AEDC-TR-77-112

AUTOMATIC DATA ACQUISITION SYSTEM FOR AN LED TEST

Zeni Batte
University of Tennessee Space Institute

ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE 37389

June 1978

Final Report for Period April 1976 – September 1977

Approved for public release; distribution unlimited.

Prepared for

NAVAL OCEANS SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

APPROVAL STATEMENT

This report has been reviewed and approved.

Marshall K. Kingery

MARSHALL K. KINGERY
Project Manager, Research Division
Directorate of Test Engineering

Approved for publication:

FOR THE COMMANDER

Marion L. Laster

MARION L. LASTER
Director of Test Engineering
Deputy for Operations

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1 REPORT NUMBER: AEDC-TR-77-112	2 GOVT ACCESSION NO.
3 RECIPIENT'S CATALOG NUMBER	
4 TITLE (and Subtitle): AUTOMATIC DATA ACQUISITION SYSTEM FOR AN LED TEST	5 TYPE OF REPORT & PERIOD COVERED: Final Report, April 1976 - September 1977
	6 PERFORMING ORG REPORT NUMBER
7 AUTHOR(s): Zeni Batte, University of Tennessee Space Institute	8 CONTRACT OR GRANT NUMBER(s)
9 PERFORMING ORGANIZATION NAME AND ADDRESS: Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, TN 37389	10 PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Program Element 65807F
11 CONTROLLING OFFICE NAME AND ADDRESS: Arnold Engineering Development Center(DOS), Air Force Systems Command, Arnold Air Force Station, TN 37389	12. REPORT DATE: June 1978
	13 NUMBER OF PAGES: 54
14 MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A

16 DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17 DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18 SUPPLEMENTARY NOTES

Available in DDC.

19 KEY WORDS (Continue on reverse side if necessary and identify by block number)

light emitting diodes
degradation
data acquisition

20 ABSTRACT (Continue on reverse side if necessary and identify by block number)

The object of the work performed was to develop a computer controlled data acquisition and data analysis capability for an uninterrupted 6,000 hour test to monitor the degradation of approximately 250 infrared light emitting diodes (LED's). The test program comprised subjecting a sampling of 254 diodes to preselected constant currents and temperatures while periodically measuring the voltage drop and the light output of each of the

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

20. ABSTRACT (Continued)

diodes. To perform the data acquisition portion of this effort, an automated data acquisition system was designed around a Hewlett-Packard 2100A computer. This system utilized a 1,000 point random access multiplexer, a 16-bit Relay Output Register and a digital voltmeter for data acquisition and transmission. Special purpose assembly language input/output routines were written for the computer's BASIC Interpreter to make this special equipment accessible to the computer. The Control program handled data storage to meet the requirements specified for the project.

PREFACE

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC) Air Force Systems Command (AFSC) at the request of the Naval Oceans Systems Center under Program Element 65807F. The results of the research were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), operating Contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee, under ARO Project Number B341-03A. The manuscript was submitted for publication on October 31, 1977.

This technical report was originally presented as a thesis in partial fulfillment of the requirements for the Master of Science degree at the University of Tennessee, Knoxville. The author wishes to express her appreciation to those who were of great assistance in the preparation of this work. A special debt of gratitude is owed to Mr. J. B. Puckett and Mr. B. W. Bomar, ARO, Inc., for their guidance and patience in the development of the software. For his valuable support, encouragement and advice during the preparation of the thesis, the author extends many thanks to Mr. A. E. Lennert, ARO, Inc., Branch Manager of Advanced Concepts. The author also wishes to acknowledge Mr. J. M. Mann, ARO, Inc., for the final draft of the drawings for the text.

CONTENTS

ILLUSTRATIONS

Page

APPENDIXES

TABLES

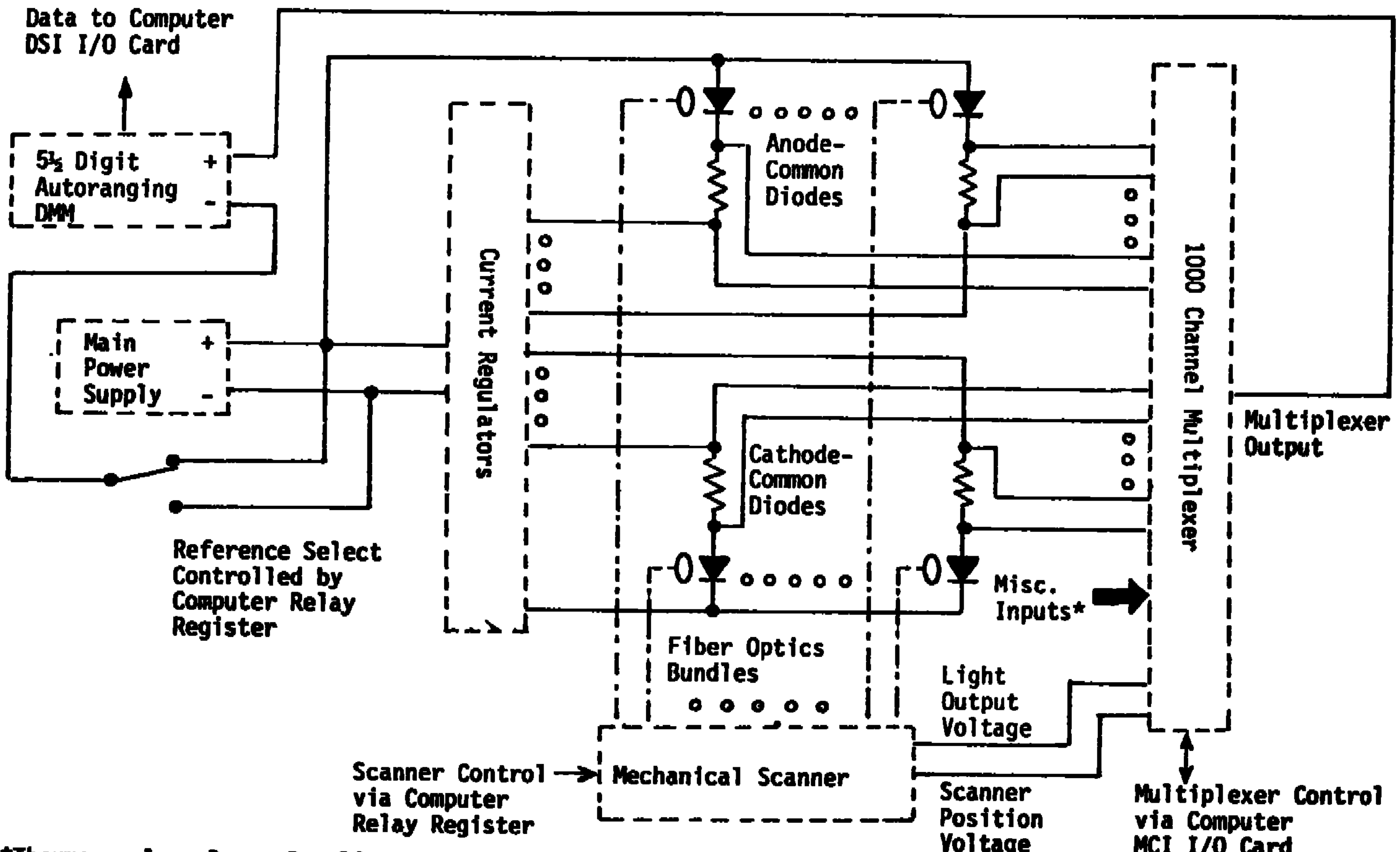
1.0 INTRODUCTION

The objective of the LED test program was to monitor the degradation of infrared light emitting diodes (LED'S) for an uninterrupted operating period of 6,000 hours. To obtain the objective a sampling of 254 diodes was subjected to predetermined constant current and constant temperature conditions while the current and heat sink temperatures were periodically verified and the voltage drop and the light output of each of the LED's was measured. An automatic data acquisition system was needed to obtain and process the resulting large volume of data for the extended length of time involved. The present report describes the software that was developed as well as the software design philosophy and the performance of the system.

2.0 OVERVIEW OF LED TEST COMPLEX

The test program was designed to monitor 48 each of 5 different types of commercial LED's. The diodes were equally divided among 4 environmental chambers maintained at the following nominal operating temperatures: (a) -65, (b) 20, (c) 90, and (d) 120°C. Twelve of each of the five types of diodes were contained within each chamber. The LED's were mounted in these chambers on specially designed heat sink racks. The heat sink and electrical connections to each of the diodes in all four chambers were designed to be as nearly identical as possible to minimize any mechanical or electrical bias in the measurements since no direct measurements within the chambers were possible. Each type LED was driven at one of four closely controlled currents by its own current regulator. Three of each type LED in each chamber were operated at the same current level. Precision mercury cells were used as references for the individual current regulators to maintain better than 0.5% current regulation throughout the test.

In order to keep the number of instruments required for acquiring data in the LED test complex to a minimum, a Hewlett-Packard 2100A computer was hard-wired from a 16-bit input/output port through a computer/manual control panel to a random access, reed-relay operated, 1,000-point multiplexer (MUX). (Schematic of the test complex is shown in Figure 1). The MUX was used in selecting the test parameter to be measured. The output of the multiplexer and a measurement-reference relay were directly connected to the input of a 5-1/2 digit auto-ranging Digital Multimeter (DMM). The BCD output of the DMM was hard-wired to the computer through a 32-bit parallel data input port. The light output of each LED was coupled through a fiber optic bundle to a specially



*Thermocouples, Power Supplies, etc.

Figure 1. Simplified schematic of test facility.

designed optical scanner which accurately positioned a calibrated photodetector (PD) in front of each bundle to measure the infrared radiation of each diode. The exact location of the photodetector was monitored by a potentiometer whose output was connected to one channel of the multiplexer. The output of the photodetector was amplified by a temperature compensated amplifier whose output was connected to another multiplexer channel by a coaxial cable. A 16-bit Relay Output Register controlled the scanner as well as the measurement-referencing relay.

The entire electrical system was protected against power failure by the automatic starting of a 20KVA diesel auxiliary generator which took approximately 12 seconds to come up to full power. During this power transition period, the LED's and their associated control electronics were powered by means of batteries connected in parallel with 5, 7, and 12-volt power supplies. Once the main power came back on line, the generator ran for a minimum of 10 minutes to insure a full charge of the 6 volt storage battery used to furnish transition LED current during power failure, and to charge the diesel start batteries.

An HP2100A computer was used as a controller for automatic data acquisition. A block diagram of the computer system used in the test is shown in Figure 2. This system had a Magnetic Tape Unit, high-speed paper tape reader and punch units, a Tektronix 4010 CRT terminal, and a teletype. Magnetic tape was used for the main storage of date, since it provides fairly rapid access to data for bulk processing. Paper tape was used for the back-up storage of data to safeguard against accidental erasure of the magnetic tape and is used by the client for additional processing of the data for his requirements. Special purpose assembly language Input/Output (I/O) routines were added permitting data to be punched on paper tape in compact binary format. The CRT terminal was used mainly for program development. The teletype printout of each computer run was used principally for trouble shooting diagnostics.

The following chapters discuss the design philosophy and details of the software program, including operational performance.

3.0 DESIGN OF COMPUTER SYSTEM

3.1 CHOICE OF LANGUAGE FOR CONTROLLING PROGRAM

Software developed for the HP2100A computer included two high level programming languages: HP FORTRAN and HP BASIC. Relocatable FORTRAN programs were produced using the HP FORTRAN Compiler under the HP BASIC

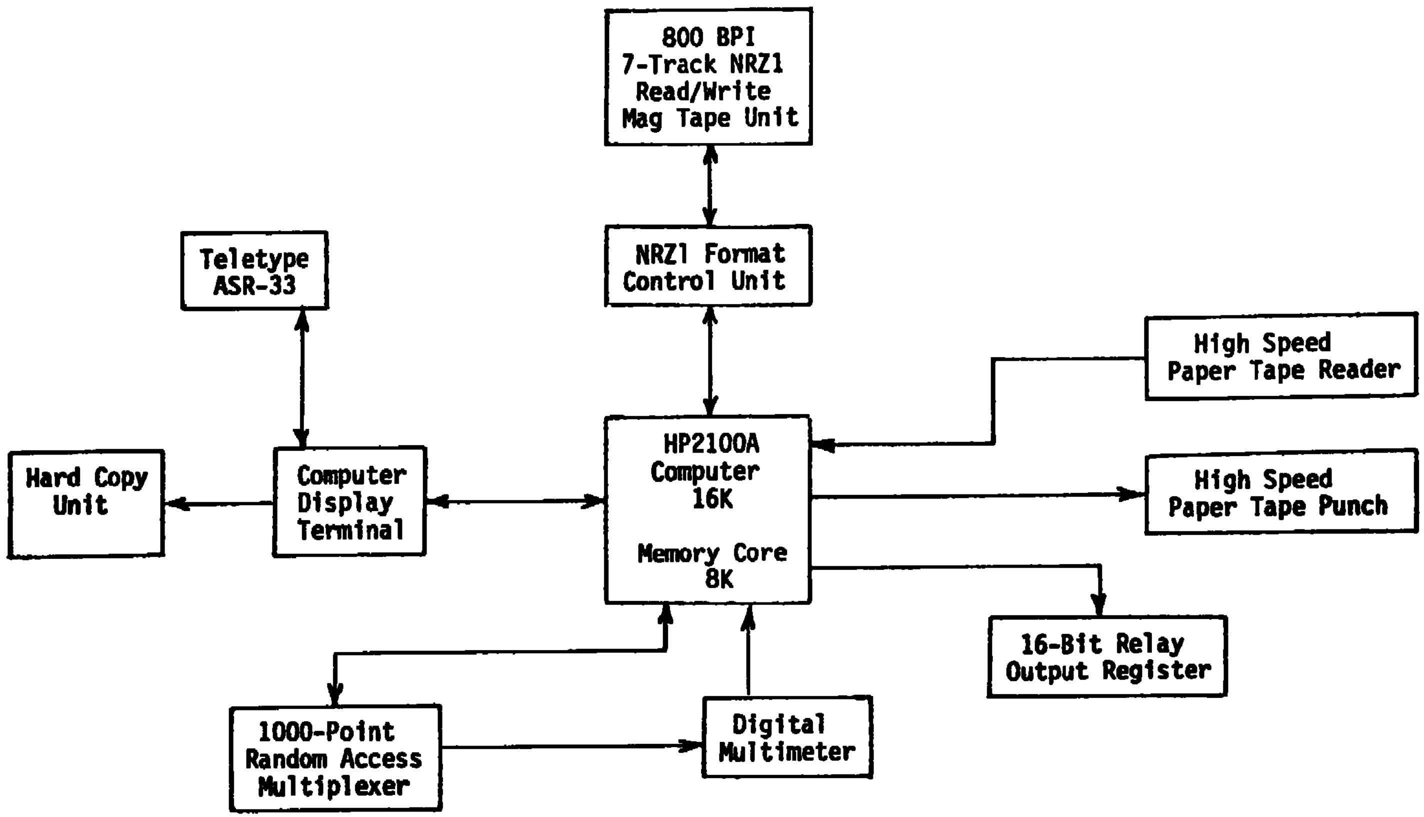


Figure 2. Block diagram of computer system.

Control System, whereas all BASIC programming was done under the BASIC Interpreter. A compiled program was translated into assembly language and then was assembled into machine language. Since this particular system had a two-pass FORTRAN Compiler. the intermediate results were punched on paper tape and reloaded. The BASIC Interpreter interprets and executes each statement without translation. As a general rule a compiled program can be created to operate with less memory; therefore, the final version can be executed more quickly. However, since an extra 8K of core memory had been previously added to the system, memory was not a critical factor in choosing a programming language. Neither was speed a critical factor, because the devices added to the system to acquire data were relatively slow. For example, the DMM through which all data passed required a quarter of a second to obtain a reading. The advantage of using the BASIC Interpreter was its ease for developing programs and altering these programs as the need arose. When a compiler is used, the entire compilation procedure has to be repeated to incorporate changes or corrections. Thus, for this particular system, BASIC was a better choice of high level language for the controlling program.

3.2 FRAMEWORK OF SPECIAL PURPOSE ASSEMBLY LANGUAGE I/O ROUTINES

In using BASIC, special purpose subroutines were added to the BASIC Interpreter to handle the special devices required for gathering data. Each of the four devices used in the measurements had a specialized purpose. The multiplexer was used to select the channel, and the Digital Multimeter was used for making all measurements. The Relay Output Register controlled the referencing of the DMM and the stepping of the Optical Scanner. The Optical Scanner positioned the photodetector to translate light output into a measurable voltage. The Optical Scanner had no direct connection with the minicomputer and thus did not need a special software routine.

Each special purpose subroutine controlled a particular function of each of the devices. One subroutine input a reading from the DMM to be returned to the controlling programs. Three subroutines were used for the Relay Output Register. One subroutine sent a number between 0 and 65, 535 to the Relay Output Register. Another changed the state of a single bit of the Register. The third input the current state of the Relay Output Register. This last routine was used mainly for checking the first two. Finally, two other subroutines were developed to control the multiplexer operation. One subroutine output a channel number to the multiplexer while the other input the previously selected channel setting. Complete listings of the subroutines appear in Appendix A.

The controlling program transferred control to the assembly language subroutine with a statement of the form "CALL" (subroutine number, parameter list). The BASIC Interpreter accessed the "called" subroutine through a subroutine table containing linkage information. Entries in the subroutine table, one per subroutine, were two words in length (16 bits per word). Bits 5-0 of the first word contained the number identifying the subroutine. Bits 15-8 contained the number of parameters passed to the subroutine. The second word contained the absolute address of the entry point of the subroutine. All entries in the subroutine table had to be contiguous, and, when subroutine entries were added, location 122_8 had to be redefined to contain the address of the last word + 1 of the subroutine linkage table. The subroutines were added in normally free space below the BASIC Interpreter in memory. To keep this area from being used for other purposes, the address of the last word + 1 of the last subroutine was stored in location 110_8 to indicate the first word of available memory (Ref. 1).

Prior to transferring control to the subroutine, BASIC evaluated the parameters and stacked the addresses of the results. Upon entering the subroutine, the A-register contained the address of this stack. A subroutine called ".ENTR" had previously been added to the Interpreter to transfer a maximum of four parameter addresses to an allocated space of memory. Calling ".ENTR" immediately after subroutine entry produced the twofold gain of freeing the A-register and decreasing the depth of indirect addressing. This method was used in all of the subroutines for the special devices.

3.3 1,000-POINT MULTIPLEXER

The random access multiplexer was interfaced to the HP computer via a Microcircuit Interface card (Figures 3 and 4). This interface card provided a 16-bit output register and a 16-bit input register for data transfers. A Device Command signal from the interface card enabled the multiplexer to perform its I/O operation. The interface card accepted a Device Flag signal from the multiplexer for a new channel, and the "standby" line was pulsed to reset the multiplexer. This line was connected to bit 15 of the output register of the interface card. The channel number (0-999) was output in packed 1248 BCD Format requiring only 12 bits. The Control Flip-Flop (FF) was set and the Flag FF was cleared. The reed relay settling time was clocked internally to the multiplexer, and a signal was returned which cleared the Control FF and set the Flag FF. After an output operation was completed (Flag FF was set), a readback input operation to check the present channel number could follow without further preparation. The input data was also in BCD format (Ref. 2).

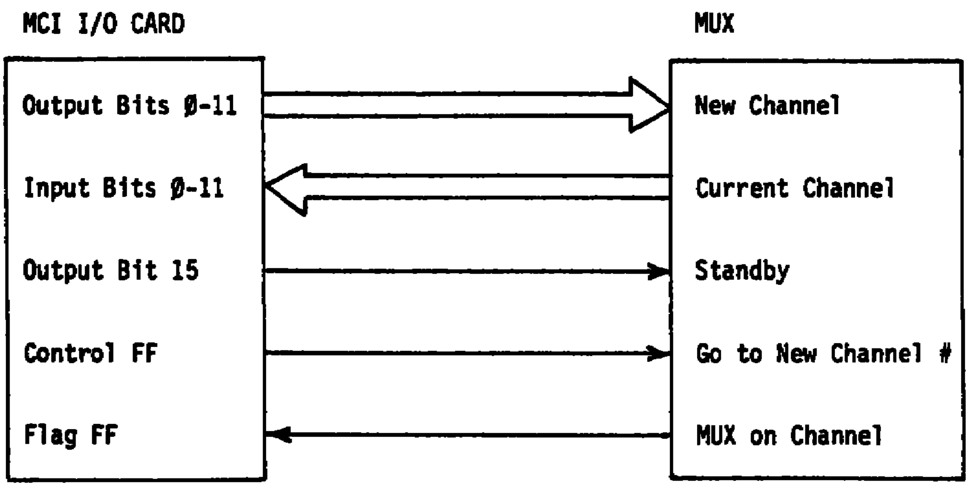


Figure 3. Block diagram of MUX.

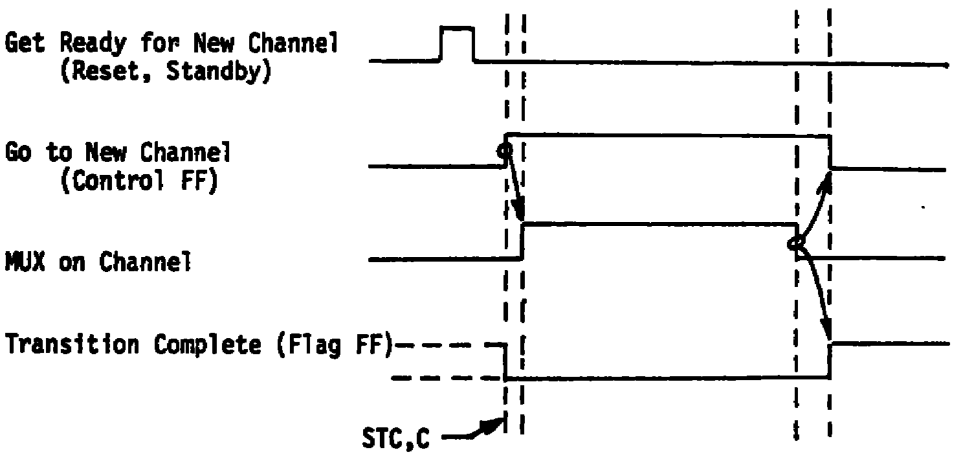


Figure 4. Control lines for MUX.

3.4 HEWLETT-PACKARD 16-BIT RELAY OUTPUT REGISTER

The Relay Output Register provided 16 low-current, single-pole, floating contact closures numbered K1 through K16 which could be used in combination or separately to control 1 to 16 devices. The Register had a maximum relay settling time of one millisecond. The 16 relays corresponded to 16 bits of the A- or B-register used for input or output by the computer. Relays were energized by logic "1" bits and de-energized by logic "0" bits output by the computer (Ref. 3). The correlation of the bits to the relays and their application in the controlling computer program is shown in Table 1. Bits 0 through 12 were unused.

Relays K16 and K15 were used to control high-current double-pole relays in the LED test complex. By energizing (or de-energizing) the single-pole relays, the circuit between the power supply and the corresponding double pole relays was opened (or closed), thus determining their state. Relay K14 was energized for a certain length of time, controlled by the calling program, in order to activate and send a pulse of current through a high-current single-pole relay to the Optical Scanner stepping motor (forward or reverse motor action) selected by K15. This pulse caused the stepping motor to move the scanner one position (15 deg). Figure 5 is a simplified schematic of the circuitry of the operational relays when in computer mode. Manually operated switches (not shown in Figure 5) controlled the functions of K14, K15, and K16 when the system was in manual mode. When the system was in computer mode, all relays of the LED test complex were controlled through a single assembly language subroutine.

Table 1. Correlation and Functions of Register Bits

Bit No.	Reference	Purpose	State "0"	State "1"
15	K16	Voltmeter Reference	Common	+7V
14	K15	Direction of Mechanical Scanner Stepping	Forward	Backward
13	K14	Step Scanner	End Pulse	Start Pulse

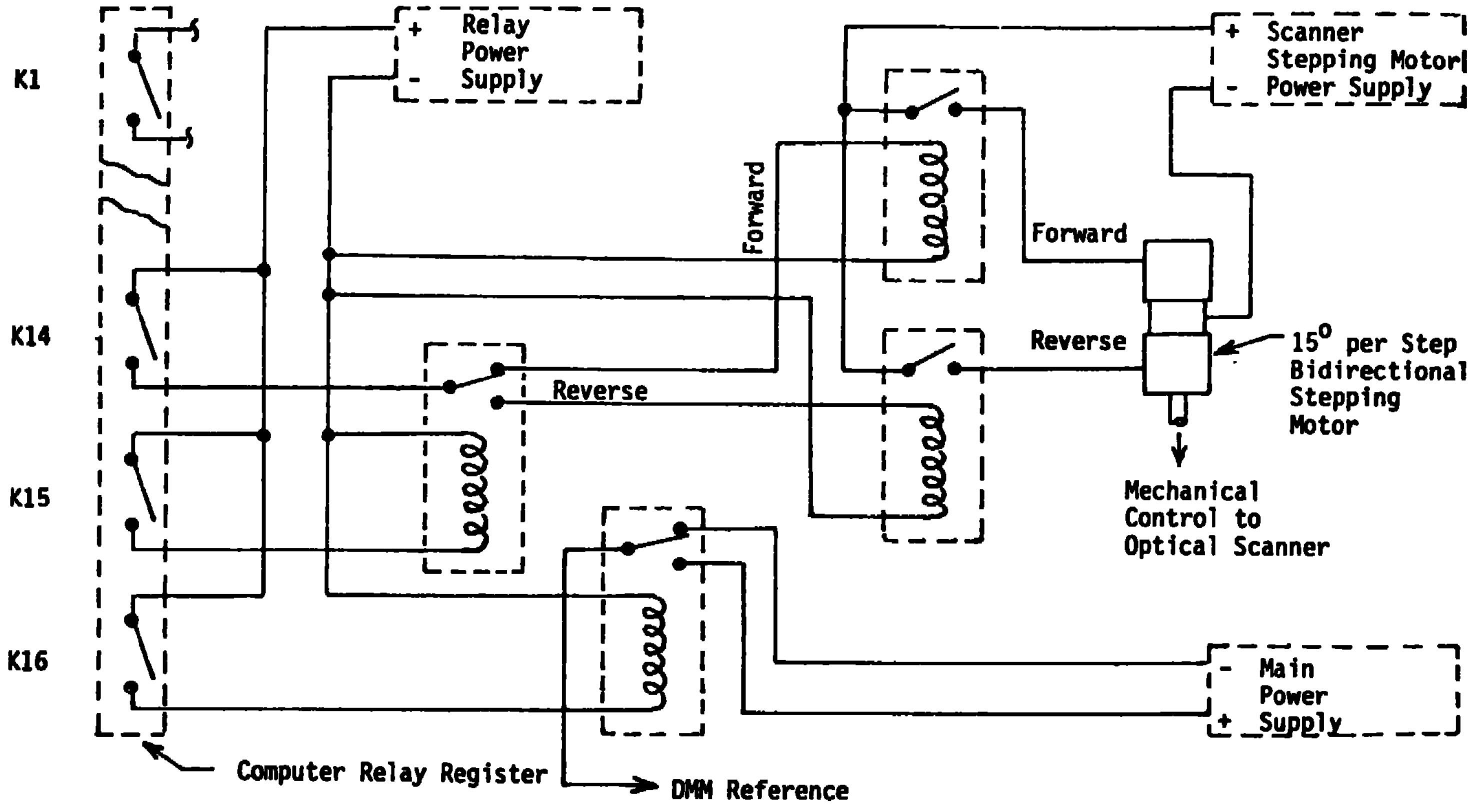


Figure 5. Simplified schematic of operational relays.

3.5 DIGITAL MULTIMETER

In the LED test complex, the 5-1/2 digit Digital Multimeter was always used as a voltmeter in the auto-ranging mode. The Digital Multimeter was interfaced to the HP2100A through an HP Data Source Interface (DSI) card to transfer up to 32 bits into the HP computer. The data lines from the DMM to the DSI card, as shown in Figure 6, remained unchanged until a request for another reading was made. The Control FF was used to signal a request, and the Flag FF was used to signal its completion. The states of the Control FF during a request for an updated reading were as shown in Figure 7. The computer initiated a request by setting the Control FF and clearing the Flag FF, causing the Busy line to be set. The Busy line remained high until a new reading was completed and the data lines had been changed accordingly. When the Busy line was cleared, the Control FF was cleared and the Flag FF was set, signalling to the computer that the updated data were ready to be input. The computer then loaded in the data words of 16 bits each. The first word transferred contained the least significant bits (0 through 15), and the second word contained the most significant bits (16 through 31) (Ref. 4).

The DMM presented the magnitude of the measurement in integer BCD format with a sign bit as shown in Figure 8. If the sign bit was logic "1," the reading was negative. A range code was included in the data to determine the proper placement of the decimal point (see Table 2). Adjustment of the decimal point was done in the assembly language subroutine before returning to the calling program. The overrange bit was set as a result of an overload condition. This bit was always checked first because if it was logic "1," the range code as well as the sign and magnitude specified a meaningless reading. Software returned a range code of "7" to the controlling program to signal this condition. This occurred whenever a reading required a range larger than the one last used. The DMM automatically stepped to the next range, but software had to command a new reading. To verify that the DMM had completed "auto-ranging," the controlling program required two consecutive readings with the same range code before checking the stability of the readings.

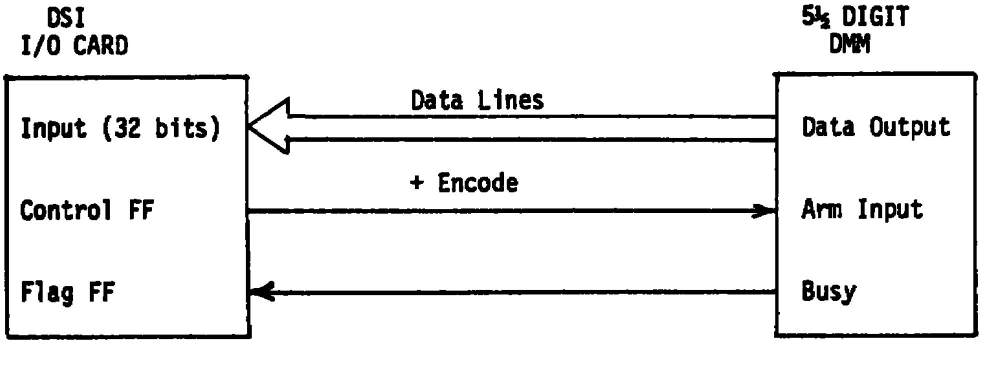


Figure 6. Block diagram of DMM interface.

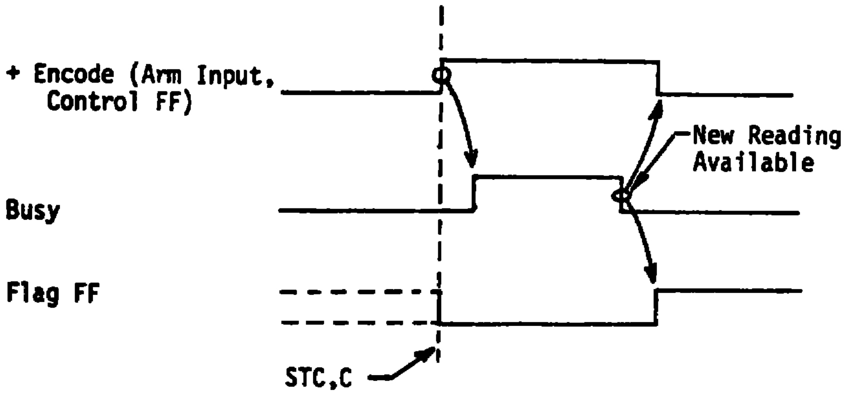


Figure 7. Control lines for DMM.

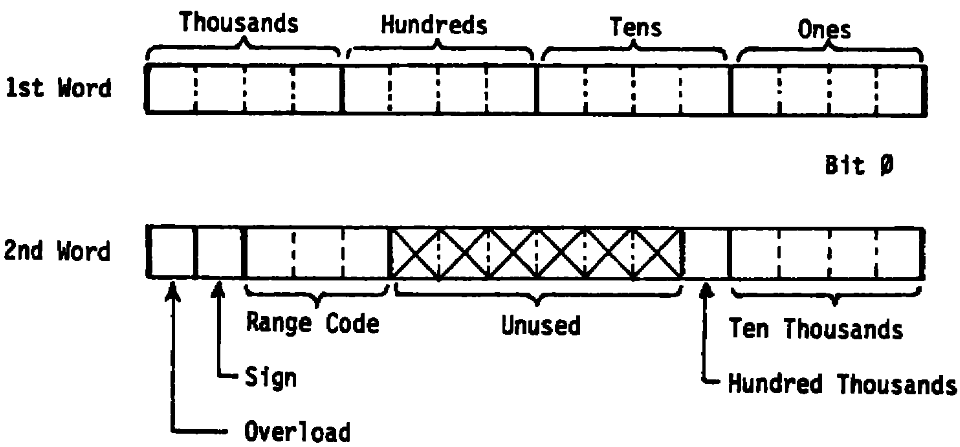


Figure 8. Format of data from digital multimeter.

Table 2. Range Codes.

Range Code	Range	Maximum
1	200MV	.199999V
2	2V	1.99999V
3	20V	19.9999V
4	200V	199.999V
5	1200V	1199.999V

3.6 OPTICAL SCANNER

The Optical Scanner. also called mechanical scanner, operated with a bidirectional stepping motor which positioned a photodetector on the inside of the scanner bonnet to measure light output. Each step moved the photodetector 15 deg in a spiral fashion. After 24 steps the photodetoctor had been raised 0.2 inches. The fiber optic bundles were fitted to the fiber optic terminal strips on 0.4-inch centers attached vertically around the scanner bonnet. These terminal strips were aligned in such a way that each level of fiber optic bundles corresponded to one revolution of the photodetector. This left alternating levels of 24 steps as "blanks," where no measurements were made. The scanner bonnet was sealed so that no outside light could enter and reflect internally to interfere with the measurement by the photodetector. The photodetector output was amplified before being sent through a multiplexer channel to the digital voltmeter.

The position of the photodetector was measured using a potentiometer operated by the scanner stepping motors. The potentiometer was set so that the position of the first light reading registered zero volts. The span of the potentiometer was set before each computer run so that each step of the scanner caused a change in potential of approximately 50 millivolts: normally variation was from 45 to 55 millivolts during a single run. This fluctuation would create an accumulative error if one tried to define a given position of the scanner as a set voltage. To avoid this accumulative error. the diode measurements were taken in the order in which the diodes were fitted around the scanner. After each step, the change of potential was checked to insure that one and only one step had been taken. and that the voltage reading was within an acceptable tolerance level.

4.0 MEASUREMENT OF DATA

The main purpose of the controlling program was. of course, to automate the acquisition of data; however, for this test the program had a second purpose which is equally important: that is, the systematic retrieval of data. The type of information as well as its source had to be identified and treated accordingly. For this purpose. the controlling program was divided into three main sections. The first task of the controlling program, as shown in the generalized flow chart of Figure 9, was to position the Magnetic Tape. Operator intervention was required to specify whether a new reel was to be used and to verify the position of the tape if not. The program then entered the first main section. which measured the parameters affecting all or a large portion of the diodes. Briefly, the procedure included a preliminary system check and a check of the heat sink temperatures and potentials. The program then proceeded to prepare for the

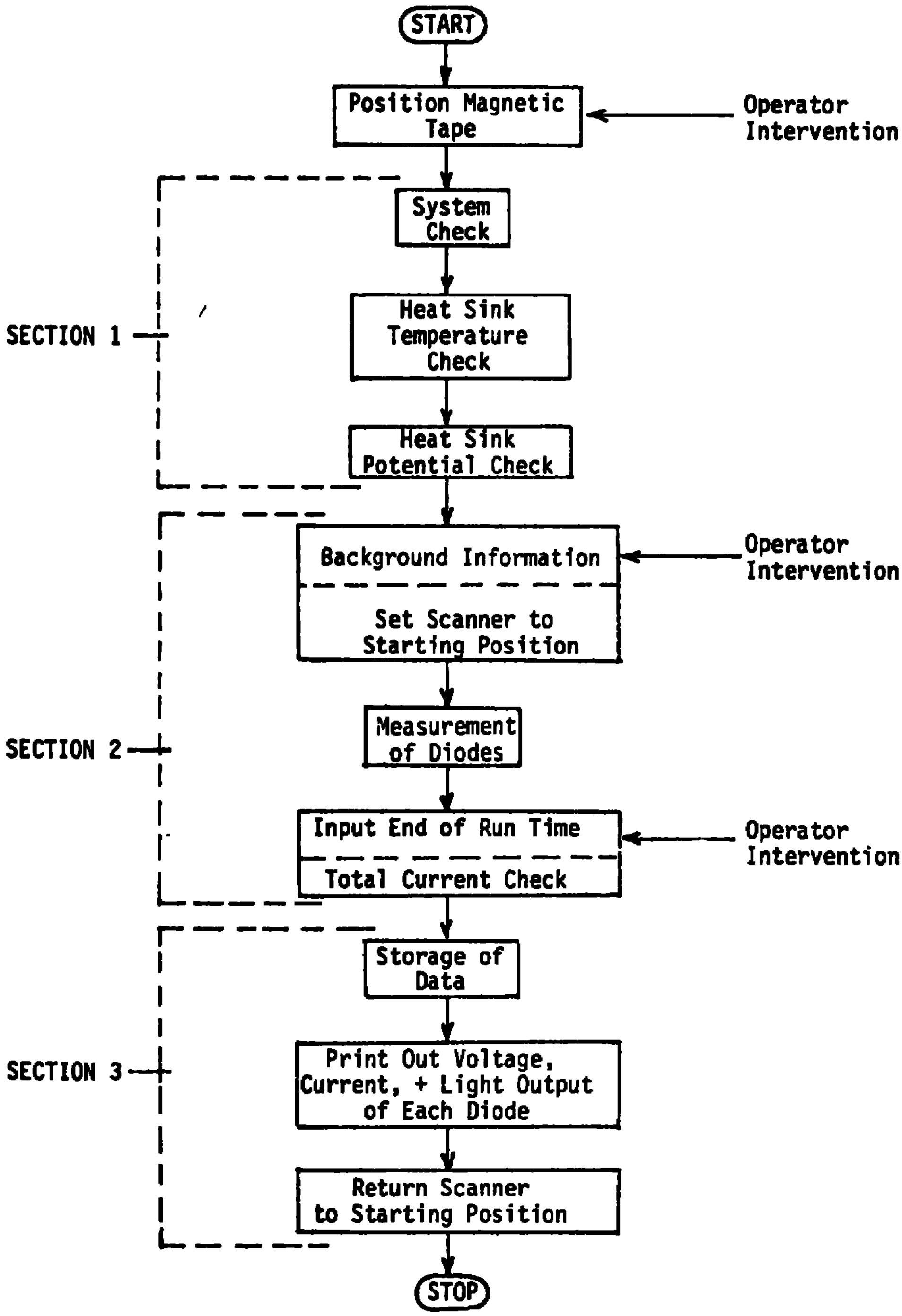


Figure 9. Generalized flow chart of controlling program.

diode parameter measurements, which constituted the second main section. Operator intervention was required to enter the time and date at the start of the diode measurements and the reading of the Run Time Meter (RTM). The scanner was positioned backward to take a background light reading before being stepped forward to take all diode data. The information concerning the individual diodes was gathered and stored in arrays. At the close of this section operator intervention was again required to enter the RTM, and the section ended with the printing of the total time required to measure the diode parameters, the sum of their currents, and the total current drawn by the system. The third section of the program stored the data on the appropriate devices after all measurements had been completed. All data was first stored on magnetic tape and paper tape, and finally the voltage. current, and light output of each diode were printed out on the Teletype. The program then returned the Optical Scanner to its starting position, in preparation for another run. The three main sections of the program are discussed more fully below.

4.1 SYSTEM CHECK

The first measurements taken by the computer program comprised a preliminary system check. Power supplies, back-up power supplies, and an auxiliary storage battery were checked. The total current drawn by the system, the span setting of the optical scanner, and the potential of the optical scanner were checked. A variation of ±5% from the expected values. or 1 millivolt in the case of the optical scanner potential, caused an error message to be printed. The program could then be halted if the situation warranted.

The next step in measurement dealt with the individual heat sink temperatures. Thermocouples were used to measure the temperature of each heat sink in proportional volts which were then translated into degrees Celsius. A 150°F thermocouple reference was used, resulting in an offset of -2.709×10^{-3} volts which had to be subtracted before a conversion equation based on zero temperature (Celsius) registering zero volts could be applied. The conversion equation required millivolts as a parameter, and thus a preliminary conversion of volts to millivolts was necessary. Given V1 as the measured voltage the conversion to degrees Celsius was as follows:

$$V3 = 1.000 \times (V1 - 2.709 \times 10^{-3})$$

$$T = 3.01361 \times 10^{-4} \times (V2^5) - 5.62523 \times 10^{-3} \times (V2^4)$$

$$+ 6.48804 \times 10^{-2} \times (V2^3) - 0.805664 \times (V2^2)$$

$$- 25.9697 \times (V2) + 2.27051 \times 10^{-2}$$

The latter equation was obtained by a least square curve fit (Ref. 5) on a millivolt-temperature conversion table. Great accuracy was not needed since there were a number of operating diodes on a heat sink rack that resulted in a varying heat source. The measured temperature was used more as an indicator than as an absolute monitor for adjusting the chamber temperature. The potentials of the heat sinks were then checked. The relay register set the reference according to whether the heat sink was anode or cathode common.

4.2 DIODE CURRENT AND VOLTAGE MEASUREMENT

Each diode was located in a heat sink bar containing a maximum of 17 positions. The heat sinks were made of a heavy bar of copper so that each heat sink portion would have essentially the same temperature equivalent potential. Each diode was connected to a terminal strip outside its environmental chamber with a 20-inch length of 20 gauge stranded wire. The voltage drop due to the wire resistance was used in the final calculation of the forward voltage of each diode. The current to each diode was measured at the point where it entered the chamber by measuring the voltage drop across a nominal 2-ohm sense resistor in series with the diode. The resistance of each sense resistor was measured to an accuracy of three decimal places prior to the test. These values were stored in the computer memory to permit precise current determination.

The potential of each heat sink bar was measured during each data run and indexed to all diodes mounted on that particular bar. These measurements were completed before any diode data measurements were begun. Data for each diode were then taken sequentially to relate the voltage, current, and light output measurements of the diodes closely in time.

Since the setup for each diode was identical, the procedure for taking data and performing the necessary calculations was the same. The potential of the heat sink (V1), as shown in Figure 10, was measured and stored at the start of each run. The potential on the side of the sense resistor nearest the diode (V2) was then taken. This potential included the voltage drop due to the connecting wire resistance (R2), the diode, and the heat sink. The potential on the other side of the sense resistor (V3) was then measured. The difference of V3 - V2 was the resistor potential drop. This difference, divided by the resistance of the sense resistor (R1), gave the current passing through the diode. The voltage across the diode (E_f) was then calculated by taking V2 and subtracting the potential drop caused by the connecting wire [(V3 - V2) x (R2/R1)] plus the heat sink potential (V1). The light output was then measured, as described in Chapter II, Section 6, and the Optical Scanner was positioned for the next diode.

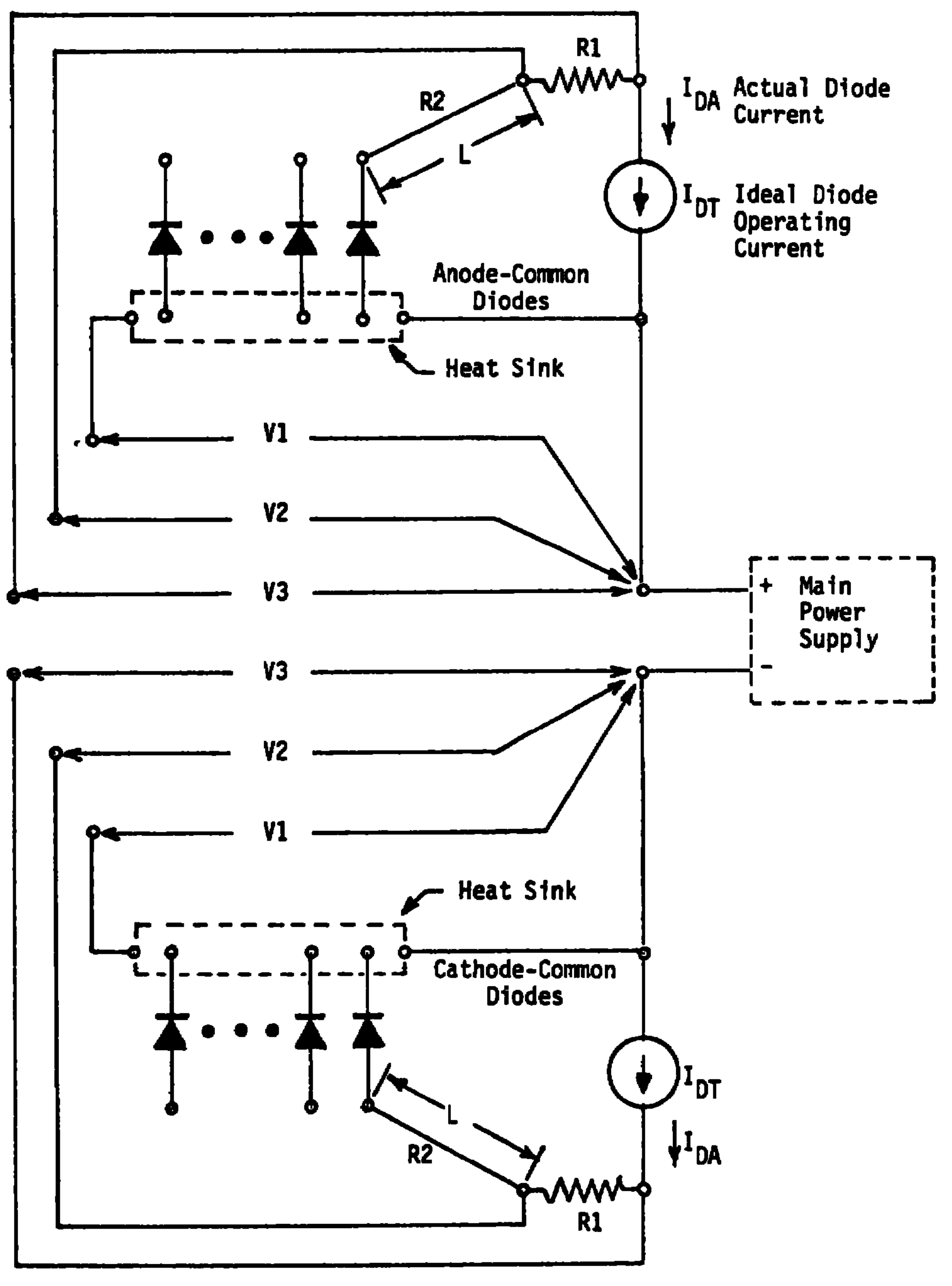


Figure 10. Setup of LED's.

All diodes were not common referenced; therefore, the relay register has to be reset before proceeding to an anode common heat sink bar. The heat sink bars were numbered in the order in which their voltages were measured. A data array indexed the array of heat sink voltages and stored the reference voltage for each diode.

Only two voltage measurements (in addition to the heat sink potential) were needed to determine the voltage and current for each diode. The light output of each diode was measured through a common multiplexer channel which connected the output of the light amplifier to the DMM. Thus, only the MUX channel numbers for the two voltage measurements, the scanner position, and the light amplifier were required for each diode data point. Although the two voltage channel numbers were consecutive, the first channel number of the pair was not in the same order as the diodes were scanned. For this reason, another array stored the first channel number for each diode to obtain proper ordering.

Overall, for the acquisition of diode data, only three data arrays stored in the program were necessary. These were 1) the heat sink number, 2) the first channel number of the sense resistor, and 3) resistance of the sense resistor for each diode. Another array was added which contained the required current of each diode for comparison with the measured value. Each diode was to be maintained within 0.5% of its required current. As the diodes were checked, any current variations out of tolerance were printed on the teletype so that manual adjustment of the current could take place at the end of the data run. Since diode currents which had dropped below 50% of the set-point could not be adjusted back within tolerance, the current values of these diodes were printed out only at the end of the run.

Figure 11 is a flow chart of the section of the controlling program which gathered the data from the individual diodes. This section refers to two subroutines, the DMM subroutine and the scanner subroutine, whose flow charts appear in Figures 12 and 13, respectively. Before this section of the controlling program was entered, a background reading of light output had been taken and the scanner had been positioned for the first diode's light output measurement.

As previously mentioned, the scanner skipped alternate rows of 24 steps. For this purpose, a counter (F3) determined when the end of a row had been reached. R1 was the resistance of the wire connecting each diode to its respective sense resistor. The variable I was a counter for the diodes and was used for indexing the data arrays. By clearing the Relay Register at the beginning of each loop through this section, the DMM was set for negative reference and the scanner was set for forward motion. Alterations to the Relay Register were made one bit at a time when necessary.

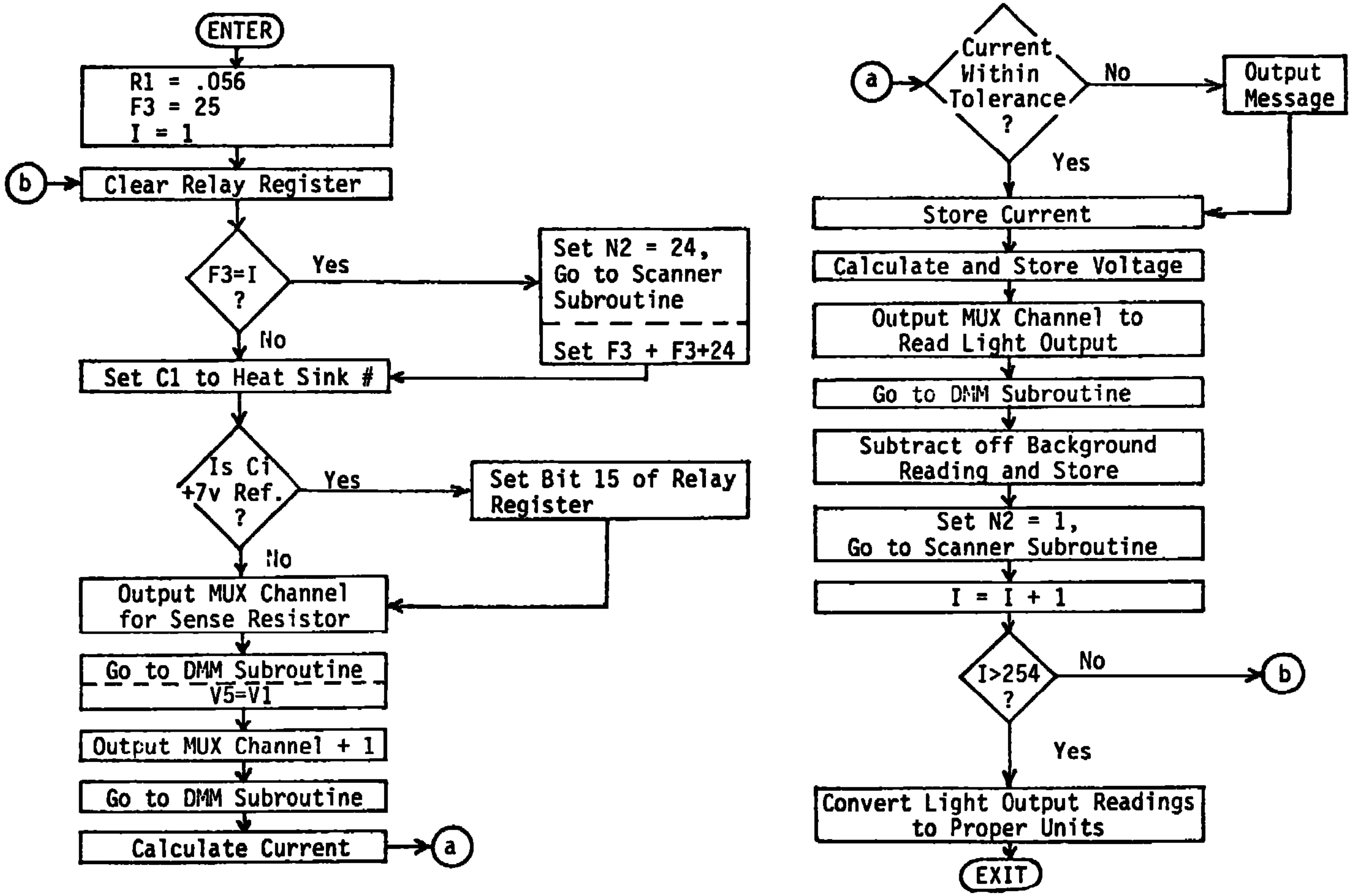


Figure 11. Flow chart of diode measurement section.

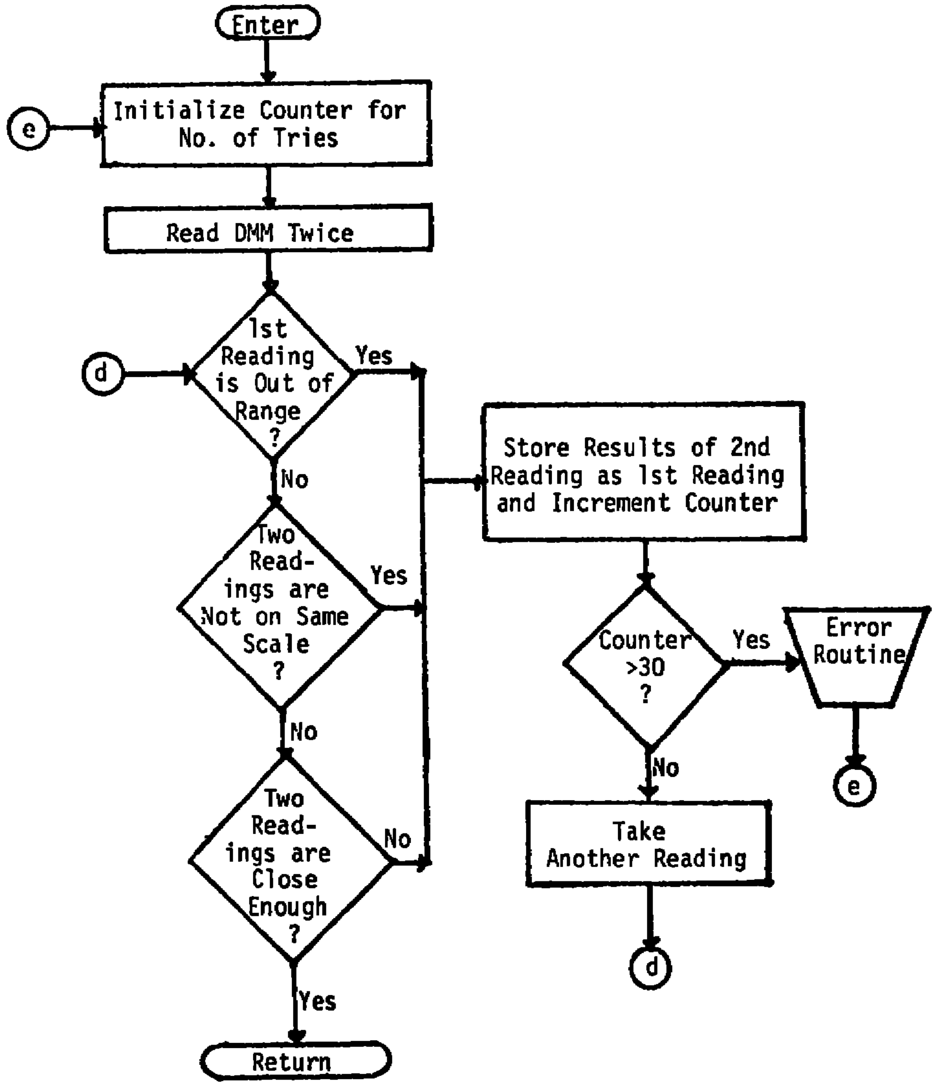


Figure 12. Flow chart of DMM subroutine.

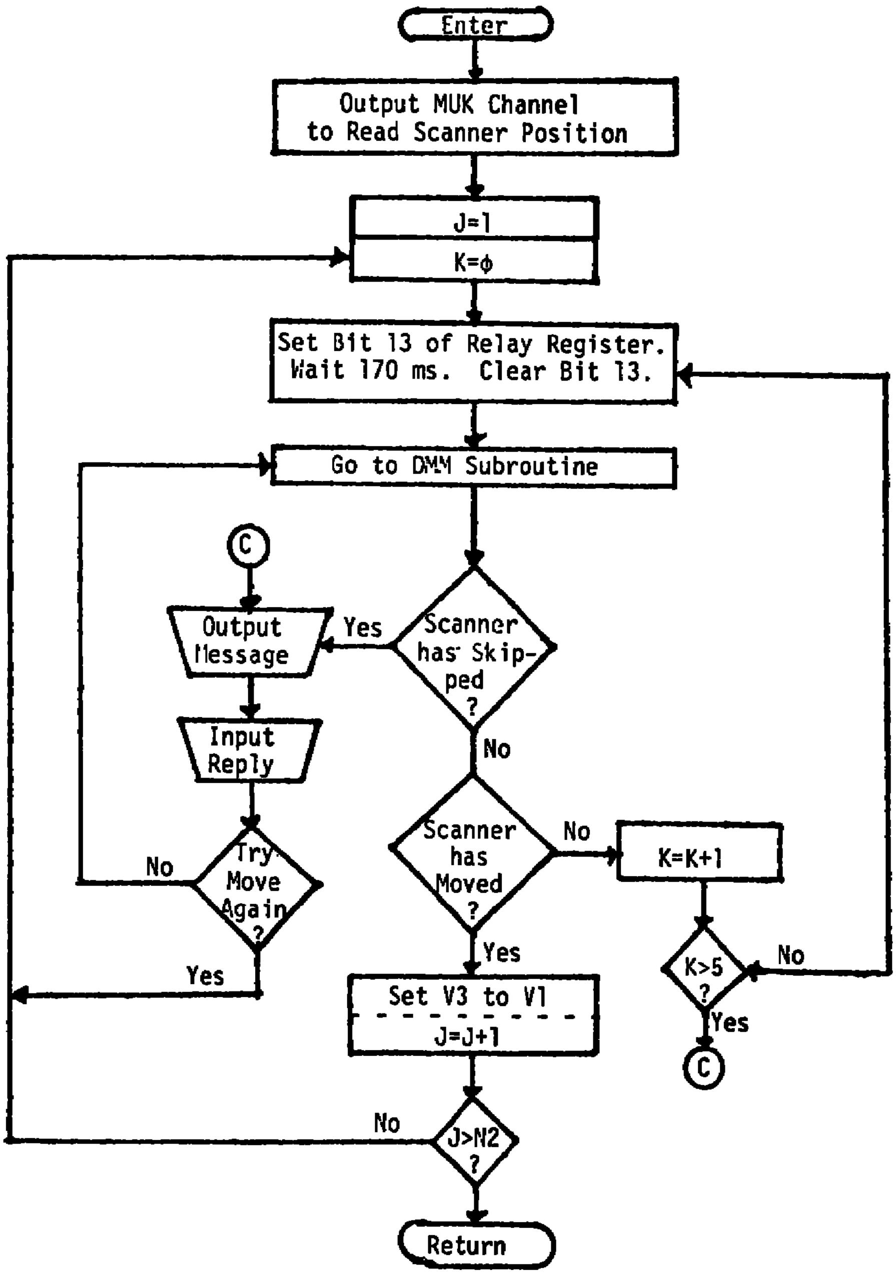


Figure 13. Flow chart of scanner subroutine.

The DMM subroutine was used to acquire a stable DMM reading and return the result in V1. Before a measurement was acceptable, the difference between two consecutive readings had to be less than 0.1% or less than 0.1 millivolt. If either of these conditions was not met, successive measurements were made until the conditions were met or until a nominal number of measurements had been made and operator intervention was required.

The scanner subroutine moved the Optical Scanner into position in the direction determined by the main program. Before this subroutine was entered for the first time, the position voltage of the scanner was measured and stored in V3. Therefore, V3 was set to the last measured voltage by this subroutine, to determine whether the scanner had moved or had skipped a position. If the scanner failed to move after five attempts or if the scanner skipped a position, an error message was printed noting the type of error, the present voltage, and the last measured voltage of a successful "move" command. With this information, the operator could make the proper adjustments for the program to continue.

The program variable J was used as a counter for the number of moves completed, and K was used as a counter for the number of attempts per "move" command. The DMM subroutine returned the position voltage as V1.

4.3 STORAGE OF DATA

All data taken in the computer program was stored on magnetic tape and paper tape, as follows:

1. Time and date at start of run.
2. Results of preliminary system check.
3. Temperature of heat sinks.
4. Voltages of heat sinks.
5. Voltage of each diode.
6. Light output of each diode.
7. Current of each diode.
8. Scanner position voltage for each diode.
9. Fiber optic data.

With the exceptions of 2, 4, and 8, all of this information was printed at some point in the computer run. Thus, visual checking could be accomplished as the program progressed. A complete printout of voltage, current, and light output for each diode with the corresponding diode numbers was provided at the end of the run.

The magnetic tape was positioned at the beginning of the run. If the operator designated that a new tape had been loaded, a filemark was placed on the tape and the program proceeded to take data. The data written on tape was followed by two filemarks. If the program objective was to find the last file on an existing data tape, it proceeded to skip a filemark and read a data point, repeating this process until it encountered a filemark instead of a data point. As a check, the program moved the tape to the last written file, read the first record, and printed the time and date of the last run so that the operator could be sure that the last file had been found. The tape was then positioned so that the second of the double filemarks would be written over. Data was written on magnetic tape and punched on paper tape after all measurements were completed. Data was stored in a common block of memory until being stored on tape. If the program was halted or an error occurred on both the magnetic tape and paper tape punch unit, data could still be recovered since the location of this memory block was known.

5.0 CONCLUSIONS

The LED test program successfully completed the 6,000 hour run with few minor complications. The total time required to take each set of measurements on 254 diodes was approximately 33 minutes. The major portion of this time was consumed in positioning the Optical Scanner. The data acquisition time could have been shortened, but since the computer-controlled system operated smoothly as the program existed, alterations were not deemed necessary. Manual operation of the system provided an easy means for checking computer-controlled data and for evaluating system reliability. Having all data acquisition under computer control made it possible to obtain more information in a given period of time than could ever have been possible by manual means. This was a necessary criterion since some LED's exhibited peculiar behavior during the first 200 hours of the test program. Under normal manual measuring conditions these peculiarities in performance would not have been observed. Having the data stored in a form accessible by the computer greatly facilitated analysis of the data.

REFERENCES

1. HP BASIC. Hewlett-Packard, Cupertino, California, 1970 (Third Edition).

2. 500/100 Channel Datareed Scanner: D-A-012501. A. D. Systems, Inc., Rochester, New York.

3. 16-Bit Relay Output Register. Instruction Set for 12551B and 12551B-001 Interface Kits. Hewlett-Packard, 1970.

4. Instruction Manual for Model 8800A Digital Multimeter. John Fluke Mfg. Co., Inc., Seattle, Washington, 1974.

5. FORTRAN IV Language for IBM System 360. IBM Corp., New York, 1968, pp. 109-115.

6. Finkel, Jules. Computer-Aided Experimentation: Interfacing to Minicomputers. John Wiley & Sons, Inc., New York, 1975.

APPENDIX A
SPECIAL PURPOSE ASSEMBLY LANGUAGE ROUTINES

The following material is a listing of the special purpose assembly language "CALL" routines added to the BASIC Interpreter to handle the Digital Multimeter (voltmeter), the 16-bit Relay Output Register, and the multiplexer. Parameters being sent to the devices were first checked for acceptability and then placed in the format suitable to the device. All parameters transferred from the devices to the calling program were placed in floating-point doubleword format. Each routine has a preface describing the routine's function and its parameters.

```
*
**
**     C A L L ( 6 , V , R )
**
**      SUBROUTINE TO INPUT VOLTMETER READING
**
**      WHERE V IS THE VOLTMETER IN VOLTS WITH SIGN.
**              ( MEANINGLESS IS R = 7 )
**       AND R IS THE RANGE CODE .
**
**           RANGE CODE            RANGE
**         ---------------      -----------
**                1               200 MV
**                2                 2 V
**                3                20 V
**                4               200 V
**                5              1200 V
**                6                 N/A
**         ------------------------------------
**                7             OVERRANGE
***
*
 14175 000000   CALL6 NOP
 14176 014030         JSB .ENTR
 14177 064432         LDB M2
 PAGE 0021 #01
```

```
14200 076255    STB SIGN        SET SIGN = -2
14201 103711    STC VMIO,C       VOLTMETER I/O
14202 102311    SFS VMIO        DELAY UNTIL
14203 026202    JMP *-1            INPUT COMPLETE
14204 102511    LIA VMIO
14205 014044    JSB CONV        CONVERT BCD TO FLT. PT. BINARY
14206 104400    DST VOLTS
14207 014257
14210 102511    LIA VMIO
14211 002020    SSA
14212 026250    JMP OVRNG       OVERRANGE IF BIT 15 = 1
14213 071734    STA COPY
14214 001200    RAL             CHECK SIGN BIT 14
14215 002021    SSA,RSS         IF SIGN BIT = 0 ,
14216 036255    ISZ SIGN           SET SIGN = -1 .
14217 001700    ALF
14220 010331    AND D7          ISOLATE RANGE BITS
14221 072253    STA RANGE
14222 105120    FLT
14223 104400    DST PARA2,I     STORE FOR RETURN
14224 100074
14225 062255    LDA RANGE
14226 040437    ADA M7          TO BE USED
14227 072255    STA RANGE             AS COUNTER
14230 061734    LDA COPY
14231 010344    AND .31         ISOLATE LAST FIVE BITS
14232 014044    JSB CONV
14233 105340    FMP TNTHD       MULTIPLY BY 10,000 (DEC)
14234 014263
14235 105000    FAD VOLTS
14236 014257
14237 036255    ISZ SIGN        IF SIGN + 1 = 0 , SKIP .
14240 114242    JSB ARINA,I       NEGATE VOLTS
14241 105060    FDV FLT10       DIVIDE BY 10.0 TO
14242 014261
```

```
1006   14243 036253          ISZ RANGE          ADJUST SCALE .
1007   14244 026241          JMP *-3
1008   14245 104400          DST PARA1,I
       14246 100373
1009   14247 125175          JMP CALL6,I
1010   14250 060331    OVRNG LDA D7
1011   14251 105120          FLT
1012   14252 104400          DST PARA2,I
       14253 100374
1013   14254 125175          JMP CALL6,I
1014*
1015   03437           M7    EQU 437B         MINUS 7
1016   03344           .31   EQU 344B         DECIMAL 31
1017   01734           COPY  EQU 1734B        TEMP STORAGE
1018   14255 000000    RANGE BSS 1
1019   14256 000000    SIGN  BSS 1
1020   14257 000000    VOLTS BSS 2
1021   14261 050000    FLT10 DEC 10.
       14262 000010
1022   14263 047040    TNTHD DEC 10000.
       14264 000034
1023   00011           VMIO  EQU 11B          VOLTMETER SELECT CODE
 PAGE 0022 #01

1056*
1057***
1058**          C A L L ( 8 , N )
1059**
1060**     ROUTINE FOR RELAY OUTPUT REGISTER
1061**     CAN HANDLE INTEGER FROM ZERO TO 65,535 (DEC.)
1062**     USES REG. A OR B FOR INPUT AND OUTPUT
1063**
1064**     N DESIGNATES DESIRED RELAY OUTPUT
1065***
1066*
```

```
14312 000000  CALL8 NOP
14313 014030        JSB .ENTR
14314 104200        DLD PARA1,I
14315 100373
14316 002020        SSA               IF PARA1 IS < 0 ,
14317 125752        JMP ERR1,I                OUT OF RANGE .
14320 105020        FSB MAXLM
14321 014346
14322 002021        SSA,RSS           IF PARA1 IS > 65,535 ,
14323 125752        JMP ERR1,I                OUT OF RANGE .
14324 105000        FAD LIMIT
14325 014350
 PAGE 0023 #31

14326 002020        SSA               IF PARA1 IS < 32,768 ,
14327 026333        JMP AGAIN                 BRING BACK ORIG. QUANTI
14330 105100        FIX
14331 030470        IOR BIT15
14332 026336        JMP OUTIT
14333 105000  AGAIN FAD LIMIT
14334 014350
14335 105100        FIX
14336 016340  OUTIT JSB RLOUT         RELAY OUTPUT ROUTINE
14337 126312        JMP CALL8,I
*
14340 000000  RLOUT NOP               RELAY OUTPUT ROUTINE ENTRY
14341 102621        OTA RELAY
14342 064460        LDB M256           MINUS 256 (DEC)
14343 034001        ISZ 1              DELAY 1.26 MILLISECONDS
14344 026343        JMP *-1               FOR RELAY TO BE COMPLETE
14345 126340        JMP RLOUT,I
*
00021         RELAY EQU 21B           RELAY REGISTER SELECT CODE
14346 040000  MAXLM DEC 65536.        = 2 ^ (16)
```

```
      14347 000042
1095  14350 040000  LIMIT DEC 32768.     = 2 ^ (15)
      14351 000040
1096*
1097***
1098**              C A L L ( 9 , B , V )
1099**
1100**        SUBROUTINE TO OPERATE ANY RELAY INDIVIDUALLY
1101**         WITHOUT ALTERING ANY OTHER RELAY .
1102**
1103**        SETS BIT B RELAY TO STATE V ON RELAY OUTPUT CARD.
1104**
1105**        IF V = 0 , BIT IS SET TO LOGIC 0 .
1106**        OTHERWISE , BIT B IS SET TO LOGIC 1 .
1107**
1108**        B MUST BE BETWEEN 0 AND 15 INCLUSIVE .
1109***
1110*
1111  14352 000000  CALL9 NOP
1112  14353 014030        JSB .ENTR
1113  14354 104200        DLD PARA1,I
      14355 100373
1114  14356 002020        SSA               IF B < 0 ,
1115  14357 125752        JMP ERR1,I                 OUT OF RANGE .
1116  14360 105100        FIX
1117  14361 072036        STA TEMP
1118  14362 040445        ADA M16
1119  14363 002021        SSA,RSS           IF B > 15 ,
1120  14364 125752        JMP ERR1,I                 OUT OF RANGE
1121  14365 062036        LDA TEMP
1122  14366 003004        CMA,INA           USE AS COUNTER FOR ROTATION
1123  14367 006404        CLB,INB           SET REG. B = 1 .
1124  14370 002024        SSA,INA
1125  14371 005200        RBL
1126  14372 002024        SSA,INA
```

```
1127  14373 026371          JMP *-2
1128  14374 076036          STB TEMP
 PAGE 0324 #01

1129  14375 104200          DLD PARA2,I
      14376 100374
1130  14377 002020          SSA                 IF V < 0 ,
1131  14400 114242          JSB ARINA,I              NEGATE .
1132  14401 105100          FIX
1133  14402 066036          LDB TEMP
1134  14403 002002          SZA
1135  14404 026411          JMP OR
1136  14405 007000          CMB
1137  14406 102521          LIA RELAY
1138  14407 010001          AND B
1139  14410 026413          JMP ROUT
1140  14411 102521    OR    LIA RELAY
1141  14412 030001          IOR B
1142  14413 016340    ROUT  JSB RLOUT           JUMP TO RELAY OUTPUT ROUTINE
1143  14414 126352          JMP CALL9,I
1144*
1145  00445           M16   EQU 445B
1146*
1147***
1148**                C A L L ( 10 , N )
1149**
1150**         RETURNS THE CURRENT STATE OF THE RELAY
1151**           OUTPUT CARD IN N .
1152***
1153*
1154  14415 000000    SB10  NOP
1155  14416 014030          JSB .ENTR
1156  14417 006400          CLB
1157  14420 102521          LIA RELAY
```

```
      14421 002020           SSA
      14422 026427           JMP MASK
      14423 105120           FLT
      14424 104400           DST PARA1,I
      14425 100073
      14426 126415           JMP S310,I
      14427 010422    MASK   AND INF          INF = 77777B
      14430 105120           FLT
      14431 105000           FAD LIMIT
      14432 014350
      14433 104400           DST PARA1,I
      14434 100073
      14435 126415           JMP S310,I
*
***
*
*                 MULTIPLEXER  ROUTINES                    *
*
*       CALL(11,C)  SETS MULTIPLEXER TO CHANNEL C          *
*
*       CALL(12,C)  RETURNS CURRENT CHANNEL SETTING        *
*
*
      14436 000000    MPXR1  NOP
      14437 014330           JSB 303          FETCH CHANNEL NO.
      14440 060470           LDA MNEG         SET SIGN BIT
      14441 102616           OTA MPXIO          PULSE THE "STANDBY"
 PAGE 0025 #01

      14442 060445           LDA DELAY             LINE TO
      14443 002006           INA,SZA                 RESET THE
      14444 026443           JMP *-1                   MULTIPLEXER .
      14445 102616           OTA MPXIO        OUTPUT ZERO
      14446 104200           DLD PARA1,I
```

```
14447 103373
14450 015753       JSB 1753B      BINARY(FLT) TO BCD
14451 103516       OTB MPXIO
14452 103716       STC MPXIO,C
14453 102316       SFS MPXIO
14454 026453       JMP *-1
14455 126435       JMP MPXR1,I
*
14456 000000 MPXR2 NOP
14457 014030       JSB 30B
14460 102516       LIA MPXIO
14461 014044       JSB 44B        BCD TO BINARY (FLT)
14462 104400       DST 733,I
14463 103373
14464 126456       JMP MPXR2,I
*
      00016  MPXIO EQU 16B        MULTIPLEXER SELECT CODE
      04700  MNEG  EQU 4700       OCT 100000
      00445  DELAY EQU 445B       DEC -16
*
***
```

APPENDIX B
SAMPLE COMPUTER RUN

The following material is a partial printout from a typical run. This example shows the normal interaction between the operator and the computer. The prompts and error messages shown in this sample typify the completeness of the information which was given to the operator during a run.

```
 * * * *  - - -     RUN # 95     - - -  * * * *
- - - - - - - - - - - - - - - - - - - - - - - - - - -

IF STORING DATA ON NEW REEL OF MAG TAPE, INPUT 1.
OTHERWISE INPUT 0 (ZERO) .
?0

LAST DATE WAS  9    : 18       6    / 20    / 1977
INPUT 0 IF DATE IS CORRECT AND PROGRAM IS TO CONTINUE.
?0

PUNCH FEED FRAMES ON PUNCH UNIT AND CHECK AMOUNT OF TAPE .

VOLTAGE READ ON CHANNEL 806  IS -.25864     VOLTS.

ACTUAL VALUE IS OFF BY  4.13600E-02   VOLTS .

VOLTAGE READ ON CHANNEL 807  IS -.25898     VOLTS.

ACTUAL VALUE IS OFF BY  4.10200E-02   VOLTS .

HEAT SINK #     TEMP. (DEG. C)

    A 1          -56.3317

    A 2          -57.6339

    A 3          -61.0806
```

A 4	-58.2414
A 5	-58.211
B 1	35.8959
B 2	34.9593
B 3	32.5252
B 4	34.2375
B 5	35.3678
C 1	99.6863
C 2	99.5793
C 3	97.3929
C 4	98.7013
C 5	98.0582
D 1	124.398
D 2	124.026
D 3	122.515
D 4	124.315
D 5	124.253
A 5X	-56.7854

D 1X 123.798

ENTER HOUR, MINUTES, DAY, MONTH, AND YEAR IN THAT ORDER.
SEPARATE EACH WITH A COMMA. (ALL ENTRIES NUMERICAL)

?12,48,24,6,1977

12 : 48 6 / 24 / 1977

ENTER RTM FOR START OF DATA RUN.
?2927.9

TOTAL TEST TIME AT START OF DATA RUN IS 4461.8 HRS.

INITIAL PHOTOCURRENT OFFSET IS 1.13087E-03

INPUT J16 READING
?.095

RATIO OF J16 TO F.O.#1 IS 7.71763E+06

CURRENT DIFFERS FROM SET-POINT ON LED'S AS FOLLOWS:

NUMBER	CURRENT DEVIATION	%ERROR
308	1.30087	.520349
356	2.51445	2.01156

TOTAL TEST TIME AT END OF DATA RUN IS 4462.33 HRS.

TOTAL RUN TIME IS .533203 HRS.

SUM OF DIODE CURRENTS IS 33.3406 AMPS. THE CURRENT CALCULATED USING THE SHUNT RESISTOR WAS 34.28 AMPS AT THE BEGINNING OF THE RUN AND 34.28 AMPS AT THE END OF THE RUN.

DIFFERENCE BETWEEN TWO MEASUREMENTS FOR SHUNT RESISTOR IS 0 AMPS.
FIRST READING MINUS SUM OF CURRENTS IS .93943 AMPS.
SECOND READING MINUS SUM OF CURRENTS IS .93943 AMPS.

NUMBER	CURRENT	VOLTAGE	LIGHT OUTPUT
1	99.955	1.85554	1.23575E-06
2	99.795	1.81825	1.29649E-06
3	99.9101	1.81154	9.82556E-07
4	199.94	1.91064	1.53983E-06
5	199.6	1.89396	1.68625E-06
6	199.87	1.91585	1.52748E-06
101	99.9095	1.496	4.54350E-07
102	100.04	1.46119	4.53949E-07
103	99.8749	1.4816	5.26595E-07
104	199.519	1.60812	9.24211E-07
105	199.7	1.54451	9.82356E-07
106	200.38	1.57137	8.05320E-07
201	99.97	1.48074	2.82716E-07
202	100.065	1.45815	2.57498E-07
203	100.12	1.4118	3.37560E-07
204	200.28	1.76222	3.63079E-07
205	200.19	1.49693	5.21501E-07
206	5.05445	5.55266	-1.70131E-09