NASA CR-134392

MODULAR, HIGH POWER, VARIABLE R DYNAMIC ELECTRICAL LOAD SIMULATOR

FINAL REPORT

Program Period:

28 June 1973 to 20 June 1974

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Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS, 77058

Contract Number NAS 9-13495

AVSD-0170-74-RR

24 June 1974

Prepared by

AVCO GOVERNMENT PRODUCTS GROUP
Systems Division
201 Lowell Street
Wilmington, Massachusetts, 01887

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DYNAMIC ELECTRICAL LOAD SIMULATOR

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ABSTRACT

This is the final report of the modular, high power, variable R dynamic electrical load simulator program conducted for the National Aeronautics and Space Administration (NASA) by Avco Corporation's Systems Division (Avco/SD) under contract NAS 9-13495. Under the program, which covered the period 28 June 1973 to 20 June 1974, six simulators (including a refurbished engineering prototype unit), along with an operating and maintenance manual, were delivered to NASA's Johnson Space Center.

The objective of the program was to extend the design of Avco/SD's previously developed basic variable R load simulator to increase its power dissipation and transient handling capabilities. The delivered units satisfy all design requirements, and provide NASA with a high power, modular simulation capability uniquely suited to the simulation of complex load responses. To permit effective application of the large number of variable R simulators presently available at NASA, Avco recommends development of simulator control techniques based on use of a general-purpose digital computer.

In addition to presenting conclusions and recommendations and pertinent background information, the report covers program accomplishments; describes the simulator basic circuits, transfer characteristic, protective features, assembly, and specifications; indicates the results of simulator evaluation, including burn-in and acceptance testing; provides acceptance test data; and summarizes the monthly progress reports.

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1.0 INTRODUCTION

This document is the final report of the Modular, High Power, Variable R Dynamic Electrical Load Simulator program. This was a twelve-month program (28 June 1973 to 20 June 1974) conducted by Avco Corporation's Systems Division (Avco/SD) for the National Aeronautics and Space Administration (NASA) under Contract Number NAS-9-13495.

This program was preceded by a three-phase development program that started in 1970 with an investigation of means of interrogating and simulating electrical loads on the power lines of manned spacecraft. Subsequent phases were undertaken to develop hardware and software capable of implementing the techniques recommened in the Phase 1 study.

The objective of the current program was to extend the design of the basic variable R simulator developed in the earlier phases to increase its power dissipation and transient handling capabilities.

Five modular, high power, variable R simulators meeting all design requirements were manufactured and delivered to NASA's Johnson Space Center (JSC) along with a refurbished engineering prototype unit. An operating and maintenance manual was also provided.

1.1 BACKGROUND

The design and development of electrical power distribution/conditioning systems is highly dependent on the characteristics of the power sources and the loads. Their influence becomes progressively more significant as the operational functions of the total integrated system become more critical, such as exemplified in complex spacecraft systems. During past manned spacecraft programs (from Project Mercury through Apollo), in order to meet projected schedules it was necessary to evaluate system performance using load simulators which, at best, could only duplicate the steady-state load conditions. Subsequent vehicle testing and flight experience has consistently uncovered system operational problems caused by the transient (or dynamic) characteristics of the various loads reflected back into the system. Identification of the problem at this point in the program resulted in costly work-around and/or corrective action. Recognizing this, a multi-phase program was undertaken to investigate concepts for providing more realistic loads, and to develop prototype hardware and software capable of implementing and evaluating these concepts.

The Phase 1 study program was undertaken to investigate various concepts and techniques for identifying and simulating both the steady-state and dynamic characteristics of electrical loads for use during integrated system test and evaluation. These investigations showed that it is feasible to design and develop interrogation and simulation equipment to perform the desired functions.

A second phase was undertaken to develop hardware capable of providing this simulation. During these activities, actual spacecraft loads were interrogated by stimulating the loads with their normal input voltage and measuring the resulting input voltage and current time-histories. Using an existing computer program with some modifications, general network models consisting of resistance (R), inductance (L), and capacitance (C) elements were optimized by an iterative process of selecting element values and comparing the time domain response of the model with those obtained from the real equipment during the interrogation. A general-purpose simulator was developed with the capability of realizing a variety of models comprised of R, L, and C elements where element values were discretely variable. The different models, each corresponding to real spacecraft equipment, are set up manually for each case by suitable switching and patching. The models are capable of duplicating the dynamic and steady-state response of real loads at full power.

Also developed during the Phase 2 program was a variable resistance (variable R) device with the capability of reproducing a resistance-time curve upon application of a suitable, externally provided control signal. In practice, the current/voltage time-history of an article of hardware is obtained during the interrogation process and this data is then processed and stored. In operation, this signal is retrieved from storage and applied as the control input to the variable R. The output resistance of the variable R, connected to the power source normally used to operate the real equipment, is then made to vary as a function of this control. Thus, the power input current is caused to vary just as the input current to the real equipment.

During the third phase, the optimization software developed during the earlier phases was documented and delivered along with a detailed software manual. Data acquisition hardware used in the interrogation process to acquire the voltage and current time-histories of the equipment to be simulated was also provided during this phase.

For details regarding these earlier programs, see the final reports (References 1, 2, and 3 for the phase 1, 2, and 3 programs, respectively).

The current program was undertaken to extend the design of the basic variable R device to provide for dissipation of up to 1500 watts, continuous, at up to 50 amperes with transient handling capability up to 240 amperes. In addition, each device was to be comprised of 3 modules, each of 500-watt capability, with provisions for independent control of each module or combination of modules.

1.2 DEFINITIONS

The terms interrogation and simulation are used extensively throughout this report. A definition of these terms follows:

> Interrogation:--The quantitative determination of those parameters of a device that describe its dynamic and steady-state electrical response on the power lines to a specified application of voltage.
>
> Simulation:--The duplication on the power lines of the dynamic and steady state response of an electrical load.

1.3 REPORT ORGANIZATION

The final report is organized as follows:

1. INTRODUCTION

   Provides background information, defines key terms, indicates the way the report is organized, and lists pertinent contractual publications.

2. CONCLUSIONS AND RECOMMENDATIONS

   Presents conclusions drawn from the program and recommendations for future action.

3. PROGRAM ACCOMPLISHMENTS

   Describes program accomplishments in the following-listed areas:

   - Hardware design, development, and manufacture.
   - Hardware test and burn-in.
   - Hardware delivery and demonstration.
   - Operating and maintenance manual preparation and submission.

4. MODULAR, HIGH POWER, VARIABLE R DESCRIPTION

Describes the modular, high power, variable R, including the basic circuits, transfer characteristic, protective features, its assembly, and specifications.

5. MODULAR, HIGH POWER, VARIABLE R EVALUATION

Summarizes the evaluation of the modular, high power, variable R, covering the results of both burn-in and acceptance testing.

6. REFERENCES

Lists appropriate references.

1.4 PUBLICATIONS

Avco Systems Division documents published under this contract are listed in Table 1-I. For summaries of the monthly progress reports, see Appendix A.

TABLE 1-I

AVCO SYSTEMS DIVISION DOCUMENTS

PUBLISHED UNDER CONTRACT NAS 9-13495

1. Modular, High Power, Variable R Dynamic Electrical Load Simulator, First Monthly Progress Report, for the period 28 June to 31 July 1973; Avco Systems Division, AVSD-0249-73-CR, 8 August 1973.

2. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Second Monthly Progress Report, for the period 1 August to 31 August 1973; Avco Systems Division, AVSD-0274-73-CR, 7 September 1973.

3. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Third Monthly Progress Report, for the period 1 September to 30 September 1973; Avco Systems Division, AVSD-0300-73-CR, 8 October 1973.

4. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Fourth Monthly Progress Report, for the period 1 October to 31 October 1973; Avco Systems Division, AVSD-0320-73-CR, 5 November 1973.

5. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Fifth Monthly Progress Report, for the period 1 November to 30 November 1973; Avco Systems Division, AVSD-0338-73-CR, 5 December 1973.

6. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Sixth Monthly Progress Report, for the period 1 December to 31 December 1973; Avco Systems Division, AVSD-0004-74-CR, 4 January 1974.

7. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Seventh Monthly Progress Report, for the period 1 January to 31 January 1974; Avco Systems Division, AVSD-0034-74-CR, 5 February 1974.

8. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Eighth Monthly Progress Report, for the period 1 February to 28 February 1974; Avco Systems Division, AVSD-0058-74-CR, 5 March 1974.

9. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Ninth Monthly Progress Report, for the period 1 March to 31 March 1974; Avco Systems Division, AVSD-0092-74-CR, 8 April 1974.

10. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Tenth Monthly Progress Report, for the period 1 April to 30 April 1974; Avco Systems Division, AVSD-0130-74-CR, 6 May 1974.

11. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Eleventh Monthly Progress Report, for the period 1 May to 31 May 1974; Avco Systems Division, AVSD-0161-74-CR, 10 June 1974.

12. Operating and Maintenance Manual, Model DC-1500 Variable R Dynamic Electrical Load Simulator; Avco Systems Division, ESDM-F420-74-198, 14 June 1974.

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

The modular, high power, variable R dynamic electrical load simulators developed during this program satisfy all design requirements, and provide NASA with a high-power simulation capability uniquely suited to the simulation of complex load responses. The modular configuration of these devices permits independent operation of each module, thereby giving NASA considerable flexibility in applying them to a variety of test programs.

A total of six modular, high power, variable R simulators were delivered to NASA's Johnson Space Center.

2.2 RECOMMENDATIONS

The program just completed provided hardware suitable for simulating complex load responses of a variety of electrical equipment at high power. The modular configuration of the equipment provides the equivalent of 18 medium power simulators--each capable of independent control and operation. This, coupled with the earlier development of two low-power simulators and the current development of two high power AC/DC variable R simulators (under separate contract), provides NASA with an equivalent total of 20 variable R simulators.

To use this number of variable R simulators effectively requires more flexible control techniques than those currently available. Therefore, it is recommended that control systems, using a general-purpose digital computer, be developed capable of controlling a quantity of variable R simulators simultaneously.

3.0 PROGRAM ACCOMPLISHMENTS

The objective of this program was the design, development, manufacture, and delivery of five modular, high power, variable R dynamic electrical load simulators, and the refurbishment and delivery of an engineering prototype variable R load simulator. Under the program these units were to be set up at NASA JSC and their operation demonstrated. In addition, an operating and maintenance manual was to be supplied.

All of these tasks have been successfully completed, as described in the following paragraphs of this section of the report.

3.1 HARDWARE DESIGN, DEVELOPMENT, AND MANUFACTURE

As noted in Section 1.0 INTRODUCTION, the fundamental concepts of the modular, high power, variable R simulator are based on work completed previously under the Phase 1 study (NASA Contract NAS 9-10429), and the Phase 2 and Phase 3 hardware and software development programs (NASA Contracts NAS 9-12016 and NAS 9-12913).

Two areas of the basic variable R required considerable re-design, as distinct from over-all upgrading of the basic approach. These two areas were:

1. The power output stage--to provide means for dissipating additional power.
2. The overload protection circuits--to provide transient overload capabilities.

These circuits, along with other simulator circuits, are described in Section 4.0.

The only problem encountered during the program was one of load current imbalance that resulted in destruction of certain of the power transistors in the output stage of several of the simulators. The problem was solved by a simple design change that involved increasing the value of the emitter resistance of the output transitors. Appendix A of the Ninth Monthly Progress Report (Reference 4) gives a detailed description of the failure and of the design change that was made to correct it.

The modular, high power, variable R hardware developed under this program has been designated Model DC-1500.

3.2 HARDWARE TEST AND BURN-IN

All hardware was calibrated to the transfer characteristic, thoroughly tested, and then subjected to an 80-hour burn-in prior to being delivered. Details of these activities are provided in Section 5.0.

3.3 HARDWARE DELIVERY AND DEMONSTRATION

All hardware was delivered to NASA's Lyndon B. Johnson Space Center where Avco personnel unpacked it, set it up, and then demonstrated its operation.

3.4 OPERATING AND MAINTENANCE MANUAL

The operating and maintenance manual for the DC-1500 variable R simulator (Reference 5) provides complete operating instructions along with circuit descriptions, schematic diagrams, safety and maintenance instructions, and specifications.

4.0 MODULAR, HIGH POWER, VARIABLE R DESCRIPTION

The Model DC-1500 Variable R Dynamic Electrical Load Simulator, shown in Figure 4-1, provides means for simulating the dynamic and steady-state response of electrical loads on the power lines. The variable R simulator is essentially an electronic circuit whose output resistance can be made to vary as a function of a control voltage. It is shown in simplified block diagram form in Figure 4-2. The 1500-watt simulator consists of three 500-watt modules that can be either operated independently or slaved to obtain either a 1000-watt or a 1500-watt capability.

The variable R can be used to simulate equipment response to application of voltage on the power lines by first interrogating the equipment and computing the input current/voltage ratio, and then using this ratio (conductance analog) as the control signal. The variable R may also be controlled by signals derived from function generators and other such devices.

The variable R 500-watt modules will respond to control signals over a frequency range of DC to 10 kHz at current levels as high as 20 amperes, continuous. The variable R may be operated at positive, non-zero-crossing, load voltage inputs of 20 to 60 volts. The maximum power dissipation is 500 watts, continuous, per module, with 1500 watts total for an integral, three-module unit.

23641A

FIGURE 4-1 Model DC-1500 Variable R Dynamic Electrical Load Simulator

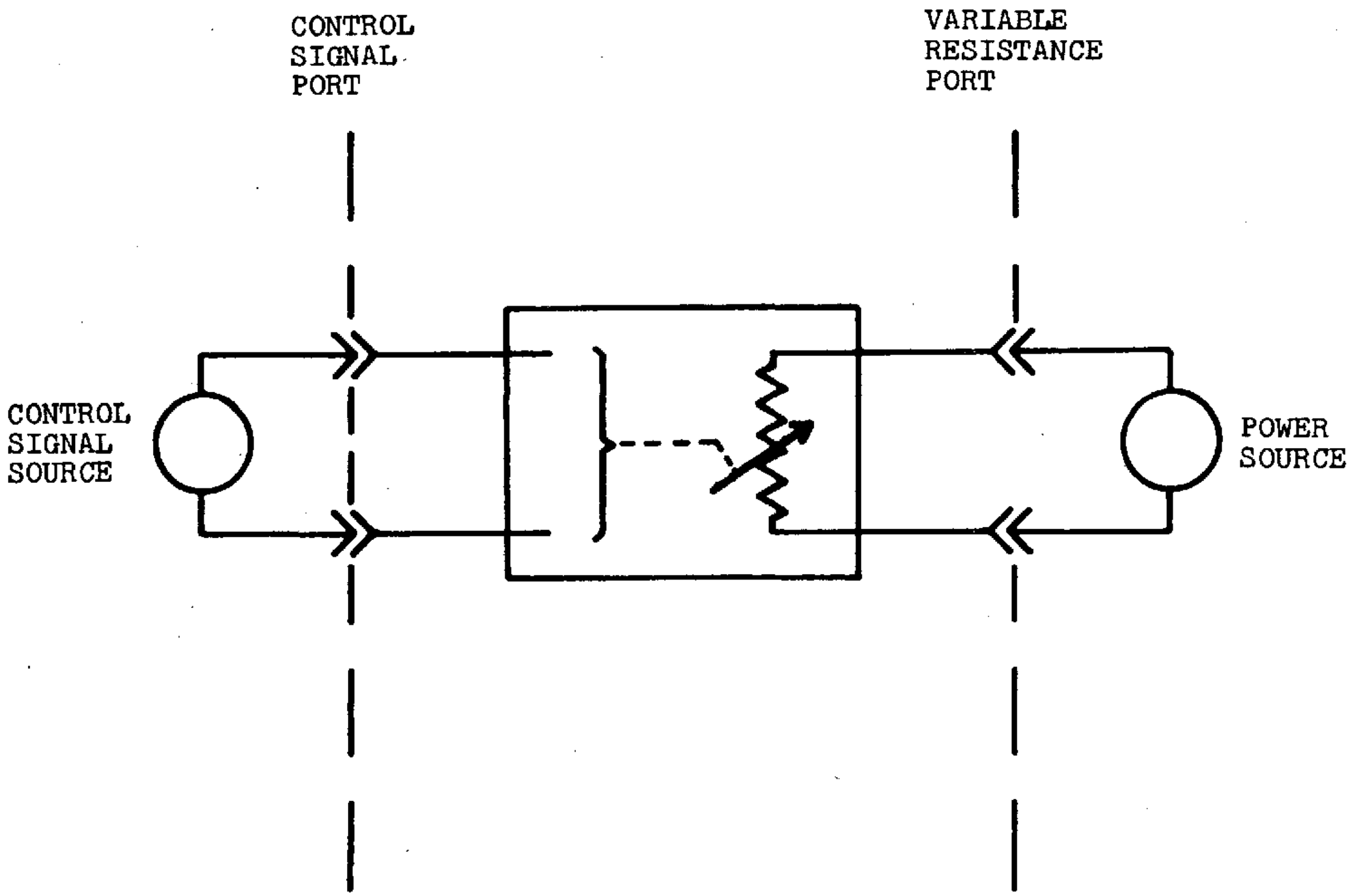


FIGURE 4-2 Variable R Concept - Simplified Diagram

Each 500-watt module is capable of operating with transient overloads of up to 80 amperes (2400 watts) for up to 20 milliseconds in duration at a 5 percent duty cycle. Thus, a 3-module simulator is capable of operating with transient overloads of up to 240 amperes (7200 watts).

Figure 4-3 is a simplified block diagram of a single 500-watt module.

The Model DC-1500 Variable R is housed in an attractive desk-top cabinet with integral cooling. Four rubber-covered feet provide sufficient clearance for circulation of cooling air and also permit stacking of the units. All controls, indicators, and connectors (except for the Overide switches and Remote connector) are located on the front panel. The multi-pin Remote connectors and the associated Override toggle switches (used to override the output relays) are on the rear panel.

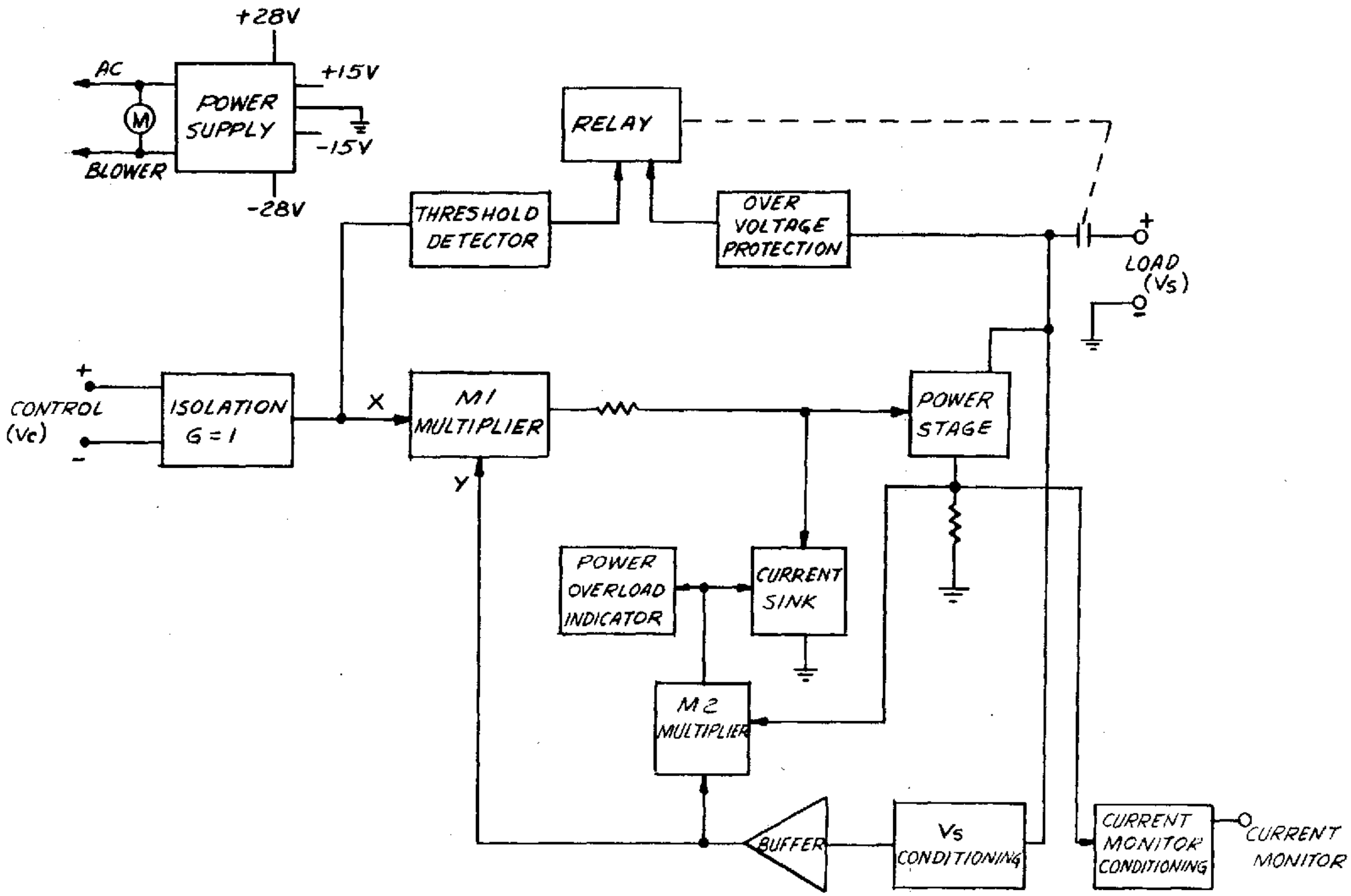


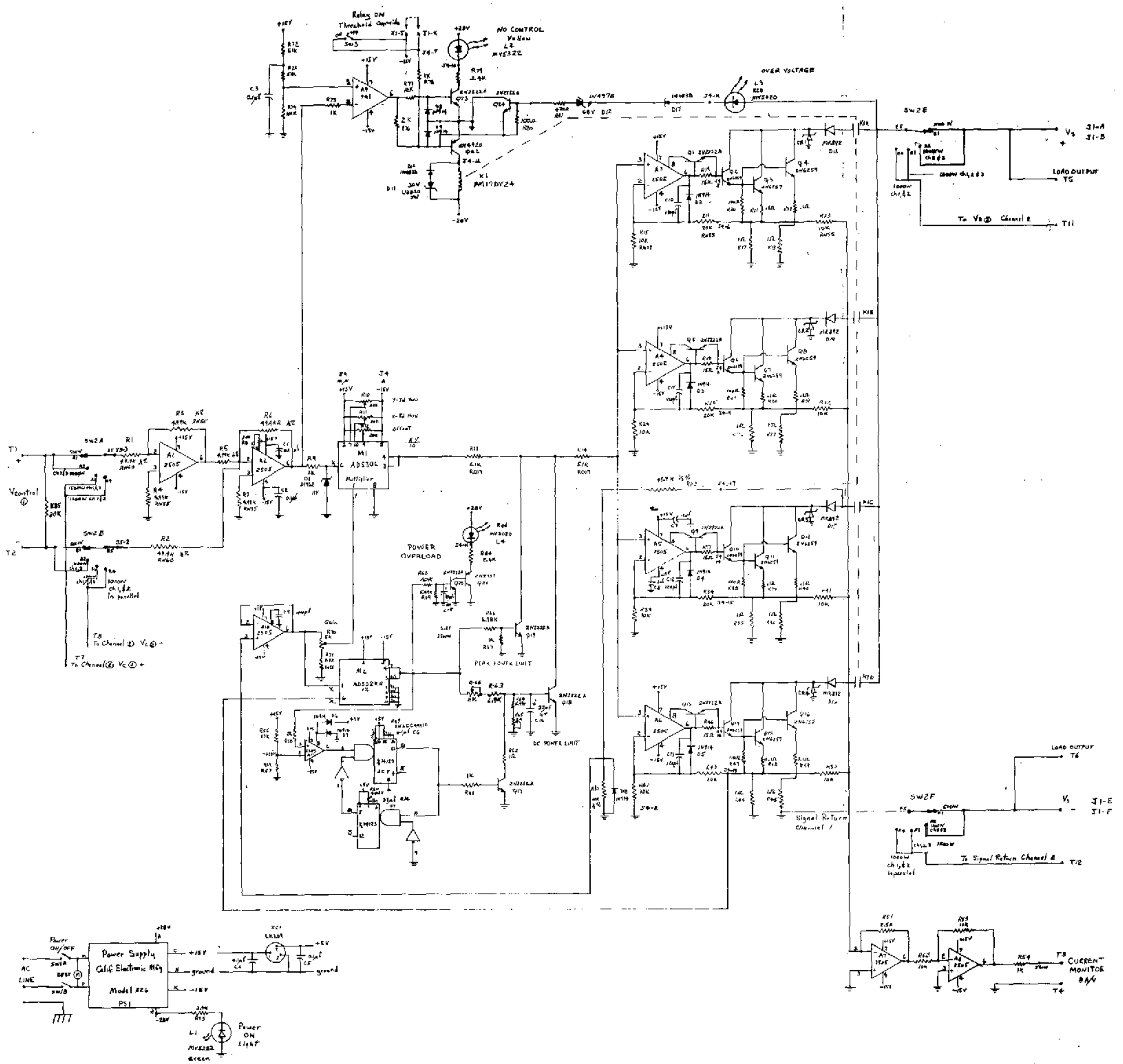
FIGURE 4-3 500-Watt Module, Variable R, Block Diagram

4.1 CIRCUIT DESCRIPTION

The DC-1500 variable R consists of three modules, each with its own control and regulation electronics, monitor and protective circuits, power stages, interface provisions, and power supply. Figure 4-4 is a schematic diagram of the DC-1500 variable R. Figure 4-5 shows the interconnecting wiring.

The control voltage, Vc, inputs are applied to inverting amplifier stages A1 and A2. A1 inverts the signal on the positive (+) input, and then the signal is summed in amplifier A2, giving unity gain for the differential signal, Vc. The output of amplifier A2 is applied to the X input of multiplier M1. Rejection of the common mode signals (signals from circuit ground to the positive (+) and negative (-) inputs) is based mainly on the match between the resistors chosen for this application.

The control voltage conditioning block (shown on Figure 4-3) is a voltage divider whose output is buffered by amplifier A10 to drive the Y input of multiplier M1. The multiplier output is proportional to the product of the X and Y inputs, and provides the drive to the power stage. This feature makes the variable R load current (Is) sensitive to the load voltage (Vs) and, therefore, provides a true resistance. The 4-section power stage is shown in Figure 4-4 with inputs at pin 3 of amplifiers A3, A4, A5, and A6. One section of the power stage consists of operational amplifier A3; transistors Q1 through Q4; diode D2; and resistors R15 through R23. The other quarters are identical except for component reference designations.



QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL OR NOTE	SPECIFICATION	ZONE	ITEM NO.
1		DF30BC	Binding Posts	T6 Blk	Superior		
1		DF30RC	Binding Posts	T5 Red	Superior		
4		111-103	Binding Posts	T2, T4 Blk	E.F. Johnson		
4		111-102	Binding Posts	T1, T3 Red	E.F. Johnson		
1		747	Fan, Sentinel [illegible]	Fan	Rotron		
1		FAHP4-CB	Heat sink	H.S.	IERC		
1		PM17DY24	Relay 4PDT 24VDC	K1	Potter & Brumfield		
1		35D203	Relay enclosure		Potter & Brumfield		
1		JMT-123	Switch SPDT	SW3			
1		103408A	Switch, Rotary 8 Pole 4 Pos.	SW2	Electro Switch Corp		
1		75L1K4	Switch, Toggle DPST	SW1			
1		Model 226	Power Supply ±15V, ±28V	PS1	California Electronic		
2		MV5020	LED Red	L3, L4	Monsanto		
1		MV5322	LED Yellow	L2	Monsanto		
1		MV5222	LED Green	L1	Monsanto		
4		TSD-38-100	Zener Diode 100V	CR1, CR2, CR3, CR4			
4		MR852	Diode rectifier 30A 200V	D13, D14, D15, D16	Motorola		
1		1N4978	Zener diode 68V 5W	D1			
1		UZ830	Zener diode 30V 3W	D1	Unitrode		
2		1N4838	Diode	D11, D17			
8		1N914	Diode SW	D2, D3, D4, D5, D6, D7, D8, D9, D18			
1		1N962B	Zener diode 11V	D			
1		SN74121N	Monostable Multivibrator	IC2	TI		
1		LM309H	Regulator, Voltage 5V 2W	IC1	National		
1		2N4920	Transistor PNP 30W	Q22			
1		2N2907	Transistor PNP .6W	Q21			
12		2N4259	Transistor NPN 250W	Q2, Q3, Q4, Q6, Q7, Q9, Q10, Q11, Q12, Q14, Q15, Q16			
10		2N2222A	Transistor NPN .6W	Q1, Q5, Q9, Q13, Q17, Q18, Q19, Q20, Q23, Q24			
1		AD532KH	Multiplier, Analog 1%	M2	Analog Devices		
1		AD530LH	Multiplier, Analog 0.5%	M1	Analog Devices		
1		LM741HC	Op Amp	A9	National		
10		HA-2-2505-5	Op. Amp.	A1, A2, A3, A4, A5, A6, A7, A8, A10, A11	Harris		
3		T52-010-336-10	Capacitor 33μf 10V 10%	C14, C15, C16	Components Inc		
4		CK05BX121M	Capacitor 120pf 200V 20%	C10, C11, C12, C13			
1		CK05BX102M	Capacitor 1000pf 200V 20%	C9			
8		CK06BX104K	Capacitor 0.1μf 50V 10%	C1, C2, C3, C4, C5, C6, C7, C8			
1		RC07GF682J	Resistor 6.8K ¼W 5%	R63			
1		RC07GF203J	Resistor 20K ¼W 5%	R68			
1		RC20GF471J	Resistor 470Ω ½W 5%	R8			
2		RC07GF513J	Resistor 51K ¼W 5%	R71, R73			
1		RN65C7501F	Resistor 7.5K ½W 1%	R72			
1		3386-1-502	Potentiometer 5KΩ	R70			
1		RN55C1001F	Resistor 1KΩ ⅛W 1%	R67			
1		RN55C6981F	Resistor 6.98K ⅛W 1%	R66			
1		3386-1-202	Potentiometer 2KΩ	R65			
2		RN55C5491F	Resistor 5.49K ⅛W 1%	R64, R69			
1		RN55C4991F	Resistor 4.99K ⅛W 1%	R62			
1		RS-1A	Resistor 1Ω 1W 1%	R62			
1		RN55C4022F	Resistor 40.2KΩ ⅛W 1%	R60			
1		RN55C4991F	Resistor 4.99KΩ ⅛W 1%	R59			
1		RN55C9090F	Resistor 909Ω ⅛W 1%	R57			
2		RN55C1002F	Resistor 10KΩ ⅛W 1%	R56, R77			
3		RC07GF242J	Resistor 2.4K ¼W 5%	R55, R79, R44			
4		RC07GF102J	Resistor 1KΩ ¼W 5%	R54, R61, R75, R78			
1		RN55C2501D	Resistor 2.5KΩ ⅛W .5%	R51			
8		RS-2B	Resistor 0.1Ω 3W 1%	R21, R22, R30, R31, R41, R49, R50, R51	Dale		
6		RC07GF101J	Resistor 100Ω ¼W 5%	R20, R29, R38, R47, R74, R80			
4		RC07GF150J	Resistor 15Ω ¼W 5%	R19, R28, R37, R46			
8		RE75G1R00	Resistor 1Ω 50W 1%	R17, R18, R26, R27, R35, R36, R44, R45	Dale		
4		RN55C2002D	Resistor 20KΩ ⅛W .5%	R16, R25, R34, R43			
11		RN55C1002D	Resistor 10KΩ ⅛W .5%	R15, R23, R24, R32, R33, [illegible], R52, R53, R83			
2		RC07GF512J	Resistor 5.1K ¼W 5%	R13, R14			
3		RC07GF202J	Resistor 2KΩ ¼W 5%	R9, R58, R76			
4		3059L-1-203	Potentiometer 20KΩ	R8, R10, R11, R12	Bourns		
2		RN55C4992D	Resistor 49.9K ⅛W .5%	R6, R42			
4		RN55C4991D	Resistor 4.99K ⅛W .5%	R3, R4, R5, R7			
2		RN60C4992D	Resistor 49.9K ¼W .5%	R1, R2			
-1	ASSY NO.						

LIST OF PARTS

UNLESS OTHERWISE SPECIFIED
TOLERANCE AND DRAWING INTERPRETATION PER D143
MACHINED ANGLES ± 0° 30'
SHEET METAL BEND ANGLES ± 2°
SURFACE ROUGHNESS √

PART CLASS. UNCLASSIFIED
DWG CLASS. UNCLASSIFIED

-1 631700 | 3 631700

CONTR NO. | RELEASE | DWG APPD | CHECKED | DRAWN | DESIGN APPROVAL | MANAGER | DESIGNER

TITLE VARIABLE-R 500 WATT MODULE SCHEMATIC

SIZE E | CODE IDENT NO. 04614 | DWG NO. 631701

FOLDOUT FRAME

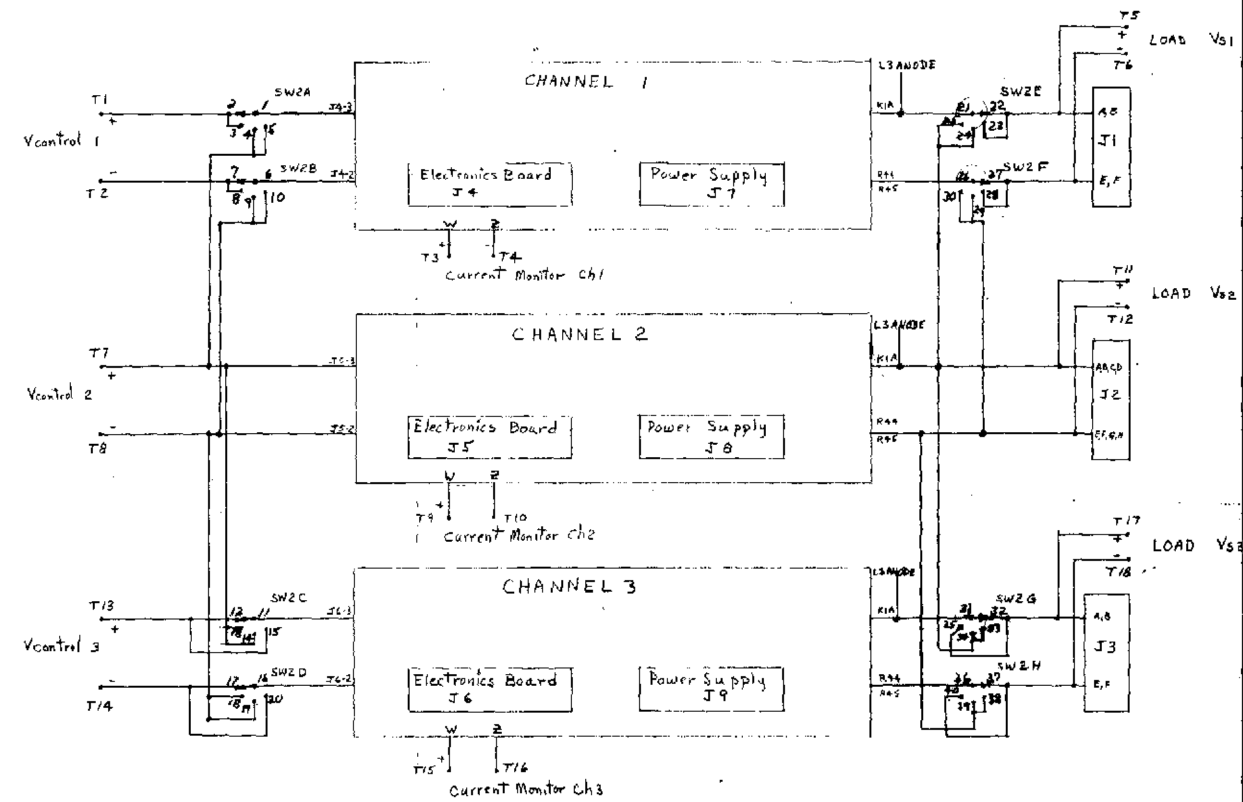
FIGURE 4-4 Model DC-1500 Variable R, 500-Watt Module, Schematic Diagram (Avco Drawing 631701)

FOLDOUT FRAME

CHANNEL 1 WIRE LIST ①

Group	FROM	TO	WIRE SIZE
POWER STAGE	J1 A	SW2-E22	16
	J1 B	SW2-E23	16
	T5	SW2-E22	16
		SW2-E23	16
	SW2-E23	SW2-E22	16
	SW2-E24	SW2-E25	16
	T11	SW2-E25	16
	T11	SW2-E24	16
	K1A ARM	SW2-E21	16
	K1A-1	SW2-E21	16
	L3-ANODE	SW2-E21	22
	K1A-NO	D13 ANODE	16
	K1A-NO	D13 ANODE	16
	D13-CATHODE	Q2-COLLECTOR	16
	D13-CATHODE	Q3-COLLECTOR	16
	D13-CATHODE	Q4-COLLECTOR	16
	K1A-ARM	K1B-ARM	16 Bus
	K1B-ARM	K1C-ARM	16 Bus
	K1C-ARM	K1D-ARM	16 Bus
	K1B-NO	D14-ANODE	16
	K1B-NO	D14-ANODE	16
	D14-CATHODE	Q6-COLLECTOR	16
	D14-CATHODE	Q7-COLLECTOR	16
	D14-CATHODE	Q8-COLLECTOR	16
	K1C-NO	D15-ANODE	16
	K1C-NO	D15-ANODE	16
	D15-CATHODE	Q10-COLLECTOR	16
	D15-CATHODE	Q11-COLLECTOR	16
	D15-CATHODE	Q12-COLLECTOR	16
	D15-ANODE	J4-17	22
	K1D-NO	D16-ANODE	16
	K1D-NO	D16-ANODE	16
	D16-CATHODE	Q14-COLLECTOR	16
	D16-CATHODE	Q15-COLLECTOR	16
	D16-CATHODE	Q16-COLLECTOR	16
	J1-E	SW2-F27	16
	J1-F	SW2-F28	16
	T6	SW2-F27	16
	T6	SW2-F28	16
	SW2-F27	SW2-F28	16
	SW2-F29	SW2-F30	16
	T12	SW2-F29	16
	T12	SW2-F30	16
	R44 (GND)	SW2-F26	16
	R45 (GND)	SW2-F26	16
	R17	R18 (GND)	Bus
	R18	R26 (GND)	Bus
	R26	R27 (GND)	Bus
	R27	R35 (GND)	Bus
	R35	R36 (GND)	Bus
	R36 R44	R45 (GND)	Bus
AC LINE	AC LINE	SW1A	line cord
	AC LINE	SW1B	line cord
	HOUSE GND	CHASSIS	line cord
POWER STAGE	J7-M	SW1A ARM	22
	J7-P	SW1B ARM	22
	FAN	SW1A ARM	22
	FAN	SW1B ARM	22
	J7-A (GRN)	L2-ANODE	22
	J7-A	L4-ANODE	22
	J7-C (GRN)	J4-M	22
	J4-N	J4-M	22

Group	FROM	TO	WIRE SIZE
POWER SUPPLY	J7-H (GND)	J4-Z	22
	J7-X	J4-A	22
	J7-Z	K1A COIL (-)	22
	D11 CATHODE	K1A COIL (-)	22
	D11-ANODE	D10 ANODE	22
	D10-CATHODE	K1B COIL (+)	22
	J4-12	K1B COIL (+)	22
	J7-Z	R55	22
	L1-CATHODE	R55	22
	J7-H	L1-ANODE	22
INPUT	SW2-A2	SW2-A3	22
	SW2-A2	T1	22
	SW2-A4	SW2-A5	22
	SW2-A4	T7	22
	SW2-A1	J4-3	22
	SW2-B7	SW2-B8	22
	SW2-B7	T2	22
	SW2-B9	SW2-B10	22
	SW2-B9	T8	22
	SW2-B6	J4-2	22
POWER STAGE	J4-5	Q2 BASE	22
	J4-6	R17 - Terminal	22
	Q2-EMITTER	Q3-Q4 BASES	22
	J4-8	Q6 BASE	22
	J4-9	R26 - Terminal	22
	Q6-EMITTER	Q7-Q8 BASES	22
	J4-14	Q10 BASE	22
	J4-15	R35 - Terminal	22
	Q10 EMITTER	Q11-Q12 BASES	22
	J4-18	Q14 BASE	22
	J4-19	R44 - Terminal	22
	Q14 EMITTER	Q15-Q16 BASES	22
MONITOR, OVERRIDE, & INDICATOR	J4-Z	R44 (GND)	22
	J4-Z	T4 (GND)	22
	J4-W	T3	22
	J4-T	SW3-ON	22
	J1-K	SW3-ON	22
	J1-T	SW3-ARM	22
	J7-X	SW3-ARM	22
	J4-K	L3 CATHODE	22
	J4-H	L4 CATHODE	22
	J4-10	L2 CATHODE	22
	CR1-CATHODE	D13-CATHODE	22
	CR2-CATHODE	D14-CATHODE	22
	CR3-CATHODE	D15-CATHODE	22
	CR4-CATHODE	D16-CATHODE	22
	CR1-ANODE	CR2-ANODE	BUS
	CR2-ANODE	CR3-ANODE	BUS
	CR3-ANODE	CR4-ANODE	BUS
	CR4-ANODE	R-36	16



Switch Position	Channel Configuration
1	ALL INDEPENDENT 500W
2	CH 2-3 1000W, CH 1 500W
3	CH 1-2-3 1500W
4	CH 1-2 1000W; CH3 500W

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

NOTES

① WIRE LIST CHANGES FOR CH 2 & 3

CH1 →	CH2 →	CH3
J1	J2	J3
J4	J5	J6
J7	J8	J9
T1	T7	T13
T2	T8	T14
T3	T9	T15
T4	T10	T16
T5	T11	T17
T6	T12	T18
LINE CORD	JUMPER AC TO FAN & P.S.-2	JUMPER AC TO FAN & P.S.-3
SW2A	—	SW2C
SW2B	—	SW2D
SW2E	—	SW2G
SW2F	—	SW2H

NOTE CHANGES IN SWITCH SW2 FOR CHANNEL 2 & 3

PART CLASS: UNCLASSIFIED
DWG CLASS: UNCLASSIFIED

NEXT ASSY: 631700 — END ITEM NUMBER: 631700

UNLESS OTHERWISE SPECIFIED — TOLERANCE AND DRAWING INTERPRETATION PER D143

LIST OF PARTS

AVCO SYSTEMS DIVISION

TITLE: VARIABLE - R WIRE LIST AND DIAGRAM

SIZE D — CODE IDENT NO. 04614 — DWG NO. 631702 — SCALE NA

DO NOT SCALE DRAWING

FIGURE 4-5 Model DC-1500 Variable R, Interconnecting Diagram (Avco Drawing 631702)

FOLDOUT FRAME 1

FOLDOUT FRAME 2

The input at pin 3 of amplifier A4 forces a corresponding signal at pin 2 by operational amplifier action, since the differential input (pin 2 to pin 3) must be zero, ideally. The resistive divider, R15 and R16, requires that the voltage across R17 be $\left[(R16 + R15)/R15\right]$ times the input signal. This, in effect, sets the emitter current of the Darlington stage transistors and forces the collector current (approximately equal to the emitter current) to flow, thus forming a voltage-input-controlled current source (Is). The current source is uni-polar. Diode D2 protects the circuit against negative input signals.

Each of the other sections of the power stage, with inputs to amplifiers A4, A5, and A6, and identical circuitry, operates in a similar manner. The four section outputs are summed, providing a current flow proportional to the control voltage, Vc, and the source voltage, Vs. Figure 4-6 is a generalized schematic diagram (i.e., one without component reference designations) of one section of the power stage.

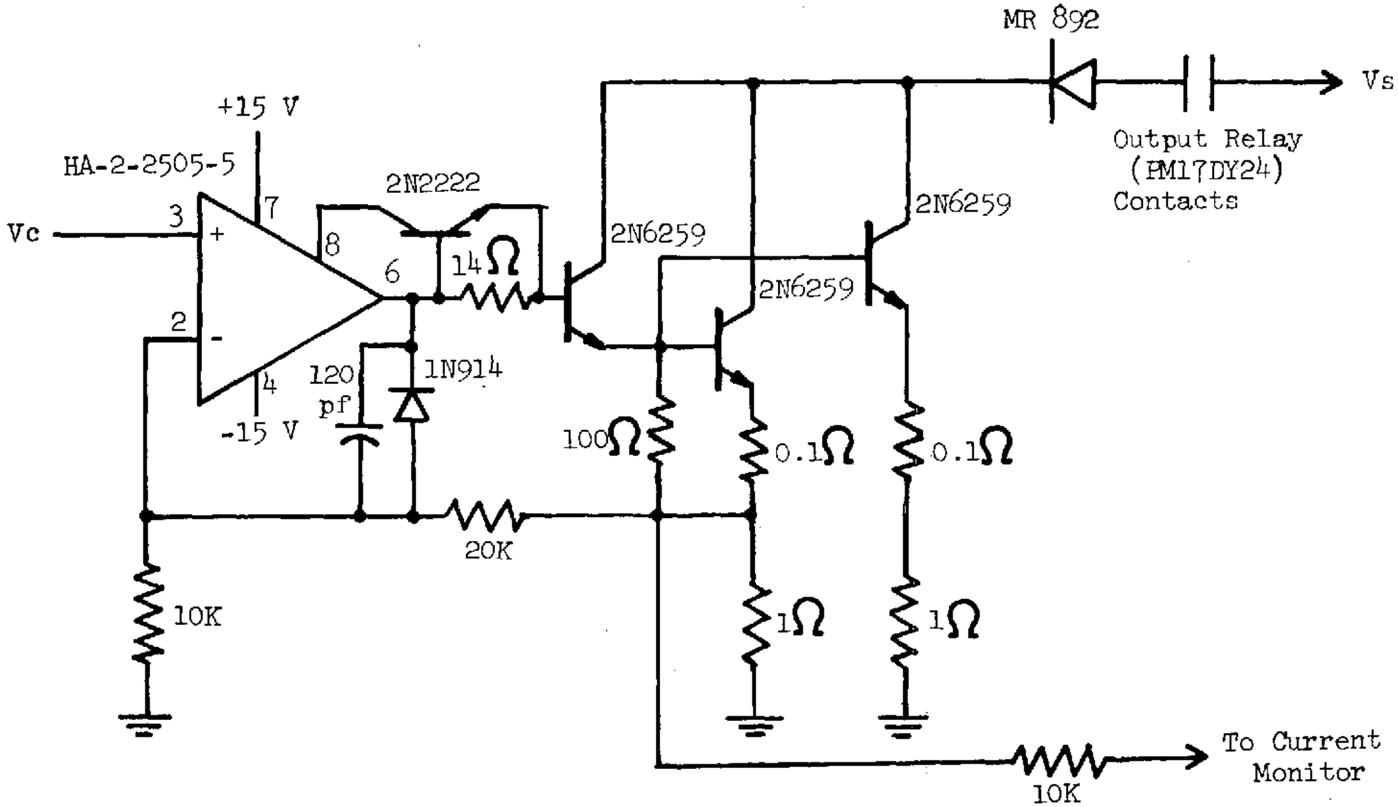


FIGURE 4-6 One Section of Power Stage, 500-Watt Variable R Module, Schematic Diagram

4.2 TRANSFER CHARACTERISTICS

The source current, Is, for a single module is given by the following expression. (The component designations are those used on Figure 4-4.)

$$Is = \left[\frac{1}{R17}\left(\frac{R16 + R15}{R15}\right) K1\ G1 \left(\frac{R83}{R83 + R82}\right) Vs\ Vc\right] \times 2 +$$

$$\left[\frac{1}{R26}\left(\frac{R25 + R24}{R24}\right) K1\ G1 \left(\frac{R83}{R83 + R82}\right) Vs\ Vc\right] \times 2 +$$

$$\left[\frac{1}{R35}\left(\frac{R34 + R33}{R33}\right) K1\ G1 \left(\frac{R83}{R83 + R82}\right) Vs\ Vc\right] \times 2 +$$

$$\left[\frac{1}{R44}\left(\frac{R43 + R42}{R42}\right) K1\ G1 \left(\frac{R83}{R83 + R82}\right) Vs\ Vc\right] \times 2$$

where:

K1 = multiplier constant (= 1/10)

G1 = gain of the A1 - A2 isolation stage.

Sustituting unity gain for G1, and 1/10 for K1; and assuming matching values for the resistors (R17, R26, R35, and R44; R15, R24, R33, and R42; and R16, R25, R34, and R43), gives a simplified expression for Is, as follows:

$$Is = \frac{8}{R17}\left(\frac{R16 + R15}{R15}\right)\left(\frac{1}{10}\right)(1)\left(\frac{R83}{R83 + R82}\right) Vs\ Vc$$

For actual values of resistance, this becomes:

$$Is = \frac{8}{1.0}\left(\frac{20K + 10K}{10K}\right)\left(\frac{1}{10}\right)(1)\left(\frac{10K}{10K + 50K}\right) Vs\ Vc$$

which gives the following general simplified equation for Is for a 500-watt module:

$$\boxed{Is = 0.4\ Vs\ Vc}$$

This is a simplified expression for the transfer characteristic of a single module. Therefore, as an example, for a constant Vs (source voltage) of 20 volts, the expression is Is = 8 Vc. Likewise, for Vs = 40 volts, Is = 16 Vc; and for Vs = 60 volts, Is = 24 Vc.

The equation for Rs, the resistance seen looking into the output terminals where Vs is applied, is

$$Rs = \frac{Vs}{Is}$$

$$= \frac{Vs}{0.4\ Vs\ Vc}$$

which gives

$$\boxed{Rs = \frac{2.5}{Vc}}$$

for Rs in ohms where Vc is in volts.

The circuitry is designed for a Vc range of 0 to 10 volts. For two 500-watt modules in parallel, the expressions for Is and Rs become:

$$\left.\begin{aligned} Is &= 0.8\ Vs\ Vc \\ Rs &= \frac{1.25}{Vc} \end{aligned}\right] \text{—— 1000-watt configuration}$$

and the transfer characteristic for three 500-watt modules in parallel is:

$$\left.\begin{aligned} Is &= 1.2\ Vs\ Vc \\ Rs &= \frac{0.83}{Vc} \end{aligned}\right] \text{—— 1500-watt configuration}$$

The components selected provide capability for handling up to 80 amperes per 500-watt module. Each module provides limiting at 80 amperes, peak, and 500 watts. The permissible voltage-current products for the 1500-watt configuration are identified in Figure 4-7 which shows the transfer characteristic curves for the simulator.

To achieve a dynamic range of 100 to 1 in the control of the variable R load current when all three modules are connected in parallel, control signal multipliers with a 0.5 percent accuracy are employed.

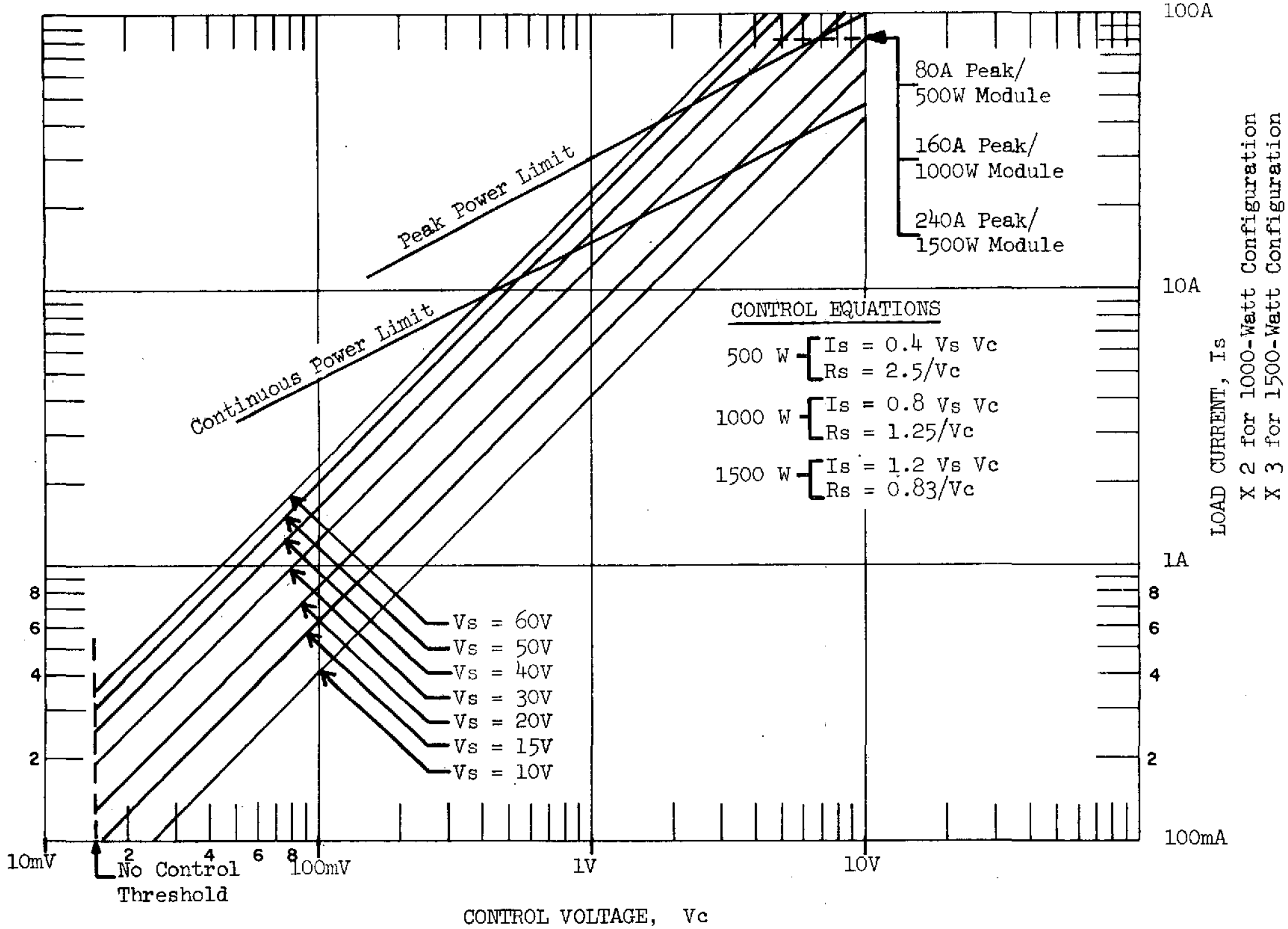


FIGURE 4-7 Transfer Characteristics, Model DC-1500 Variable R Dynamic Electrical Load Simulator

4.3 PROTECTIVE FEATURES

The Model DC-1500 Variable R incorporates the following features for protection against overloads and other abnormal conditions.

4.3.1 Over-voltage Protection

Over-voltage protection is provided by diode D12 and transistor Q24. In combination, these sense the over-voltage and shunt the drive from A9 to the relay driver, transistor Q22. This releases relay K1 which opens the circuit from the load terminal, and lights the amber lamp, L2, as an indication that an over-voltage condition exists. In addition to the opening of the relay contacts, each section of the power stage of the 500-watt module is protected against fast transients by a Zener diode used for transient protection. These diodes (CR1, CR2, CR3, and CR4) are each 100-volt devices capable of dissipating 1 KW for 1 msec, and 150 watts for 1 second.

4.3.2 Power Overload Protection

Multiplier M2 performs a product function whereby the load current (Is) and load voltage (Vs) are sensed and used to drive M2 to provide an output proportional to the output power (Vs Is). The output of M2 is used to drive a threshold detector, Q18, to limit the drive to the power stage. Therefore, any Vs Is product equal to or greater than the threshold value will prevent further drive to the power stages, thereby limiting power. The power limit is set at 500 watts, minimum, per module. A separate threshold detector circuit (Q20 and Q21) is used to drive the red lamp, L4, which provides indication of a power overload condition.

4.3.3 Peak Power Overload Protection

A third threshold detector circuit (transistor Q19) is employed as a peak power limiter. It limits the peak power to 2400 watts per module, 4800 watts for a parallel configuration of two 500-watt modules, and 7200 watts for a parallel configuration of all three 500-watt modules. Figure 4-7 shows the peak power limit curves.

A duty cycling limiting circuit in the DC power limiter: (1) prevents the DC limiter from limiting the peak power handling capability for short pulses, and (2) imposes on the simulator a duty cycle of approximately 5 percent should the pulse width exceed 20 milliseconds for 2400 watts, maximum. It should be noted that the DC limit will take effect after the low-pass filter capacitor, C16, becomes charged to the threshold value of the DC power limiter. C16 is periodically discharged when the timing circuit (R60, C14, and monostable multivibrator, MSMV, IC2) times out, allowing the comparator to discharge the DC limit capacitor C16.

If an over-power condition persists, the operating sequence is as follows:

1. The peak power limiter, Q19, limits peak power.
2. The DC limiter turns on after the pulse width of the control signal reaches 20 milliseconds for 2400 watts power--and for pulse widths greater than 20 milliseconds for reduced power dissipation. (Generally, the lower the power to be dissipated, the wider the pulse than can be tolerated.)
3. At the same time that the peak power occurs, the timing circuit (R20, C14, IC2) starts timing. Approximately 500 milliseconds later it allows another peak power pulse to occur by discharging the DC limiter and starting the cycle over again.

This peak power duty cycle limiting is necessary: (1) to prevent peak power duty cycles from exceeding 5 percent, and (2) to discharge the DC power limiter from a steady-state power level approaching 500 watts so that full pulse widths at peak power limits can be handled.

4.3.4 Reverse Polarity Protection for Load Voltage, Vs

Diodes D13, D14, D15, and D16 in the Vs input line protect the circuits from reversed Vs polarity.

4.3.5 Additional Features

Each of the features described below is provided in each module. The modules, therefore, can operate independently.

Leakage Current

A mechanical switch is used to provide a low-level leakage current under zero voltage control conditions. Operational amplifier A9 serves as a comparator with its input (at pin 3) set for approximately 15 millivolts. As the control signal at the multiplier input exceeds 15 millivolts, the amplifier output swings positive, turning on transistor Q22 and relay K1. As a result, contacts K1A, K1B, K1C, and K1D close on Vs.

For signals below 15 millivolts, relay K1 is OFF and indicator lamp L2 is ON. This provides a leakage current of 10 microamperes, maximum, through the output stages for control signals up to approximately 15 millivolts.

Current Monitor

Amplifiers A7 and A8 form a summing amplifier, inverter, buffer amplifier combination that provides an output voltage whose level is proportional to the source current, Is. The scaling is 8 amperes per volt. The output is a direct representation of the current waveform and has sufficient bandwidth and slewing rate capability to accurately follow the current waveform. A full-scale output of 10 volts represents the 80-ampere peak current possible for a module.

Power Supply

The power supply is a commercially available unit that provides unregulated +28 volts for relay and indicator lamp operation, and a regulated ±15 volts at 300 milliampere capability for the electronic circuits. The supply line and load regulation are specified as 0.05 percent for a 10 percent line variation over the range from no load to full load. A type 3AG, 3/4-ampere fuse and short circuit protection are both included in the power supply itself.

4.4 ASSEMBLY

The Model DC-1500 Variable R is housed in a standard, instrument-type, desk-top enclosure with provisions for mounting it in a standard 19-inch relay-rack-type console. Four rubber-tipped feet permit the units to be stacked--and allow circulation of cooling air. The unit measures approximately 19 inches wide, by 8-3/4 inches high, by 18 inches deep. The control electronics, protective components, and monitor circuits for each 500-watt module are located on individual printed circuit boards--one board assembly for each module.

The Model DC-1500 Variable R is shown in Figure 4-1. Figure 4-8 is a rear view of the simulator. Figure 4-9 shows the internal arrangement of its components.

The high power resistors are installed on metal mounting plates to provide adequate heat sinking. The power transistors for each module are mounted on a heat sink with an integral fan for cooling. The heat sink is capable of dissipating up to 500 watts. The transistors are required to dissipate only about 400 watts--with the remainder of the 500 watts being dissipated in the power resistors.

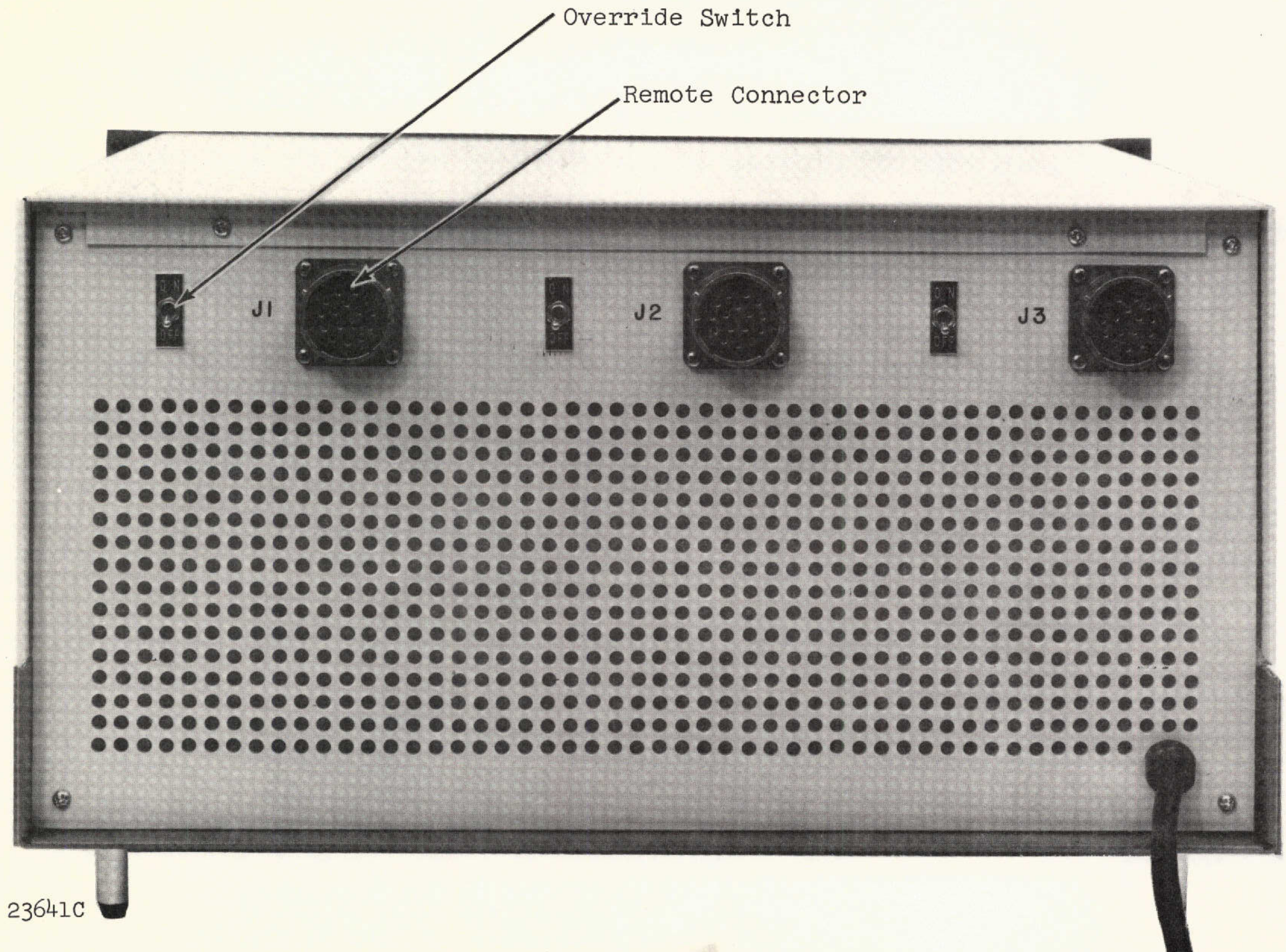


FIGURE 4-8 Rear View, Model DC-1500 Variable R Dynamic Electrical Load Simulator

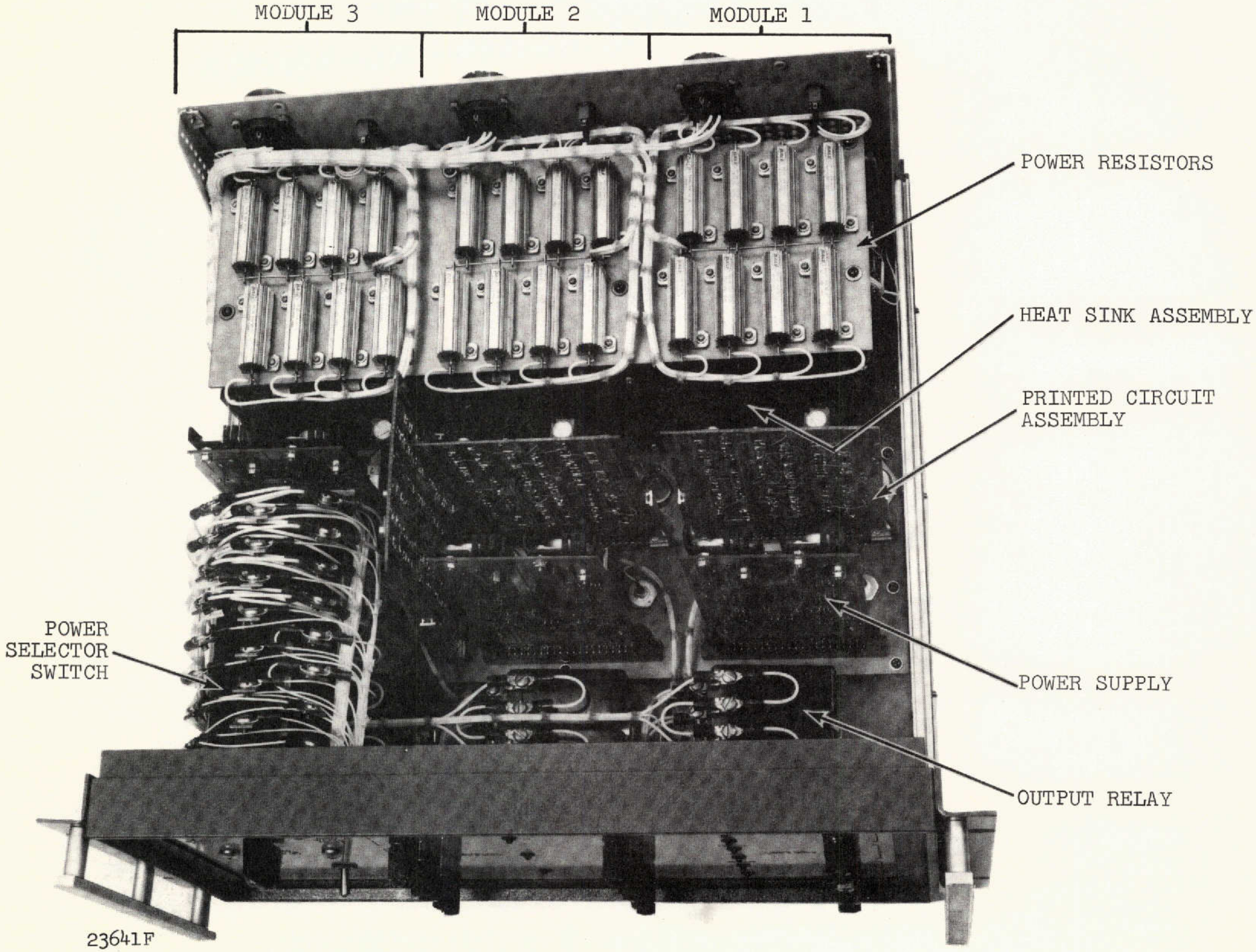


FIGURE 4-9 Internal Arrangement, Model DC-1500 Variable R Dynamic Electrical Load Simulator

4.5 SPECIFICATIONS

4.5.1 Electrical

Load Voltage	+20 VDC to +60 VDC
Load Current (per module)	
Continuous	Up to 20 amperes
Transient	Up to 80 amperes, peak, for 20 milliseconds at a 5 percent duty cycle
Power Dissipation (Continuous)	
Independent Operation	Up to 500 watts (per module)
Two Modules in Parallel	Up to 1000 watts
Three Modules in Parallel	Up to 1500 watts
Transient Response	Less than 50 microseconds
Control Voltage	0 to +10 volts

4.5.2 General

Power Requirements	115 volts, 60 Hz, single-phase
Size	19" W x 8-3/4" H x 18" D
Environment	Laboratory ambient (temperature 25° C, nominal)

5.0 MODULAR, HIGH POWER, VARIABLE R EVALUATION

Performance evaluation tests were conducted on breadboard and prototype models of the modular, high power, variable R simulator circuits to: (1) assess their ability to satisfy design objectives, and (2) determine the effectiveness of the various protective features. In addition, both burn-in and acceptance tests were carried out on each deliverable unit. The following paragraphs of this section briefly summarize the burn-in and acceptance tests.

5.1 BURN-IN TESTS

Each unit was subjected to a minimum of 80 hours of burn-in testing at 80 percent of its rated load. The testing was carried out in two steps--static burn-in and transient burn-in.

During static burn-in a control voltage input adjusted to yield a load current of 11.5 to 14.5 amperes at a load voltage of 30 to 34 volts, DC, was applied to each module of the simulator. The load voltage to each module was adjusted to yield a power dissipation of 400 watts. In general, burn-in testing on a unit was continuous. However, some burn-in testing was conducted intermittently because of the failures that occurred early in the tests (see Section 3.0).

Transient burn-in testing was conducted at a load voltage setting of 23 to 24 volts. A pulse generator was used to provide 10-volt pulses to the control terminals. The pulses were applied manually by appropriate operation of the pulse generator controls. A minimum of 100 pulses was applied to each unit. The pulse width was set at 1 millisecond to maintain the load energy at a level consistent with the capabilities of the power sources available.

5.2 ACCEPTANCE TESTS

Acceptance tests were conducted on each unit prior to its delivery. These tests verified the static transfer characteristics, the accuracy of the current monitor output, and the operation of the protective circuits. The static transfer characteristics were checked at load voltages of 20, 30, and 60 volts, DC. Data taken during these tests was provided with the units, and is shown in Appendix B of this report.

6.0 REFERENCES

1. A Study of Dynamic Load Simulators for Electrical Systems Test Facility, Final Report; Avco Systems Division, AVSD-0364-70-RR, 17 August 1970.

2. Dynamic Load Simulator, Final Report; Avco Systems Division, AVSD-0076-72-RR, 23 June 1972.

3. Dynamic Electrical Load Simulator, Final Report: Avco Systems Division, AVSD-0166-73-RR, 22 June 1973.

4. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Ninth Monthly Progress Report, for the period 1 March 1974 to 31 March 1974; Avco Systems Division, AVSD-0092-74-CR, 8 April 1974.

5. Operating and Maintenance Manual, Model DC-1500 Variable R Dynamic Electrical Load Simulator; Avco Systems Division, ESDM-F420-74-198, 14 June 1974.

APPENDIX A

SUMMARY - PROGRESS REPORTS

This appendix summarizes the eleven monthly progress reports published by Avco Systems Division under the Modular, High Power, Variable R Dynamic Electrical Load Simulator program, NASA Contract NAS 9-13495.

APPENDIX A

SUMMARY - PROGRESS REPORTS

1. Modular, High Power, Variable R Dynamic Electrical Load Simulator, First Monthly Progress Report, for the period 28 June 1973 to 31 July 1973; Avco Systems Division, AVSD-0249-73-CR, 8 August 1973.

   SUMMARY

   Describes Avco's efforts in the three following-listed areas of concentration:

   1. Development of a program schedule.

   2. Initiation of design activities.

   3. Procurement of long-lead-time hardware for breadboard construction.

2. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Second Monthly Progress Report, for the period 1 August to 31 August 1973; Avco Systems Division, AVSD-0274-73-CR, 7 September 1973.

   SUMMARY

   Covers efforts in the following-listed areas:

   1. Continuation of circuit design.

   2. Initiation of breadboard fabrication.

   3. Initiation of packaging design.

   4. Conduct of a progress review meeting.

3. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Third Monthly Progress Report, for the period 1 September to 30 September 1973; Avco Systems Division, AVSD-0300-73-CR, 8 October 1973.

   SUMMARY

   Describes efforts in:

   1. Completion of the preliminary design.

   2. Breadboard fabrication.

   3. Material procurement.

4. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Fourth Monthly Progress Report, for the period 1 October to 31 October 1973; Avco Systems Division, AVSD-0320-73-CR, 5 November 1973.

SUMMARY

Describes efforts in the areas of:

1. Breadboard fabrication and evaluation.

2. Material procurement.

3. Design review.

4. Initiation of fabrication.

5. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Fifth Monthly Progress Report, for the period 1 November to 30 November 1973; Avco Systems Division, AVSD-0338-73-CR, 5 December 1973.

SUMMARY

Describes Avco/SD's efforts in the areas of:

1. Breadboard fabrication.

2. Simulator production.

6. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Sixth Monthly Progress Report, for the period 1 December to 31 December 1973; Avco Systems Division, AVSD-0004-74-CR, 4 January 1974.

SUMMARY

Covers Avco'SD's continuing efforts in:

1. Breadboard fabrication.

2. Simulator production.

7. Modular, High Power, Varibale R Dynamic Electrical Load Simulator, Seventh Monthly Progress Report, for the period 1 January to 31 January 1974; Avco Systems Division, AVSD-0034-74-CR, 5 February 1974.

SUMMARY

Describes production of the deliverable units.

8. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Eighth Monthly Progress Report, for the period 1 February to 28 February 1974; Avco Systems Division, AVSD-0058-74-CR, 5 March 1974.

SUMMARY

Covers Avco/SD's continuing efforts in producing deliverable units.

9. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Ninth Monthly Progress Report, for the period 1 March to 31 March 1974; Avco Systems Division, AVSD-0092-74-CR, 8 April 1974.

SUMMARY

Describes efforts in the areas of:

1. Production of deliverable units

2. Correction of a problem in the power output stages (imbalance in current distribution).

10. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Tenth Monthly Progress Report, for the period 1 April to 30 April 1974; Avco Systems Division, AVSD-0130-74-CR, 6 May 1974.

SUMMARY

Covers activities during the reporting period. They were concentrated on:

1. Delivery of the first modular, high power variable R simulator.

2. Continuation of production of the remaining deliverable units.

11. Modular, High Power, Variable R Dynamic Electrical Load Simulator, Eleventh Monthly Progress Report, for the period 1 May to 31 May 1974; Avco Systems Division, AVSD-0161-74-CR, 10 June 1974.

SUMMARY

Describes activities in the areas of:

1. Completion of performance testing and burn-in of the remaining five simulators.

2. Shipment of the remaining units to NASA's Johnson Space Center.

APPENDIX B

ACCEPTANCE TEST DATA

APPENDIX B

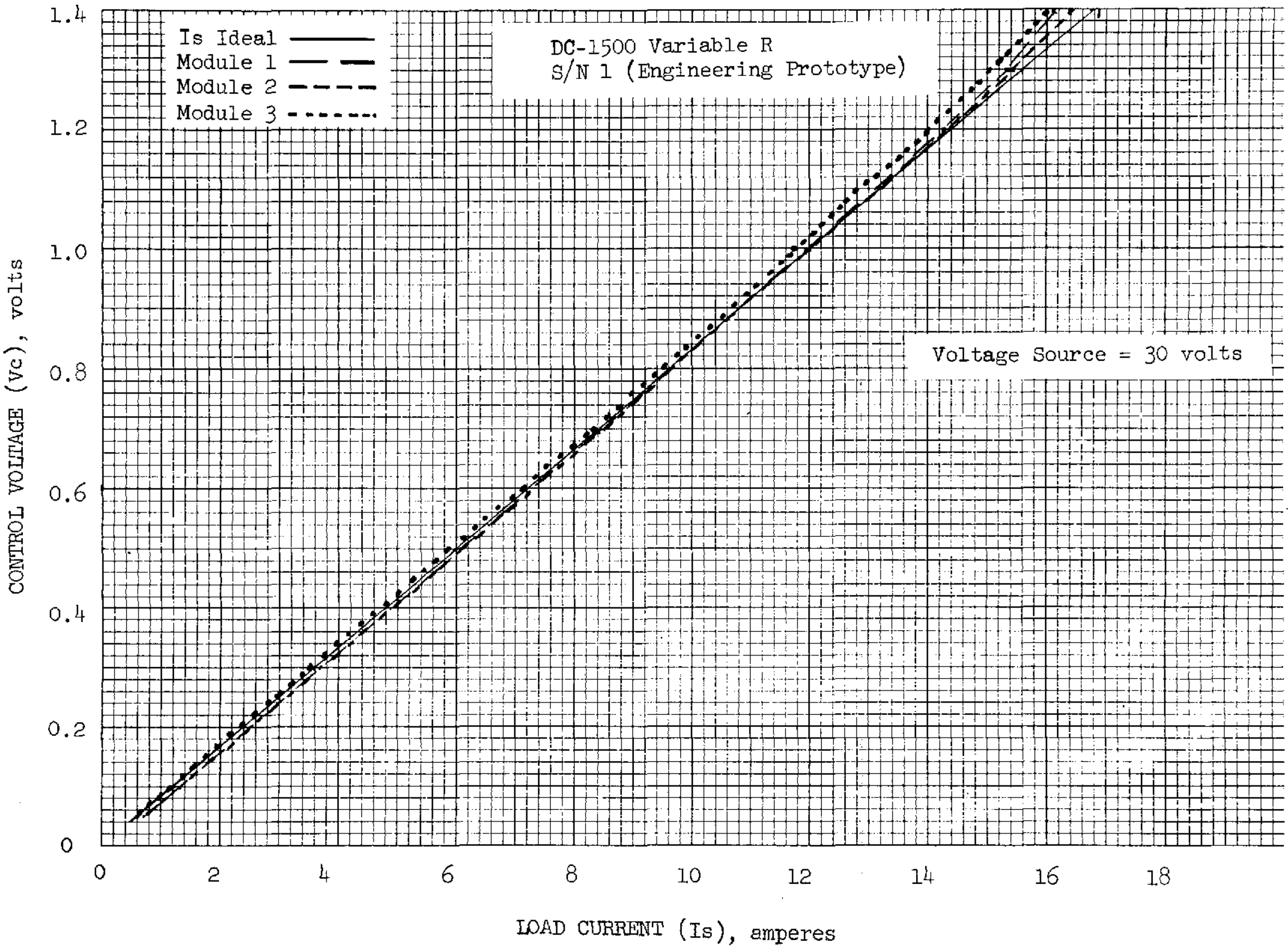
ACCEPTANCE TEST DATA

This appendix presents acceptance test data for the six DC-1500 modular, high power, variable R dynamic electrical load simulators delivered to NASA under Contract NAS 9-13495.

The data for each unit includes:

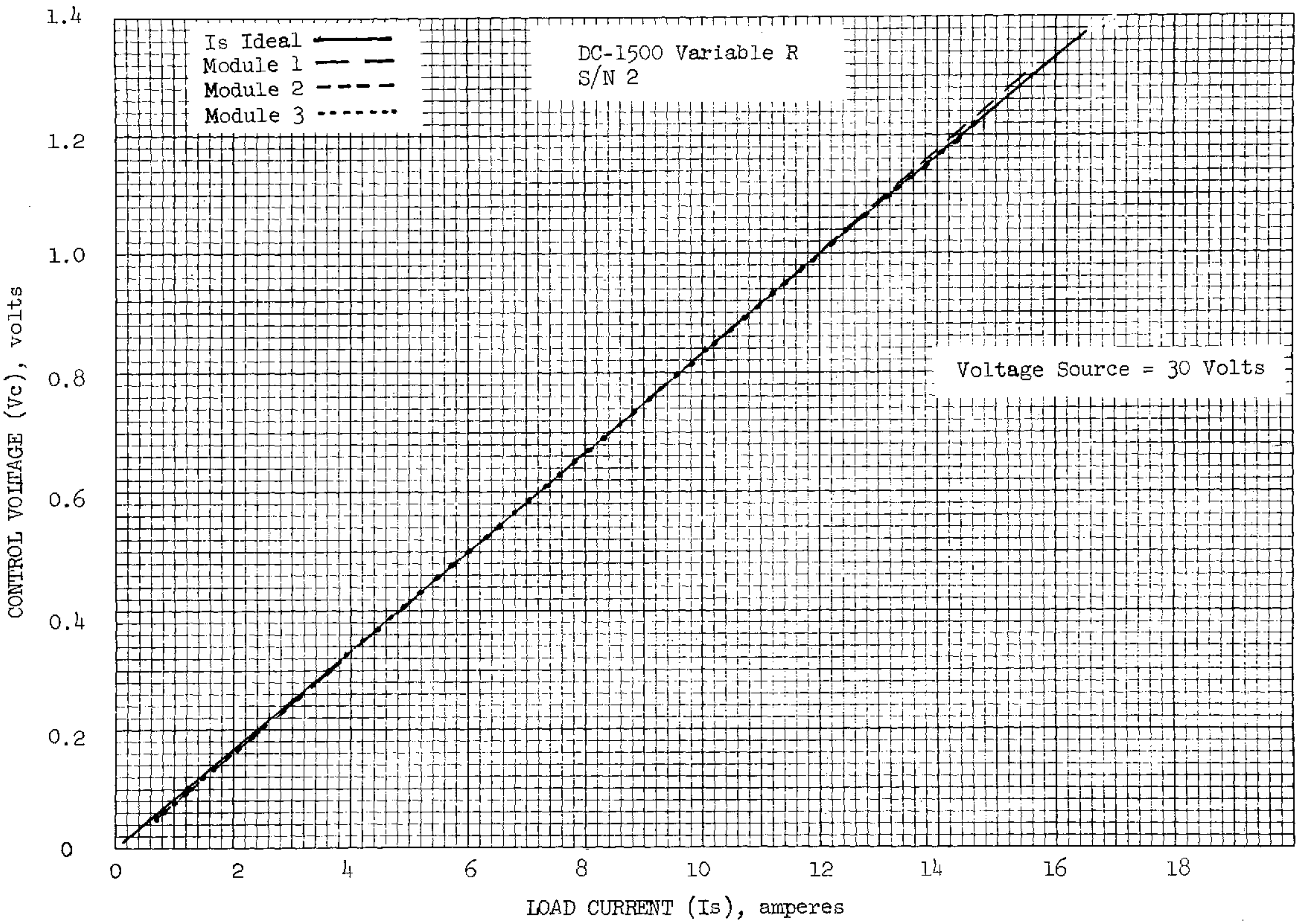
1. A plot showing the ideal transfer characteristic (control voltage, Vc, versus load current, Is) and the measured transfer characteristic for each module in the unit for a load voltage (Vs) of 30 volts.

2. A tabulation of static transfer characteristic data for the unit's modules at three different values of load voltage (Vs)--20 volts, 30 volts, and 60 volts.


Is Ideal
Module 1
Module 2
Module 3
DC-1500 Variable R
S/N 1 (Engineering Prototype)
Voltage Source = 30 volts
CONTROL VOLTAGE (Vc), volts
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
2
4
6
8
10
12
14
16
18
LOAD CURRENT (Is), amperes

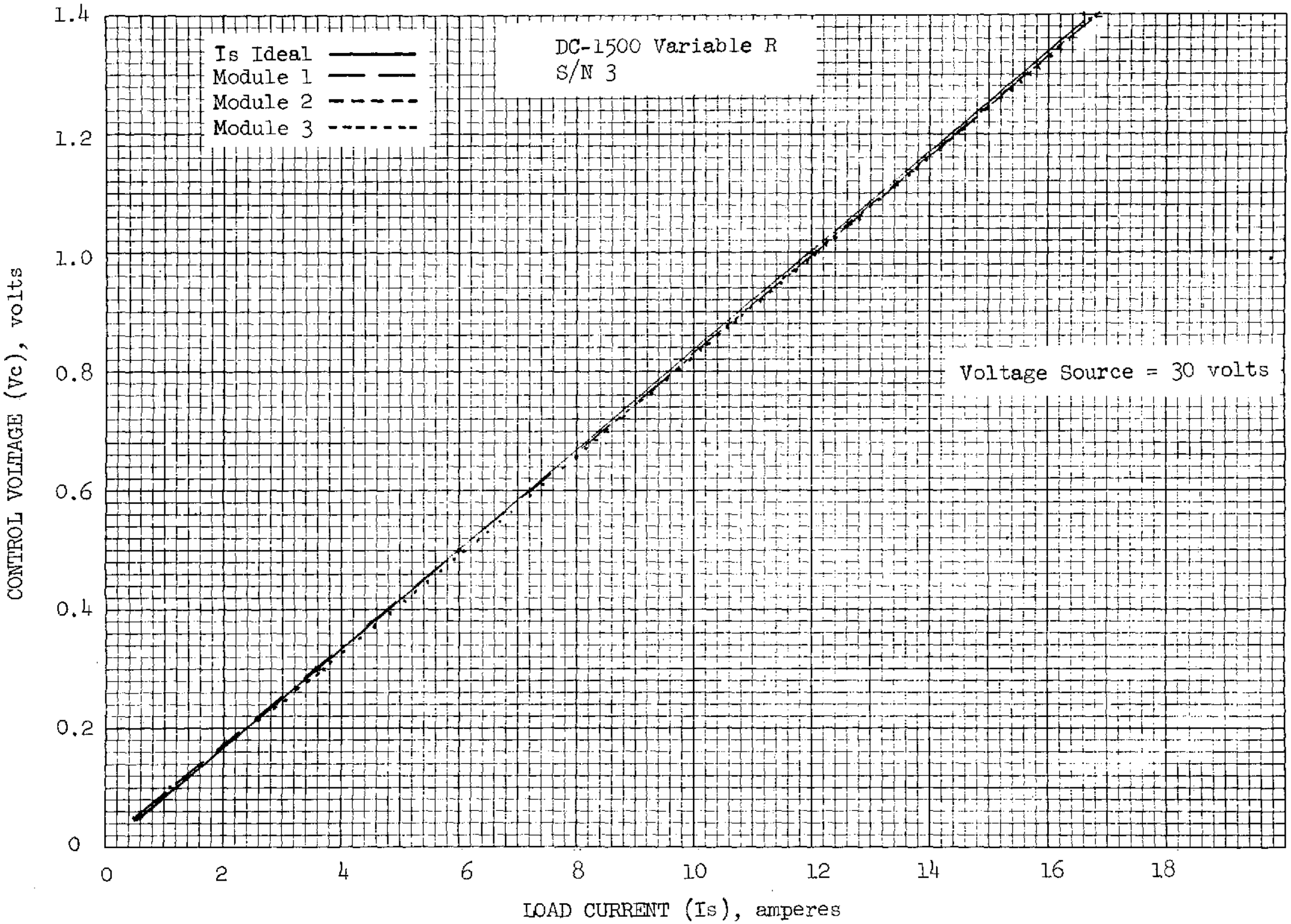
DATA FOR STATIC TRANSFER CHARACTERISTIC

CONTROL VOLTAGE, Vc	CALCULATED LOAD CURRENT, Is	MEASURED LOAD CURRENT, Is		
		Module 1	Module 2	Module 3
Volts	Amperes	Amperes	Amperes	Amperes
		Load Voltage, Vs = 20 Volts		
0.05	0.4	0.5	0.5	0.4
0.1	0.8	0.9	0.9	0.8
0.3	2.4	2.5	2.5	2.4
0.5	4.0	4.1	4.1	3.9
0.7	5.6	5.7	5.7	5.5
1.0	8.0	8.0	8.0	7.9
1.5	12.0	12.0	11.9	11.7
2.0	16.0	15.9	15.8	15.5
2.5	20.0	19.6	19.6	19.4
3.0	24.0	23.3	23.3	23.2
3.125	25.0	24.0	24.4	24.0
		Load Voltage, Vs = 30 Volts		
0.05	0.6	0.7	0.7	0.6
0.10	1.2	1.3	1.3	1.2
0.30	3.6	3.7	3.7	3.5
0.50	6.0	6.1	6.1	5.9
0.70	8.4	8.5	8.4	8.3
1.00	12.0	12.0	12.0	11.7
1.20	14.4	14.3	14.3	14.0
1.30	15.6	15.3	15.4	15.0
1.39	16.67	16.1	16.4	16.0
		Load Voltage, Vs = 60 Volts		
0.02	0.48	0.75	0.7	0.6
0.04	0.96	1.25	1.2	1.1
0.08	1.92	2.2	2.15	2.0
0.10	2.4	2.7	2.6	2.5
0.15	3.6	3.85	3.8	3.65
0.20	4.8	5.0	4.9	4.85
0.25	6.0	6.2	6.15	6.00
0.30	7.2	7.3	7.3	7.15
0.347	8.33	8.05	8.3	8.00


Is Ideal
Module 1
Module 2
Module 3
DC-1500 Variable R
S/N 2
Voltage Source = 30 Volts
CONTROL VOLTAGE (Vc), volts
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
18
LOAD CURRENT (Is), amperes

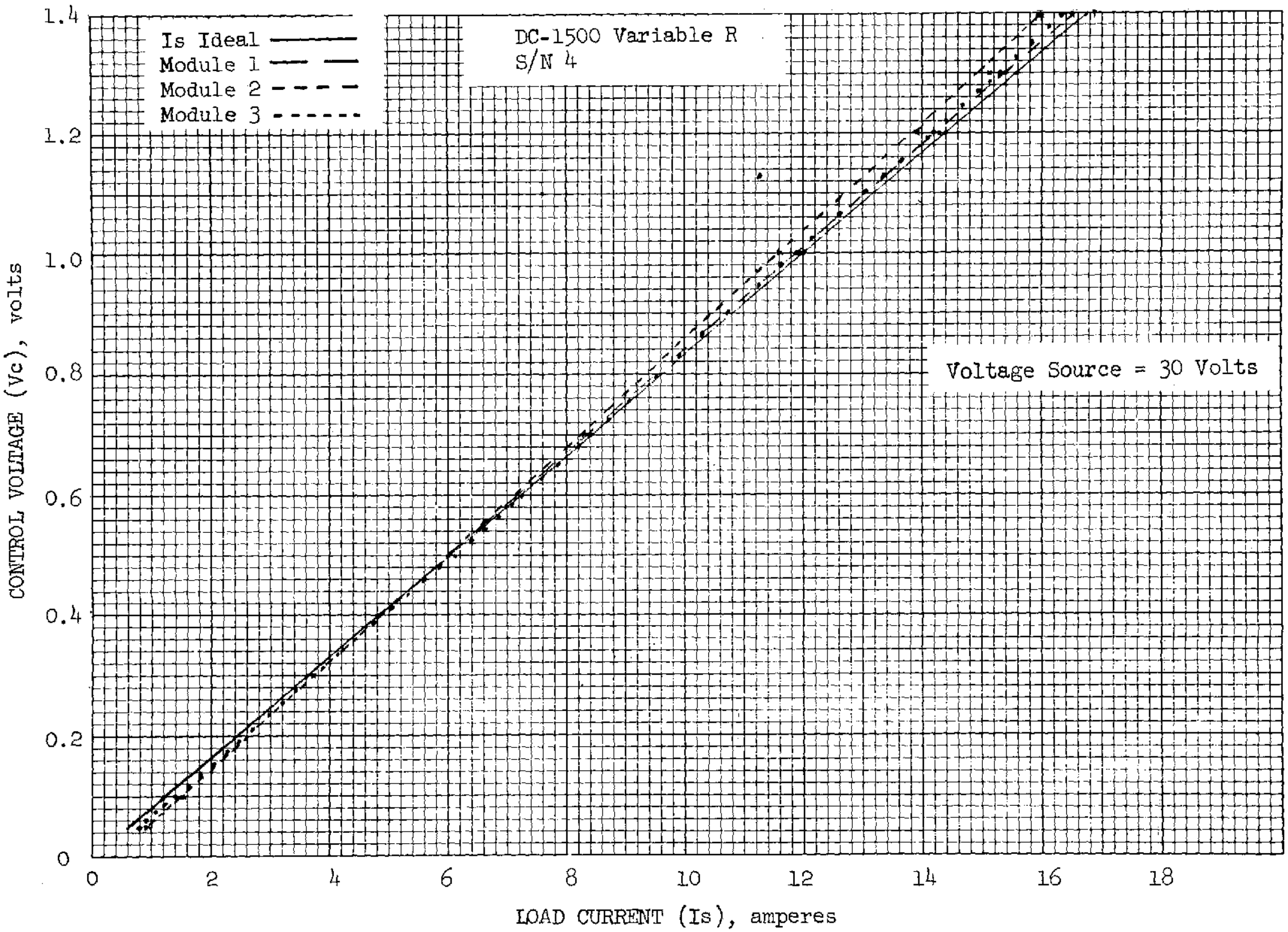
DATA FOR STATIC TRANSFER CHARACTERISTIC

CONTROL VOLTAGE, Vc	CALCULATED LOAD CURRENT, Is	MEASURED LOAD CURRENT, Is		
		Module 1	Module 2	Module 3
Volts	Amperes	Amperes	Amperes	Amperes
		Load Voltage, Vs = 20 Volts		
0.05	0.4	0.42	0.4	0.45
0.10	0.8	0.82	0.8	0.9
0.30	2.4	2.42	2.4	2.45
0.50	4.0	4.0	4.0	4.0
1.00	8.0	8.0	8.0	8.0
1.50	12.0	11.9	12.0	12.0
2.00	16.0	15.8	15.9	15.9
2.50	20.0	19.6	19.9	19.6
		Load Voltage, Vs = 30 Volts		
0.05	0.6	0.7	0.6	0.7
0.10	1.2	1.25	1.2	1.3
0.30	3.6	3.62	3.6	3.7
0.50	6.0	6.0	6.0	6.5
0.70	8.4	8.4	8.4	8.4
1.00	12.0	12.0	12.0	12.0
1.20	14.4	14.3	14.4	14.4
1.30	15.6	15.5	15.6	15.6
		Load Voltage, Vs = 60 Volts		
0.02	0.48	0.7	0.5	0.72
0.04	0.96	1.3	1.0	1.2
0.08	1.92	2.1	2.0	2.2
0.1	2.4	2.58	2.45	2.7
0.15	3.6	3.8	3.7	3.88
0.20	4.8	5.0	4.9	5.05
0.25	6.0	6.3	6.1	6.3
0.30	7.2	7.35	7.3	7.45
0.34	8.2	8.33	8.33	8.33


Is Ideal
Module 1
Module 2
Module 3
DC-1500 Variable R
S/N 3
Voltage Source = 30 volts
CONTROL VOLTAGE (Vc), volts
LOAD CURRENT (Is), amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
2
4
6
8
10
12
14
16
18

DATA FOR STATIC TRANSFER CHARACTERISTIC

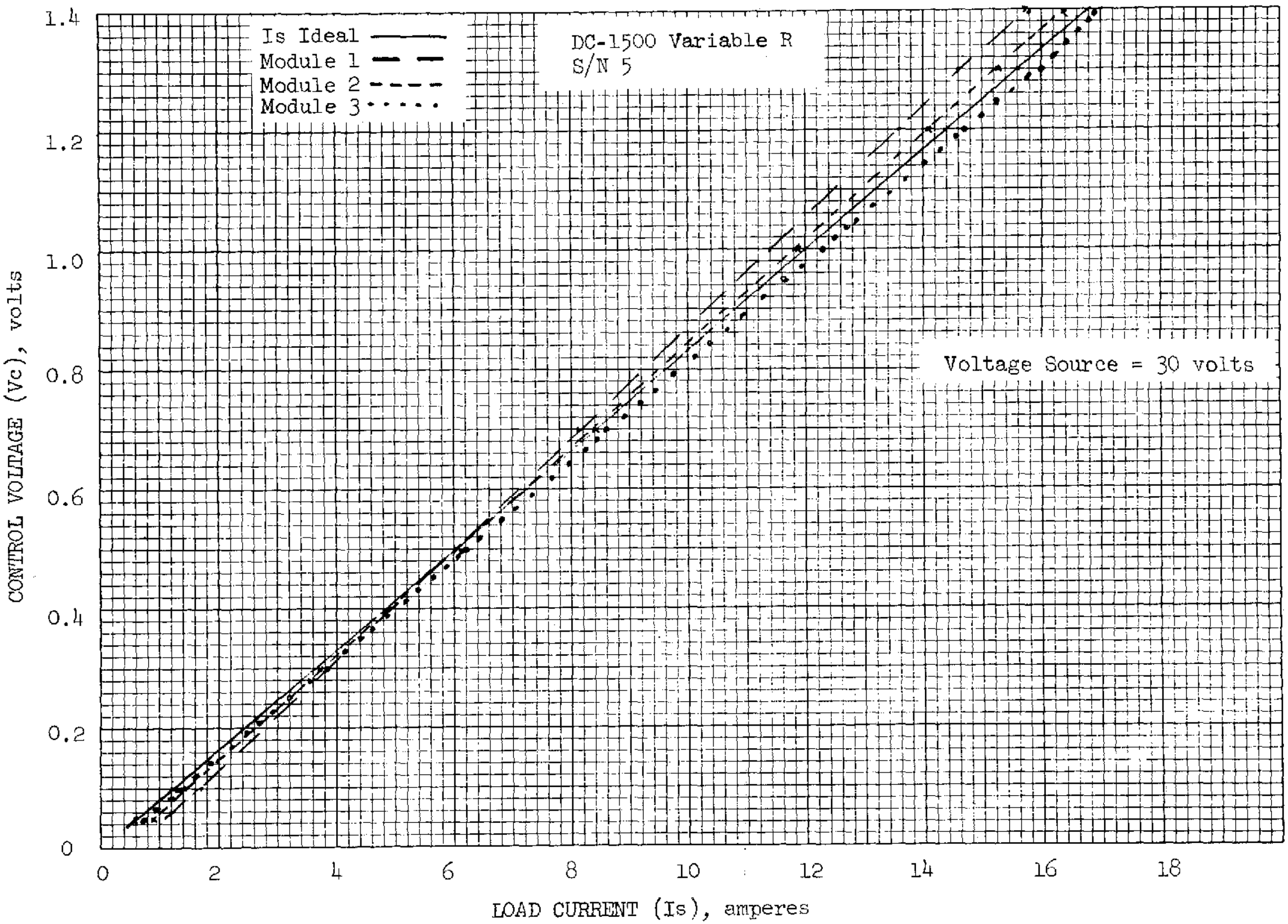
CONTROL VOLTAGE, Vc	CALCULATED LOAD CURRENT, Is	MEASURED LOAD CURRENT, Is		
		Module 1	Module 2	Module 3
Volts	Amperes	Amperes	Amperes	Amperes
		Load Voltage, Vs = 20 Volts		
0.05	0.4	0.3	0.4	0.4
0.1	0.8	0.78	0.8	0.8
0.3	2.4	2.4	2.4	2.4
0.5	4.0	4.0	4.0	4.0
1.0	8.0	8.0	8.0	8.1
1.5	12.0	12.0	12.0	12.0
2.0	16.0	16.0	16.0	16.0
2.5	20.0	19.9	20.0	19.9
3.0	24.0	23.8	23.9	23.7
		Load Voltage, Vs = 30 Volts		
0.05	0.6	0.58	0.6	0.6
0.10	1.2	1.18	1.2	1.2
0.30	3.6	3.6	3.6	3.7
0.50	6.0	6.02	6.0	6.1
0.70	8.4	8.5	8.5	8.5
1.0	12.0	12.18	12.1	12.18
1.2	14.4	14.5	14.42	14.5
1.3	15.6	15.7	15.7	15.7
1.38	16.6	16.7	16.6	16.7
		Load Voltage, Vs = 60 Volts		
0.02	0.48	0.48	0.55	0.55
0.04	0.96	1.00	1.05	1.02
0.08	1.92	2.00	2.02	2.01
0.10	2.40	2.48	2.51	2.48
0.15	3.60	3.70	3.76	3.73
0.20	4.80	4.92	4.98	4.95
0.25	6.00	6.15	6.20	6.20
0.30	7.20	7.35	7.41	7.38
0.34	8.2	8.35	8.35	8.34



DC-1500 Variable R
S/N 4
Is Ideal
Module 1
Module 2
Module 3
Voltage Source = 30 Volts
CONTROL VOLTAGE (Vc), volts
LOAD CURRENT (Is), amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
2
4
6
8
10
12
14
16
18

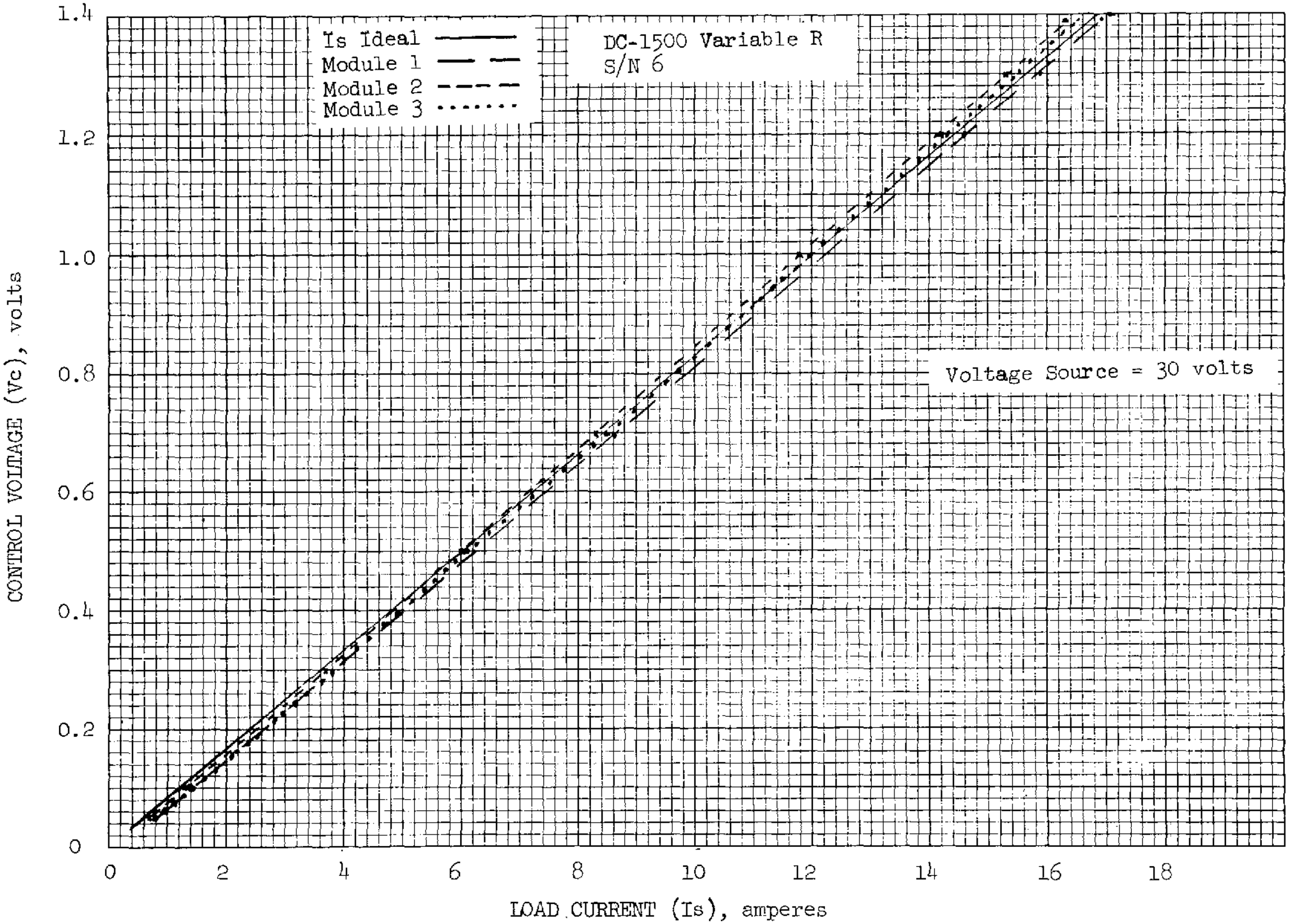
DATA FOR STATIC TRANSFER CHARACTERISTIC

CONTROL VOLTAGE, Vc	CALCULATED LOAD CURRENT, Is	MEASURED LOAD CURRENT, Is		
		Module 1	Module 2	Module 3
Volts	Amperes	Amperes	Amperes	Amperes
		Load Voltage, Vs = 20 Volts		
0.05	0.4	0.4	0.7	0.6
0.1	0.8	0.8	1.0	0.9
0.3	2.4	2.4	2.5	2.5
0.5	4.0	4.0	4.0	4.1
0.7	5.6	5.6	5.6	5.6
1.0	8.0	7.9	7.8	8.0
1.5	12.0	11.8	11.5	11.8
2.0	16.0	15.8	15.2	15.5
2.5	20.0	19.7	19.0	19.4
3.0	24.0	23.4	22.5	23.0
3.125	25.0	24.3	23.3	23.9
		Load Voltage, Vs = 30 Volts		
0.05	0.6	0.6	0.9	0.8
0.10	1.2	1.2	1.5	1.4
0.30	3.6	3.6	3.7	3.7
0.50	6.0	6.0	6.0	6.1
0.70	8.4	8.38	8.3	8.4
1.00	12.0	11.9	11.6	11.9
1.20	14.4	14.3	13.9	14.2
1.30	15.6	15.4	14.9	15.3
1.39	16.67	16.5	15.9	16.3
		Load Voltage, Vs = 60 Volts		
0.02	0.48	0.55	0.9	0.82
0.04	0.96	1.00	1.38	1.3
0.08	1.92	1.95	2.3	2.2
0.10	2.4	2.45	2.75	2.7
0.15	3.6	3.7	3.9	3.85
0.20	4.8	4.88	5.0	5.0
0.25	6.0	6.1	6.15	6.2
0.30	7.2	7.3	7.25	7.32
0.347	8.33	8.33	8.2	8.3


Is Ideal
Module 1
Module 2
Module 3
DC-1500 Variable R
S/N 5
Voltage Source = 30 volts
CONTROL VOLTAGE (Vc), volts
LOAD CURRENT (Is), amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
2
4
6
8
10
12
14
16
18

DATA FOR STATIC TRANSFER CHARACTERISTIC

CONTROL VOLTAGE, Vc	CALCULATED LOAD CURRENT, Is	MEASURED LOAD CURRENT, Is		
		Module 1	Module 2	Module 3
Volts	Amperes	Amperes	Amperes	Amperes
		Load Voltage, Vs = 20 Volts		
0.05	0.4	0.8	0.6	0.5
0.10	0.8	1.2	1.0	0.9
0.3	2.4	2.6	2.5	2.5
0.5	4.0	4.1	4.1	4.2
0.7	5.6	5.6	5.7	5.7
1.0	8.0	7.7	8.0	8.
1.5	12.0	11.3	11.9	12.2
2.0	16.0	14.9	15.7	16.2
2.5	20.0	18.4	19.5	20.0
3.0	24.0	21.9	23.3	23.8
3.125	25.6	22.9	24.1	24.7
		Load Voltage, Vs = 30 Volts		
0.05	0.6	1.1	0.9	0.7
0.10	1.2	1.7	1.4	1.3
0.30	3.6	3.8	3.7	3.8
0.50	6.0	6.0	6.1	6.2
0.70	8.4	8.1	8.4	8.6
1.00	12.0	11.4	11.9	12.3
1.20	14.4	13.6	14.1	14.7
1.30	15.6	14.6	15.3	16.0
1.39	16.67	15.8	16.4	16.9
		Load Voltage, Vs = 60 Volts		
0.02	0.48	1.3	0.85	0.6
0.04	0.96	1.75	1.35	1.05
0.08	1.92	2.65	2.25	2.05
0.10	2.4	3.1	2.75	2.55
0.15	3.6	4.15	3.9	3.75
0.20	4.8	5.25	5.1	4.95
0.25	6.0	6.3	6.25	6.2
0.30	7.2	7.4	7.4	7.4
0.347	8.33	8.33	8.33	8.33


Is Ideal
Module 1
Module 2
Module 3
DC-1500 Variable R
S/N 6
Voltage Source = 30 volts
CONTROL VOLTAGE (Vc), volts
LOAD CURRENT (Is), amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
2
4
6
8
10
12
14
16
18

DATA FOR STATIC TRANSFER CHARACTERISTIC

CONTROL VOLTAGE, Vc	CALCULATED LOAD CURRENT, Is	MEASURED LOAD CURRENT, Is		
		Module 1	Module 2	Module 3
Volts	Amperes	Amperes	Amperes	Amperes
		Load Voltage, Vs = 20 Volts		
0.05	0.4	0.5	0.6	0.6
0.10	0.8	0.9	0.9	1.0
0.30	2.4	2.5	2.6	2.6
0.50	4.0	4.1	4.1	4.1
0.70	5.6	5.6	5.7	5.7
1.00	8.0	8.0	8.0	8.1
1.50	12.0	12.0	11.9	11.9
2.0	16.0	15.9	15.8	15.7
2.5	20.0	19.8	19.5	19.5
3.0	24.0	23.6	23.2	23.4
3.125	25.0	24.5	24.1	24.3
		Load Voltage, Vs = 30 Volts		
0.05	0.6	0.8	0.7	0.8
0.10	1.2	1.4	1.3	1.4
0.30	3.6	3.8	3.7	3.8
0.50	6.0	6.2	6.0	6.1
0.70	8.4	8.6	8.3	8.5
1.00	12.0	12.3	11.8	12.0
1.20	14.4	14.6	14.2	14.3
1.30	15.6	15.9	15.3	15.5
1.39	16.67	16.8	16.3	16.5
		Load Voltage, Vs = 60 Volts		
0.02	0.48	0.8	0.75	0.85
0.04	0.96	1.3	1.25	1.35
0.08	1.92	2.25	2.2	2.25
0.10	2.4	2.7	2.65	2.75
0.15	3.6	3.9	3.85	3.9
0.20	4.8	5.15	5.05	5.1
0.25	6.0	6.35	6.25	6.3
0.30	7.2	7.5	7.45	7.5
0.347	8.33	8.33	8.33	8.33