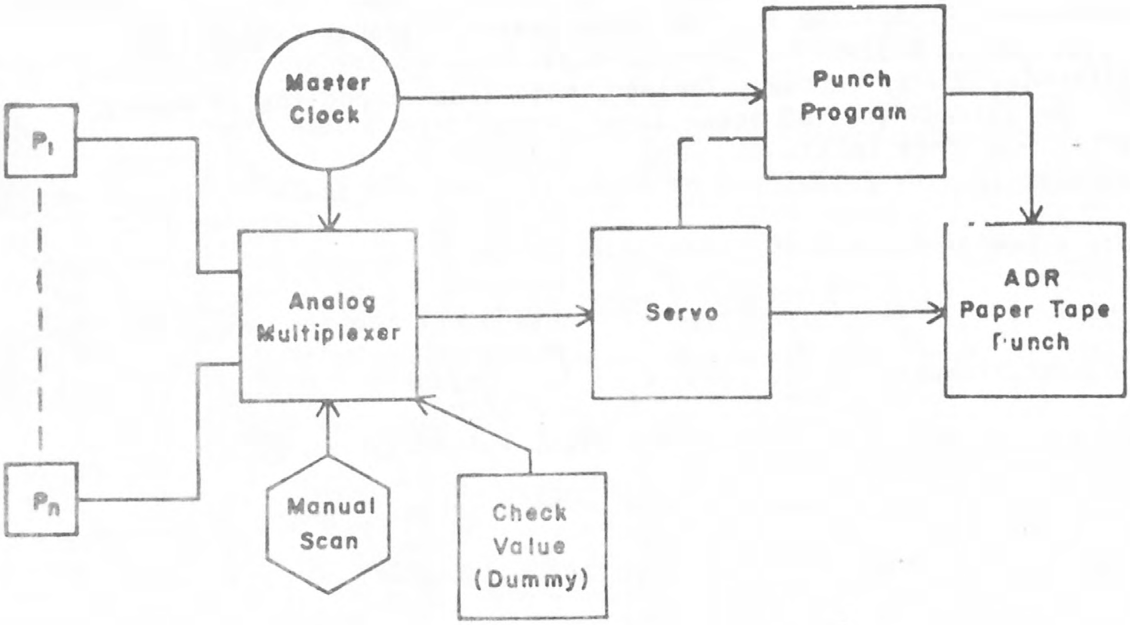
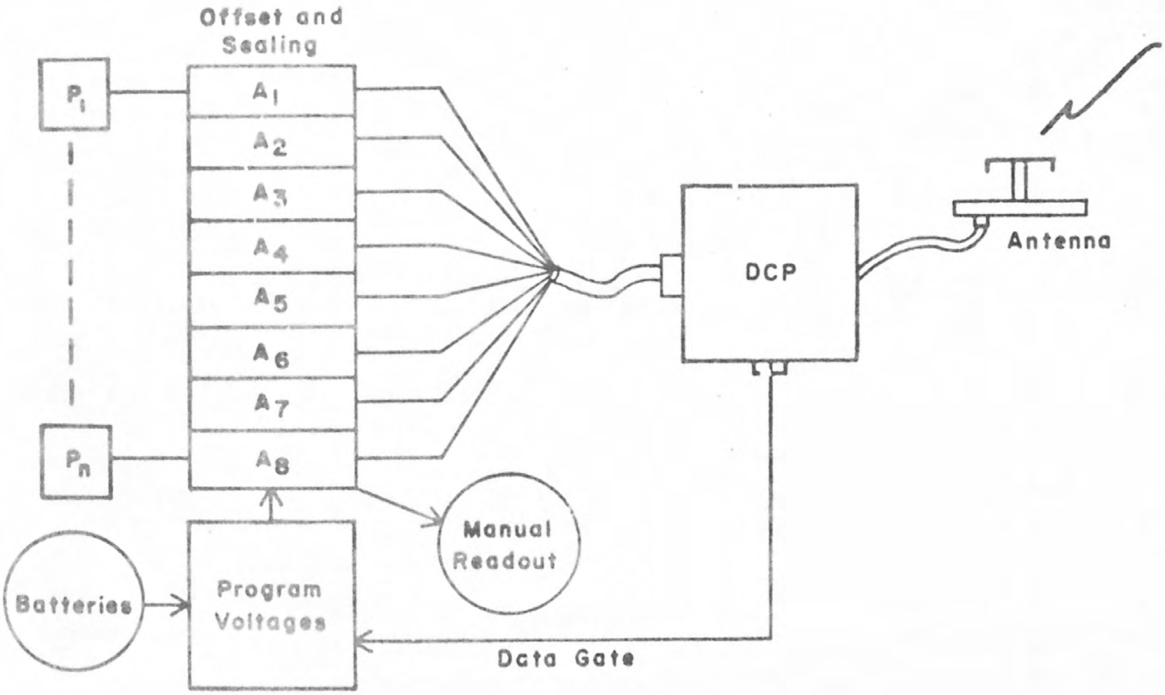


Figure 5.1--Multipoint Temperature Scanner



Thermistor Input to DCP

Figure 5.1

systems used at Boiling Springs Lake, Lassen Volcanic National Park, California, and at Surtsey, Iceland, were Fischer and Porter Analog to Digital Recorders (ADR).

5.5.0 Data Collection Platform Stations

DCP stations for temperature monitoring were sited at Surtsey, Iceland; Mount Baker, Washington; Mount Saint Helens, Washington; Devil's Kitchen and Bumpass Hell, both in the Lassen volcanic region, California (figures 5.m; 5.n; 5.o and 5.p). General locations of the Cascade Range stations are shown on figure 5.q. Specific site maps appear in appropriate sections of this report. (For example, the site map for Surtsey is figure 1.1 (part 1).)

The present section of Part 5 (5.5.0) gives a tabulation of characteristics of the sensing system of each DCP station (see also figure 5.v), as well as site coordinates, elevation, and the period for which transmitted temperature data were tabulated and analyzed.

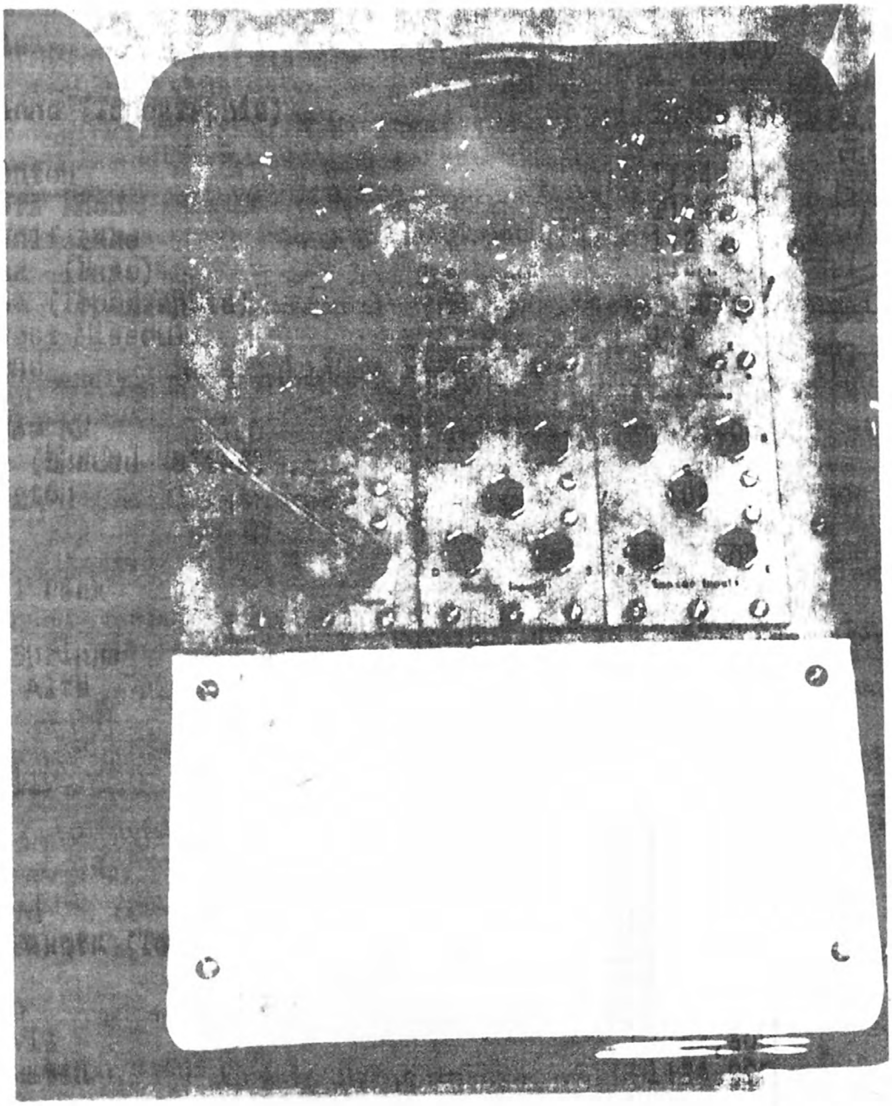


Figure 5.m-Instrument panel of Data Collection Platform including sensor preamplifiers and program control, interfaced with electronic thermal-sensing system, as designed for a site in the Lassen volcanic region, California.

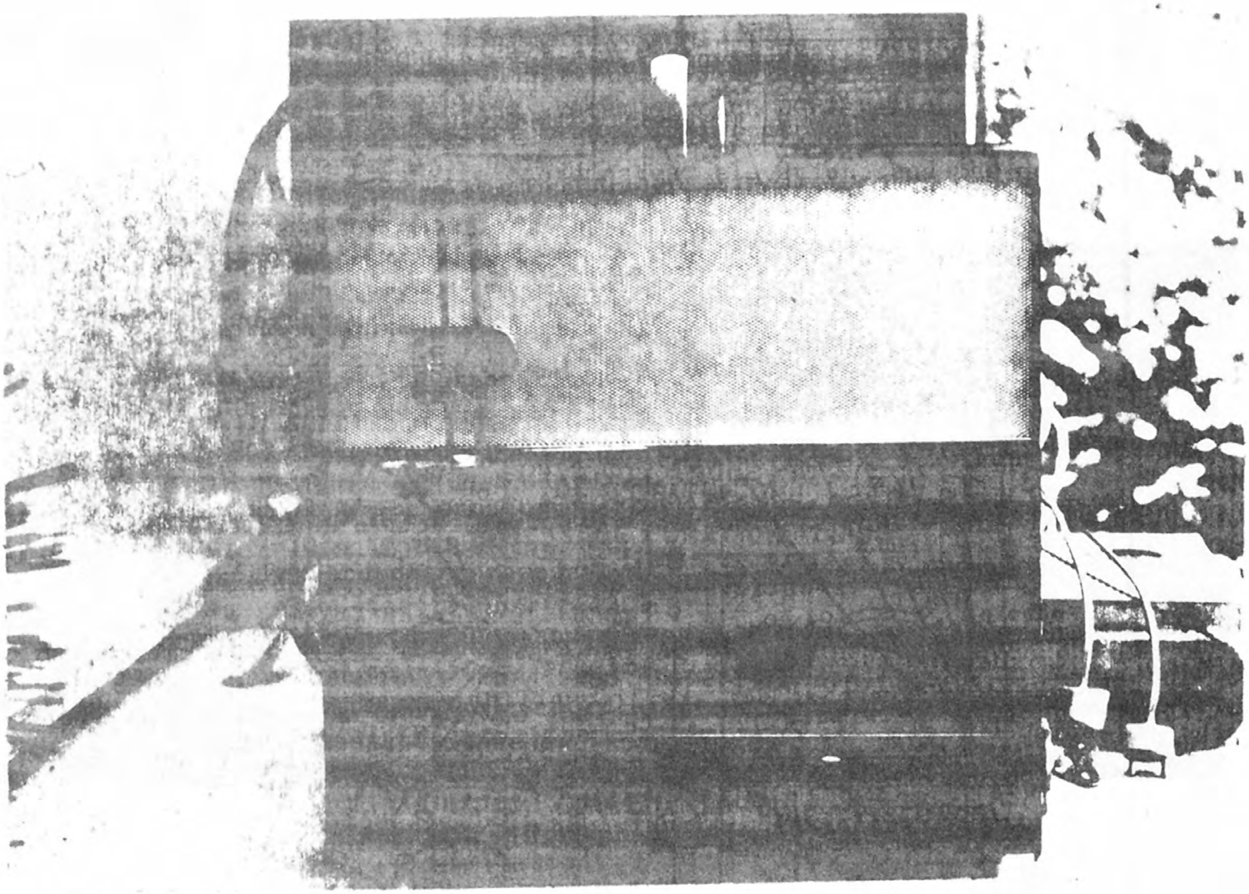


Figure 5.n-Fischer-Porter Analog to Digital Recorder, integrated with servo mechanicm, electronic thermal-sensing system, and Data Collection Platform to a site in the Lassen volcanic region, California.

Figure 5.o-Installation of Data Collection Platform, electronic thermal-sensing system and integrated paper-punch tape system in the Lassen volcanic region, California.

Figure 5.p-Original GE antenna with plexiglass dome at DCP site, Bumpass Hell, Lassen volcanic region, California. Antenna was crushed under heavy snow in the winter of 1972-73.

Figure 5.q-Location of volcanoes of the Cascade Range where thermal anomalies have been recorded. (A) Mt. Baker, (B) Mt. Rainier, (C) Mt. St. Helens, (D) Crater Lake (hydrologic anomalies), (E) Lassen Volcanic National Park, (F) Mt. Adams, (G) Mt. Hood, and (H) Mt. Shasta. Thermistor arrays transmitting surface temperatures via DCP's and Landsat-1 satellite are sited at (A), (C), and (E) (two sets). Mt. Baker, Mt. St. Helens, and Lassen have been active within the last two centuries.

5.5.1 Data Collection Platform 6056, Surtsey, Iceland, November 14, 1972 - December 25, 1972.
$63^{\circ}18'$N, $20^{\circ}36'$W; elevation = 130 m MSL.

DCP analog channel	Paper tape recording order	Sensor type and YSI #	Probe site and depth	Sensor temperature range and accuracy (°C)	Relationship between output voltage and temperature (T°C)
1	IA	YSI 44203	Ambient air 1 m above ground (protected from sun)	-25 to 25 ± 1	T = - 25 + 10 (V)
2	C	YSI 44203	Geothermal ground surface (altered tephra)	-25 to 25 ± 1	T = - 25 + 10 (V)
3	D	YSI 44201	Blank (reads 3.43V)	N.A.	N.A.
4	E	YSI 30K 44008	1-m depth in altered tephra near DCP station (geothermal ground)	45 to 110 ± .5	T = 39.07 + 13.71 (V)
5	IIA	YSI 44201	1-m depth in altered tephra downslope from DCP station (geothermal ground)	0 to 100 ± 1	T = 20 (V)
6	B	YSI 44201	Blank (reads 2.40V)	N.A.	N.A.
7	C	YSI 44201	1-m depth in altered tephra upslope from DCP station (geothermal ground)	0 to 100 ± 1	T = 20 (V)
8	D	YSI 44201	Blank (reads 1.44V)	N.A.	N.A.

5.5.2 Data Collection Platform 6251, Mount Baker, Washington, July 20, 1973 - March 15, 1974. 48°45'N, 121°40'W; (Dorr fumarole field, north slope); 2400 m MSL.

DCP analog channel	Sensor type and number	Probe site and depth	Sensor temperature range and accuracy (°C)	Relationship between output voltage and temperature (T°C)
1	IA YSI 44203	Instrument station (inside enclosure)	-40 to 60 ± 2	T = -40 + 20 (V)
2	IB YSI 44203	Ambient air 1-m above ground (protected from sun)	-40 to 60 ± 2	T = -40 + 20 (V)
3	IC YSI 44203	Non-geothermal ground surface (2 m east of station under snow bank. 6 m thick)	-10 to 40 ± 1	T = -10 + 10 (V)
4	ID 104MB	Fumarole vent (6 m west of station; 15 cm into vent)	30 to 130 ± 2	T = 30 + 20 (V)
5	IIA 104B	Fumarole vent (2 m south of station; 15 cm into vent)	30 to 130 ± 2	T = 30 + 20 (V)
6	IIB 104MB	30-cm depth in geothermal ground (6 m east of station)	30 to 130 ± 2	T = 30 + 20 (V)
7	IIC YSI 44201	Geothermal ground surface (same location as 6)	18 to 58 ± 1	T = 18 + 8 (V)
8	IID 104MB	50-cm depth in geothermal ground (same location as 6)	30 to 130 ± 2	T = 30 + 20 (V)

5.5.3 Data Collection Platform 6166, Mount Saint Helens, Washington, July 20, 1973 - April 18, 1974. 46°9'N, 122°17'W; elevation = 3000 m MSL.

DCP analog channel	Sensor type and number	Probe site and depth	Sensor temperature range and accuracy (°C)	Relationship between output voltage and temperature (T°C)
1	YSI 44203	Instrument station (inside enclosure)	-40 to 60 $\pm$ 2	T = -40 + 20 (V)
2	YSI 44203	Ambient air 1 m above ground (protected from sun)	-40 to 60 $\pm$ 2	T = -40 + 20 (V)
3	YSI 44203	Non-geothermal ground surface	-10 to 40 $\pm$ 1	T = -10 + 10 (V)
4	YSI 44201	Resistor plug	N.A.	N.A.
5	YSI 44201	15-cm depth in geothermal ground	5 to 75 $\pm$ 1	T = 5 + 14 (V)
6	YSI 44201	Geothermal ground surface	5 to 75 $\pm$ 1	T = 5 + 14 (V)
7	YSI 44201	15-cm depth in geothermal ground	5 to 75 $\pm$ 1	T = 5 + 14 (V)
8	RSE 104MB	50-cm depth in geothermal ground	0 to 100 $\pm$ 1	T = 20 (V)

5.5.4 Data Collection Platform 6104, Devil's Kitchen, Lassen volcanic region, November 14, 1972 - July 10, 1974. $40^{\circ}25'$N, $121^{\circ}26'$W; elevation = 2030 m MSL.

DCP analog channel	Sensor type and number	Probe site and depth	Sensor temperature range and accuracy ($^{\circ}$C)	Relationship between output voltage and temperature (T $^{\circ}$C)
1	IIA YSI 44203	Boiling pool	40 to 100 $\pm$ 1	T = 40 + 12 (V)
2	IB YSI 44203	Ambient air 1 m above ground (protected from sun)	-10 to 60 $\pm$ 2	T = -40 + 20 (V)
3	IC YSI 44203	Non-geothermal ground surface	-10 to 40 $\pm$ 1	T = -10 + 10 (V)
4	ID YSI 44201	Fumarole vent	40 to 100 $\pm$ 1	T = 40 + 12 (V)
5	IA YSI 44203	Instrument station (inside enclosure)	-40 to 60 $\pm$ 2	T = -40 + 20 (V)
6	IIB YSI 44201	15-cm depth in geothermal ground	40 to 100 $\pm$ 1	T = 40 + 12 (V)
7	IIC surface disc thermistor	Geothermal ground surface	5 to 75 $\pm$ 1.5	T = 5 + 14 (V)
8	IID RSE 104MB	50-cm depth in geothermal ground	30 to 130 $\pm$ 2	T = 30 + 20 (V)

5.5.5 Data Collection Platform 6020, Bumpass Hell, Lassen volcanic region, California, October 17, 1972-November 19, 1972 and July 12-16, 1972. 40°27'N, 121°30'W; elevation = 2740 m MSL.

DCP analog channel	Sensor type and number	Probe site and depth	Sensor temperature range and accuracy ($^\circ$C)	Relationship between output voltage and temperature (T$^\circ$C)
1	IF YSI 44203	Instrument station (inside enclosure)	-40 to 60 $\pm$ 2	T = -40 + 20 (V)
2	IE YSI 44203	Ambient air 1 m above ground (protected from sun)	-40 to 60 $\pm$ 2	T = -40 + 20 (V)
3	IC YSI 44203	Non-geothermal ground surface	-10 to 40 $\pm$ 1	T = -10 + 10 (V)
4	ID YSI 44201	Fumarole vent	40 to 100 $\pm$ 1	T = 40 + 12 (V)
5	IIA YSI 44201	Solfatara vent (boiling mudpot)	40 to 100 $\pm$ 1	T = 40 + 12 (V)
6	IIB YSI 44201	Solfatara vent (boiling mudpot)	40 to 100 $\pm$ 1	T = 40 + 12 (V)
7	IIC YSI 44201	Geothermal ground surface	5 to 75 $\pm$ 1.5	T = 5 + 14 (V)
8	IID RSE 104MB	50-cm depth in geothermal ground	30 to 130 $\pm$ 2	T = 30 + 20 (V)

5.5.6 DCP installation

The thermal surveillance project enabled a unique test of DCP design and installation technique. Because the objects of study were volcanic thermal areas, the test sites were limited to areas of rugged terrain, high altitude, heavy snow accumulation, adverse weather and corrosive vapors (figures 5.r; 5.s; 5.t; 5.u).

Each system was installed in a painted 61cm x 61cm x 122cm hinged plywood box which was secured to the site. The Landsat DCP antenna was mounted on a 5-cm pipe section which was firmly guy wired in place. The probes were placed, cables buried, and a calibration check made. All switches and covers were made secure before departure. As soon as a telephone could be reached, NASA operations control was contacted to check if messages had been received from the newly installed platform. The received value of each probe temperature was compared with those anticipated.

Three recommendations may be made for future projects involving satellite telemetry under rigorous environmental conditions as were encountered in this project:

1. Equipment which is provided on contract should be available by specified dates so that installation can be made under optimum weather conditions. Inordinate delays in delivery of the DCP's to the Principal Investigator resulted in substantially increased cost and manhours for installation of the three Lassen Park sets* because of road closure and impassable terrain due to winter snow: sets were

* Includes the Boiling Springs Lake instrument station, which does not have a transmitter.

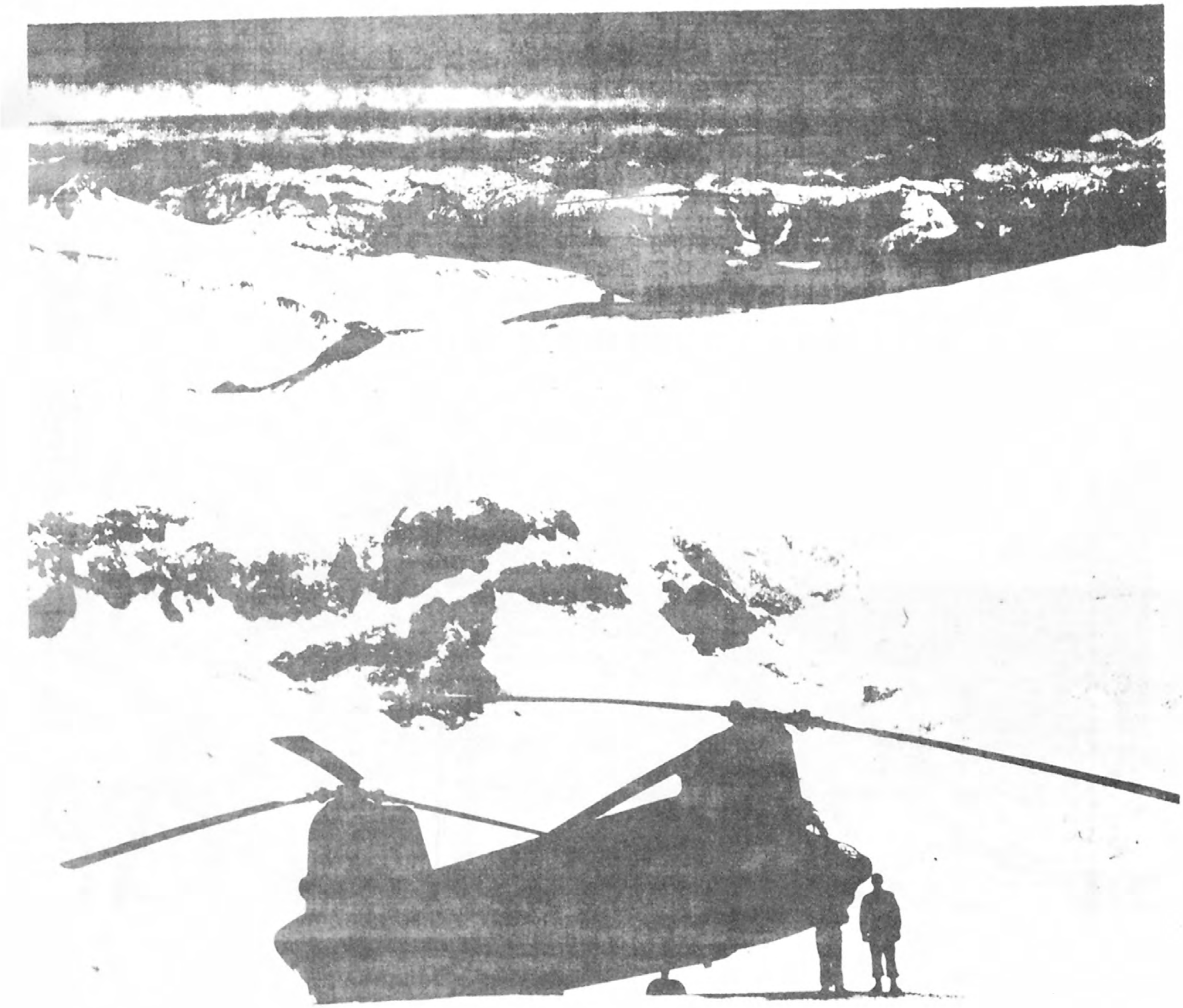


Figure 5.r-Installation site for DCP 6251 on north slope of Mount Baker, Washington near 300 m elevation, and military helicopter used by installation team.

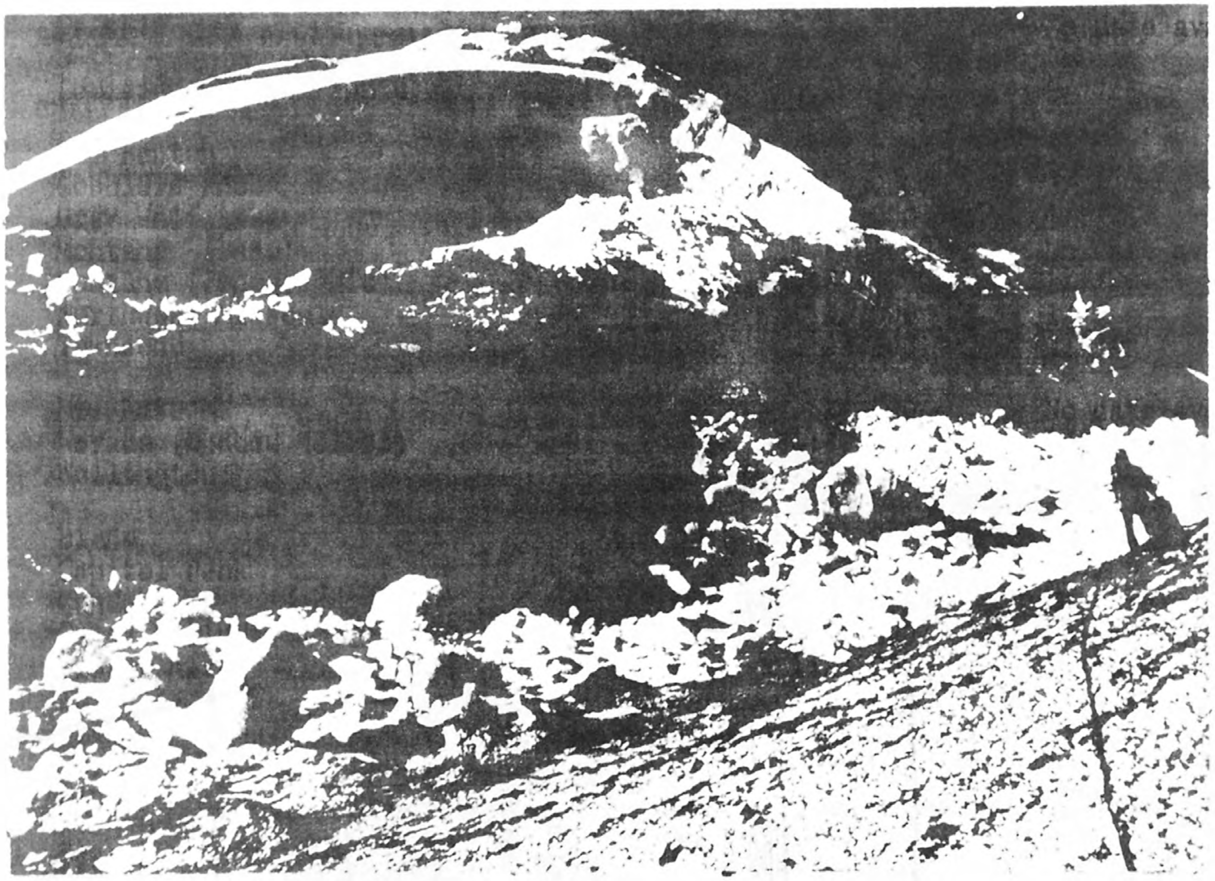


Figure 5.s-DCP 6251 site at Dorr fumarole field on north slope of Mount Baker, Washington, below the summit ice dome.

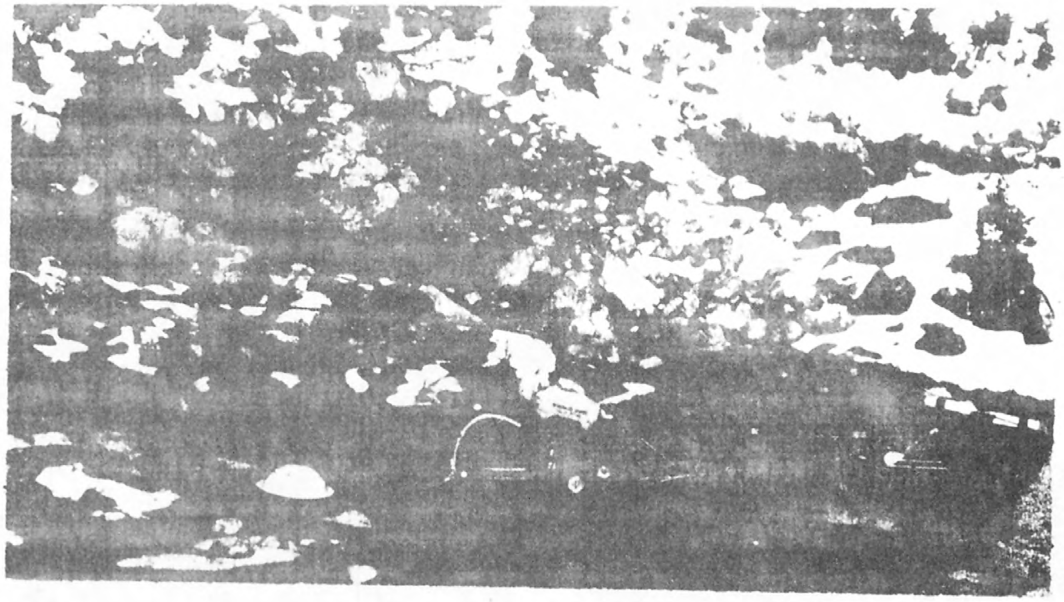


Figure 5.t-Bell helicopter used by installation team at Devil's Kitchen DCP 6104 site, Lassen volcanic region, California.

Figure 5.u-Installation of DCP 6056 at volcanic site on Surtsey Island at latitude 63^{O}N.

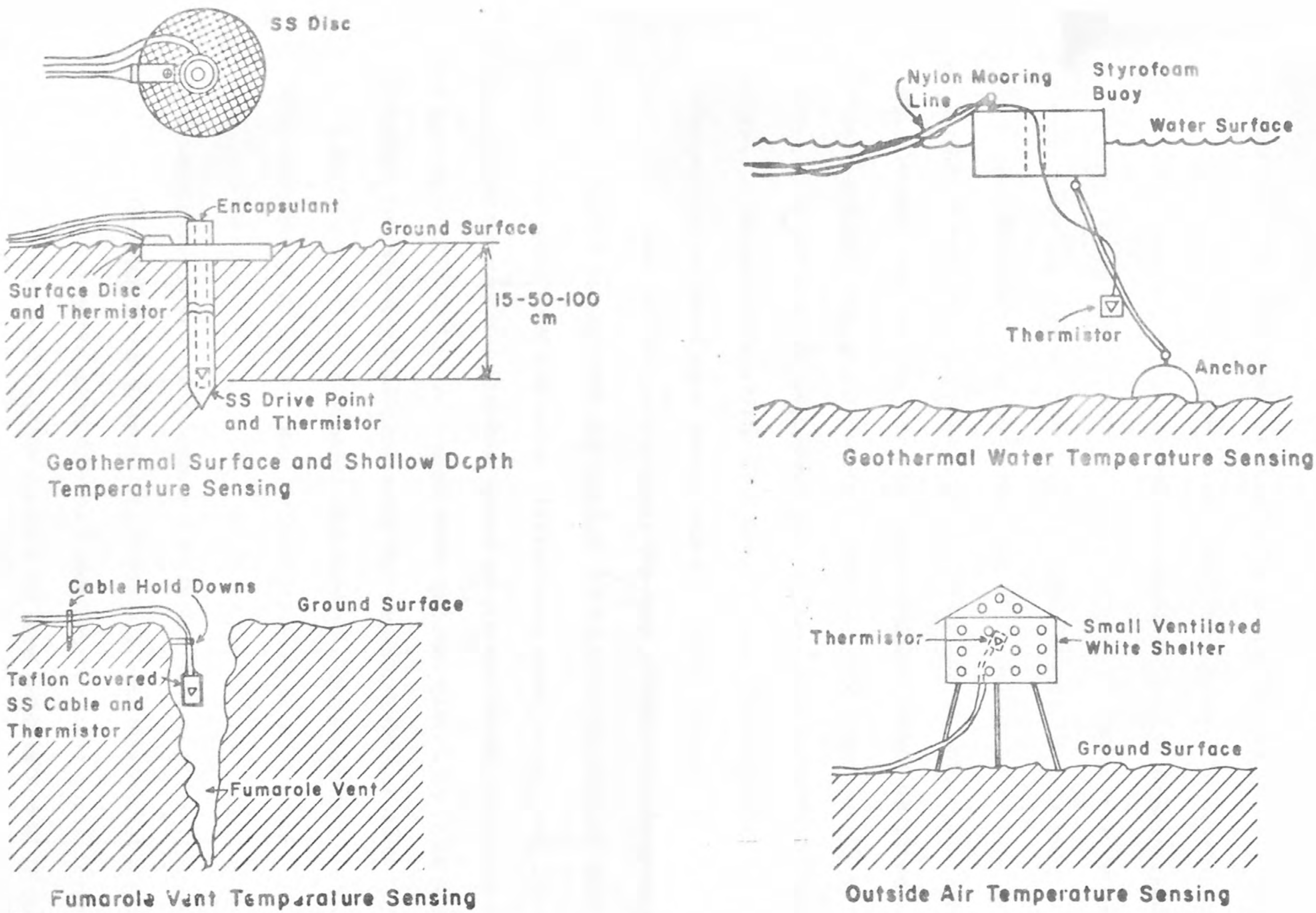


Figure 5.v

Figure 5.v--Mode of emplacement of thermal sensors in experiment SR 251.

scheduled for July 1972 delivery but were not received until October 1972. Because of late delivery and winter conditions, installation of the Washington sets could not be made until 4 to 7 months after receipt of the DCP's.

2. In every installation, helicopters were necessary and were operated under hazardous conditions. In the Lassen region, a small Bell helicopter was used to carry in the instrument stations and shelters; at the Devil's Kitchen, Bumpass Hell, and Boiling Springs Lake sites, each located in bowl- to amphitheater-shaped topographic depressions at 2000- to 2700-m elevations, it was necessary to land the helicopter on thermally unstable ground (figure 5.t) within a few meters of active fumaroles; near-ground visibility was almost zero owing to the vapor and fume emission from the thermal area.

Site conditions at Mount St. Helens and Mount Baker (figures 5.r and 5.s), Washington, were considerably worse and more hazardous. At high elevations (2400-3400 m), on steep mountain slopes near the summits of these two volcanoes, landing sites were poor and dangerous in high winds. The installation teams and instrument-station equipment were carried into these sites by large U.S. Army helicopters of the 92nd Aviation Company, Paine Field, Everett, Washington, under near-storm conditions.

A similar helicopter-installation expedition was carried out at the Surtsey, Iceland site (figure 5.u), where a small helicopter carried the installation team and equipment across 20 km of open sea to reach Surtsey from the staging area of Heimaey in the Vestmannaeyjar archipelago off the south coast of Iceland. The station there was installed on a clear but cold and windy November 15.

It is strongly recommended that adequate funding be budgeted for future installation and removal by helicopter of temperature-monitoring DCP stations at all hazardous, remote, or high-altitude volcano sites.

3. Equipment should be designed to survive normal snow pressures. The original disc-type antennas were inadequate for the task. Although the antenna dipoles were protected by plexiglas domes and antennas were installed on warm geothermal ground, severe damage resulted from snow accumulation. In most cases the dipoles were bent or broken, conductor wires severed and disc ground planes bent. Subsequently, we substituted simple dipole, Chu-type antennas which were used throughout the later phase of the experiment; they were found to be immensely more satisfactory because their small size permitted them to be constructed more ruggedly.

Corrosion-resistant parts should be used. Severe corrosion from moisture and volcanic acidic fume affected electrical connectors and electrical wire on the antenna and cabinet screws on the DCP.

During initial checkout, it was noticed that any sensor cabling which was in the antenna field pattern would cause erroneous digital/analog conversion. Once this fact was noticed, the circumstances which caused this could be easily avoided.

The following list notes the correctible failures which affected system performance most, in order of importance:

1. Antenna could be crushed by snow load or blown away by high

winds.

2. Thermistor probe failure, as explained earlier.

3. Maintaining calibration and records of 40 data channels.

5.5.7 Typical DCP-electronic thermal array sensing system

For a full description of a typical volcano-temperature monitoring DCP system as installed, the reader is referred to the description and technology of DCP 6056, Surtsey, Iceland, (Friedman and others, 1976, Section 1.4.2, p. 41-48, figures 1.9 through 1.12 and Table 1.4). See also figures 5.m; 5.n; 5.o; 5.p, this report.

5.6.0 Recommendations for Modifications for Future DCP Systems for Volcanic-Temperature Monitoring

5.6.1 Solar power supply

Several solar power supplies are available for use with the DCP's. These units have a panel size of 15cm x 51cm. They are equipped with a 2 A-Hr rechargeable, sealed, lead-acid battery, and a regulator which floats the battery set at the recommended 1.0 volts per cell (27.6 volts for 12 cells). The battery has enough capacity to supply the DCP (on 180-second transmission interval) with 3 weeks of power without any charging. Only 20 hours of sunshine were required during that 3-week period to maintain full battery voltage (about 4 percent duty cycle). Units are available from Spectrolab of Sylmar, California, as Model LECA 24V1.5W, or from Solarex of Rockville, Maryland.

5.6.2 Chu antenna

The most awkward part of shipping or installing a DCP is the handling of its 117-cm antenna. Several tests have used other antennas. One test performed by NAVOCEANO confirmed that the Chu and spiral antennas both perform adequately. Figure 5.w describes the results of a test performed jointly ty USGS and NOAA at the Mississippi Test Facility. This test compares the Chu volute antenna with the GE Landsat antenna. The upper half of figure 5.w shows comparative scale sketches of the two antennas. As can be seen, the Chus antenna is much smaller. Both antennas were operated with DCP's

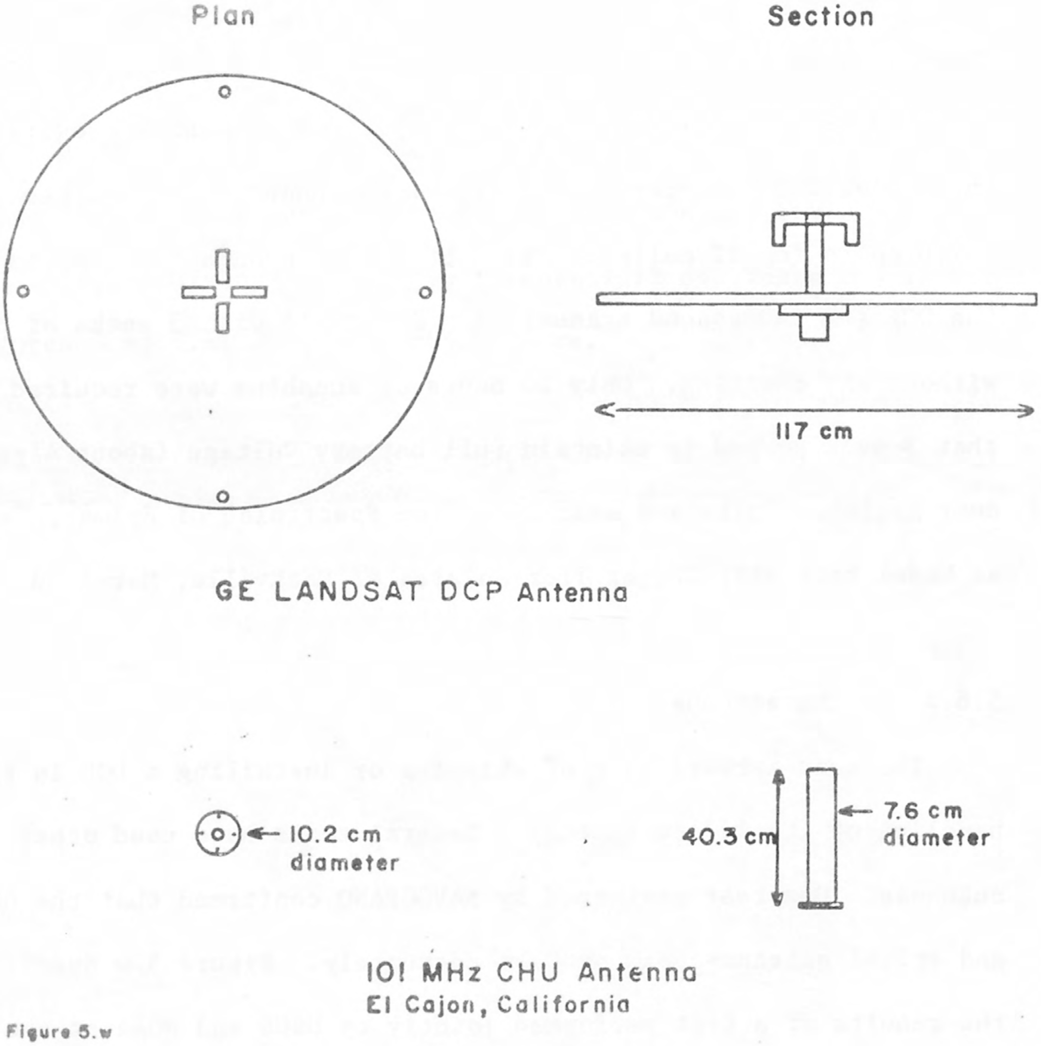


Figure 5.w--Comparison of Chu antenna with GE Landsat antenna.

which had fixed digital inputs and were on a 90-second transmission rate. They were operated at different power levels over the period of November 27 to December 19, 1972. The number of messages possible was calculated from satellite orbital information and compared with the number of '7' level messages received. The Chu antenna was from 46-104 percent as effective as the GE Landsat antenna; the average figure was 78 percent. However, at higher power levels (6W), it appears that the Chu will perform adequately for most sites. A 10 percent reduction in message number may not be too great a price to pay for easing transportation and installation problems (figure 5.p). Antennas are available from Chu Association of El Cajon, California.

5.6.3 DCP memory unit

A desirable accesory to aid in recording full diurnal-temperature cycles is the proposed DCP memory unit (figure 5.x). The purpose of this unit is to allow previously stored data to be transmitted as well as real-time data. Most DCP sites have three to fifteen messages completed per day. If a 90-second transmission rate were used, three to fifteen messages per 12-hour period would be completed. The memory functions and controls are outlined in figure 5.x. The formatted bit stream will be interrupted just prior to entry into the DCP encoder. This allows the DCP analog and digital inputs to be used to convert and format the inputs. There are four formatting controls in the memory: write frequency, number of active memory sets, bit length of memory set, and number of bits stored per write cycle. An example of

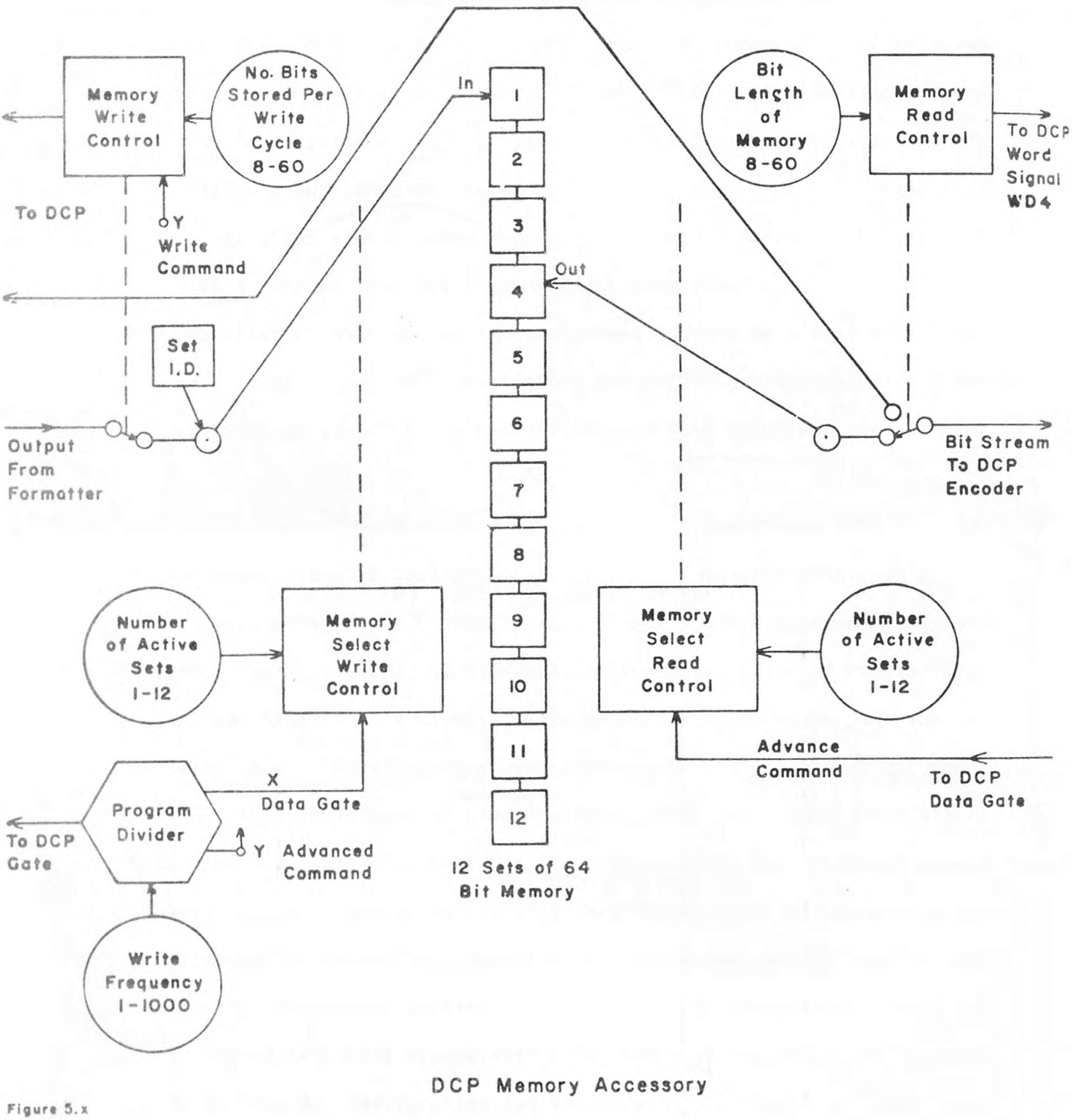


Figure 5.x--Proposed DCP memory accessory.

the way these controls are used might be:

Number of memory sets used	12
Active bit length of memory	30
Number of bits stored per write cycle	30
Write frequency (determines the number of data gate pulses between write cycles)	41

41 x 89 sec. trans. interval = 0.01 hours

This setting would allow 30 bits to be stored each write cycle. Each transmission would be composed of 34 bits of stored data (30 bits memory and 4 bits memory set I.D.) and 30 bits of real-time data. Each write cycle would store data in a different memory before it started over with set 1; therefore, since about a one-hour write cycle has been chosen there would be 12 hours of data in storage. Twelve transmissions would be required to transmit all stored data; subsequent transmissions would step through all 12 memory sets and repeat. These controls were selected to provide maximum versatility for both data and site selection. Use of this memory unit should add an interesting capability to the present Landsat Data Collection System.

5.6.4 Additional recommendations

Additional recommendations for modification or improvement of the DCP's and associated temperature-sensing systems have been made in appropriate parts of this report; for example, see Part 1, Section 1.5, p. 49-50, and Preface p. XIV-XVI. They include recommendations for the inclusion and use of (1) several thermistor probes greater than 1 m in length, (2) a recording anemometer, (3) a recording radiometer for ground-surface and sky radiance, and (4) a barograph.

The problems of teflon permeability and selection of a conductive alloy (for thermal probes) that has maximum resistance to corrosion by volcanic fume and vapors deserve special attention. Recommendations in these topics await the results of future experimentation.

5.7.0 Conclusions

It was found, as the result of this experiment, the electronic thermal-probe arrays suitable for sensing temperatures of thermally anomalous ground and fumaroles in remote and rugged volcanic environments (at high altitudes and high latitudes) could be successfully designed, constructed, and electronically integrated with Landsat DCP's. A total accuracy of 1.15^{o}C could be obtained on warm ground surfaces and 2.05^{o}C at hot fumaroles. Five DCP-thermistor systems functioned successfully and transmitted 3260 messages comprising 26,080 ambient, surface and near-surface temperature records over 1121 instrument days between November 14, 1972 and April 17, 1974.

The experiment has thus demonstrated the feasibility, with rugged equipment and antennas and with adequate power supplies, of relatively long-term transmission of diurnal temperature variations from inaccessible locations. It can be inferred that the DCP's are well suited as the basis for a temperature-monitoring system at forcefully active primary fumaroles at which gas temperatures are volcanologically significant, provided that corrosion problems can be overcome.

The Data Collection Platform, originally equipped with a large antenna, would be easier to install in harsh, windy, high-altitude or high-latitude volcanic environments with a smaller dipole or Chu-type antenna. Use of 16 kg of alkaline batteries as a power supply for the DCP-thermistor sensing systems when operated at a low duty cycle was estimated to result in a battery life of five to eight months. The DCP thermal-sensing systems were interfaced electronically and operated in an analog mode. Special methods of data handling such as data storage via a memory or data-bunching-and-dumping system are recommended to increase the significance of the twice-daily data reception.

Refinements in the temperature-monitoring system that were incorporated in experiment SR 251 included (1) a multipoint temperature scanner and an analog to digital recording system to function as a backup to the DCP transmitter; (2) the development of an improved method to obtain a seal between teflon cable insulation and the probe encapsulant by etching the cable in hot hydrofluoric acid prior to encapsulation; and (3) an improvement in probe design and construction by incorporation of a small printed circuit board to hold all components securely in place.

5.8.0 Symbols and Abbreviations, Part 5

ADR = Analog to digital recorder

COS/MOS = Complementary silicon metallic oxide semiconductor

DCP = Data Collection Platform

DCS = Data Collection System

MOS = Metallic oxide semiconductor

MTF = Mississippi Test Facility

NEDA = National Electrical Devices Association

SS = Solid state

TTL = Transistor transistor logic

YSI = Yellow Springs Instrument Company thermistor series

5.9.0 Glossary of Special Terms, Part 5

Chu antenna -	Volute UHF antenna manufactured by Chu Corporation
Data gate -	Signal from DCP which alerts interface circuitry when a transmission is about to occur
Memory accessory -	Additional accessory for storing parameter values prior to transmission
Multiplexer -	Circuit through which multiple signals can be switched on command
Multipoint temperature scanner -	Unit which is capable of reading temperatures from multiple thermistors
Thermistor signal conditioner -	Amplifier unit which converts variable resistance input from thermistors into a calibrated 0-5.0-volt signal which is accepted by the DCP

5.10.0 References Cited

Friedman, J. D., Frank, David, Preble, D. M., and Jakobsson, Sveinn, 1976, Thermal surveillance of active volcanoes using the Landsat-1 Data Collection System, Preface and Part 1--The Surtsey, Iceland, temperature data relay experiment via Landsat-1: Prepared for Goddard Space Flight Center, available from U.S. Dept. Commerce Natl. Tech. Inf. Service, Springfield, Va., 22161, 55 p.

National Aeronautics and Space Administration, 1971, Earth Resources Technology Satellite data users handbook: NASA Goddard Space Flight Center, 218 p.