FOREWORD

This developmental study was initiated in September 1962 by the Biomedical Laboratory, 6570th Aerospace Medical Research Laboratories. This report represents one phase of the research and development programs being conducted by the Biothermal Branch, Physiology Division, Biomedical Laboratory, under Project 7164, "Biomedical Criteria for Aerospace Flight," Task 716409, "Human Thermal Stress."

The consultant services of Mr. William J. Hovey of the Research Institute, University of Dayton, Dayton, Ohio were made possible through contract AF 33(657)-8521 with the University of Dayton.

The authors acknowledge with thanks the support and advice rendered by Mr. Fritz K. Klemm, also of the Biothermal Branch, and Mr. David H. Brand, Instrumentation Systems Development Branch, Data Systems Division, Aeronautical Systems Division.

ABSTRACT

An automatic data acquisition system has been designed to minimize the data reduction of biomedical test data. The overall system consists of two main parts; a hardware group, which digitizes and records the raw data, and a computer program, which reduces the data and presents it in tabular form for ready analysis. The system is capable of simultaneously recording up to 27 thermocouple, 27 thermistor, and 24 miscellaneous data channels during any given experiment. The sampling speed is such that it takes approximately 6 seconds to record all 78 channels. Major design considerations were ease of use, utility, flexibility, and reliability. All scale factors and calibrations, both linear and nonlinear, will be effected by the computer program; the recording hardware only digitizes and records voltage levels.

PUBLICATION REVIEW

This technical documentary report is approved.

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AN AUTOMATIC LOGGING SYSTEM FOR BIOMEDICAL TEST DATA

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INTRODUCTION

In support of the Aerospace Medical Research Laboratories project to determine human tolerance to various thermal environments, an impressive array of instruments and instrumentation equipment have been acquired over the past few years. Current experiments require many different instruments to be used simultaneously during a typical test run; some for test monitoring and others for recording purposes so that detailed analysis may be accomplished at a later time. Each different instrument normally has its own oscillographic recorder on which an analog record is obtained, giving the time history of the phenomenon being measured. Several multichannel recorders are employed for temperature data.

After a typical test is completed the project engineer is faced with a group of serveral oscillograms which must be read, correlated, synchronized, and otherwise processed. This is a tedious and time-consuming task. Future requirements anticipate a significant increase in the amount of data. The problems associated with manual data reduction are such that it seems imperative that improvements be made in the data acquisition and processing effort. The data acquisition system described in this report has been designed to overcome a major portion of the data reduction problem. The test results will be machine tabulated in digital form with a capability of up to 78 input channels along with time and identification data. All manual data reduction is completely eliminated by the use of the IBM 7094 digital computer.

SYSTEM DESCRIPTION

The heart of the basic recording system is the AST Model 1 Digitizer and low-speed commutator. This equipment was originally designed and fabricated by the Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, for airborne instrumentation. The first vacuum tube unit was placed in operation in 1956 and the transistorized version was introduced in 1959. The system has been very satisfactory from both a performance and reliability standpoint and many units have been fabricated and utilized during thousands of flight hours. The output of the digitizer is recorded on a Honeywell Model 4001 digital magnetic tape transport. This recorder uses 1-inch tape and has a tape speed of 2 inches per second and a capacity of 600 feet. Details of the basic commutator-digitizer-recorder system have been reported by Conover.*

Input Panel

The input panel has been designed to offer a convenient and flexible means of electrically connecting the measuring instruments to the low speed commutator. The commutator consists of three stepping switches, each having two poles and 29 positions. Typical commutator circuits are illustrated and described in Appendix I. The operation is programmed so that only one switch is connected to the digitizer at any time. The stepping time is approximately 2 seconds per switch so that a total of 6 seconds is required to commutate through all of the input channels.

Most of the biothermal experiments involve several thermocouples located to measure wall temperatures, clothing temperatures, air temperatures, etc. Since each test is instrumented according to the requirements of the experiment, the input connecting method for thermocouples must be quick, easy, and flexible, as well as reliable. The input panel for the data acquisition system contains screw-type terminal strips for all thermocouple channels. The screw-type terminal strip offers the greatest flexibility and utility. In addition, the use of thermocouple connectors did not seem warranted because of the expense involved.

One of the three commutator switch boxes is reserved for thermocouple data. Of the 29 positions available, one is reserved for a zero level (32° F) and a second for an arbitrary up-scale level (approximately 160° F). The system uses a standard automatic temperature-compensated thermocouple reference junction in place of an ice bath. A second compensated reference junction is used for the zero-level signal, while a thermostatically controlled oven houses the thermocouple for the up-scale level; these are used for calibration purposes as well as for monitoring for system drift. The compensated reference junction is the type required for copper-constantan thermocouples. Appendix II contains additional details on the thermocouple channels.

The input panel for the thermistors (fig. 1) is somewhat more complicated than that for the thermocouples. The data acquisition system must first of all be capable of recording in parallel with a skin and body temperature computer. This instrument uses, as a sensor, a garment containing 17 skin-contacting thermistors and rectal probe for a total of 18 thermistor channels. The instrument is actually an analog

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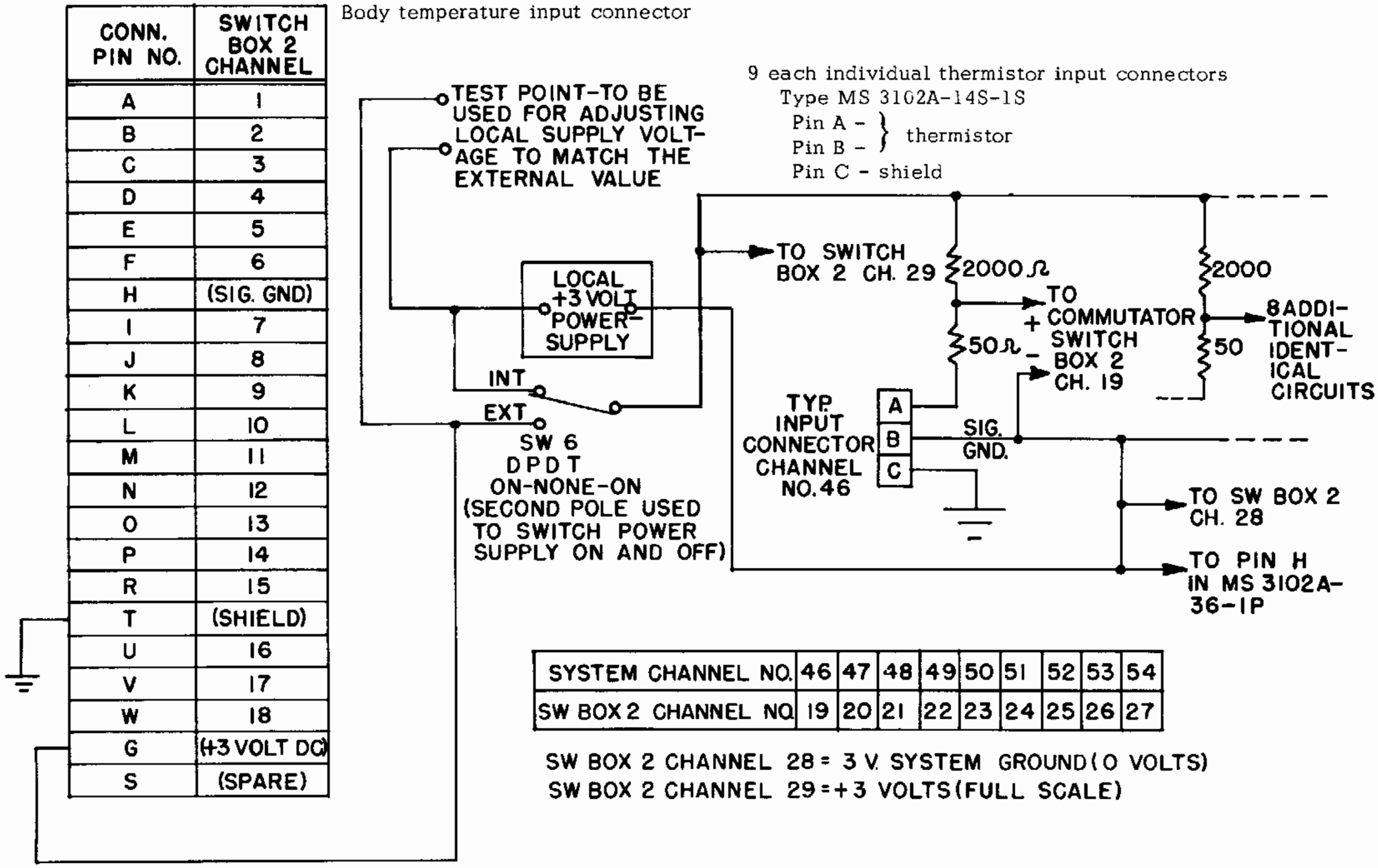
*Conover, Richard E., Automatic Data Recording and Processing System, Wright Air Development Center Technical Report 58-185, Wright-Patterson Air Force Base, Ohio, June 1958. DDC No. AD 151179



CONN. PIN NO.	SWITCH BOX 2 CHANNEL
A	1
B	2
C	3
D	4
E	5
F	6
H	(SIG. GND)
I	7
J	8
K	9
L	10
M	11
N	12
O	13
P	14
R	15
T	(SHIELD)
U	16
V	17
W	18
G	(+3 VOLT DC)
S	(SPARE)

SYSTEM CHANNEL NO.	46	47	48	49	50	51	52	53	54
SW BOX 2 CHANNEL NO.	19	20	21	22	23	24	25	26	27

SW BOX 2 CHANNEL 28 = 3 V. SYSTEM GROUND (0 VOLTS)
SW BOX 2 CHANNEL 29 = +3 VOLTS (FULL SCALE)

Figure 1

THERMISTOR DATA - COMMUTATOR SWITCH BOX 2 computer that combines the 17 skin measurements, with various weighting factors, to compute an average skin temperature, and then combines the average skin temperature with the rectal measurement to compute a total body temperature. The skin and body temperature computer records all 18 thermistor measurements along with the two computed channels. In operation, the thermistor garment, is connected to the computer by a cable and electrical connector. The computer contains the power supply and resistance networks necessary to convert resistance to voltage. The data acquisition system taps into the computer circuits, ahead of the weighting factor pots, so that the voltage generated by the 18 thermistors can be presented to the low speed commutator. Thermister outputs along with the instrumentation power supply voltage are transmitted to the new data acquisition system by a multiconductor cable and a single electrical connector. Computation of the average skin temperature and body temperature will be accomplished by the IBM 7094 computer. The reason for transmitting the 3-volt instrumentation signal is to standardize the digitizer as well as to compute voltage ratios for more precise resistance calculations in the computer.

Of the 29 positions on the thermistor commutation switch box, one is short-circuited to furnish a zero-volt signal, a second position receives the 3-volt reference signal from the body temperature computer, and 18 channels will be reserved for the thermistor measurements. The remaining 9 positions can be used for individual thermistor probes that may be required during miscellaneous tests. The input panel contains nine individual connectors for use in electrically connecting the miscellaneous thermistor probes to the system. A 3-volt power supply and resistor networks, identical to those used in the body temperature computer, are built into the new data system for use by these nine channels. A switch allows operation either with the local 3-volt power supply or with the one in the body temperature computer. Also, a test point is available that can be used to adjust the voltage of the local 3-volt supply in order to match it to the voltage of the body temperature computer.

The third commutation switch box is used to scan voltages from a miscellaneous group of measurements. The inputs for the miscellaneous group can be made through individual connectors, each reserved for a particular channel. As yet no assignments have been made for the miscellaneous channels, therefore, no examples can be presented. The general requirements for this group are that the full-scale voltage range be greater than ±20 mv and that a resistive load of approximately 2000 ohms be permitted on the transducer output circuit. Attenuation resistors are provided in the data system for those signals greater than ±20 mv. In addition, the relationship between voltage output and phenomenon input must be known, and be consistent, so that valid calibration equations can be placed in the computer for processing these channels.

As with the other two switch boxes, zero and full-scale levels are placed on two of the 29 positions of the miscellaneous switch box. In addition, three other channels are reserved for auxiliary data, leaving only 24 positions for miscellaneous data. The three auxiliary channels record the test number, the frame number, and time. The time signal is a digital number representing elapsed time, which can be presented in either seconds or minutes. The frame number is a sequentially advancing number which advances one count each time the commutator completes one sweep. The test number is to be used as the primary identification for a particular test run; it advances one count each time the system is started and remains fixed all during that test run.

System Control

The control panel (fig. 2) for the automatic data acquisition system contains six switches, an indicator lamp, an intervalometer, and two digital number displays. A mode switch is provided to select the commutator switch boxes that will be used. Four mode positions are possible: (1) box one only, (2) box one and two, (3) box one and three, and (4) all boxes. Switch box one is the miscellaneous group, containing all identification numbers; box two is the thermistor data; and box three, the thermocouple data. Different modes are provided because, at times, not all types of data will be required and the recording time is reduced for each commutation sweep that does not involve all three switch boxes.

The start-stop switch initiates the system for a test run. When activated, the test number is advanced one digit and the system commences to record data until the stop-switch is activated. The test number is displayed on the control panel along with the frame number.

Another control is the automatic-continuous switch. When in the later position, the commutator sweeps continuously once the system is started. In the automatic position the sweep sequence is initiated periodically, the time between sweeps being controlled by the setting on the intervalometer. When an automatic sweep is initiated, three continuous sweeps are made; the reason for this is that at times noise will occur, giving false readings. By providing three concurrent readings, the false signals can be spotted more easily. A manual frame push-button switch has been provided to permit manual measurement between automatic frames if the test director so desires. This would be used, for instance, in the event that some uncommon occurrence was noted 2 minutes after a sweep, during a test in which the intervalometer was set for 10-minute intervals.

DATA IDENTIFICATION

Very seldom, if ever, would all 78 data channels be used during a test. In addition, there is little likelihood that any particular configuration would become a standard test set-up. The problems associated with identifying particular data inputs with corresponding system channels becomes one of efficient bookkeeping. The method planned for this system is to provide a master form for the lead technician on which he will enter such information as the test number (read from the display on the control panel), date, time, and the title associated with the experiment. The form will also contain a set-up log, identifying each active system channel (1 thru 78) with the corresponding input data. An example would be "channel 2 - thermocouple chin, left side;" "channel 53 - thermistor, left forearm;" etc. From the master form, a second data sheet, or computer control sheet, would be produced giving

CONTROL PANEL

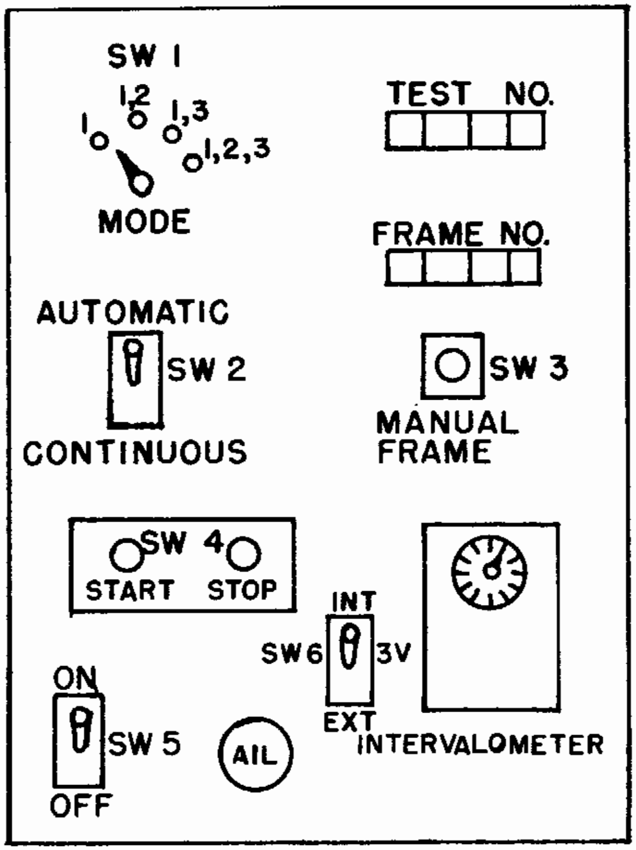


Figure 2

CONTROL PANEL FUNCTION

ITEM	FUNCTION
SW 1	Mode switch-select commutator box 1 only, or 1 and 2, or 1 and 3, or all 3.
SW 2	Selects either continuous digitization or automatic control by the intervalometer (see note).
SW 3	Push button switch that causes one set of three sweeps or frames to occur. This provides for recording data between normal intervalometer controlled frames.
SW 4	Start - stop switch; starts the system by activating the automatic/continuous control network.
SW 5	Main power switch
AIL	Amber indicator light (power on)
Test No.	Advances each time start button is pushed. This number is recorded on the tape and is the primary test identification.
Frame No.	Advances each time commutator makes one full sequence (full sequence as controlled by mode switch) this number to be used by test director to correlate events as required. Frame defined as one commutator sweep.
Interval-ometer	Controls the amount of time between measurements in the automatic mode.
SW 6	Selector switch, 3 volt, thermistor, internal or external 3-volt power supply.
NOTE:	When in the automatic position, each time a "read" command is received the system will make three continuous frames before being turned off. This is to help eliminate noise-induced erroneous measurements.

The test number and the number of all active channels for that particular test. The computer control sheet data will be used by the computer program to properly sort the valid data from the unused channels; thus, the computer will only process and tabulate data from the active channels. Noise and other random signals on the unused channels will be bypassed.

The calibration data for copper-constantan thermocouples from NBS circular 561* have been analyzed and empirical equations derived relating voltage and temperature. For the best curve fit, two equations should be used, one for the voltage range of -2.559 mv (-100° F) to 5.280 mv (+250° F); and the other from 5.280 mv (+250° F) to 17.421 mv (+650° F). The two equations are as follows:

Voltage Range -2.559 to +5.280 mv (-100° F to +250° F)

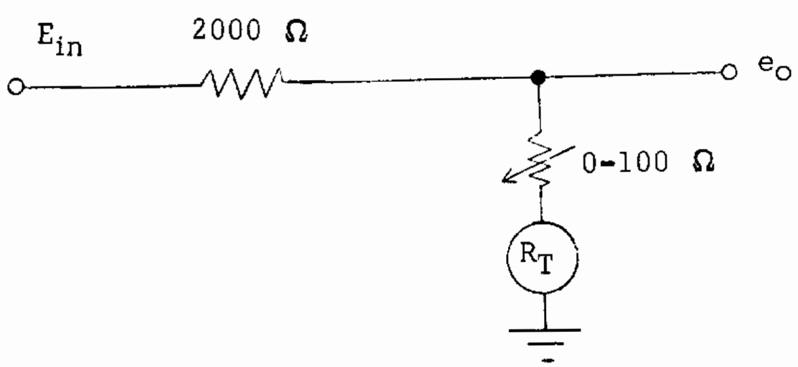
$$T = 0.098\,V^3 - 1.560\,V^2 + 46.8\,V + 32.2 \quad (°F)$$

Voltage Range 5.280 to 17.421 mv (250° F to 650° F)

$$T = -0.33\,V^2 + 40.3\,V + 46.5 \quad (°F)$$

where T is the thermocouple temperature in degrees F and V is the thermocouple output in millivolts.

For the thermistor data two equations must be solved serially to establish temperatures. The first equation relates resistance to voltage and the second relates temperature to resistance. From the instruction manual of the body temperature computer the typical circuit used is as follows:



*National Bureau of Standards circular 561, Reference Tables for Thermocouples, 84 pp, 1955.

where E_{in} is +3 VDC and the 0-100 ohm resistor is used for setting linearity. For simplification purposes, it will be assumed that the 100-ohm resistor is adjusted to the mid-position of 50 ohms. The resulting equation for resistance is therefore:

$$R_T = \frac{2000}{1 - \frac{e_o}{E_{in}}} - 2050 \text{ ohms}$$

The factor $\frac{e_o}{E_{in}}$ is readily available since the 3-volt input voltage (E_{in}) is recorded during each frame along with the thermister output of e_o. This equation is exact if the variable 100-ohm resistor is set at its mid-point; the only errors in calculating the resistance occur in measuring e_o and E_{in}.

An empirical equation was generated relating resistance and temperature for the Yellow Springs Instrument Company Thermistemp® thermistor probes. The data for the equation was obtained from the data sheet published by the manufacturer of these probes. The thermistor equation is as follows:

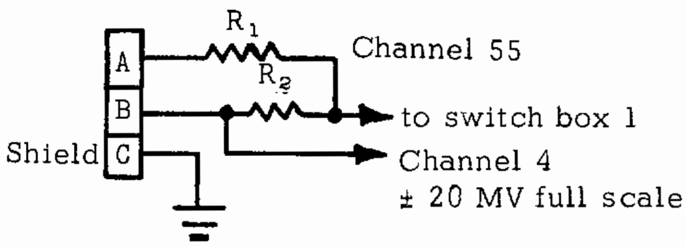
$$T_C = \frac{2.1856342 - \ln(\ln R_T)}{0.00567238} \quad \text{or} \quad T_C = \frac{0.5867513 - \log(\log R_T)}{0.00245834}$$

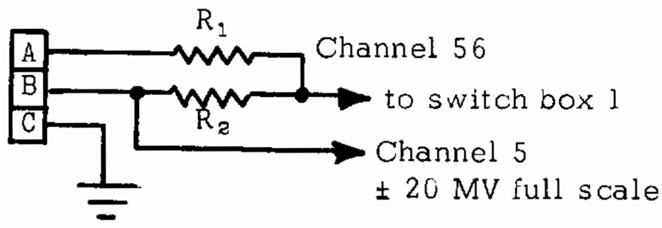
where T_C is the thermistor temperature in degrees C, R_T is the thermistor resistance in ohms, ln R_T is the natural logarithm of R_T, and log R_T is the logarithm base 10 of R_T. The equation relating T_C and R_T matches the tabulated data on the manufacturers data sheet to an accuracy of ±0.1° C from 0° C to 100° C.

APPENDIX I

TYPICAL COMMUTATOR CIRCUITS

System Channels 55 thru 78 Switch Box 1
Miscellaneous Channels





1. One different type connector for each channel, types to be specified.
2. Up to 24 total channels.
3. System channel numbers 55 thru 78 connect to switch box channels 4 thru 27.
4. Resistors R_1 and R_2 to be determined for each individual channel.
5. Zero volts on switch box channel 28.
6. ±20 MV on switch box channel 29.
7. Record test number on switch box channel 1.
8. Record frame number on switch box channel 2.
9. Record time on switch box channel 3 (0-999 sec. or 0-999 min; to be specified later).

System Channels 28 thru 54 Switch Box 2
Thermister Channels

1. All commutator input signals range from 0 to +3 volts DC.
2. Output of commutator connected to Philbrick Amplifier, high input impedance.
3. Output of amplifier to 0 to +30 MV low impedance. This signal to digital converter unit.
4. One single connector for body temperature measurements. 18 channels (28 thru 45). 0 to 3 volt signal for each channel.
5. Nine additional connectors, one for each channel 46 thru 54. No voltage input, thermistors connected through input connectors.
6. Local circuitry provided for changing up to nine thermistor resistances into 0 to +3 volt signal.
7. Provisions for using either local 3-volt power supply or power supply in the total body temperature computer.
8. Zero and full-scale calibration points to be recorded for each frame (commutator sweep).

System Channels 1 thru 27 Switch Box 3
Thermocouple Channels

1. All input signals to range from -1.7 MV to +9.5 MV.
2. Inputs connected through screw type terminal strips.
3. One 3 element terminal strip for each channel.
4. Automatic compensated reference junction used on output of commutation switch for +32° F reference temp.
5. Zero and up-scale calibration points to be recorded for each frame.

   a. Zero provided by second reference junction.
   b. Up-scale provided by oven enclosed thermocouple.

APPENDIX II

THERMOCOUPLE INPUT — COMMUTATOR

SWITCH BOX 3

1. Twenty-seven individual terminal strips (Cinch-Jones, Type 3-140, Barrier-Type Terminal strip) are used for thermocouple input signals.

2. Each terminal strip is identified by a channel number from 1 to 27.

3. Each channel is wired so that the copper wire goes on the left, the constantan wire in the center, and the shield on the right when a thermocouple is attached.

4. A standard compensated reference junction is used.

5. All thermocouples are connected to commutator box number 3; thermocouple channel 1 connects to switch box channel 1, etc, through channel 27.

6. Switch box channel 28 is connected to a second thermocouple compensated reference junction for a 32° F reference signal.

7. Switch box channel 29 is connected to an oven-enclosed thermocouple maintained at a temperature of approximately 160° F.