

UNCLASSIFIED

AD NUMBER

ADB016517

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; OCT 1976. Other requests shall be referred to Air Force Aero Propulsion Lab., Wright-Patterson AFB, OH 45433.

AUTHORITY

AFWAL ltr 9 Sep 1983

THIS PAGE IS UNCLASSIFIED

AD

BO 16517

AUTHORITY:

AFWAL

1tr, 9 Sep 83



✓
AFAPL-TR-76-95 ✓

ADB016517

TEST AND EVALUATION OF SOLID STATE POWER CONTROLLERS

VEHICLE POWER BRANCH
AEROSPACE POWER DIVISION



DECEMBER 1976

TECHNICAL REPORT AFAPL-TR-76-95
FINAL REPORT FOR PERIOD JULY 1974 THROUGH JUNE 1976

Distribution limited to U. S. Gov't agencies only (test and evaluation); statement applied 18 October 1976. Other requests for this document must be referred to the Air Force Aero Propulsion Laboratory (AFAPL POP-2), Wright-Patterson Air Force Base, Oh 45433.

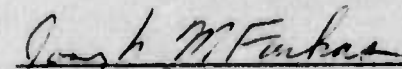
AD No. _____
DDC FILE COPY

✓
AIR FORCE AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

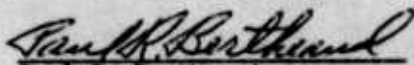
NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Distribution limited to U. S. Government agencies only; Test and Evaluation October 18, 1976. Other requests for this document must be referred to Air Force Aero Propulsion Laboratory/POP-2, Wright-Patterson AFB, Ohio 45433.


Joseph M. Farkas
Project Engineer

FOR THE COMMANDER


Paul R. Bertheaud
Actg Technical Area Manager

ACQUISITION FOR	
NTIC	☐
DIC	☐
UNIT	☐
DATE	☐
BY	
DISTRIBUTION/AVAILABILITY CODE	
DISC. A. 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100.	
B	

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER (14) AFAPL-TR-76-95	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9) rept.	
4. TITLE (and Subtitle) (6) Test and Evaluation of Solid State Power Controllers	5. TYPE OF REPORT & PERIOD COVERED Final ✓ July 74 - June 76		
7. AUTHOR(s) (10) Joseph M. Farkas		6. PERFORMING ORG. REPORT NUMBER	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Aero Propulsion Laboratory/POP-2 Wright-Patterson AFB OH 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (17) 29 31452929 62203F	
11. CONTROLLING OFFICE NAME AND ADDRESS (Same as No. 9 above)		12. REPORT DATE (11) December 1976	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 45p.		13. NUMBER OF PAGES 37	
		15. SECURITY CLASS. (of this report) UNCLASSIFIED	
16. DISTRIBUTION STATEMENT (of this Report) Distribution limited to U.S. Gov't agencies only (test and evaluation); statement applied October 1976. Other requests for this document must be referred to the Air Force Aero Propulsion Laboratory (AFAPL/POP-2), Wright-Patterson Air Force Base, Oh 45433.			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Solid State Power Controllers Solid State Power Distribution AC Power Controller Power Controllers Electrical Multiplex System EMUX			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report covers the in-house test and evaluation of solid state power controllers developed by Westinghouse under contracts F33615-71-C-1400 and F33615-73-C-2082. Among these power controllers were units intended for use on the B-1.			

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

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

011 570

1B

FOREWORD

This report contains the results of the testing of solid state power controllers as developed by the Westinghouse Corporation for AFAPL. The work was performed by the Aerospace Power Division, Vehicle Power Branch of the Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio, under Project 3145, Task 314529, and Work Unit 31452929. This effort was conducted by Mr. Joseph M. Farkas, AFAPL POP-2, during the period July 1974 through June 1976.

TABLE OF CONTENTS

SECTION	PAGE
I. Introduction	1
II. Evaluation	1
III. Conclusions	9
IV. Recommendations	10
Appendix: Powertran Listing for Data Handling System	29

LIST OF ILLUSTRATIONS

FIGURES	PAGE
1 Power Controllers Tested	15
2 Turn On of Westinghouse Power Controller	16
3 Turn Off of Westinghouse Power Controller	16
4 Voltage Drop Across B-1 Power Controller with 1.5 Amp Load	17
5 Voltage Drop Across B-1 Power Controller with 0.15 Amp Load	17
6 Trip Curves for Westinghouse Power Controllers	18
7 Trip Curves for B-1 Prototype Solid State Power Controllers	19
8 Zero Voltage Turn On. B-1 Power Controller with 1.5 Amp Resistive Load	20
9 Zero Current Turn Off. B-1 Power Controller with 1.5 Amp Resistive Load	20
10 Turn On and Turn Off of B-1 Power Controller with B-1 Transformer Rectifier as Load	21
11 Magnified View of Figure 10 Showing Zero Voltage Turn On	21
12 Magnified View of Figure 10 Showing Zero Current Turn Off	22
13 B-1 Power Controller Life Test Configuration	23
14 B-1 Power Controller and Laboratory EMUX Test Configuration	24
15 Power Controller/EMUX Wiring	25
16 Current Limit Circuit for B-1 Power Controllers	26
17 List of Loads for Power Controller/EMUX Test	27

LIST OF TABLES

TABLES	PAGE
1 Electrical Characteristics of Westinghouse Power Controllers (1A & 2A)	11
2 Electrical Characteristics of Westinghouse Solid State Power Controllers (5A)	12
3 B-1 Power Controller Data Prior to Life Test Electrical Characteristics	13
4 B-1 Power Controller at 2000 Hours of Life Test Electrical Characteristics	14

I. Introduction

This report covers the in-house test and evaluation of solid state power controllers developed by the Westinghouse Corporation for AFAPL under Contracts F33615-71-C-1400 and F33615-73-C-2082. Among these power controllers were units intended for use on the B-1.

A total of 45 power controllers were tested from July 1974 through June 1976.

II. Evaluation Procedures and Results

A total of 45 power controllers were subjected to various electrical tests. The power controllers were the end products of two contracts.

Delivered under the first contract were:

1. 1-230 volt, 1.0 ampere rated power controller
2. 5-230 volt, 2.0 ampere rated power controllers
3. 6-230 volt, 5.0 ampere rated power controllers

The second contract was coordinated with the B-1 System Program Office.

The power controllers were designed to meet the needs of the B-1 electrical system. Delivered and tested were:

1. 1-230 volt, 1.5 ampere rated breadboard power controller
2. 7-230 volt, 1.5 ampere rated B-1 prototype power controllers
3. 25-230 volt, 1.5 ampere rated B-1 prototype power controllers

with Integrated Wire Terminal System (IWTS) connectors. Figure 1 shows examples of the power controllers tested. Detailed electrical specification testing was performed on all but the IWTS power controllers. The IWTS power controllers were configured on a test bench and operated with the in-house Electrical Multiple System (EMUX). The electrical characteristics tested were:

1. Turn on and turn off control voltage and current

2. Turn on and turn off delay
3. Power pass element voltage drop
4. Power dissipation
5. Overload time trip characteristics
6. Zero turn on and turn off accuracy
7. Trip and status indicator voltage drop
8. Power pass element leakage current

All specification tests were performed at room temperature.

The numerical results of the specification tests are listed in Tables 1-4.

An explanation of the necessity for making the measurements, the method by which they were accomplished, and some of the results obtained are as follows:

1. Turn on and turn off voltage and current. The turn on voltage is the minimum voltage that applied to the control inputs, allows the power controller to pass load current. In a similar manner the turn off voltage is the control voltage that results in the "on" power controller in turn "off". These voltages, and the resulting currents, are in the 5 volt and 10 milliamperes range, making these power controllers compatible with solid state logic. Oscillatory operation of the power controller is prevented by the hysteresis designed into the control input circuit.

2. Turn on and turn off delay. The delay to turn on is the time from application of a 5 volt control signal to the actual application of the current to the load. The turn off delay is the time from removal of the 5 volt control signal to the time the load current goes to zero. The delays experienced with these power controllers were by

design to meet the B-1 specifications. Figures 2 and 3 show the typical turn on and turn off delay.

3. Pass element voltage drop. The voltage drop was measured between the power controllers 230 volt input and 230 volt output leads with various loads applied. This voltage was measured with a Fluke 8300A true RMS reading digital voltmeter and with an oscilloscope. Figure 4 and Figure 5 show pictures of the typical voltage drops observed.

This measurement is made to determine if the voltage drop due to a solid state power controller would be great enough to have an undesirable effect on aircraft loads. No problems were observed due to a voltage drop, the typical drop being about 1.7 volts RMS with a 1.5 ampere load.

4. Power dissipation. Power dissipation is one of the most critical and one of the most difficult to measure parameters. It is composed of the sum of all the individual circuit losses within the power controller. This includes the pass element, ground circuit, control input, and status and trip indicator losses. The pass element and ground circuit losses form the majority of the power loss in these power controllers.

Two methods were used to obtain the sum of the losses in the pass element. One method was to obtain the two losses individually and sum the results. The power switch loss was computed by measuring the RMS voltage drop and multiplying by the RMS current. This gives the average power dissipation in the pass element.

The ground circuit loss was more difficult to measure. Westinghouse uses a capacitor voltage divider to supply power for the internal circuitry. This results in a ground current of large magnitude but small power factor. A Philips multiplying oscilloscope was used to take the

product of the line voltage and ground current and give a DC output signal directly proportional to the real power loss. This output was applied to a digital voltmeter which, in combination with the proper oscilloscope input and current probe settings, would display power dissipation directly in milliwatts. This number was added to the number calculated for the power switch loss to give the total power dissipation.

A second method was to use an instrument built in-house specifically to measure the losses in these two sections. This was comprised of 2 analog multipliers and a summing amplifier. This instrument outputted a DC voltage proportional to the power dissipation. This instrument was used to measure the power dissipation of the power controllers under life test after 2300 hours of operation. The two methods gave very nearly the same results; that the power controller was under the 4 watt full-load dissipation limit and over the 0.5 watt off state dissipation limit specified by the B-1.

5. Overload time trip characteristics. Overload time trip characteristics were determined to verify the power controllers to protect aircraft wiring and open a fault. Up to 500 amperes were passed by the 5 ampere rated prototypes for $\frac{1}{2}$ cycle under fault conditions. The B-1 prototypes contained an internal resistor to limit fault currents. Up to 260 amperes were conducted by these units under fault conditions. Typical trip characteristics are plotted in Figures 6 and 7.

6. Zero turn on and turn off accuracy. One of the reasons for utilizing solid state power controllers is the advantage of zero voltage turn on and zero current turn off. Zero voltage turn on results in a "softer" turn on for inductive and lamp loads, thus reducing EMI and increasing lamp filament life. Contact bounce associated with relay control of load current is

eliminated, making the life of power controllers many thousands of hours. Zero current turn off reduces the voltage spike created when the current through an inductive load is suddenly brought to zero. These power controllers utilize Silicon Controlled Rectifiers (SCR's) as the power pass element which theoretically turn off on zero current. These devices turn off within 10 microseconds after the zero current crossover point. Figures 8 and 9 show the turn on and turn off voltage and currents with a resistive load, and Figures 10, 11, and 12 show turn on and turn off with a transformer-rectifier as a load.

7. Trip and status indicator voltage drop. The trip and status indicators are transistor switches that close when the power controller has tripped or when gate drive is supplied to the SCR's. The drop across these switches is minimal up to the 10 milliamperes rating.

8. Power pass element leakage current. Leakage current of the pass element was measured by a digital milliamp meter between the 230 volt output and neutral with the power controller control at zero. This measurement was made to check for potential shock hazard to personnel working on loads connected to turned off power controllers. These currents were less than 100 microamperes.

These power controllers were operated with various loads including three phase motor, relays, various inductors, lamps, capacitors, and transformer-rectifiers. No problems were observed in the operation of any of these loads. A life test fixture was set up consisting of six B-1 prototypes, 4 loads and a timing circuit. Figure 13 shows the life test configuration. These controllers were subjected to a 50% duty cycle, 100 cycles per hour, for about 9 hours per working day. The loads included a B-1 transformer-rectifier, 150 ohm resistor, two 120 volt, 150 w lamps,

and a 200 volt 3 phase aircraft fan. These power controllers were connected line-to-line across the 400 Hertz source and the voltage upped to 230 volts line-to-line. Three 30 ohm resistors were added in line to the 3 phase fan to drop the voltage to 200 volts line-to-line. The power controllers were subjected to specification test and then placed under life test. At 500 hours the six power controllers were again tested, and then placed back into life test operation.

At 800.3 hours of operation, Westinghouse unit #21 failed. The failure has been attributed to the failure of one of the capacitors in the input power supply voltage divider. This capacitor according to Westinghouse failure analysis, was damaged upon installation on the hybrid chip. This turned out to be a potential problem in all of the B-1 power controllers.

The failed power controller was replaced with unit #20. After an additional 1150.1 hours, this replacement power controller failed, the cause being the same as in the previous failure. This unit was not replaced. The failure was not attributed to any peculiarities in the test configuration or to the load, which may have increased the stress on the power controller.

At 2000 hours the 5 remaining power controllers were again tested. During this testing, 40 volts DC was inadvertently applied to the control terminals of controller #25. This caused a zener diode in the input circuitry to fail short, making the power controller inoperative. Five volts at several amperes was then applied to the control terminals in an attempt to "burn out" the shorted zener diode. This was successful, and the power controller was again operative. But further testing revealed that the power controller would no longer trip on overloads.

The reason for this has not been determined.

Comparison of the data revealed little change in characteristics over the 2000 hours. Any differences can be attributed to improved test procedures that result in more accurate data or changes in the test equipment during the passing of one year. A rise in the off state power dissipation has been detected. This has been attributed to leakage of the power supply voltage divider capacitors. This increase may be a prelude to the eventual failure of one of these capacitors.

Eighteen of the solid state power controllers with IWTS connectors were installed on a test bench to be controlled by the Laboratory EMUX system, see Figure 14. A test box delivered with the EMUX system was modified to provide an interface between the power controllers and the remote terminals of the EMUX system. These test boxes provide a means of entering and displaying "ones" and "zeros" into and from the remote terminals, and also provide external jacks for entering and receiving data from other sources.

Figure 15 shows the modification and method of connecting the power controllers control, trip, and status. With this configuration, the trip and status can be taken from the power controller or forced to one or zero from the switches. This allowed simulated trips to be made without actually placing a fault on a power controller.

Originally 24 of the IWTS power controllers were to be connected to the EMUX system. Six failed before it was realized that a problem existed with the voltage divider capacitors. Once the reason for the failures was discovered, a current limit circuit was built and inserted into the neutral return lead of each of the remaining power controllers. This circuit, Figure 16, would limit the current to the power controller

to 100 ma. This would prevent excessive currents from flowing through the capacitors during turn on and hopefully prevent additional failures. None of these protected power controllers has failed because of a power supply capacitor failure.

A variety of loads, listed in Figure 17, were connected to the 18 power controllers. A program was written in the Powertran language to configure the EMUX system. This program provided automatic cycling or manual control of the loads, reset of tripped power controllers, and 3 phase load control. The Appendix contains a listing of this program.

During the automatic cycling mode, the 3 phase load, in this case a motor, would operate in one phase sequence for 30 seconds, then off for 2 seconds, then run in a different phase sequence for 30 seconds. This would reverse the 3 phase motor. A trip input from any one of these power controllers would turn all of the power controllers off.

Power controllers that trip are reset a maximum of three times. On the receipt of the third trip signal the control is turned off and a message sent to the EMUX's Crew Control and Display Panel to notify that the power controller has tripped. Reset of the power controller is accomplished by moving the control input switch to "zero" and back to "one."

The 18 power controllers have been manually and automatically cycled for over 350 hours.

At 340 hours a failure within the EMUX system forced all outputs to "one." This resulted in the power controllers in the three phase circuit to be turned on line-to-line. These power controllers tripped immediately and continued to operate properly after the EMUX system was restored to normal operation. But a checkout of the remaining power con-

trollers revealed that two others had failed in the on state. The power pass section in power controller no. 8 had failed. This was verified when removal of the neutral return from the power controller had no effect on its operation. Power controller number 11 had a failure within the control circuitry. Removal of its neutral return would turn the power controller off. No attempt has been made to analyze the power controller internal workings to find out why they failed. The hermetic construction of the controllers makes any attempt to open the container extremely difficult.

It was not possible to determine if the failure of these two power controllers was related in any way to the failure of the EMUX system. The shorting of the two phases by the three phase load power controllers may have created a disturbance on the line of sufficient amplitude to affect the controllers.

III. Conclusions

These power controllers developed by Westinghouse are capable of performing to the specifications to which they were designed. They are not recommended for flight test because of the manufacturing problem that may result in the failure of the power supply capacitor. Also, the effect of line transients on the power controller should be fully investigated before such units are flight tested.

The operation of these power controllers with various loads and with an EMUX system has been successful. No compatibility problems have arisen in the 18,800 hours accumulated by the power controllers to date. Life testing will continue with the intent of uncovering any long term degradation that may occur in solid state power controllers.

IV. Recommendations

In the light of the failure of two power controllers controlled by the EMUX system, it is highly recommended that the effects of power line transients on power controllers be investigated. Transients similar to the ones that occurred during the temporary failure of the EMUX system may happen during normal or emergency bus switching procedures or the application and removal of large loads from the electrical bus. The effect of these transients on solid state power controllers will have to be investigated and documented.

Upon completion of the High Speed Data Acquisition System in the Power Generation and Distribution Laboratory at AFAPL, transient tests will be performed on a simulated aircraft bus with solid state power controllers. The information obtained from this testing will be made available to the manufacturers of solid state power controllers.

Table 1. Electrical Characteristics of Westinghouse Solid State Power Controllers

Unit Number	6	1	2	3	4	5	6
Rating	1 A	2 A	2 A	2 A	2 A	2 A	2 A
Control							
V on	2.21 V	2.29 V	2.28 V	2.30 V	2.29 V		
V off	2.16 V	2.22 V	2.21 V	2.22 V	2.22 V		
Turn on delay	7.7 msec	7.5 msec	7.0 msec	8.9 msec	6.0 msec		
Turn off delay	6.6 msec	7.0 msec	7.0 msec	6.7 msec	7.2 msec		
Pass Section							
V drop							
@ rated load	8.0 V _{p-p}	1.92 V _{rms}	1.88 V _{rms}	1.88 V _{rms}	1.86 V _{rms}	NOT TESTED	DEFECTIVE
@ no load	4.0 V _{p-p}	8.7 V _{p-p}	6.8 V _{p-p}	4.8 V _{p-p}	6.8 V _{p-p}		
		1.67 V _{rms}	1.25 V _{rms}	1.67 V _{rms}	1.64 V _{rms}		
		5.6 V _{p-p}	4.2 V _{p-p}	4.6 V _{p-p}	4.2 V _{p-p}		
Overcurrent Protection							
Minimum pickup	1.4 A _{rms}	3.1 A _{rms}	3.0 A _{rms}	2.8 A _{rms}	2.9 A _{rms}		
½ cycle trip	20.8 A _{peak}	43 A _{peak}	40 A _{peak}	43 A _{peak}	46 A _{peak}		

Table 2. Electrical Characteristics of Westinghouse Solid State Power Controllers

Unit Number	1	2	3	4	5	6
Rating	5 A	5 A	5 A	5 A	5 A	5 A
Control						
V on	2.29 V	2.33 V	2.30 V	2.30 V	2.33 V	2.31
V off	2.23 V	2.26 V	2.23 V	2.23 V	2.25 V	2.23
Turn on delay	8.4 msec	8.4 msec	6.3 msec	6.8 msec	7.2 msec	8.5 msec
Turn off delay	6.7 msec	5.9 msec	7.2 msec	7.6 msec	7.0 msec	6.5 msec
Pass Section						
V drop						
@ rated load	1.44 V _{rms}	1.44 V _{rms}	1.52 V _{rms}	1.45 V _{rms}	1.44 V _{rms}	3.62 V _{rms}
	8.2 V _{p-p}	9.6 V _{p-p}	8.0 V _{p-p}	9.2 V _{p-p}	8.1 V _{p-p}	42 V _{p-p}
@ no load	1.61 V _{rms}	1.67 V _{rms}	1.66 V _{rms}	1.65 V _{rms}	1.68 V _{rms}	17.76 V _{rms}
	4.0 V _{p-p}	4.4 V _{p-p}	4.1 V _{p-p}	4.4 V _{p-p}	4.5 V _{p-p}	58 V _{p-p}
Overcurrent Protection						
Minimum pickup	7.5 A _{rms}	7.5 A _{rms}	7.3 A _{rms}	7.3 A _{rms}	7.1 A _{rms}	7.5 A _{rms}
1/2 cycle trip	111 A _{peak}	102 A _{peak}	107 A _{peak}	100 A _{peak}	110 A _{peak}	100 A _{peak}

Table 3. B-1 Power Controller Data Prior to Life Test Electrical Characteristics

Life Test Unit Number/ Westinghouse No.	1/11	2/21	3/23	4/24	5/25	6/39
Control						
I @ 5 V	6.59 mA	6.50 mA	6.46 mA	6.37 mA	6.79 mA	6.84 mA
Turn on V&I	3.13 V, 2.10 mA	3.13 V, 2.09 mA	2.86 V, 1.40 mA	2.93 V, 1.56 mA	2.91 V, 1.62 mA, 2.94 V	1.66 mA
Turn off V&I	3.01 V, 1.80 mA	3.03 V, 1.87 mA	2.78 V, 1.23 mA	2.84 V, 1.39 mA	2.84 V, 1.49 mA, 2.87 V	1.59 mA
Turn on delay	12.0 msec	12.4 msec	7.5 msec	6.0 msec	7.0 msec	12.0 msec
Turn off delay	12.0 msec	12.5 msec	12.5 msec	12.0 msec	12.0 msec	12.0 msec
Pass Section						
V drop @ rated load	1.614 V _{rms}	1.600 V _{rms}	1.597 V _{rms}	1.629 V _{rms}	1.614 V _{rms}	1.610 V _{rms}
Leakage	4.1 V _{p-p}	4.05 V _{p-p}	4.0 V _{p-p}	4.1 V _{p-p}	4.1 V _{p-p}	4.0 V _{p-p}
Overcurrent Protection	0.09 mA	0.08 mA	0.09 mA	0.14 mA	0.15 mA	0.07 mA
min I & T	2.2 A-10 sec	2.2 A-7 sec	2.2 A-5 sec	2.1 A-9 sec	2.2 A-9 sec	2.2 A-5 sec
3.0 A _{rms}	1.2 sec	0.9 sec	1.1 sec	0.8 sec	0.9 sec	1.2 sec
10.0 A _{peak}	120 msec	92 msec	100 msec	100 msec	130 msec	122 msec
1/2 cycle	40 A _{peak}	40 A _{peak}	38 A _{peak}	35 A _{peak}	40 A _{peak}	50 A _{peak}
Trip Circuit						
V drop @ 10 mA	60 mV	75 mV	87 mV	82 mV	90 mV	57 mV
Power Dissipation						
Off	0.49 w	0.45 w	0.46 w	0.45 w	0.47 w	0.45 w
On with 1.5 A load	3.82 w	3.75 w	3.78 w	3.82 w	3.81 w	3.79 w
Tripped	1.09 w	1.02 w	1.08 w	1.05 w	1.02 w	1.01 w

Table 4. B-1 Power Controller at 2000 Hours of Life Test Electrical Characteristics

Life Test Unit Number/ Westinghouse No.	1/11	2/21	2/20	3/23	4/24	5/25	6/39
Control							
I & S V	6.60 mA			6.61 mA	6.56 mA	Failed	6.70 mA
Turn on V&I	3.14 V, 2.09 mA			2.87 V, 1.52 mA	2.94 V, 1.66 mA	Before Completion	2.94 V, 1.66 mA
Turn off V&I	3.02 V, 1.83 mA			2.78 V, 1.32 mA	2.87 V, 1.33 mA		2.87 V, 1.59 mA
Turn on delay	11.6 msec			7.5 msec	8.4 msec	9.0 msec	8.8 msec
Turn off delay	12.4 msec			12.8 msec	12.0 msec	12.0 msec	12.0 msec
Pass Section							
V drop	1.645 V _{rms}			1.659 V _{rms}	1.660 V _{rms}		1.610 V _{rms}
	4.2 V _{p-p}			4.2 V _{p-p}	4.2 V _{p-p}	4.2 V _{p-p}	4.2 V _{p-p}
Leakage	0.3 mA			0.1 mA	0.1 mA	0.1 mA	0.1 mA
Overcurrent Protection		Failed	Failed				
min I & T	2.2 A-9 sec			2.2 A-8 sec	2.2 A-8.2 sec	2.5 A-9 sec	2.2 A-8.4 sec
3.0 A _{rms}	1.2 sec			1.0 sec	1.0 sec	2.4 sec	0.9 sec
10.0 A _{peak}	136 msec			108 msec	112 msec	155 msec	120 msec
1/2 cycle	38 A			34 A	38 A		40 A
Trip Circuit							
V drop @ 10 mA	62 mV			85 mV	83 mV		56 mV
Power Dissipation							
Off	0.58 W			0.60 W	0.57 W	0.78 W	0.62
On with 1.5 A load	3.89 W			3.79 W	4.02 W	3.74 W	3.98
Tripped	1.15 W			1.17 W	0.89 W		0.86

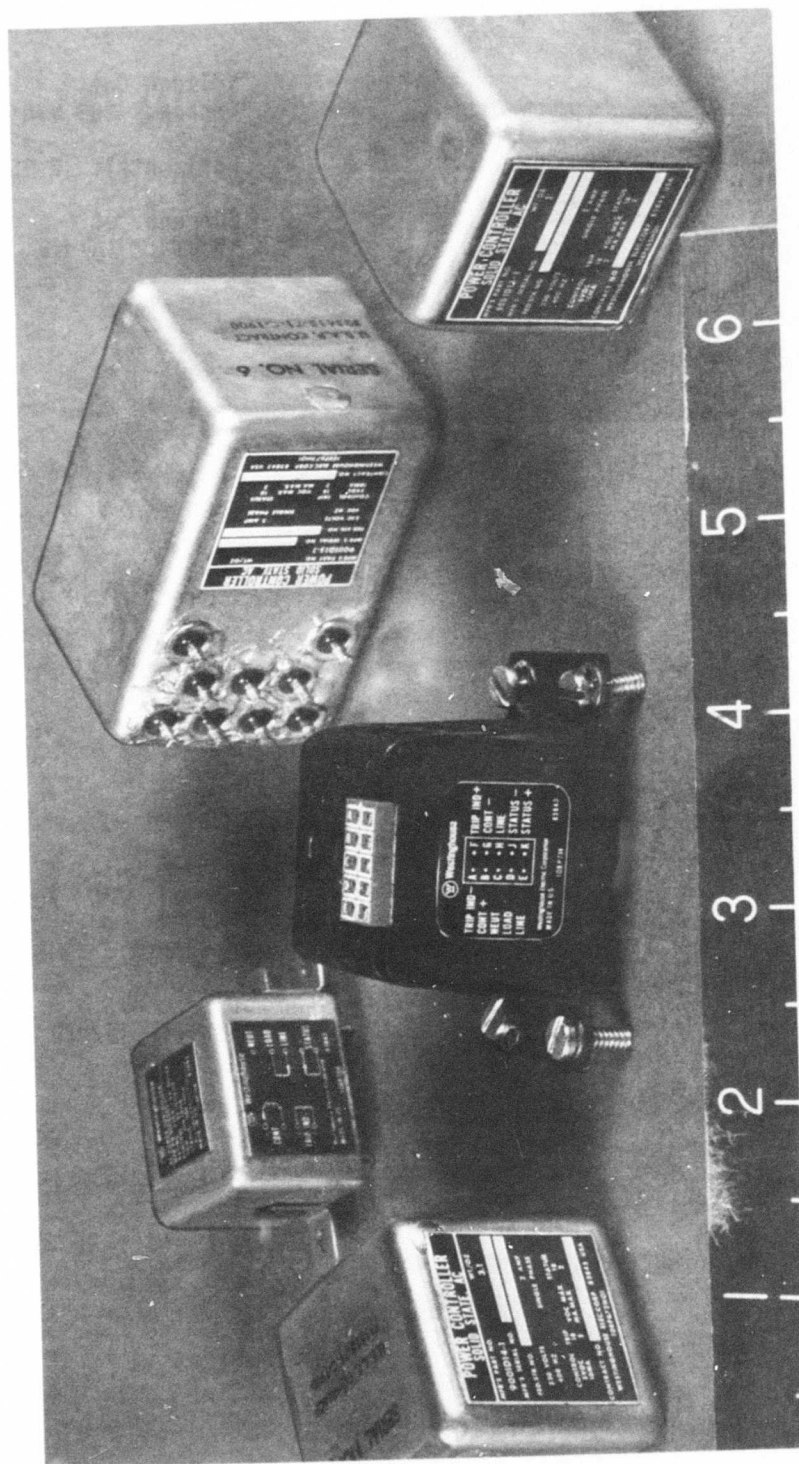
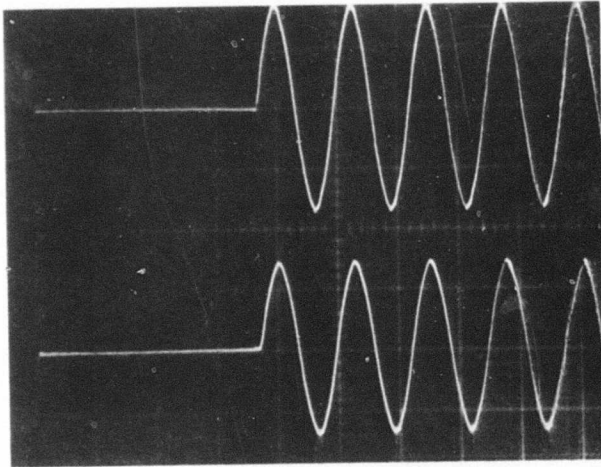


Figure 1 Power Controllers Tested
(Clockwise from Left)

1. 2 Amp, 230 Volt, Power Controller
2. 1.5 Amp, 230 Volt, B-1 Prototype Power Controller
3. 5.0 Amp, 230 Volt, Power Controller
4. 1.0 Amp, 230 Volt Power Controller
5. 1.5 Amp, 230 Volt B-1 Power Controller with IWT connector



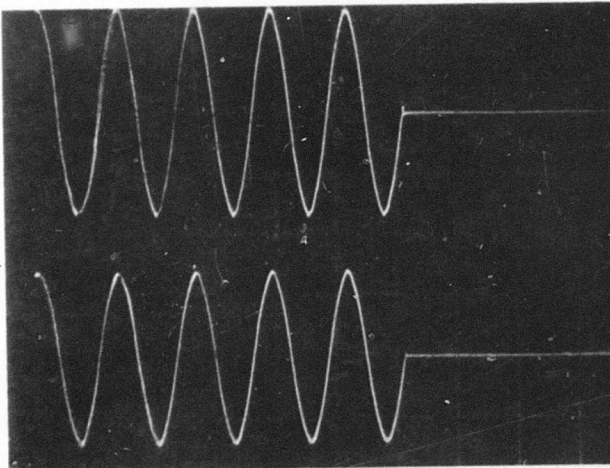
Voltage Out
Scale: 200 V/div

Horizontal: 2 MS/div

Current Out
Scale: 1A/div

↑
Control On

FIGURE 2 Turn On of Westinghouse Power Controller



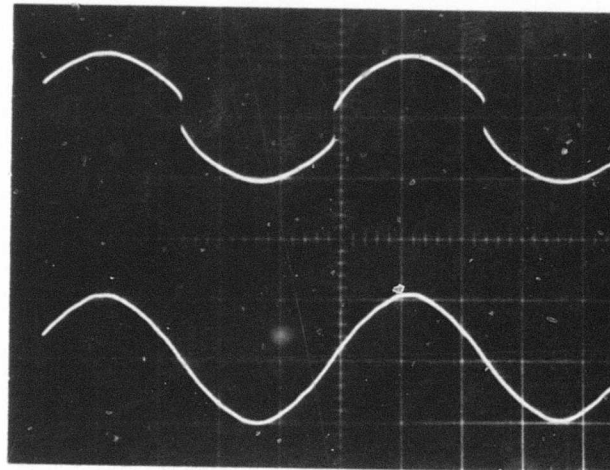
Voltage Out
Scale: 200 V/div

Horizontal: 2MS/div

Current Out
Scale: 1A/div

↑
Control On

FIGURE 3 Turn Off of Westinghouse Power Controller

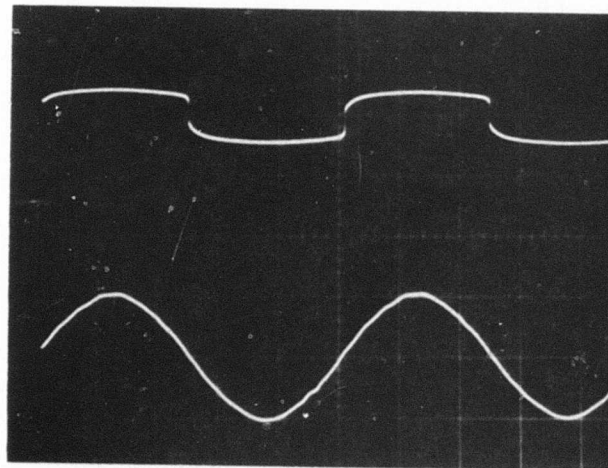


Voltage Drop
2.0 Volt/div

Load Current
2.0 Amp/div

Horizontal Scale
2mS/div

Figure 4 Voltage Drop Across B-1 Power Controller with 1.5 Ampere Load



Voltage Drop
2.0 Volt/div

Load Current
0.2 Amp/div

Horizontal Scale
2mS/div

Figure 5 Voltage Drop Across B-1 Power Controller with 0.15 Ampere Load

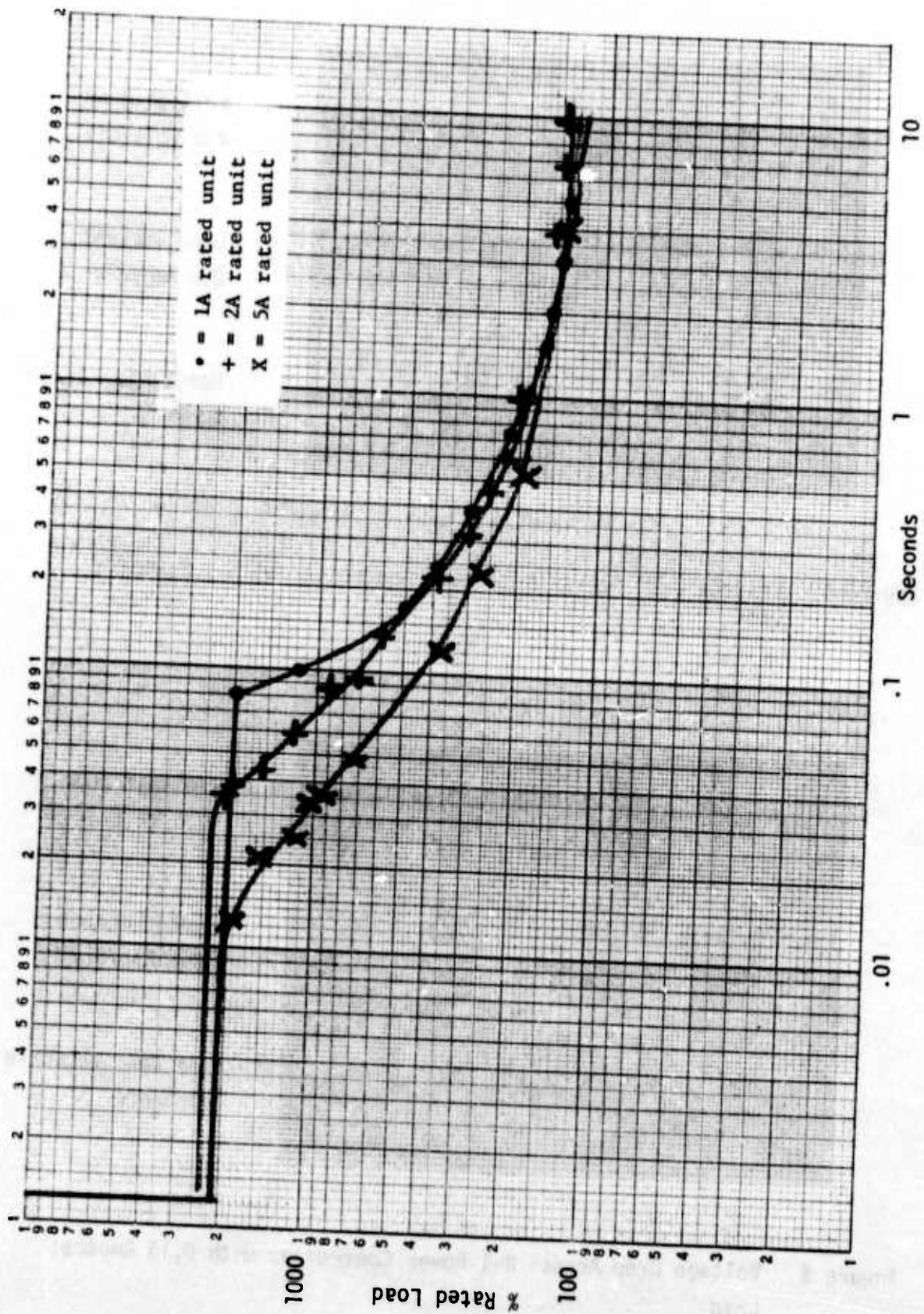


Figure 6. Trip Curve for Westinghouse Prototype Solid State Power Controllers

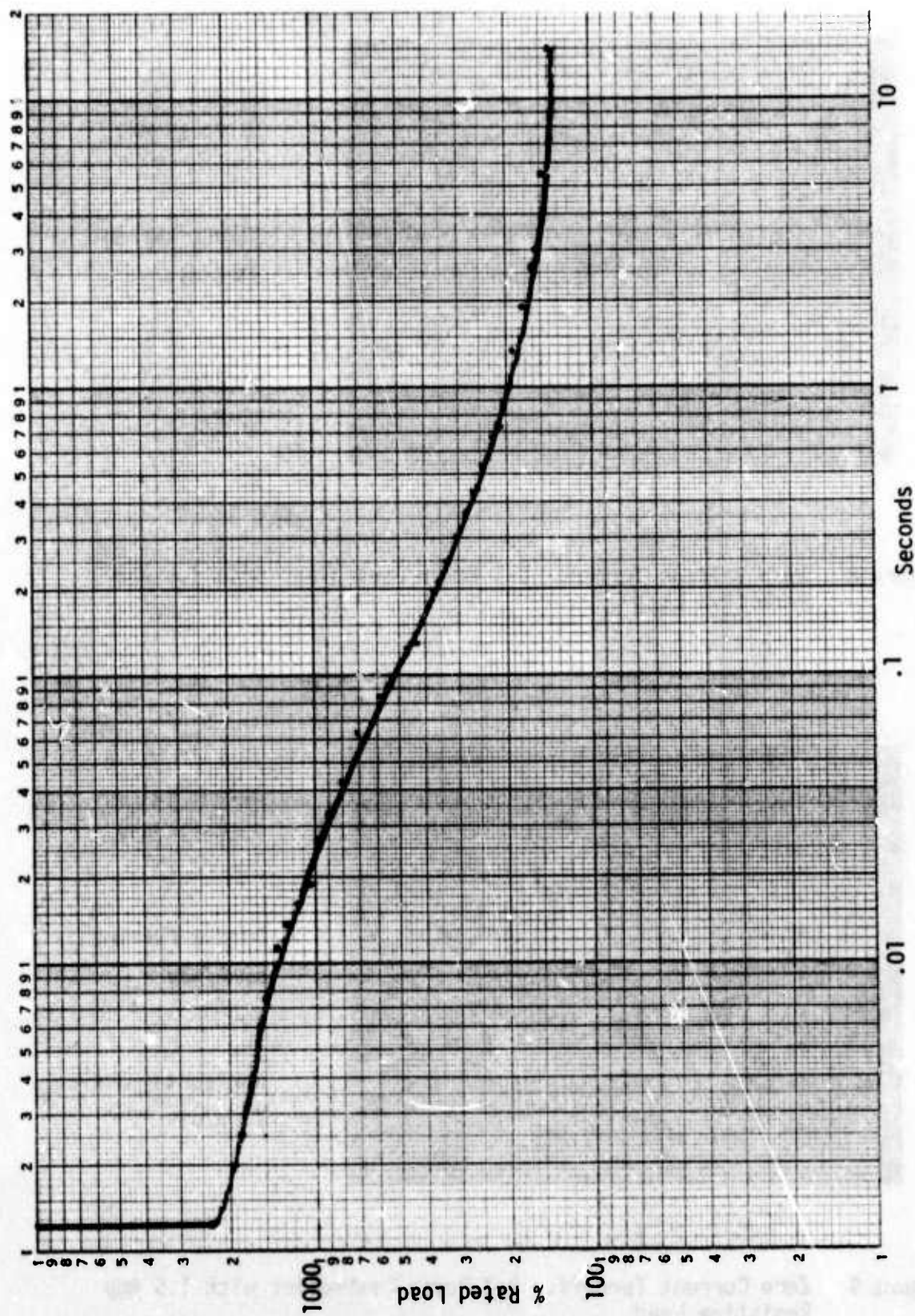
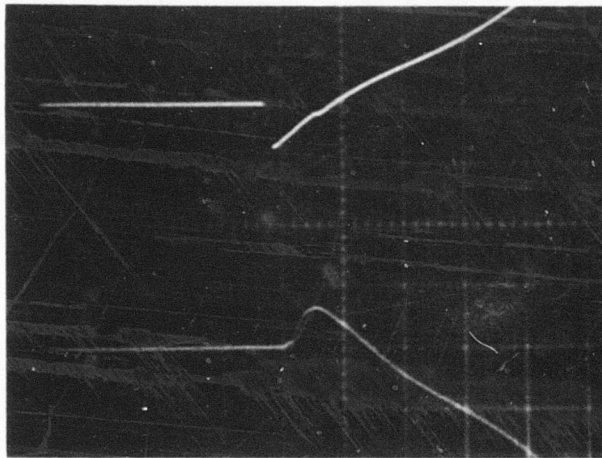


Figure 7. Trip Curve for B-1 Power Controllers

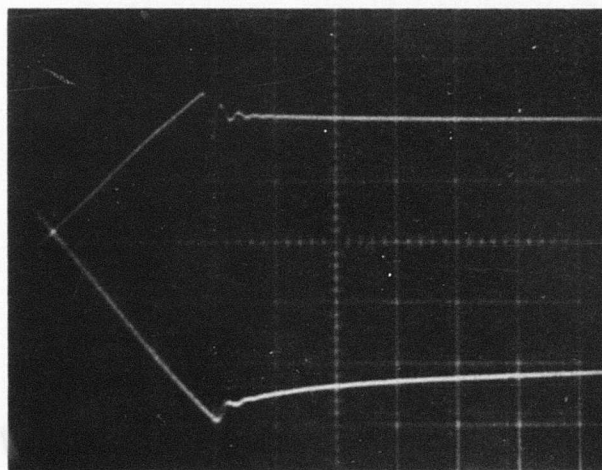


Output Voltage
10 Volts/div

Output Current
50mA/div

Horizontal Scale
10 μ S/div

Figure 8 Zero Voltage Turnon. B-1 Power Controller with 1.5 Amp Resistive Load

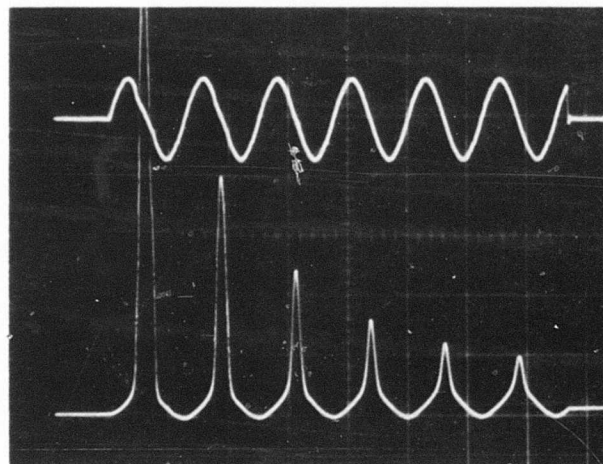


Output Voltage
10 Volts/div

Output Current
50mA/div

Horizontal Scale
10 μ S/div

Figure 9 Zero Current Turnoff. B-1 Power Controller with 1.5 Amp Resistive Load



Output Voltage

500 Volts/div

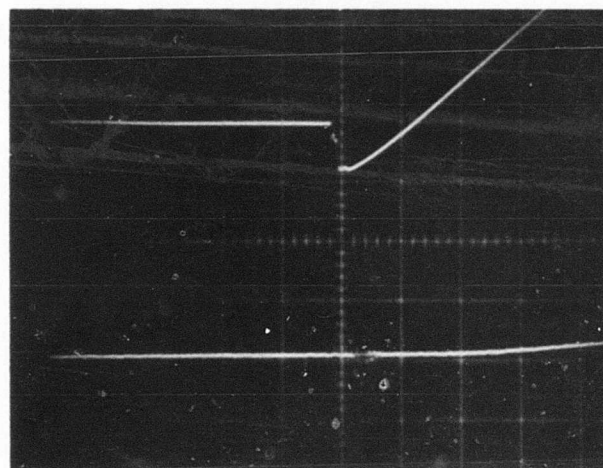
Output Current

1 Amp/div

Horizontal Scale

2mS/div

Figure 10 Turnon and Turnoff of B-1 Power Controller with B-1 Transformer-Rectifier as Load



Output Voltage

10 Volts/div

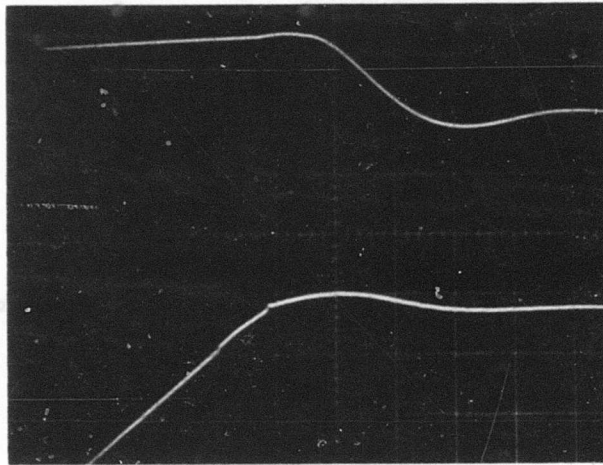
Output Current

10mA/div

Horizontal Scale

10 μ S/div

Figure 11 Magnified View of Figure 10 Showing Zero Voltage Turnon



Output Voltage
200 volts/div

← zero

Output Current
10mA/div

← zero

Horizontal Scale
10 μ S/div

Figure 12 Magnified View of Figure 10 Showing Zero Current Turnoff

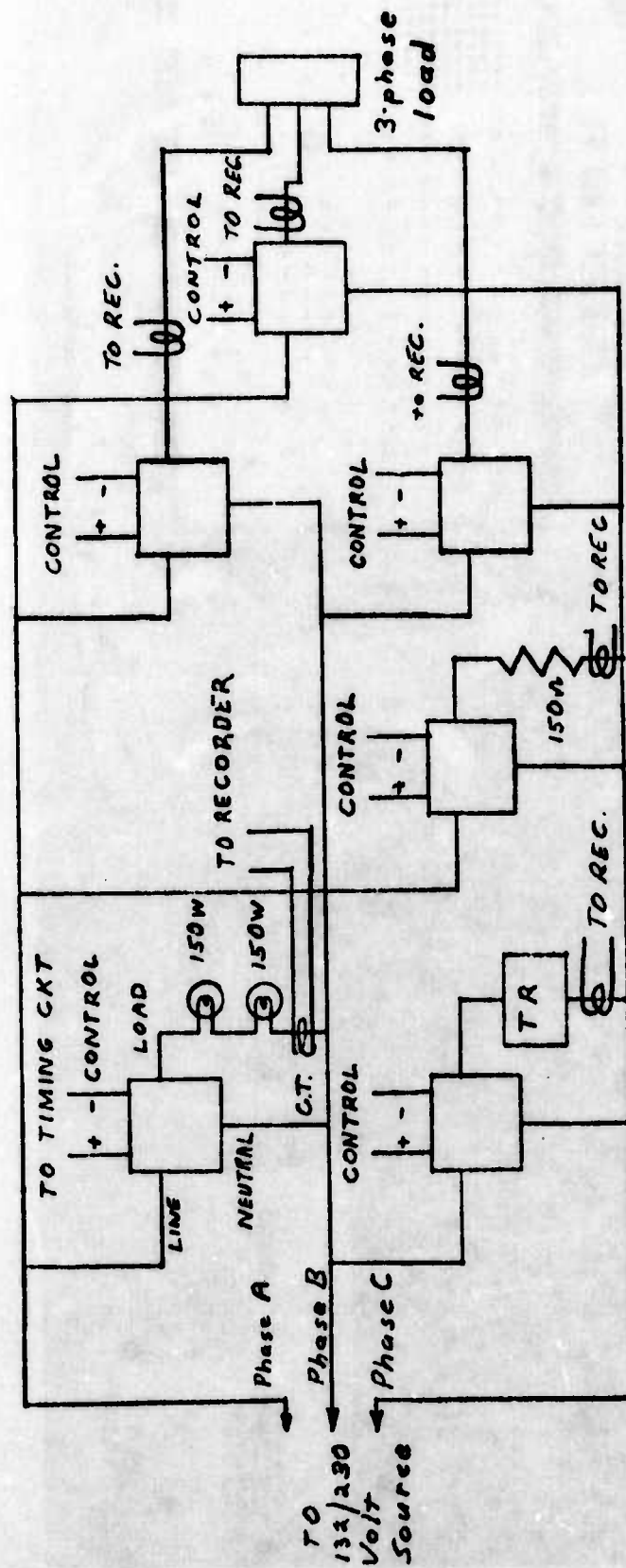


Figure 13 B-1 Power Controller Life Test Configuration

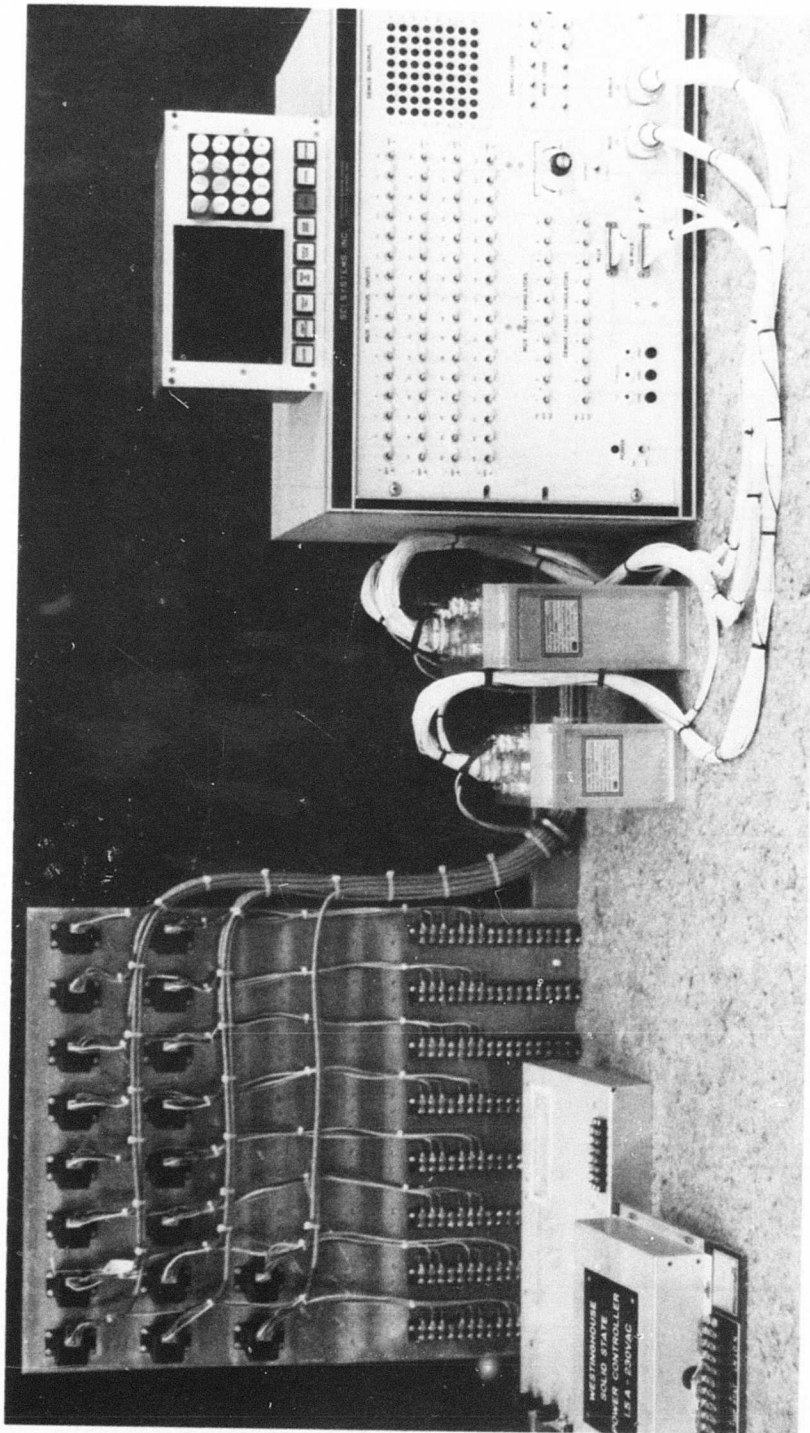


Figure 14 B-1 Power Controller and Laboratory EMUX Test Configuration

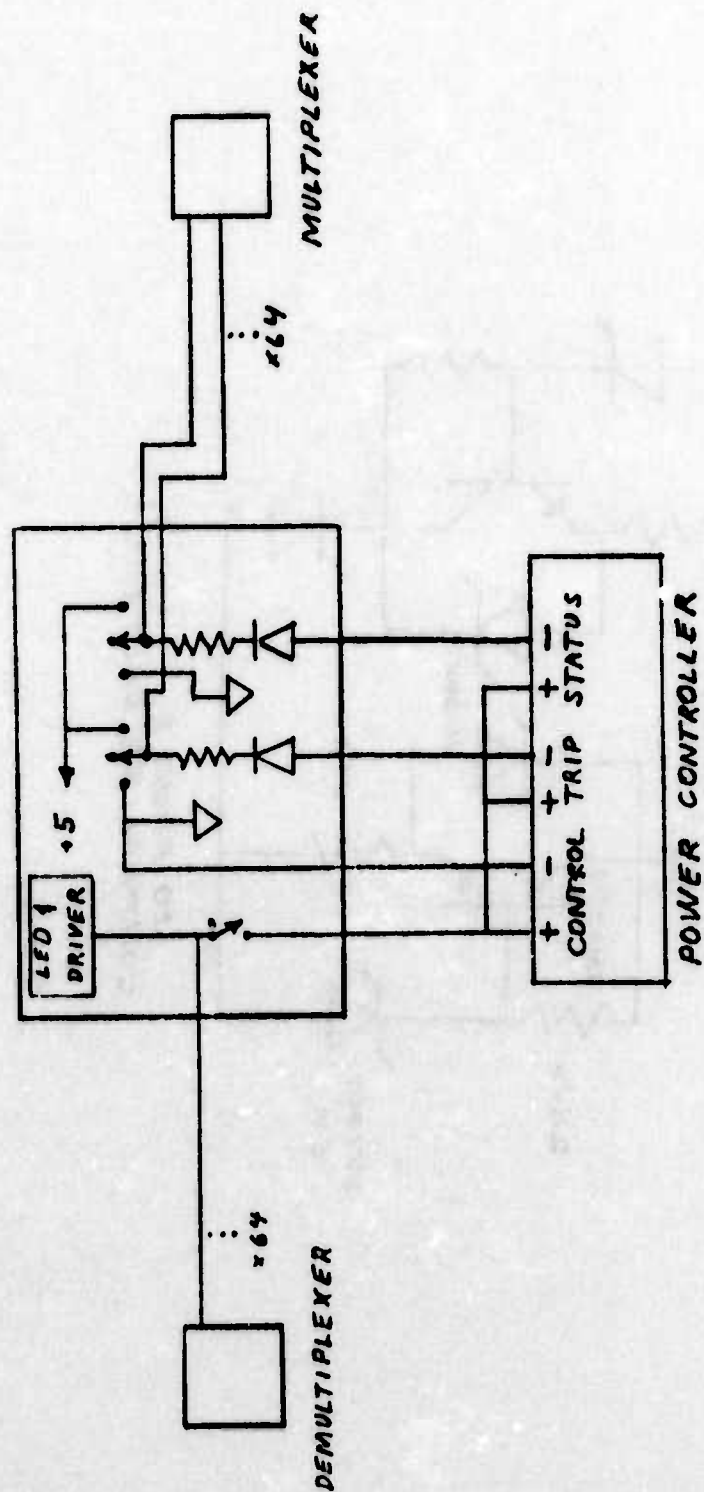


Figure 15 Power Controller/EMUX Wiring

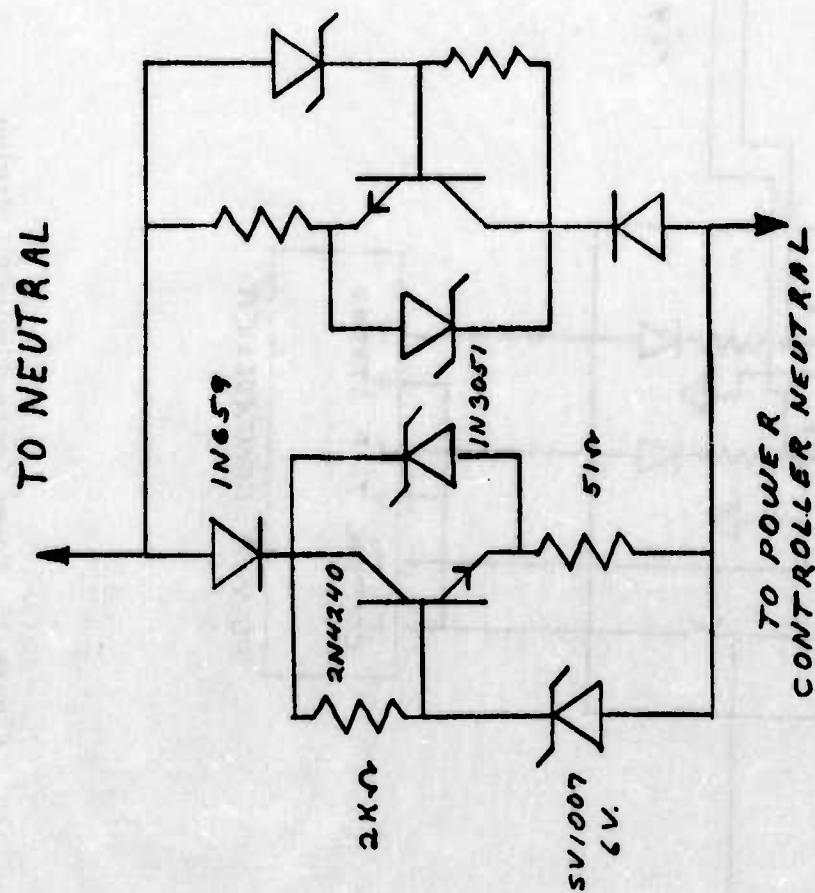


Figure 16 Current Limit Circuit for B-1 Power Controllers

<u>Load</u>	<u>Power Controller Number</u>
1) 3 Phase	1, 2, 9, 10, 17
2) 1.0 A resistive	3
3) 0.5 A resistive	11
4) 50 w lamp	5
5) 300 w lamp	13
6) 2.4 H inductive	12
7) 1/2 wave (B-1 relay)	4
8) Capacitive	6, 14
9) Light resistive	7, 15
10) Two power controllers in series to 0.5 A load	8, 16

Figure 17 List of Loads for Power Controller/EMUX Test

APPENDIX

POWERTRAN LISTING FOR DATA HANDLING SYSTEM

```

POWERTRAN VER. 1 MOD. 0 J TERM DEFINITIONS PAGE 1
1 1234567890123456789012345678901234567890123456789012345678901234567890
/ ..... P C T E S T .....
/
/ THIS PROGRAM OPERATES WITH THE POWER CONTROLLER TEST HARDWARE
/ UP TO TWENTY POWER CONTROLLERS CAN BE MANUALLY SWITCHED
/ ON OR OFF, OR AUTOMATICALLY CYCLED AT SEVERAL RATES
/ TRIP INPUTS CAN BE SIMULATED BY SWITCHING THE RESPECTIVE
/ SWITCH TO ONE, THEN TO OFF, TO ONE AGAIN, ETC, EITHER 2 OR 3
/ TIMES. DEPENDING ON THE COUNTER LIMIT THE STATUS CAN BE
/ CHECKED VIA THE CCOP IN THE USUAL MANNER /
/
/ UNITS/
/ CCOP = D32
/ MTR = M07
/ QTR = D07
/
/ DUMMY VARIABLES /
/
PCT = DUMMY / POWER CONTROLLER TRIPPED
CON = DUMMY / CONTROL OUTPUT
OVL = DUMMY / OVERLOAD TRIP INPUT
STS = DUMMY / STATUS INPUT
FLC = DUMMY / FLASH-AUTO CYCLE
AAA = DUMMY / TRIP SUBTERM - DELAY
AAG = DUMMY / TRIP SUBTERM - INPUT TO TRIP COUNTER
ACC = DUMMY / TRIP SUBTERM - OUTPUT FROM TRIP COUNTER
AEC = DUMMY / TRIP COUNTER RESET - ON ZERO OF SWITCH
RES = DUMMY / RESISTOR LOAD TERM + TRIP
COL = DUMMY / INDUCTIVE LOAD TERM + TRIP
LMP = DUMMY / LAMP LOAD TERM + TRIP
SER = DUMMY / 2 PC'S IN SERIES + TRIP
CAP = DUMMY / CAPACITOR LOAD TERM + TRIP
LTE = DUMMY / LIGHT RESISTIVE LOAD TERM + TRIP
MLD = DUMMY / NO LOAD TERM + TRIP
FWR01 = DUMMY / MOTOR FORWARD
REV01 = DUMMY / MOTOR REVERSE
MOT01 = DUMMY / MOTOR TRIPPED
/
/ COUNTERS/
/
C(WAA00,1,3) = AAC01(1),ACC01(1),AEC01(1)
C(WAC00,1,3) = AAC06(1),ADC06(1),AEC06(1)
C(WAE00,1,3) = AAC07(1),ACC07(1),AEC07(1)
C(WAF00,1,3) = AAC08(1),ACC08(1),AEC08(1)
C(WAG00,1,2) = AAC09(1),ACC09(1),AEC09(1)
C(WAH00,1,3) = AAC10(1),ACC10(1),AEC10(1)
C(WAL00,1,3) = AAC11(1),ACC11(1),AEC11(1)
C(WAM00,1,2) = AAC12(1),ACC12(1),AEC12(1)
C(WAN00,1,2) = AAC13(1),ACC13(1),AEC13(1)
C(WAO00,1,2) = AAC14(1),ACC14(1),AEC14(1)
C(WAP00,1,2) = AAC15(1),ACC15(1),AEC15(1)

```

1 2 3 4 5 6 7 8
 123456789012345678901234567890123456789012345678901234567890

C(WAR00,1,2) = AAC16(1),ACC16(1),AEC16(0)
 C(NAS00,1,2) = AAC17(1),ACC17(1),AEC17(0)
 C(WAT00,1,2) = AAC18(1),ACC18(1),AEC18(0)

/ STATUS INPUTS

STS01 = MTR01
 STS02 = MTR02
 STS03 = MTR03
 STS04 = MTR04
 STS05 = MTR05
 STS06 = MTR06
 STS07 = MTR07
 STS08 = MTR08
 STS09 = MTR17
 STS10 = MTR18
 STS11 = MTR19
 STS12 = MTR20
 STS13 = MTR21
 STS14 = MTR22
 STS15 = MTR23
 STS16 = MTR24
 STS17 = MTR33
 STS18 = MTR34

/ TRIP INPUTS

OVL01 = MTR09
 OVL02 = MTR10
 OVL03 = MTR11
 OVL04 = MTR12
 OVL05 = MTR13
 OVL06 = MTR14
 OVL07 = MTR15
 OVL08 = MTR16
 OVL09 = MTR25
 OVL10 = MTR26
 OVL11 = MTR27
 OVL12 = MTR28
 OVL13 = MTR29
 OVL14 = MTR30
 OVL15 = MTR31
 OVL16 = MTR32
 OVL17 = MTR41
 OVL18 = MTR42
 OVL19 = MTR43
 OVL20 = MTR44

/ SWITCH INPUTS

/

51
 52
 53
 54
 55
 56
 57
 58
 59
 60
 61
 62
 63
 64
 65
 66
 67
 68
 69
 70
 71
 72
 73
 74
 75
 76
 77
 78
 79
 80
 81
 82
 83
 84
 85
 86
 87
 88
 89
 90
 91
 92
 93
 94
 95
 96
 97
 98
 99
 100

000500
 000510
 000520
 000530
 000540
 000550
 000560
 000570
 000580
 000590
 000600
 000610
 000620
 000630
 000640
 000650
 000660
 000670
 000680
 000690
 000700
 000710
 000720
 000730
 000740
 000750
 000760
 000770
 000780
 000790
 000800
 000810
 000820
 000830
 000840
 000850

000560
 000570
 000580
 000590
 000600
 000610
 000620
 000630
 000640
 000650
 000660
 000670
 000680
 000690
 000700
 000710
 000720
 000730
 000740
 000750
 000760
 000770
 000780
 000790
 000800
 000810
 000820
 000830
 000840
 000850

1	2	3	4	5	6	7	8
123456789012345678901234567890123456789012345678901234567890							

THE FOLLOWING MJX/DEMUX TERMINAL ADDRESSES HAVE NOT BEEN ASSIGNED

MJX

DEMUX

- | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|----|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|---|---|---|---|---|---|---|---|---|----|

1	2	3	5	7	8
12345678901234567890123456789012345678901234567890					
171	OTR42 = ONE				001340
172	OTR43 = S33				001350
173	OTR44 = ONE				001360
174	OTR45 = ONE				001370
175	OTR46 = S33				001380
176	OTR47 = ONE				001390
177	OTR48 = ZERO				
178	OTR49 = ZERO				
179	OTR50 = ONE				001400
180	OTR51 = ZERO				
181	OTR52 = ZERO				
182	OTR53 = ZERO				
183	OTR54 = ZERO				
184	OTR55 = ONE				001410
185	OTR56 = ZERO				
186	OTR57 = ZERO				
187	OTR58 = ONE				001420
188	OTR59 = ZERO				
189	OTR60 = ZERO				
190	OTR61 = ZERO				
191	OTR62 = ZERO				
192	OTR63 = ONE				001430
193	/				
194	/				
195	/				001440
196	/				
197	/				
198	/				
199	/				
200	/				
201	/				
202	/				
203	/				
204	/				
205	/				
206	/				
207	/				
208	/				
209	/				
210	/				
211	/				
212	/				
213	/				
214	/				
215	/				
216	/				
217	/				
218	/				
219	/				
220	/				

	1	2	3	4	5	6	7	8
221	1234567890123456789012345678901234567890123456789012345678901234567890							
222	/	T1(200),REV01 = -S33-S1-S2+-FLC03-S33						001710
223	/	OFF ON ANY TRIP	/					
224	225	T1(25),T0(25),AAA01=OVL01+OVL02+OVL09+OVL10+OVL17						001720
226	227	/	IM PUT TO COUNTER	/				
228	229	/	AAA01 = AAA01					001730
230	231	/	RESET COUNTER ON ZERO OF CONTROL SWITCH	/				
232	233	/	AEC01 = S1					001740
234	235	/	M(2),MOT01 = ACC01 /NOTIFY TRIP					
236	237	/	RESISTIVE LOAD	/				001760
238	239	/	CON03=RES11--AAA06--ACC05					
240	241	/	CON11=RES12--AAA07--ACC07					001790
242	243	/	RES11=S6 +FLC07					001800
244	245	/	RES12=S7+FLS02					001810
246	247	/	T1(25),T0(25),AAA06=OVL03					001820
248	249	/	AAC06= AAA06					001830
250	251	/	AEC06=S6					
252	253	/	M(2),RES01=ACC06					001850
254	255	/	T1(25),T0(25) AAA07=OVL11					001860
256	257	/	AEC07=AAA07					001870
258	259	/	M(2),RES02=ACC07					
260	261	/	INDUCTIVE LOAD	/				001890
262	263	/	CON04=COL11--AAA08--ACC08					
264	265	/	CON12=COL12--AAA09--ACC09					001920
266	267	/	COL11-S8 +FLC07					001930
268	269	/	COL12=S9+FLS01					001940
270		/	T1(100),T0(100),AAA08=OVL04					001950
		/	AAC08=AAA08					001960
		/	AEC08=S8					001970
		/	T1(25),T0(25),AAA09=OVL12					001980
		/	AAC09=AAA09					001990
		/	AEC09=S9					
		/	M(2),COL01=ACC08					
		/	M(2),COL02=ACC09					
		/	LAMP LOAD	/				002020
		/	CON05=LAMP11--AAA10--ACC10					

[illegible]

1 2 3 4 5 6 7 8
 123-567890123456789012345678901234567890123456789012345678901234567890

SYSTEM INTERNAL TABLE STATUS

COMMENT	% FULL	TABLE NAME
13		SYMBOL TABLE

GENERATED TABLE STATUS

COMMENT	% FULL	TABLE NAME
40		SCRATCHPAD TEMPORARY STORAGE
11		PROTECTED IOC
10		UNPROTECTED IOC
6		PROTECTED EQUATION PARAMETER
17		UNPROTECTED EQUATION PARAMETER
7		DATA BIT STORAGE
25		NOTIFICATION TABLE

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.