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A Raytheon Company

Instruction Manual for

QRD Series Power Supplies

Manual covers QRD models:

15-2	40-2
20-4	60-.5
30-1	60-1.5
40-.75	

Document Number 14-6409 Rev C (8/86)

FIVE-YEAR WARRANTY

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SECTION I
INTRODUCTION AND DESCRIPTION

1-1. INTRODUCTION.

1-2. This manual contains operation and maintenance data on the QRD Series, fast-programmable power supplies, manufactured by Sorensen Company, Manchester, New Hampshire. Its purpose is to familiarize the user with unit functions, to introduce the varied configurations to which the unit is convertible and to provide sufficient maintenance data to assure long operating life. Note that the series consists of 7 models in the 30- and 80-watt classes with outputs ranging to 60 Vdc. Differences in models will be highlighted where required.

1-3. Six major sections form the manual divisions. Section I contains a description of the Series and its features, a tabular listing of complete unit specifications, and a set of characteristic curves. Details on initial inspections and checkout procedures are given in Section II. Operating instructions, including methods for adapting units to various applications, comprise Section III. Sections IV and V provide the principles of operation and maintenance procedures, respectively. A replacment parts list, Section VI, concludes the manual.

1-4. DESCRIPTION.

1-5. Designed for either bench use or rack mounting (para 1-23), a typical QRD fast-programmable power supply provides a precisely regulated d-c output, adjustable over a wide range. It operates from any of three nominal a-c inputs and, in addition, exhibits extremely fast programming-time characteristics as well as rapid response to transients, both load and line. (For a complete tabulation of standard-programming specifications, refer to Table 1-1. Fast-programming characteristics which are unique or which differ from standard-programming specifications are listed in Table 1-2.)

1-6. All semiconductors used in the QRD are silicon types and contribute significantly to the unit ambient-temperature characteristics. High-dissipation transistors are mounted to a cast aluminum-alloy heatsink; low-dissipation devices are located on a plug-in printed-circuit board. Cooling is by convection. Mechanical design permits easy component accessibility, with no sacrifice in unit size (see Figure 1-4).

1-7. Other mechanical features include a human-engineered front panel that mounts all operating controls and indicators used in normal operation. These include two dual-tandem potentiometers which give fine and coarse control over the output voltage and current range, a volt-ammeter with selector switch, an input-power switch and a power-on light. In addition, fluted-nut, miniature binding posts from which the output may be taken are situated on the front panel. At the rear, a mode-selector terminal board and the input fuse holder are mounted directly below the heatsink. By manipulating terminal-board links, the unit may be selected to such applications as fast and standard voltage-mode programming, fast and standard current-mode programming, parallel operation and remote sensing. A set of output terminals is also provided on the board.

1-8. OPERATING MODES. QRD Models have two basic operating modes, constant voltage and constant current. In the former, the output voltage is regulated at the front-panel selected or programmed value, and the output current varies with the load. In constant-current operation, the output-current is regulated at the selected value while the output voltage varies as a function of load.

1-9. AUTOMATIC CROSSOVER. The automatic-crossover system enables the unit to transfer operating modes as a function of load requirements. If, for example, load current attempts to increase above the setting of the current-adjust control, the unit will switch operation automatically from the voltage to current mode. If the load requirements are lowered, return to the voltage mode will occur automatically.

	QRD MODELS							
	ALL	15-2	30-1	40-.75	60-.5	20-4	40-2	60-1.5
INPUT								
Voltage Ranges (Vac)	105-125 200-240 210-250							
Frequency Range (Hz)	48-440							
Phase	1							
Max.Current (Aac)								
at 115 Vac		0.95	0.95	0.95	0.95	2.3	2.3	2.3
at 230 Vac (1)		0.5	0.5	0.5	0.5	1.15	1.15	1.15
Power Factor (1)		0.86	0.86	0.86	0.86	0.78	0.78	0.78
Efficiency (%)		35	35	35	35	42	42	46
OUTPUT								
Voltage Mode								
Range (Vdc)		0-15	0-30	0-40	0-60	0-20	0-40	0-60
Coarse Adj.Range	Full Range							
Fine Adj.Range (mV)		150	300	400	600	200	400	600
Resolution (typical) (mV)		1.5	3.0	4.0	6.0	2.0	4.0	6.0
Output Current Range at 55°C (2) (Adc)		0-2	0-1	0-.75	0-.5	0-4	0-2	0-1.5
Current Mode								
Current Range	(See Volt.Mode)							
Coarse Adj.Range	Full Range							
Fine Adj.Range (mA)		30.0	15.0	12.0	8.0	60.0	30.0	25.0
Resolution (typical) (µA)		300	150	120	80	600	300	250
Voltage Compliance	Full Volt.Range							
Current/Volt.Crossover Static (typical)	See Fig.1-2							

(1) At nominal input and full rated output.
(2) For derating characteristics, see Figure 1-1.

Table 1-1. Unit Specifications (Sheet 1 of 4)

	QRD MODELS							
	ALL	15-2	30-1	40-.75	60-.5	20-4	40-2	60-1.5
PERFORMANCE (3)								
Voltage Mode Regulation (4)	±0.005% or ±0.75 mV (5)							
PARD (Ripple) (6) 50 to 60 Hz Input								
Max. RMS Volt. (μV) (10Hz-7MHz bandwidth)	200							
Max. P-P Volt. (mV) (0-25 MHz bandwidth)	3							
PARD (Ripple) 400 Hz Input								
Typical RMS Volt. (μV)	500							
Typical P-P Volt. (mV)	10							
Transient Response (7) (μs)	50							
Output Impedance	R + JωL							
Low Frequencies (f < 1KHz)								
R (mohms)		0.4	1.5	2.5	6.0	0.25	1.0	2.0
L (μh)		0.5	1.2	2.0	3.0	0.4	0.8	1.5

Output impedance at 100 KHz is less than 0.2 ohms and at 600 KHz is less than 1.0 ohms.

Temperature Coefficient	(0.015% + 200 μV)/°C
Drift (8) (typical)	0.025% E_o (9)
Remote Error Sensing Compensation (max)	1 volt/load lead

(3) Output performance specifications are valid at rear terminals only.
(4) For a combined full line swing and a no load-to-full load (or full load-to-no load) change.
(5) Whichever is greater.
(6) With chassis ground tied to input ground.
(7) For a step load change, no load to full load or full load to no load, and recovery to within a ± 10 mV band.
(8) 8 hours after warm up at constant line voltage, load and ambient temperature.
(9) E_o is the output voltage.

Table 1-1. Unit Specifications (Sheet 2 of 4)

	QRD MODELS							
	ALL	15-2	30-1	40-.75	60-.5	20-4	40-2	60-1.5
Remote Prog. Coefficient								
Resistance	100±.5 ohms/volt							
Volt.Signal	1 volt/volt							
Overload Protection	Crossover to Current Mode							
Output Voltage Turn-On, Turn-Off Overshoots	None							
Max.Capacitive Load	Any							
Current Mode (10) Regulation	±(.01% + β)							
β(μA)		125	125	125	125	250	250	250
PARD (Ripple) 50 to 60 Hz Input (6)								
Max.RMS Current (μA) (10Hz-7MHz bandwidth)		150	150	150	150	400	300	300
Max.P-P Current (mA) (0-25 MHz bandwidth)	2							
PARD (Ripple) 400 Hz Input								
Typical RMS Ripple (μA)	100							
Typical P-P Current (mA)	8							
Transient Response	See Note 11.							
Output Impedance	See Fig.1-3 (12)							
Temperature Coefficient	(.015% + 50μA)/°C							
Drift (8) (Typical)	(0.1%+50μA)							

(10) For a combined full line swing and load change of short circuit to E max (or E max to short circuit) and recovery to a ±1% band.
(11) Function of $R_L C_o$ time constant (R_L = load resistance, C_o = value of output capacitor C19).
(12) Characteristic is typical for a Model 20-4. Typical curves for other specific models will be supplied upon request.

Table 1-1. Unit Specifications. (Sheet 3 of 4)

	QRD MODELS							
	ALL	15-2	30-1	40-.75	60-.5	20-4	40-2	60-1.5
Remote Prog.Coefficient Resistance (ohms/A) Signal (volts/A)		500 0.5	1000 1.0	1330 1.33	2000 2.0	250 0.25	500 0.5	667 0.67
Accuracy	± 10%							
Overload Protection	Crossover to Voltage Mode							
Output Current Turn-On, Turn-Off Overshoots	None							
MISCELLANEOUS Ambient Temp Range	-20 to +71°C(2)							
Series Operation	Max.200 Vdc System Output							
Parallel Operation	Master-Slave							
Cooling	Convection							
Isolation Voltage to Grd Input Output	 1000 Vdc 200 Vdc							
Dimensions	See Fig.1-4							
Weight (lb)		12.5	12.5	12.5	12.5	19.25	19.25	19.5
Meters- Voltage Range (Vdc) Current Range (Adc)		 0-15 0-3	 0-30 0-1.5	 0-50 0-1	 0-60 0-.6	 0-25 0-5	 0-50 0-2.5	 0-80 0-2
Accuracy	±3%							

Table 1-1. Unit Specifications (Sheet 4 of 4)

	QRD MODELS							
	ALL	15-2	30-1	40-.75	60-.5	20-4	40-2	60-1.5
OUTPUT								
Current/Volt.Crossover								
Crossover Time	See Fig.1-5							
Volt-to-Cur.Mode (typ)	280 µs							
Cur.-to-Volt. Mode (typ)	160 µs							
PERFORMANCE(1)								
Voltage Mode								
PARD (Ripple)(2)								
50-60 Hz Input								
Max.RMS Volt. (µV) (10Hz-7MHz bandwidth)	300							
Typical P-P (mV) (0-25 MHz bandwidth)	8							
PARD (Ripple)								
400 Hz Input								
Typical RMS Volt. (mV)	1							
Typical P-P Volt. (mV)	20							
Transient Response(3)	70 µs							
Output Impedance (f< 600KHz)	R + JωL							
R (mohms)		0.4	1.5	2.5	6.0	0.25	1.0	2.0
L (µh)		0.7	2.0	3.3	8.0	0.6	1.1	2.7
Prog.Time (10-90%)	See Fig.1-6 and Para 1-18							
0-E max (typ)(µs)	25							
E max-0 (typ)(µs)	10							

(1) Output performance specifications are valid at rear terminals only.
(2) With chassis ground tied to input ground.
(3) For a step change no load to full load or full load to no load and recovery to within a ±10 mV band.

Table 1-2. Fast-Programming Specifications (Sheet 1 of 2)
(which are unique or which differ from standard specifications)

	QRD MODELS							
	ALL	15-2	30-1	40-.75	60-.5	20-4	40-2	60-1.5
Sinusoidal Freq.Response Gain (Eo/E in): Phase Shift: Max.Capacitive Load	See Note 4 Equivalent to R-C lag network where R = value of R47 or of external programming resistance and C = value of C17. 0.02 µF(5)							
Current Mode PARD (Ripple)(2) 50-60 Hz Input Max.RMS Current (µA) (10Hz-7MHz bandwidth)		300	300	300	300	800	600	600
Typical P-P Current (mA) (0-25 MHz bandwidth)	2							
PARD (Ripple) 400 Hz Input Typical RMS Current (µA)		300	300	300	300	800	600	600
Typical P-P Current (mA)	8							
Transient Response (typ)(6) E max. to 0 (µs) 0 to E max. (µs)		150 40	160 45	350 60	700 250	150 40	150 200	250 400
Output Impedance (typ)	1/(JωC)							
C (µF)		0.35	0.18	0.16	0.07	0.4	0.18	0.16
Output Current Overshoot Turn on Turn off	None above 30% I max. Function of load current, output voltage at less than 30% I max. None							
Programming Time 0 - I max (10-90% points) I max - 0 (90-10% points)	800 µs 200 µs							
Sinusoidal Freq.Response Max.Frequency	$850 \frac{I_{max}}{I_{pp}}$ Hz							

(4) Max.Frequency, with average output voltage equal to (E max/2), is approximately (230/Epp)KHz.(Ref: Para 1-19 & Fig.1-7).
(5) For additional details, write or call Raytheon Co., Sorensen Operation.
(6) For a step load change of E max to short circuit or short circuit to E max, and recovery to a ± 1% band.

Table 1-2. Fast-Programming Specifications (Sheet 2 of 2)
(which are unique or which differ from standard specifications)

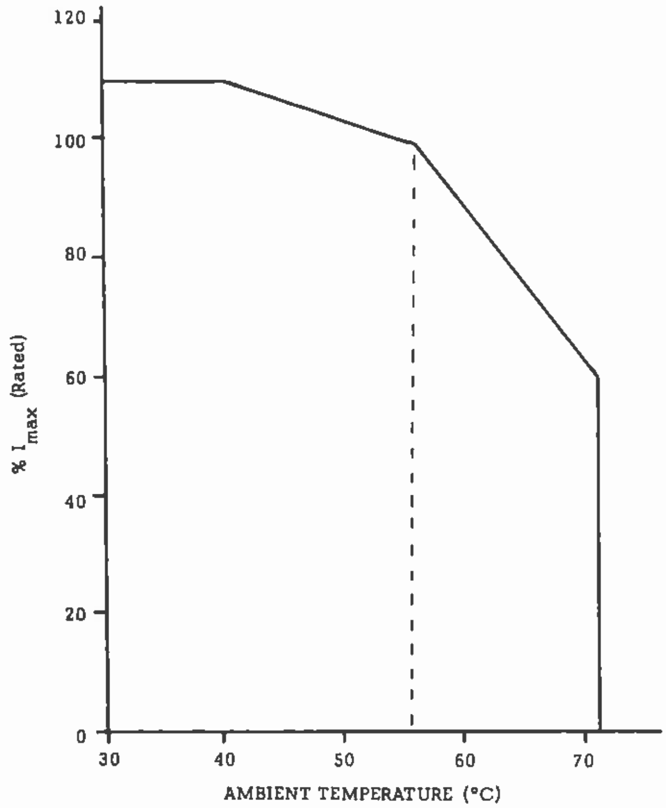


Figure 1-1. Current Derating Characteristics

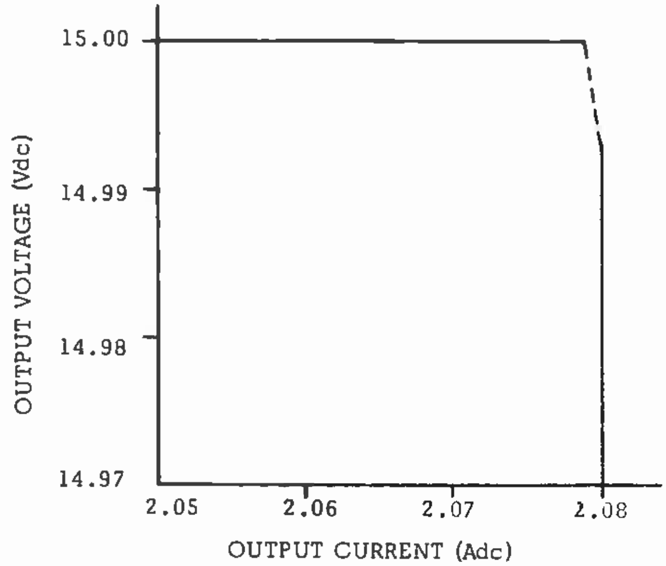
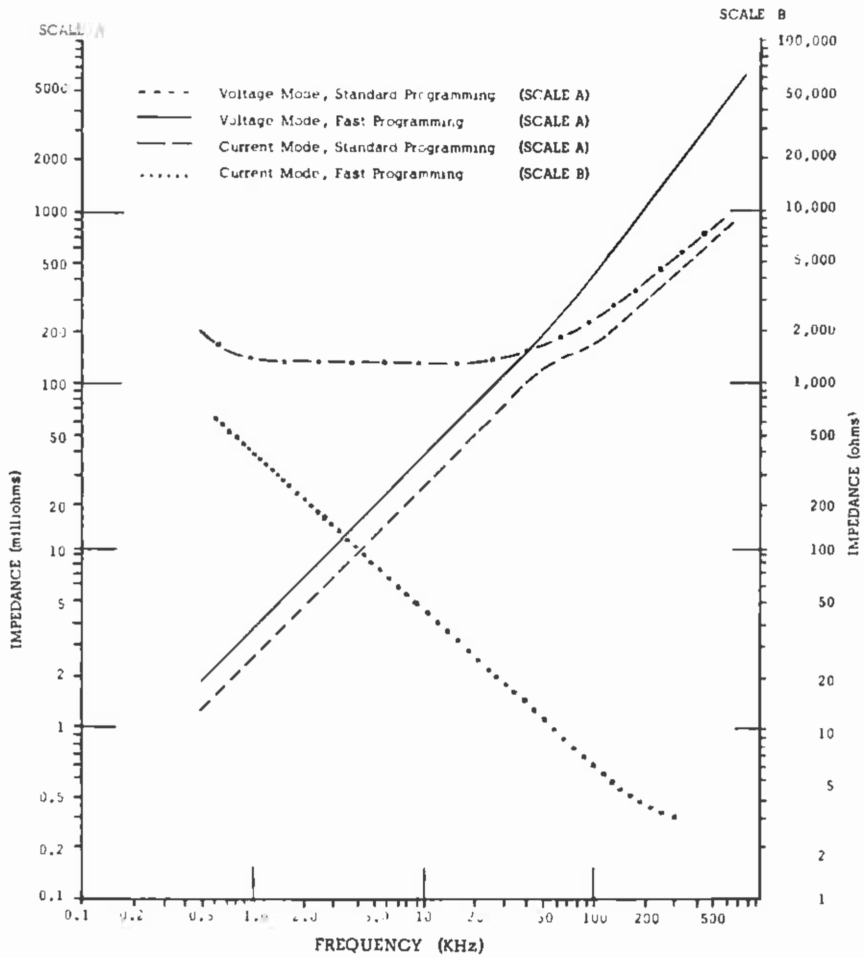
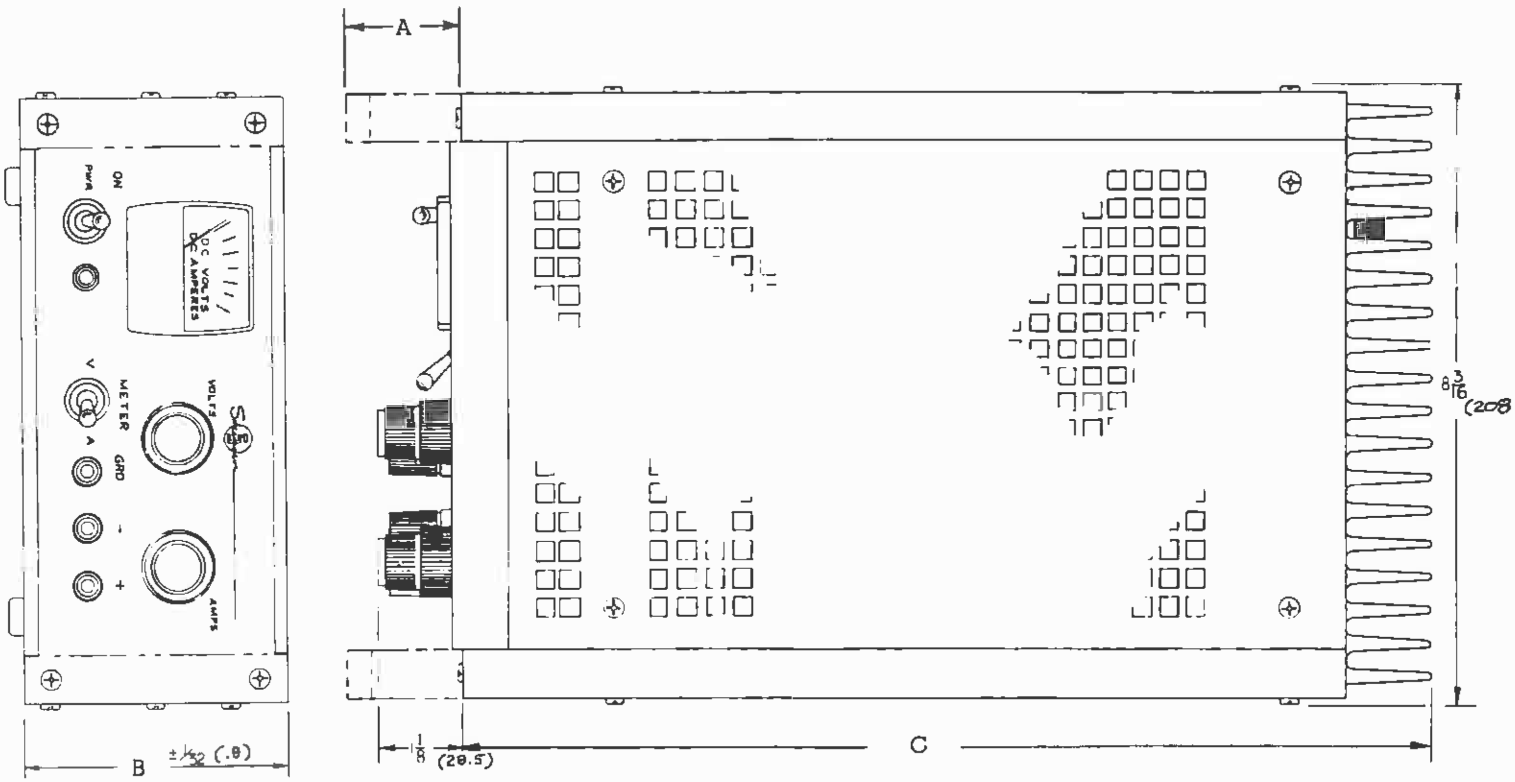


Figure 1-2. Typical Crossover Characteristics (Model QRD 15-2)

Figure 1-3. Output Impedance (Log-Log Plot) (Model QRD 20-4)





	QRD MODELS						
	15-2	20-4	30-1	40-.75	40-2	60-.5	60-1.5
A	1-1/2(38.1)	1-3/4(44.4)	1-1/2(38.1)	1-1/2(38.1)	1-3/4(44.4)	1-1/2(38.1)	1-3/4(44.4)
B	3-15/32(88)	5-7/32(132.5)	3-15/32(88)	3-15/32(88)	5-7/32(132.5)	5-7/32(132.5)	5-7/32(132.5)
C	12-3/4(323.9)	13(330.2)	12-3/4(323.9)	12-3/4(323.9)	13(330.2)	12-3/4(323.9)	13(330.2)

Note: All dimensions are in inches (mm)

Figure 1-4. Outline Dimensions.

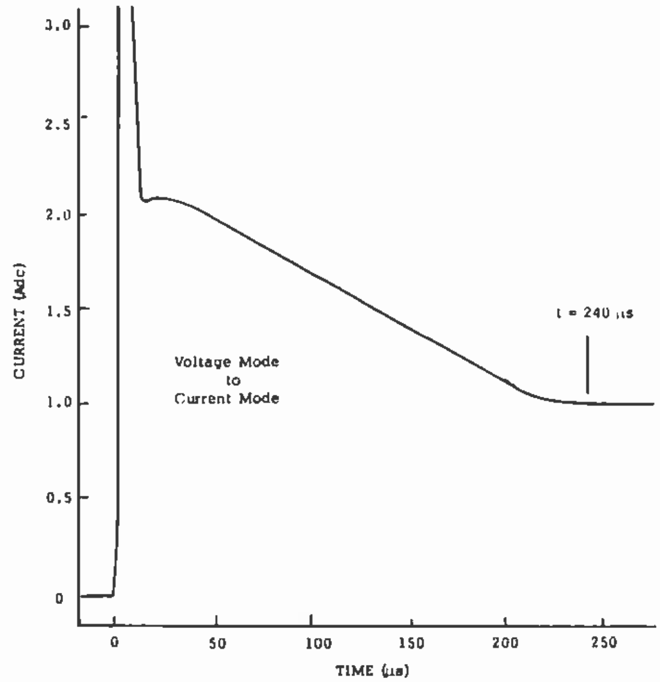


Figure 1-5A. Typical Crossover Time, Voltage to Current Mode (Model QRD 30-1)

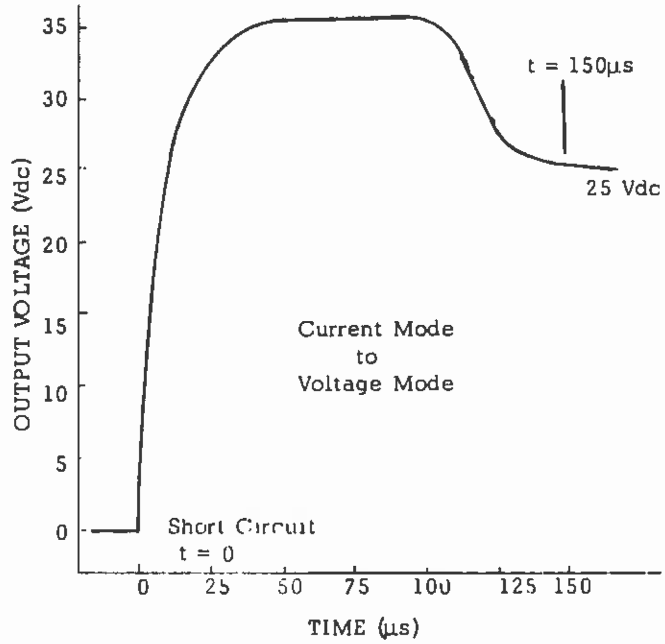


Figure 1-5B. Typical Crossover Time, Current to Voltage Mode (Model QRD 30-1)

1-10. REMOTE PROGRAMMING. Any QRD Model may be remotely programmed, i.e., its output altered from a distant location, in either the voltage or current mode by introducing a calculated resistance or signal into the appropriate programming circuit. This may be readily accomplished through the link arrangements at the rear terminal board.

1-11. FAST PROGRAMMING. Fast programming, used in conjunction with remote programming, enables the output voltage or current to track precisely, programming resistance or signal changes which are as fast as 10 µs (typical, down programming). As with remote programming and sensing, conversion to fast programming is accomplished by a link alteration at the rear terminal board. Because a definition for programming time has as yet not been standardized, para 1-18 defines the specification and briefly compares this definition with respect to others less widely used.

1-12. REMOTE SENSING. Terminals located on the rear-terminal board offer the means of extending a unit's regulating point from the output terminals to the load. This, in effect, compensates for variations in the load-lead IR drop. The maximum drop for which a unit will compensate is 1 volt per load lead.

1-13. SERIES OPERATION. For applications requiring voltages higher than a single QRD can provide, a number of units may be connected in series. Maximum system output is specified at 200 Vdc. Regulation in series operation is the sum of the regulations for all units. In series operation, external rectifiers to protect units against reverse voltage developed by a unit malfunction are unnecessary. Reverse-voltage protection is designed into the unit.

1-14. PARALLEL OPERATION. Parallel operation may be used to service those applications requiring a higher output current than a single QRD can provide. Paralleling is indirect through a "master-slave" approach, i.e., the amplifier of the "master" unit controls the output of all units in the system. In parallel operation, derate each unit's maximum output current to 90%.

1-15. PROTECTION FEATURES. Protection against the effects of overloads and internal short circuits is provided, in the first case, by automatic crossover and, in the second, by the input fuse. In addition, open sensing leads or links will not drive the unit into high output voltage. Internal rectifiers preclude this by clamping the output to about 1-1/2 volts above output setting.

1-16. SPECIFICATION EXPLANATION.

1-17. PARD. The term PARD is an acronym for Periodic And Random Deviations and encompass-

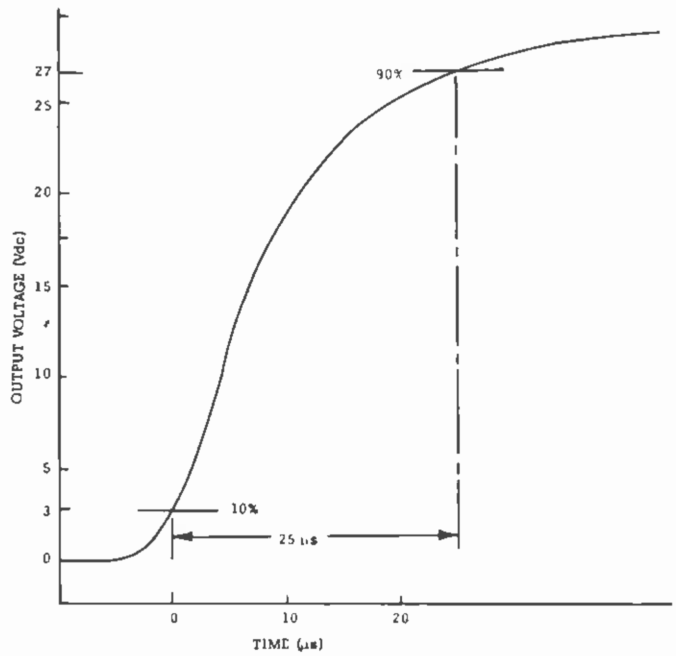


Figure 1-6A. Typical Up-Programming Time
(Model QRD 30-1)

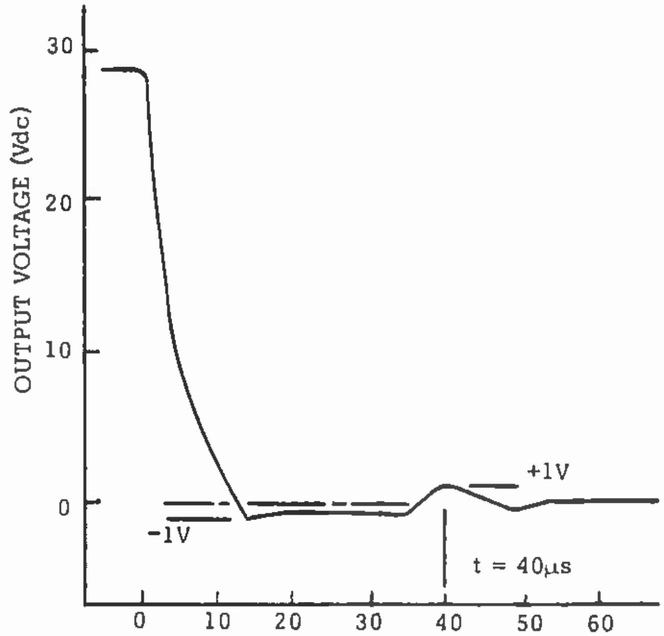
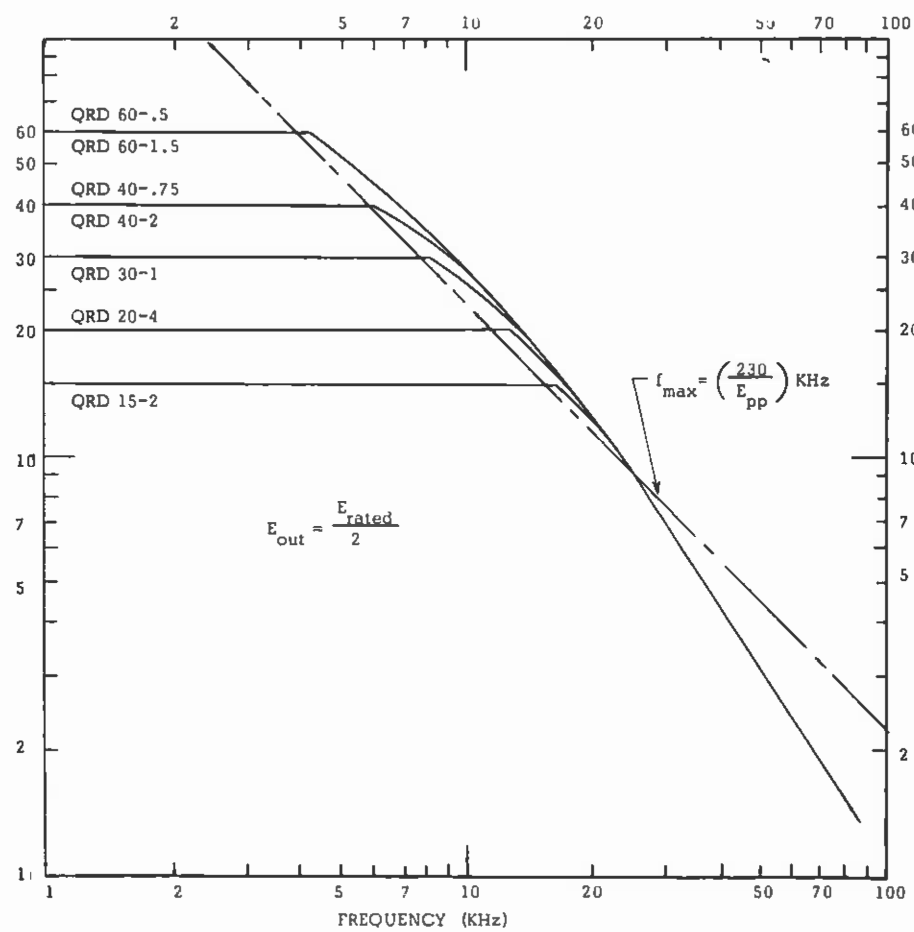


Figure 1-6B. Typical Down-Programming Time
(Model QRD 30-1)

Figure 1-7. Fast Programming
Sinusoidal Frequency
Response
(Log-Log Plot)



Voltage Control, 10-Turn QRD Model	Control Designation	Sorensen P/N With Std. Knob	Sorensen P/N With Calibrated, 3-Digit Dial (D2)
15-2	VC-2	29-528-2 & 42-244	29-528-2 & 42-265
20-4	VC-3	28-528-3 & 42-244	29-528-3 & 42-265
30-1	VC-4	29-528-4 & 42-244	29-528-4 & 42-265
40-.75 & 40-2	VC-5	29-528-5 & 42-244	29-528-5 & 42-265
60-.5 & 60-1.5	VC-6	29-528-6 & 42-244	29-528-6 & 42-265
Current Control, 10-Turn			With Calibrated, 3-Digit Dial (D1)
All Models	CC-1	29-528-1 & 42-244	29-528-1 & 42-265

Ordering

Order options by adding designations to basic model number. For example, a Model QRD 40-2 VC-5D2 is equipped with the 10-turn voltage control plus the 3-digit calibrated dial.

Table 1-3. Optional Equipment

es those variations in output previously designated ripple and noise. Precisely, PARD is the deviation in output voltage from its average value, over a specified bandwidth (10Hz-7MHz, 0-25MHz) with all external and environmental parameters held constant.

1-18. PROGRAMMING TIME. Programming time is defined as that time following a programmed input change for the power-supply output to change to a new value as measured at the 10 and 90% points between the initial and final values. QRD units are specified between 0 and rated output (up programming) and rated output and 0 (down programming). Figure 1-6 is a reproduction of an actual characteristic curve.

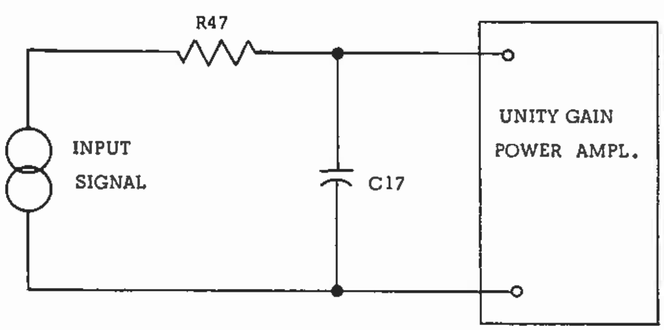


Figure 1-8. Equivalent Circuit, Voltage Signal Phase-Shift Network

In the voltage mode, as an approximation, the 0-90% time, which is an alternate definition, is typically about 30 µs and the time for a 0 - 99% change is close to 50 µs (typical).

1-19. SINUSOIDAL-FREQUENCY RESPONSE. The maximum sinusoidal frequency to which a QRD Model will respond is determined by the slopes of (1) the output sine wave and (2) the programming quasi-exponential curve. In all cases, as a criterion, the slope of the former must be less than that of the latter at corresponding points. For the voltage mode, typical data, experimentally obtained, indicate that the maximum sinusoidal frequency which can be followed (with negligible distortion) is calculable from the expression (230/Epp)KHz, when the average output voltage equals one-half the maximum rated output voltage. This figure of 230 indicates that the slope of the programming curve, at $(E_{max}/2)$, is approximately 750,000 V/s. Figure 1-7 illustrates the inverse relationship between the frequency and amplitude of the input sine wave.

1-20. GAIN AND PHASE SHIFT. If the QRD is programmed by voltage signal in the voltage mode, it exhibits a lagging phase shift and a gain less than unity. These characteristics result from an RC network formed by capacitor C17 and potentiometer R47. The equivalent circuit

QRD MODELS	RACK MOUNT ADAPTERS				HANDLE SETS	
	1-Unit		2-Unit			
	RP12	RP13	RP14	RP15	HS-1	HS-2
15-2	X		X		X	
20-4		X		X		X
30-1	X		X		X	
40-.75	X		X		X	
40-2		X		X		X
60-.5	X		X		X	
60-1.5		X		X		X

Table 1-4. Accessory Equipment

may be represented as shown in Figure 1-8. An idea of the magnitude of gain diminution and phase shift may be illustrated by an example. If R47 in a 40-volt unit is adjusted to 2000 ohms and a 30K Hz signal is impressed on the programming circuit, the gain (E out/E in) will typically be 0.77 and the phase shift will be about -40 degrees. At frequencies up to 30K Hz, the phase shift may be decreased to -5 degrees or less by relocating capacitor C17. The procedure is outlined in para 3-10.

1-21. OPTIONAL EQUIPMENT.

1-22. Any model in the QRD series may be ordered with factory-installed optional 10-turn controls (in lieu of the dual, tandem standard controls) which increase the output-adjust linearity and slightly improve drift characteristics. The controls are equipped with fluted black knobs, or if desired, may be outfitted with calibrated three-digit dials. Table 1-3 lists the optional equipment and the combinations which are available.

1-23. ACCESSORIES.

1-24. Handles and single- or two-unit rack-mounting adapters are offered as accessories to the QRD Series. Easily installed, the adapters, which are no greater in height than the units, offer the optimum in rack-space utilization. For a listing of accessories and their designators, refer to Table 1-4.

SECTION II
PREPARATION FOR USE

2-1. GENERAL.

2-2. After unpacking, initial inspections and preliminary checkout procedures should be performed to assure that unit is in good working order. Basically, these consist of visually checking for damaged parts and components, and of making an electrical check. If it is determined that the unit is damaged, notify the carrier immediately. The carrier's claim agent will then prepare a report of damage. The user is required to send this report to the Service Dept., Sorensen Company, Manchester, N.H. Sorensen will, in turn, advise the user as to what action is required to repair or replace the supply.

2-3. In addition to inspection and checkout procedures, this section contains instructions to adapt unit for rack use and or altering unit input wiring for either 220 or 230 volt operation.

2-4. INITIAL INSPECTION.

2-5. Proceed as follows to inspect for damage incurred during shipment:

a. Inspect panel and chassis for dents, paint chips and obvious signs of structural damage.

b. Check action of rear-mounted fuseholder. Assure that holder contains a properly rated fuse. Fuse ratings for both 115 and 220/230 Vac inputs appear above holder.

c. Turn front-panel controls from stop-to-stop. Rotation should be smooth.

d. Set PWR switch to ON and then off; then test METER switch. Switching action should be both positive and audible.

e. Check for cracked or broken indicator-lamp lens.

f. Inspect for a cracked meter window. If pointer is off zero, reset using adjust screw (80-watt units only).

g. Check input cord for physical damage. Tug lightly on cord near chassis to make certain relief grommet grips cord.

h. Inspect terminal board. Links should be firmly connected across barriers and between terminals 2-3, 3-4, 5-6, 7-8, 9-10 and 11-12.

i. Remove screws retaining top cover to chassis. Inspect printed board and components for damage. Reinstall cover unless unit is to be adapted for rack mounting (para 2-6) or 220/230 Vac input (para 2-10).

2-6. ACCESSORY INSTALLATION.

2-7. Table 1-4 lists the various accessories designed for use with the QRD Series. These include handles and two types of rack-mount adapters. The following paragraphs give installation instructions for the accessories excluding the handles. These are easily attached to the front panel through tapped holes with the screws provided.

2-8. SINGLE-UNIT ADAPTER. There are two single-unit adapters, one for low-power units and the other for high-power models. However, the adapters are similar and the methods of assembling are identical. The installation is depicted in Figure 2-1. When installing, remove top-cover screws, and then unit feet. Interchange top-cover and feet-mounting screws. Loosely assemble parts, place entire assembly on a flat surface to properly align all parts, and then tighten screws.

2-9. TWO-UNIT ADAPTER. Two-unit adapters are available for both low- and high-power units. The adapters are similar, and methods of assembly are identical. Figure 2-2 illustrates adapter installation. Remove screws from units' top covers, detach feet on each unit, interchange top-cover and feet-mounting screws, and remount covers. Loosely assemble adapter and units. Next, with assembly resting on a flat surface, align all edges, and then tighten screws.

2-10. ELECTRICAL INSTALLATION.

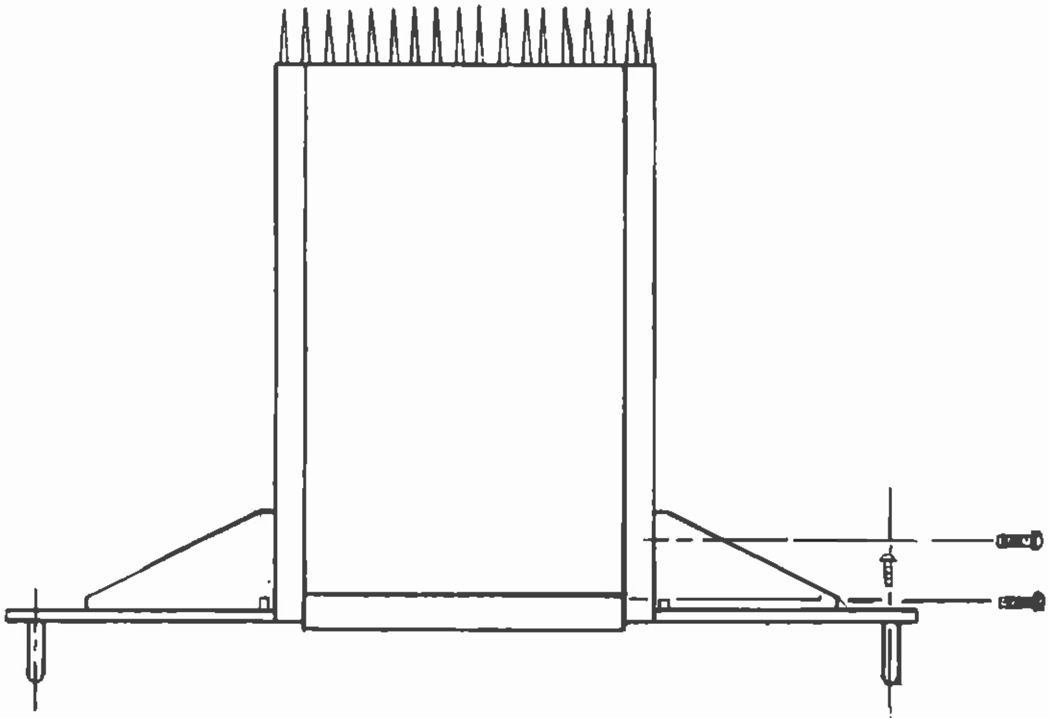


Figure 2-1. Single-unit Rack-Mount Adapter

2-11. Units in the QRD Series are factory-wired to accept a nominal 115-Vac input. However, either of two alternate inputs may be used by making a few simple alterations.

2-12. 220-VOLT OPERATION. To adapt a QRD unit to 220- Vac input, proceed as follows:

a. Remove top cover.

b. At transformer T1, remove jumpers across taps 11 and 13, and 12 and 15 (Figure 2-3).

c. Solder a jumper across taps 12 and 13.

d. Disconnect white wire at tap 15 and reconnect at tap 14.

e. Change input fuse to a .75 A rated for 30-watt models or to a 1.5 A rated for 80-watt models.

f. Remount cover.

2-13. 230-VOLT OPERATION. Procedures for adapting a QRD unit to 230-Vac input are identical to those provided in para 2-12 with this exception: do not relocate white wire at tap 15 to tap 14.

2-14. INPUT-POWER CORD. The input-power cord terminates externally in a three-prong polarized plug. The unit chassis is wired to the plug through the line cord, and therefore, insertion of the plug into a compatible receptacle will automatically ground the unit. If a grounded input is not available, use an adapter, making sure that the adapter's external lead is well grounded.

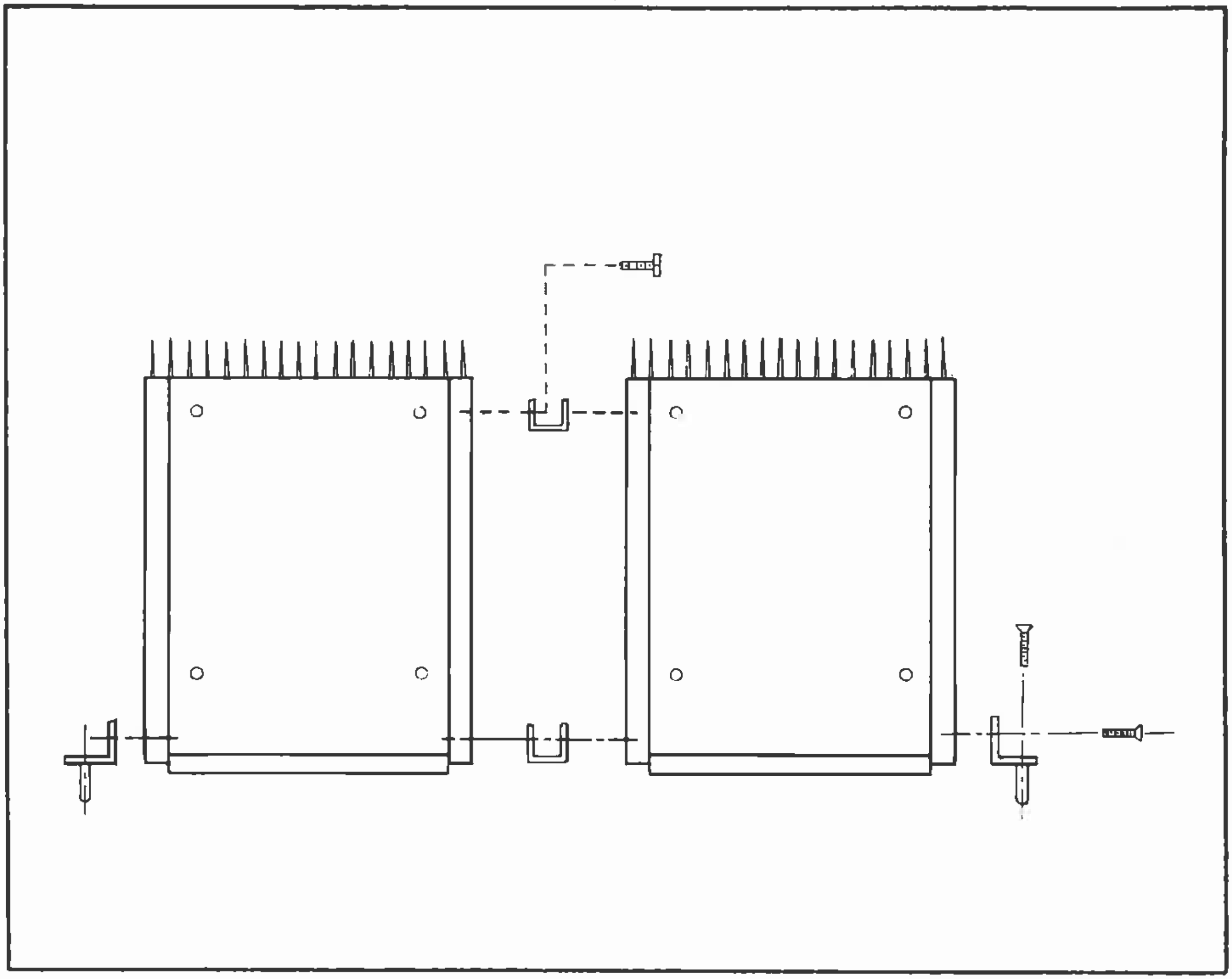


Figure 2-2. Two-unit Rack-Mount Adapter

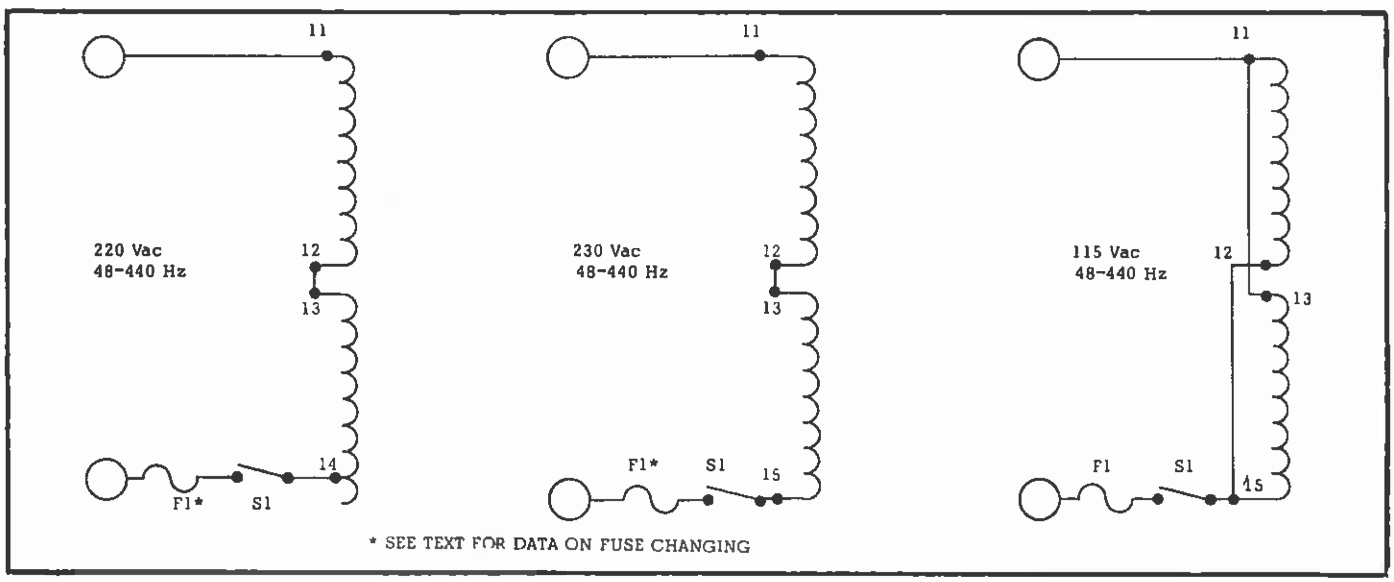


Figure 2-3. Alternate Input Connections

2-15. ELECTRICAL INSPECTION.

2-16. The following paragraphs describe the procedure for making an initial electrical inspection. If specification verification is required at incoming inspection, refer to para 2-19.

2-17. VOLTAGE MODE. To check voltage-mode operation, proceed as follows:

a. Rotate VOLTS and AMPS controls fully counterclockwise.

b. Connect a test voltmeter across output terminals (4 and 5 on terminal board or "+" and "-" binding posts on front panel). Select a voltmeter range compatible with unit output rating.

Note

Do not loosen or remove interconnecting links on terminal board.

c. Insert power cord into a suitable receptacle, and set PWR switch to ON.

d. Set METER selector switch to the V position.

e. Slowly rotate VOLTS control clockwise. Minimum control range should be from 0 to maximum rated output voltage (Table 1-1).

f. Set PWR switch to off.

2-18. CURRENT MODE. To check current-mode operation, proceed as follows:

a. Set METER selector switch to A position.

b. Rotate coarse VOLTS control and AMPS controls fully counterclockwise.

c. Turn fine VOLTS control fully clockwise.

d. Connect a d-c ammeter between terminals 4 and 5 on terminal board or between front-panel binding posts. Select leads of sufficient current-carrying capacity and an ammeter range compatible with unit's rated current output.

e. Set PWR switch to ON.

f. Rotate AMPS control slowly clockwise. Control range should be from 0 to maximum rated output (Table 1-1 and Figure 1-1). Compare test meter indication with front panel indicator.

2-19. SPECIFICATION VERIFICATION.

2-20. Sensitive instruments, as units in the QRD Series are, require rigorous testing methods if a true evaluation of performance is to be made. Wherever possible, use twisted leads with test equipment to reduce stray pickup. At the power-supply terminal board, these leads must be

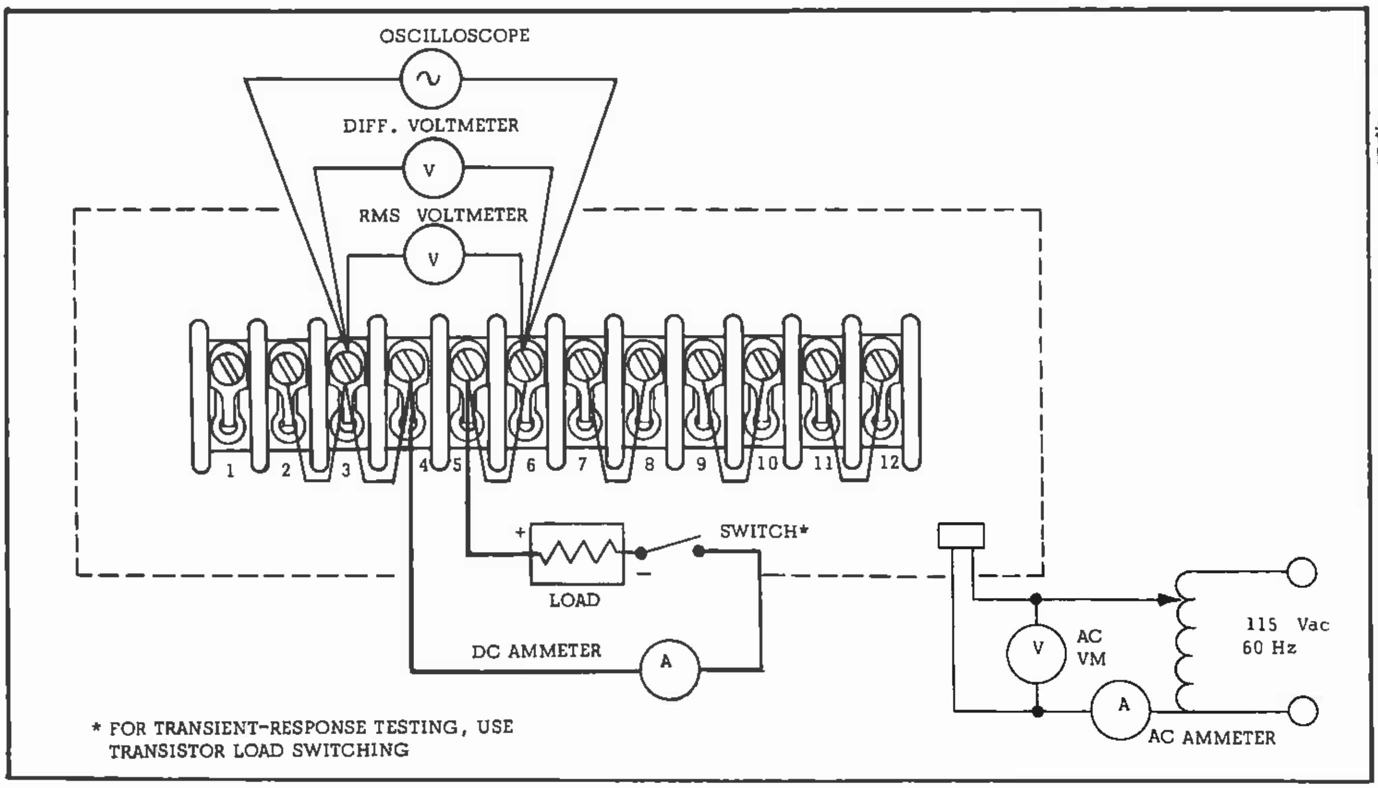


Figure 2-4. Voltage-Mode Regulation, PARD and Response Setup

firmly screwed to the terminals. Alligator clips and similar types of connectors are not suitable. Note that the output specifications are applicable at rear terminals only. (Front-panel binding posts sometimes introduce errors which, although small, are sufficient to adversely influence measurements.) In addition, grounding techniques in which more than one device in the test system is grounded (excluding a-c inputs) may, through ground loops, introduce extraneous ripple. If generated, this ripple, although unrelated to supply output, will be displayed on the test oscilloscope.

2-21. VOLTAGE-MODE REGULATION. To check voltage-mode regulation, first connect test system as shown in Figure 2-4. For regulation testing, the oscilloscope and RMS voltmeter are not required. Use a variable autotransformer for a-c input, connect an a-c voltmeter across transformer output terminals and then proceed as follows:

a. At no load, adjust unit output voltage to maximum rated.

b. Adjust differential voltmeter's internal voltage to obtain a null indication.

c. With input set at 115 Vac, load the unit until d-c ammeter indicates rated output current (at 55°C). Record deviation from null position.

d. Set the input to 105 Vac, and readjust voltmeter's internal voltage to regain the null position. Then, with full load on unit, vary the input voltage to 125 Vac. Note the deviation from null.

e. Sum the deviations recorded in steps "c" and "d". Total should be equal to or less than that stipulated in Table 2-1.

2-22. VOLTAGE-MODE PARD. To check periodic and random deviations in the voltage mode, connect a true RMS voltmeter and oscilloscope across unit sense terminals as shown in Figure 2-4. RMS voltmeter should have a 10Hz-7MHz bandwidth and bandwidth of oscilloscope should be 0-25 MHz. Remove link between terminals 2 and 3 and retighten terminal screw at 3.

a. Apply 115 Vac to input.

b. At no load, adjust unit output voltage to maximum rated.

c. Apply load until d-c ammeter indicates rated output current at 55°C.

d. Observe oscilloscope and voltmeter. Maximum RMS voltage should be no greater than 300 µV and typical peak-to-peak voltage should be equal to or less than 8 mV. This completes the fast-programming test.

e. Set unit PWR switch to off and reinstall link between terminals 2 and 3 in order to check in standard-programming mode. Link should be fitted between test lead and link which interconnects negative sense/output interconnecting link.

f. Repeat steps "b" and "c." Maximum RMS voltage should be equal to or less than 200 µV and typical peak-to-peak voltage should be no greater than 3 mV.

2-23. VOLTAGE-MODE TRANSIENT RESPONSE. In

		QRD MODELS						
		15-2	30-1	40-.75	60-.5	20-4	40-2	60-1.5
Volt.Mode Regulation	(mV)	1.5	3.0	4.0	6.0	2.0	4.0	6.0
Cur.Mode Regulation	(µA)	650	450	400	350	1300	900	800
Cur.Mode PARD (Stand.Prog.)	RMS(µA)	150	150	150	150	400	300	300
Cur.Mode PARD (Fast Prog.)	RMS(µA)	300	300	300	300	800	600	600
Current Mode Transient Response In a step load change E max. to 0	(µs)	150	160	350	700	150	150	250
0 to E max.	(µs)	40	45	60	250	40	200	400

Table 2-1. Performance Specifications at Test Points

checking transient response, it is more convenient to repetitively load and unload at a rate of 100 to 1000 Hz. To obtain the load-switching rate required (switching time should be small in comparison to rated response time) transistor load switching is recommended. Leads in the test system should be short to reduce inductance, and load resistors should be noninductive. Both standard- and fast-programming transient response may be taken. Standard-programming specification is 50 µs or less to return to a 10 mV band following a full load-to-no load, or no load-to-full load change. Remove link between terminals 2 and 3, and check fast-programming transient response. Specification is 70 µs (typical) for conditions previously stipulated for standard programming.

2-24. CURRENT-MODE REGULATION. To obtain meaningful current-mode regulation data, tests should be run in the fast-programming mode, i.e., without the output capacitor (C19). This is a suggested procedure inasmuch as the compliance time constant, determined by the load resistance and the output capacitance, delays recovery to the regulation band. This delay may be sufficiently long (2 to 5 seconds at light load currents) to allow line transients and short-term drift to become significant (and perhaps major) components of the output deviation. Without the output capacitor, the exponential recovery effect is virtually eliminated, and consequently return to the regulation band is extremely rapid. If standard-programming current-mode regulation data are required, take fast-programming regulation and add output capacitor (C19) leakage current (measured separately).

2-25. A current-mode regulation test consists of measuring the voltage-drop deviation, resulting from a full-line swing and a full-load change across a shunt resistor. To set up test system, see Figure 2-5. A 1-ohm, ± 1% shunt is recommended. To reduce temperature-coefficient effects, the shunt selected should be capable of dissipating 10 times the maximum power output attainable. The load must be able to absorb the full compliance voltage. For regulation testing, the true RMS voltmeter and oscilloscope are unnecessary.

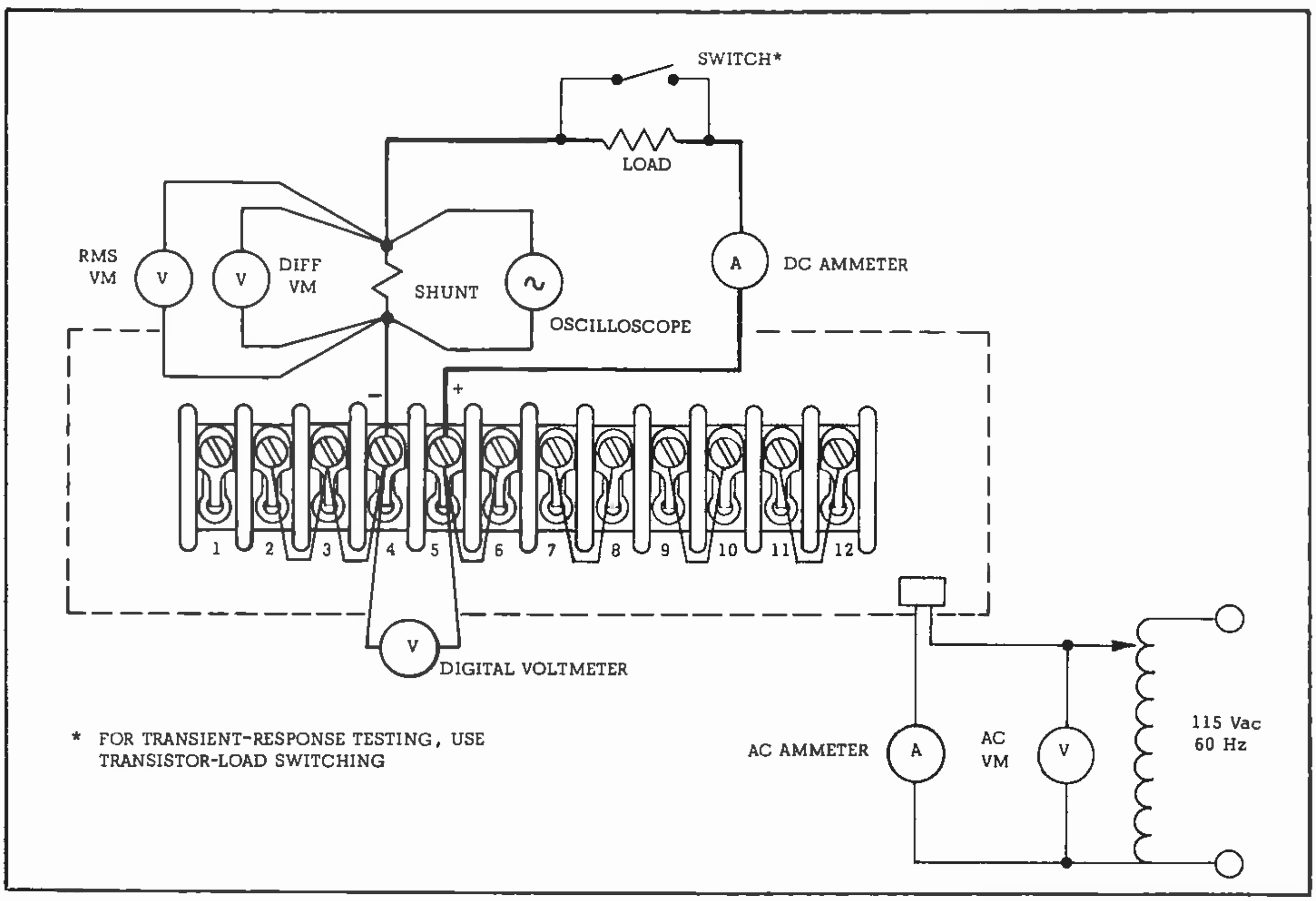


Figure 2-5. Current-Mode Regulation, PARD and Response Setup

a. Remove link between terminals 2 and 3, and with no load applied, rotate both VOLTS controls fully clockwise. Note output voltage indicated by digital voltmeter.

b. Apply load until output voltage drops to exactly the maximum rated compliance voltage (refer to Table 1-1).

c. Set internal voltage of differential voltmeter to obtain a null indication.

d. Close load shorting switch and record deviation.

e. Open switch and adjust input voltage to 105 Vac. If necessary, reset voltmeter to null position and then vary the input to 125 Vac. Note any deviation.

f. Sum the deviations. Total obtained should be no greater than that specified in Table 2-1. Reinstall link between terminals 2 and 3.

2-26. CURRENT-MODE PARD. To check current-mode periodic and random deviations, connect a true RMS voltmeter and an oscilloscope across shunt as shown in Figure 2-5. The differential voltmeter is not required. Load resistor should be noninductive.

a. Set input voltage to 125 Vac.

b. Apply sufficient load to obtain maximum compliance-voltage indication on digital voltmeter.

c. Observe RMS voltmeter and oscilloscope. Maximum allowable peak-to-peak current is 2 mA (0-25 MHz bandwidth) and RMS current should not be greater than that specified in Table 2-1.

d. Repeat measurements with link removed between terminals 2 and 3, i.e., fast programming mode. RMS current specification is given in Table 2-1.

2-27. CURRENT-MODE TRANSIENT RESPONSE. To measure current-mode transient response, the only test instrument required is an oscilloscope connected across the shunt. The load should be noninductive and leads in the test system should be as short as possible. Transistor load switching between 100 and 300 Hz is recommended. Remove link between terminals 2 and 3. The response times to recover to within ± 1% of the initial steady-state current are listed in Table 2-1.

2-28. PROGRAMMING TIME. Programming time is checked in the fast-programming mode, i.e., with link removed between terminals 2 and 3. Use an oscilloscope at the output terminals and a mercury-wetted relay to switch the programming resistance at a 60-cycle rate. In programming from 0 to Eo max., the time from .1 Eo max. to .9 Eo max. should be approximately 25 µs and the time from .9 Eo max. to .1 Eo max. should typically be 10 µs.

2-29. DRIFT. Both voltage- and current-mode drift are measured in the standard-programming mode, i.e., link firmly in place between terminals 2 and 3. Run drift tests on a strip-chart recorder at constant load, line and ambient temperature. Allow one-half hour for voltage-mode warmup and a full hour for current-mode warmup. Specification for voltage-mode drift is 0.025% of the output voltage (typical) and that for current mode is 0.1% of the output current plus 50 µA (typical).

SECTION III
OPERATING INSTRUCTIONS

3-1. GENERAL.

3-2. In this section, procedures required to convert a QRD unit to any of its various operating configurations are presented, including remote sensing, voltage- and current-mode programming (both fast and standard) and series and parallel operation. A list of controls and indicators (Table 3-1), keyed to Figure 3-1, is also provided.

3-3. VOLTAGE-MODE OPERATION.

3-4. LOCAL SENSING. All models in the QRD series are shipped ready for use with local sensing, i.e., sensing point is at the output terminals. If variations in load-lead drops are expected to be high relative to unit's specified regulation, use remote sensing (para 3-6).

3-5. To operate unit in local sensing, proceed as follows:

a. To set current-limit value, short unit output terminals, set PWR switch to ON and METER switch to A, and use AMPS control to adjust current-limit value, indicated on ammeter.

b. Set PWR switch to off, remove short and set METER switch to V.

c. Apply input power, and rotate coarse and fine VOLTS controls to obtain desired output. Set PWR switch to off.

d. Observing polarity, run load leads to either front or rear output terminals (at rear terminals, link should be fitted between binder screw head and lead); then reapply input. Unit supplies power to load, with output voltage regulated at unit terminals.

3-6. REMOTE SENSING. If variations in load-lead voltage drops are high when compared with unit's specified regulation, it may be desirable to use remote sensing. To adapt unit for remote-sensing operation, follow procedures outlined in 3-5, but before setting PWR switch to ON, remove links between terminals 3 and 4, and 5 and 6 (Figure 3-2). Then connect sensing leads, observing polarity. Use coaxial cable or a twisted pair of wires for sensing leads and make certain that leads are firmly connected, both at unit terminals and load. Current in the sensing leads is below 100 mA. In remote-sensing standard-programming operation, transient-response characteristics may degenerate slightly. (In the fast-programming mode, there is no degeneration.) If unit's response is a critical factor, remove link from between terminals 2 and 3, and connect a

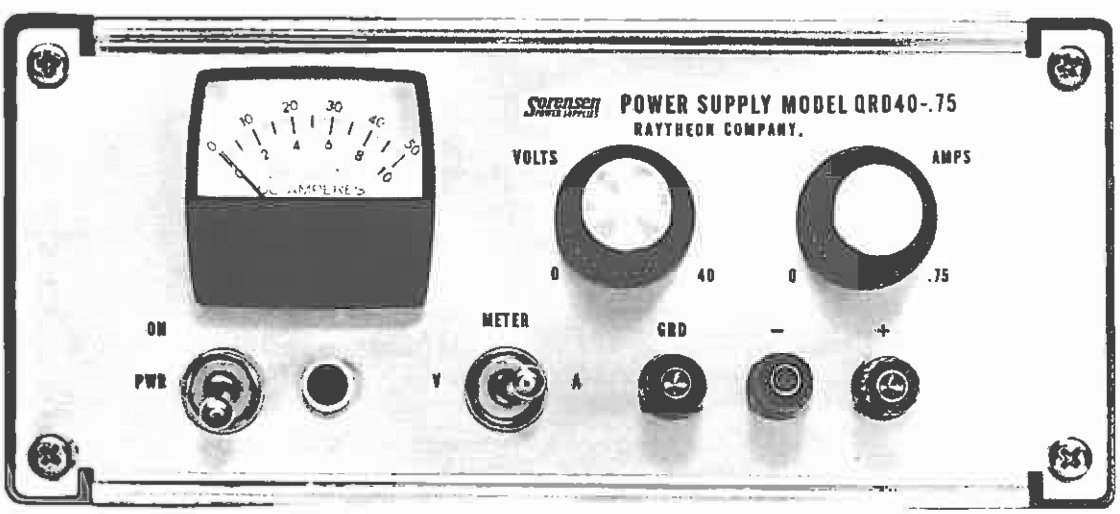


Figure 3-1. Controls and Indicators

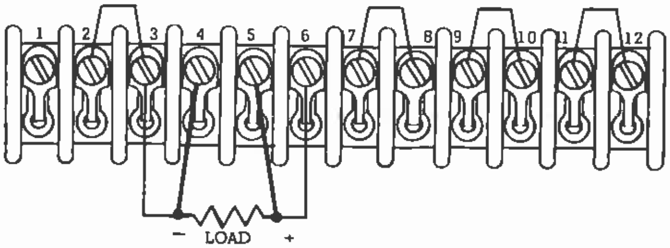


Figure 3-2. Remote Sensing

capacitor, equivalent to C19, across the load terminals. Unit will then meet its transient-response specifications.

3-7. REMOTE PROGRAMMING. In voltage-mode, remote-programming operation, unit output voltage is controlled by external resistance or voltage-signal commands. Both types may be used with either of two general programming modes, i.e., fast programming or standard programming. As the nomenclature implies, the predominant difference between the two is that in fast programming the unit is capable of tracking abrupt signal changes, while in standard programming, tracking delays are encountered due to a number of factors including the load-output capacitor relationship and the sensing-network capacitance. However, with standard programming, transient-response and ripple characteristics are slightly better than those exhibited in fast programming.

3-8. Resistance. If the output voltage is to be controlled by resistance programming, calculate the resistance required using the ratio of 100 ±0.5 ohms/volt, i.e., for every volt of output desired approximately 100 ohms are required. In selecting a programming resistor, choose one with a low temperature coefficient (±20 ppm/°C) and a wattage ten times that calculated (programming current is 10 mA). Note that resistance programming may also be used to improve a unit's drift characteristic. For example, if a fixed output is required, a fixed resistor may be

CONTROL/INDICATOR	FUNCTION
PWR Switch	A 10 A, 250 Vac, double-pole, single-throw switch (connected as a SPST). Used to connect or disconnect power to or from the primary of transformer T1.
Volt-Ammeter	A dual-function meter which indicates output voltage or current depending on position of METER switch.
PWR Light	A red lamp which glows when power is applied to the primary of transformer T1.
METER Switch	A 250 Vac, double-pole, double-throw switch. Used to select meter function.
VOLTS Control	A dual, tandem potentiometer which provides both fine and coarse control of the output voltage during voltage-mode operation. Connected in the voltage programming circuit. Also used to set compliance range in current-mode operation.
AMPS Control	A dual, tandem control connected in the current-programming circuit and providing both fine and coarse control over the output current with unit in current-mode operation. Also used to set current limit in voltage-mode operation.

Table 3-1. Controls and Indicators

selected. This would eliminate the variable contact resistance which is inherent in any potentiometer and which contributes to the drift characteristic. If abrupt changes in output voltage are to be made by switching the programing resistance, use a make-before-break switch.

3-9. To adapt unit to resistance programming, proceed as follows:

a. Short unit output terminals, set PWR switch to ON and METER switch to A, and then use AMPS control to adjust current-limit value.

b. Set PWR switch to off, remove short and set METER switch to V position.

c. Rotate VOLTS controls fully counterclockwise.

d. If fast-programming is desired, remove link between terminals 2 and 3 (Figure 3-3).

e. Remove link between terminals 11 and 12, and connect programming resistor (see Figure 3-3). Use twisted or shielded wire for leads.

CAUTION

Operating the unit with open programing leads or links will result in high output voltage.

f. Remove links between terminals 3 and 4, and 5 and 6. Observing polarity connect load leads to terminals 4 and 5. If output is to be remote-sensed, run sensing leads from terminals 3 and 6 to the load. If remote sensing is not to be used, reinstall links between terminals 3 and 4, and 5 and 6 with link fitted between binder screw head and load lead.

g. Set PWR switch to ON. Unit supplies programmed voltage.

Note

With programming resistor connected across terminals 11 and 12, VOLTS control remains in circuit. Rotation of this control will alter programmed voltage. If this is an undesirable feature, connect resistor across terminals 3 and 11 to effect complete bypass.

3-10. Voltage Signal. Procedures for adapting a unit to voltage-signal programming are identical to those given in para 3-9, with one exception: instead of connecting a programming resistance across terminals 11 and 12, connect the signal-generating device. Volt/volt coefficient is 1, i.e., for every volt of output desired, one volt of signal must be applied. In selecting a programming device, use one that is floating (ungrounded), is capable of absorbing the 10 mA programming current and produces a low-noise, low-ripple signal. To improve phase shift characteristics (para 1-20), disconnect capacitor C17 and reconnect locally across potentiometer R47. For common input-output connections, signal generator can be installed in series with an external programming resistor between terminals 3 and 11. See Figure 3-4.

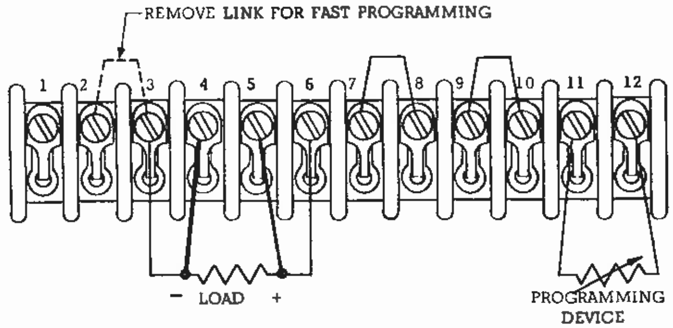


Figure 3-3. Voltage-Mode Programming (with Remote Sensing)

3-11. CURRENT-MODE OPERATION.

3-12. To operate a QRD unit in the current-mode, proceed as follows:

a. Rotate all front-panel controls fully counterclockwise.

b. Short the output terminals.

c. Rotate fine VOLTS control clockwise, set METER switch to A position and close PWR switch.

d. Turn coarse and fine AMPS controls clockwise to select the desired output current.

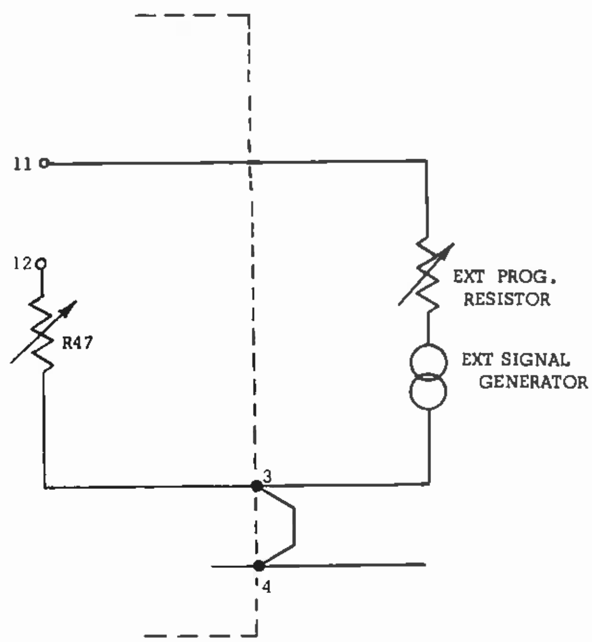


Fig.3-4. Voltage-Signal Common Input-Output Connections

e. Open PWR switch, set METER switch to V and remove short from output terminals.

f. Set PWR switch to ON and adjust output voltage, using VOLTS control,to desired compliance setting.

g. Open PWR switch, and observing polarity, connect load to terminals 4 and 5. Reapply input power.

Note

If compliance voltage exceeds VOLTS control setting, crossover to voltage-mode operation occurs automatically.

3-13. REMOTE PROGRAMMING. In current-mode, remote-programming operation, the regulated output current may be controlled externally by resistance changes or voltage signals. In either case, standard or fast programming may be used. Fast programming offers rapid response to input commands and improved transient-response characteristics. In standard programming, on the other hand, the supply exhibits slightly lower RMS ripple and greater stability.

3-14. Resistance. For resistance programming, calculate the value of resistor required by using the ohms/ampere coefficient listed by Model in Table 1-1. Use a resistor with a low temperature coefficient (±20 ppm/°C), and a wattage rating at least ten times calculated value (programming current is approximately 1 mA).

3-15. To adapt unit for current-mode resistance-programming operation, proceed as follows:

a. Close PWR switch, set METER switch to V position, adjust output voltage to desired compliance setting.

b. Open PWR switch, set METER switch to A position and rotate AMPS controls fully counterclockwise.

c. If fast programming is desired, remove link between terminals 2 and 3 (Figure 3-5).

d. Remove link between terminals 7 and 8, and connect in programming resistor.

CAUTION

Operating unit with open programming leads or links will result in high output current with possible crossover to voltage mode. If step changes in output current are to be made by abrupt resistance alterations, use make-before-break switching.

e. Run load leads to terminals 4 and 5, observing polarity.

f. Set PWR switch to ON. Unit supplies regulated programmed current to the load.

Note

Any rotation of the AMPS control will alter the output current.

3-16. Voltage Signal. To adapt a QRD unit to voltage-signal programming, follow procedures outlined in para 3-15 with this exception: connect signal-producing device across terminals 7 and 8, instead of the programming resistor. The volt/ampere coefficients are listed by Model in Table 1-1. The programming device should be floating (ungrounded), be capable of absorbing the 1 mA programming current, and have a low-noise, low-ripple output signal.

3-17. SERIES OPERATION.

3-18. For applications which require voltages higher than a single QRD model can provide, use series operation. Maximum rated output of any series connected system is 200 Vdc. System regulation is the sum of the regulations for all units. In QRD Models, there is no need to connect reverse-voltage rectifiers across the output terminals. Reverse-voltage protection has been designed into the entire Series.

3-19. To connect units in series proceed as follows:

a. Adjust output voltage of each unit so that their sum is equal to the desired system output. Set PWR switches of both units to off.

b. Remove links between terminals 3 and 4, and 5 and 6, on both units.

c. Connect load leads as shown in Figure 3-6. Observe polarity.

d. Run sensing leads from unit to load, observing polarity. Wherever possible, use twisted or shielded leads. At load and unit ter-

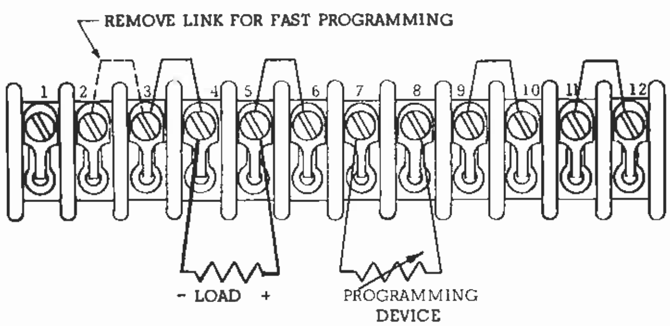


Figure 3-5. Current-Mode Programming

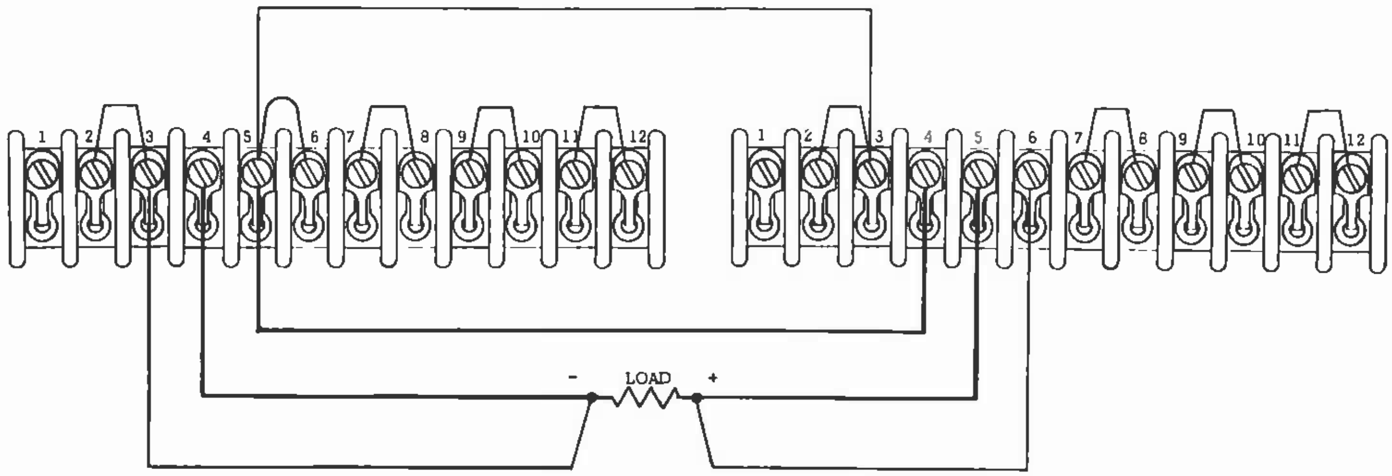


Figure 3-6. Series Operation

minals, place sensing leads between binder-screw head and load lead.

e. Set PWR switches to ON. System supplies regulated to load.

3-20. PARALLEL OPERATION.

3-21. Parallel operation may be used to obtain currents greater than any single Model can supply. The maximum rated output of any parallel-connected system is the sum of the maximum outputs of each unit derated to 90%.

3-22. To connect two units in parallel (extend procedure to hook up additional units), proceed as follows:

a. Apply nominal input power to master unit (see Figure 3-7), adjust output voltage to desired load voltage and then set PWR switch to off.

b. Short the master unit's output terminals, apply input power and adjust output current to I_{so}/X, where I_{so} is the system output current and X is the number of units in system. Remove input power.

c. At slave unit, remove link across terminals 9-10, and 11-12, and reconnect a lead from terminal 9, slave unit, to terminal 9, master unit.

d. Observing polarity, run leads from load to terminals 4 and 5 on both units. If remote sensing is desired, connect coaxial cable or a twisted pair of wires from terminals 3 and 6 to the load, again observing polarity.

e. Set PWR switches of both units to ON.

Note

If the output of any unit drops to zero either through an internal failure or by opening a PWR switch, the output of entire system will go to zero.

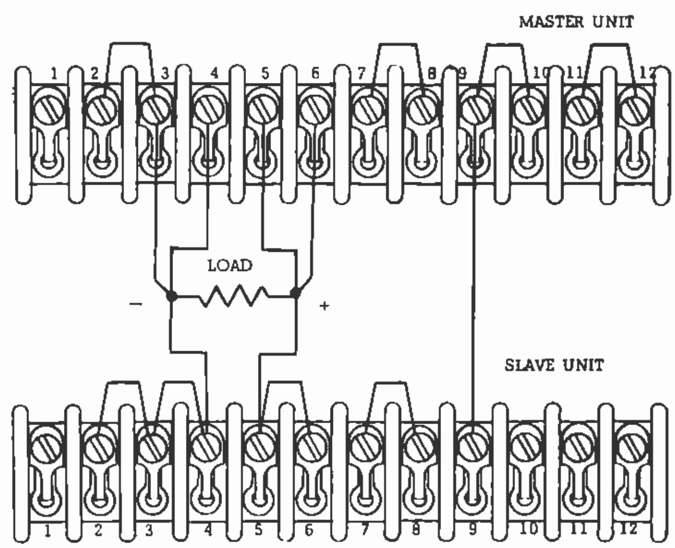


Figure 3-7. Parallel Operation (with Remote Sensing)

SECTION IV
PRINCIPLES OF OPERATION

4-1. GENERAL.

4-2. This section discusses the basic theory of series-pass regulation, describes the block functions of various circuits and then details the operation of each circuit. If used as a supplement to the troubleshooting data provided in Section V, it will aid in the rapid, logical isolation of unit faults. Schematic locations of the reference designations used throughout this section will be found in Figure 5-3.

4-3. SERIES-PASS PRINCIPLE.

4-4. The QRD utilizes the series-pass principle to regulate unit output. With this approach, a variable impedance absorbs the difference between the filtered "brute-force" dc and the desired output voltage in the voltage-mode and the compliance voltage in the current-mode. The variable impedance is provided by a number of transistor stages, connected in parallel, all of which react simultaneously to an output-related control signal. Operation of the transistors, which are called passing stages, is idealized in Figure 4-1.

4-5. BLOCK-DIAGRAM DISCUSSION.

4-6. The following discusses in a general manner the internal operation of a QRD. A more detailed treatment of the various sections is presented in subsequent paragraphs. Refer to Figure 4-2: the a-c power is stepped down by the input transformer and applied across a full-wave bridge rectifier. Output from the rectifier is filtered, fed through the passing stages, and applied across the output terminals. This passing stage is, of course, the regulating device absorbing the difference between the unregulated d-c and the desired or compliance voltages. In voltage-regulating operation, the voltage-mode section senses the output voltage, develops and amplifies error signals, and feeds these signals through a number of drivers to the passing stages. In current-regulating operation, the current-mode section monitors the output current through a sensing resistor and regulates the voltage developed across the resistor by applying control signals to the drivers and consequently the passing stage. Unregulated supplies provide reverse-bias voltage to the passing stages and forward bias for the current-mode differential amplifiers.

4-7. REFERENCE SUPPLY.

4-8. The precisely regulated voltage required for output comparison and error-signal development is provided by a reference supply consisting of an unregulated supply (T1, CR1 and CR4), filter capacitor (C1), an error bridge (R5, R9 and CR5), two double-differential amplifiers (Q4, Q5 and Q2, Q3) and a low-power passing stage (Q1). Resistor (R2) is a starting resistor, i.e., at turn on, it shunts current across the passing stage to allow the reference supply to start functioning.

4-9. In general, the supply operates as follows: the precise reference voltage developed by zener diode (CR5) is compared with a portion of the output voltage developed across R9. Error signals

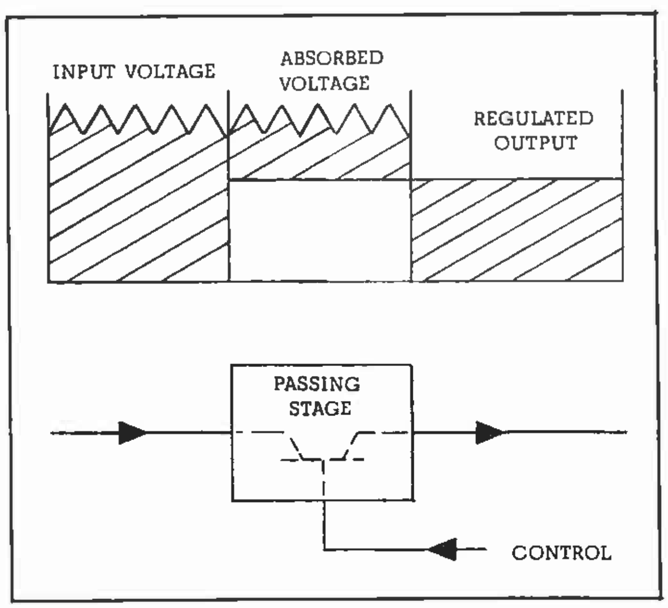


Figure 4-1. Series-Pass Principle

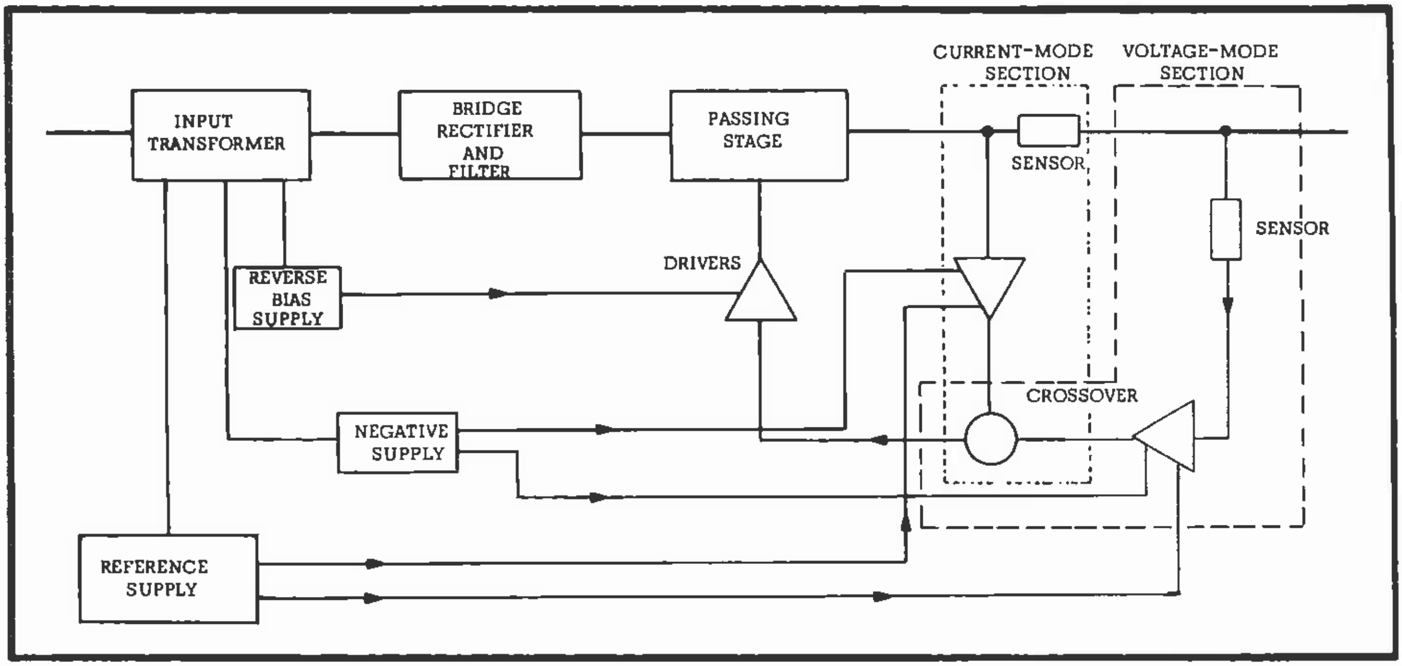


Figure 4-2. Block Diagram.

which develop are amplified first by differential amplifier (Q4,Q5) and then by amplifier (Q2, Q3). The amplified signal is then applied to the base of Q1, where it alters stage impedance and therefore the absorbed voltage.

4-10. As a specific example of circuit operation, assume that, as a result of an input line change, supply output voltage starts to increase. The voltage across R9 will then increase, and the base of Q5 will become more positive with respect to Q4's base. Q5 will then conduct more current and Q4 less. (Note that the sum of the currents through Q4 and Q5 is held constant by the zener voltage across R7.) With an increase in current, the voltage developed across R8 increases, while that across R6 decreases. Q2's base will therefore become more negative with respect to the base of Q3. As a result, Q2 will conduct less current, and the drive on Q1 will diminish. Q1 will increase its absorbed voltage, thereby regulating the output to a precise 8.9 volts.

4-11. VOLTAGE-MODE SECTION.

4-12. The voltage-mode section consists basically of two double-differential amplifiers (Q16, Q17 and Q12, Q13), a constant-current generator (Q18) and sensing string (R26, R47A and B). The section functions to sense unit output voltage, to detect differences between the desired and the actual output voltages, and to convert and amplify these differences into error signals used to control passing-stage (Q21) impedance.

4-13. To clarify circuit operation, a specific example is given. Suppose that, as a result of a load change, the output voltage begins to increase. The increase is sensed across R47A and B, and Q16's base becomes more negative with respect to the base of Q17. Current through Q16 decreases while that through Q17 increases. (The sum of Q16's and Q17's operating currents is fixed by constant-current generator Q18, R31, CR11, CR12). The decreasing current through R28 lowers the voltage across R28 while that across R30 increases. As a result, Q12's base becomes less negative with respect to the base of Q13, and Q12's operating current decreases. Now this operating current is, in fact, the signal current to the drivers and passing stages, and any changes in it are reflected in changes in passing-stage impedance and consequently output voltage. Therefore, a decrease in signal current, resulting from an increase in output voltage, increases passing-stage impedance to reduce the output to the desired voltage.

4-14. Transistor Q15, diode CR9 and resistor R25 form the down-programming-time circuit. Under normal operating conditions, Q15 is nonconducting due to insufficient base-emitter voltage. However, when a programming-resistance or voltage-signal change is made to lower the output voltage, Q15 goes rapidly into conduction and almost instantaneously shunts the signal current, mentioned previously, into the sensing string. As a result, no signal is impressed on the drivers and the passing-stage impedance increases, absorbing more voltage.

Now, as the bases of Q16 and Q17 regain their equilibrium, Q15 reverts to its nonconducting state and normal regulation, at the programmed voltage, takes place.

4-15. CURRENT-MODE SECTION.

4-16. The current-mode section serves two functions. In constant-voltage operation, it protects the load from excessive currents by limiting action, and in constant-current operation, it regulates the output current to the desired value. Main components include differential amplifiers (Q6, Q7 and Q9, Q10), constant-current generator (Q11), sensing resistor (R40), switch (Q14) and potentiometers (R22A and B). Potentiometer (R14) is a calibration resistor used to adjust amplifier (Q9, Q10) zero-set point.

4-17. Basically, the section functions as follows: the voltage across sensing resistor (R40), developed by the load current, is compared to a fixed reference. This reference is derived from the 8.9-V regulated supply and the constant-current generator (CR8, R21 and Q11). Error signals which develop are amplified first by Q9, Q10 and next by Q6, Q7. The amplified signals are then applied to the base of switch Q14. Q14 then functions as a variable impedance to control the signal from the voltage-mode section to the drivers and passing stages. It should be noted that the signal from the voltage-mode section is at full strength and that, in voltage-mode operation, Q14 is saturated.

4-18. As a specific example of current-mode-section operation, suppose that the load current begins to drop below the setting of the output current adjust (R22A and B). The voltage across R40 decreases, and Q9's base becomes more negative with respect to the base of Q10. The operating current through Q9 increases, and more voltage builds up across R18. As a result, the base of Q6 becomes more positive with respect to Q7's base. The operating current through Q6 will then increase while that through Q7 decreases. As a result, the voltage developed across R12 drops, and the drive on Q14 increases. Q14's impedance will decrease, and the signal current to the drivers and passing stages will be greater. Consequently, passing-stage impedance decreases, and output current increases to the regulator setting.

4-19. DRIVERS AND PASSING STAGES.

4-20. Basic components in the drivers and passing stages include transistors Q19, Q20, and Q21. Driver Q19 amplifies the signal produced by either the voltage- or current-mode sections, and applies it to Q20's base for further amplification. The amplified signals are then applied to the passing stages' bases where they act to alter stage impedance, thereby controlling the output voltage or current. Resistors (R38) assure equal current sharing by the passing stages.

4-21. REVERSE-BIAS SECTION.

4-22. The reverse-bias section functions (1) during "load-off" transients to improve response time by rapidly cutting off the passing stages and (2) to absorb "thermal-effect" current generated by high-junction temperature. The section is comprised of two unregulated supplies and a number of biasing resistors. A secondary of transformer (T1), rectifiers (CR17 and CR18), and capacitor (C14) form a supply which feeds reverse bias through resistors (R36 and R37) to transistors (Q20 and Q21). A half-wave, center-tapped rectifier (CR19) and filter capacitor (C12) supply reverse bias to Q19 through resistor (R34). Resistor (R39) serves as preload.

4-23. METER SECTION.

4-24. The meter section consists basically of volt-ammeter (M1), selector switch (S2), voltage-sampling resistors (R44, R45), current-sensing resistor (R43), calibration potentiometer (R42), and resistor (R41). With switch (S2) in the V position, meter (M1) is placed across voltage-sampling resistor (R45) and, in the A position, is across current-sensing resistor (R43).

4-25. STABILIZATION.

4-26. A tendency toward instability under certain operating conditions is inherent in the operation of any high-gain feedback amplifier. To preclude unstable operation, the QRD's have been equipped with a number of stabilization networks and capacitors. In the voltage-mode section, these include networks C17-R46, C11-R29 and C10-R24 and capacitor C8. (In fast-programming operation, C18-R48 also serves as a stabilization network). The current-mode section incorporates network C7-R15 and capacitor C9. Network C4-R3 and capacitor C3 are used in the reference supply, and capacitors C15, C16 stabilize drivers Q19, Q20.

4-27. INPUT-POWER SECTION.

4-28. The input-power section accepts the a-c input, steps down the voltage through transformer T1, and applies it to a full-wave bridge rectifier. Rectifier output is capacitor filtered before being supplied to passing stages. Main components include transformer (T1), rectifiers (CR13-CR16) and capacitor (C13). The input line includes a fast-blow fuse (F1) and a toggle switch (S1). Resistor (R35) serves as a bleeder. The two primaries of T1, normally connected in parallel for 115 Vac operation, may be placed in series for 220/230 volt operation. The power-indicating light is connected across a primary winding of transformer T1.

SECTION V
MAINTENANCE

5-1. GENERAL.

5-2. This section provides troubleshooting data, periodic-servicing information, and calibration procedures. The troubleshooting data should be used in conjunction with both the schematic diagram (Figure 5-3), which gives voltage-check points, and Section IV, which outlines the principles of operation. Figures 5-1 and 5-2 physically locate the parts appearing on the schematic. Any questions pertaining to repair should be directed to the nearest Sorensen representative, or directly to the Service Department, Sorensen Company, Manchester, New Hampshire 03103. Include the model and serial numbers in any correspondence. Should it be necessary to return a unit to the factory for repair, authorization from the Sorensen Service Dept. must be obtained first. Sorensen Company will not assume responsibility for units returned without prior authorization.

5-3. PERIODIC SERVICING.

5-4. Units in the QRD Series require no periodic servicing. However, it is recommended that whenever a unit is removed from the line it be cleaned. Use naptha, or an equivalent solvent, on painted surfaces. Wash front panel with a weak solution of soap and warm water. Use compressed air at a pressure of 5 psi to blow dust from in and around parts.

5-5. TROUBLESHOOTING.

5-6. Table 5-1 provides a list of malfunction symptoms along with a tabulation of the possible cause or causes for each symptom. Note that the failure of one component may result in a "chain reaction" effect. For example, if one or more of the passing stages (Q21) opens, the remainder of the Q21's may become overloaded and subsequently fail. In a like manner, if a diode in one of the four, full-wave rectifiers fails, its complementary rectifier and the main transformer may be damaged.

5-7. The data listed in Table 5-1 are based on prototype reliability studies, not on actual solutions to field problems, and therefore may be incomplete. Where the probable cause for a symptom lists a transistor short, it is either a base-collector, emitter-collector or base-emitter-collector short. Base-emitter shorts may give an entirely different set of symptoms. It is therefore recommended that before a particular section is checked for failures, each transistor within the section be tested for base-emitter shorts. (Normal base-emitter voltage is approximately 0.6 V.)

5-8. CALIBRATION.

5-9. Following the replacement of any differential-amplifier components, recalibration is recommended. Differential amplifiers are used in the reference supply, current-mode and voltage mode sections. If any of the internal adjustment potentiometers are replaced, recalibration is required.

5-10. To calibrate any model in the QRD Series, proceed as follows:

a. On component board, turn potentiometers R9, R14 and R42 to midpoint in rotation range.

b. Turn fine VOLTS and AMPS controls fully counterclockwise.

c. Rotate coarse VOLTS and AMPS controls to approximately midrange.

d. At rear terminal board, remove link between terminals 11 and 12, and connect a precision resistance box, ± 0.1% accuracy, between terminals 11 and 3. Set resistance exactly to that value specified in row A, Table 5-2. Assure that leads are firmly connected both at terminal board and at box.

e. Connect a precision voltmeter (Fluke or equivalent) across rear output terminals.

f. With 105 to 125 Vac at 60 Hz applied to input, set POWER switch to ON. Pilot light should glow.

g. Set METER switch to V position.

h. Adjust potentiometer R9 to obtain output voltage specified in row B, Table 5-2. Apply

SYMPTOM		PROBABLE CAUSE
I. No Output - Current or Voltage Modes	a.	Check external a-c input and position of PWR switch.
	b.	Check for blown fuse F1*.
II. Low or No Output - Voltage Mode	a.	Check output of 8.9V supply at C6. If output is low, try to adjust with R9 and then if necessary, check for open Q1, Q2, or Q4, or shorted Q5 or Q3.
	b.	Place a short across transistor Q14. If trouble persists, go to "c" and "d". If symptom disappears, remove short and check for shorted Q10, Q7 or Q14 b-e short. Test for Q9 or Q14 open.
	c.	In voltage-mode section, test for open Q16, Q18 or Q12 or shorted Q17, Q13.
	d.	In drivers and passing stages, check for open Q19, Q20 or Q21.**
III. High Output - Voltage Mode	a.	Check reference supply output. Should be ripple-free 8.9 Vdc. If output is high, attempt to adjust with R9. If adjustment is not possible, check for shorted Q2, Q4 or Q1. Test for open Q5 or Q3.
	b.	In voltage-mode section, check for open Q17 or shorted Q16 or Q12.
	c.	Check for shorted Q19, Q20 or Q21** in drivers and passing stages.
IV. Low Output - Current Mode	a.	Measure voltage across CR8. Should be approximately 2.7 V. Next, measure drop across R21. Should be 0.6 V less than CR8 voltage. If it is not, Q11 is defective.
	b.	In current-mode section, Q6 open, or Q10 or Q7 shorted.
V. High Output - Current Mode	a.	Measure voltage across CR8. Should be approximately 2.7 V. Next measure drop across R21. Should be 0.6 V less than CR8 voltage. If it is not, Q11 is defective.
	b.	In current-mode section, Q10 or Q7 open, or Q6 or Q9 shorted.

* Repetitive fuse blowing is indicative of shorting in either the input transformer or secondary-side rectifiers.

** When replacing Q20 or Q21, coat underside of transistor and heat sink mounting surface with a few drops of silicone oil (Silicone Fluid 200, Dow Corning Co., Midland, Michigan.)

Table 5-1. Troubleshooting Data (Sheet 1 of 2)

SYMPTOM	PROBABLE CAUSE
VI. In Voltage Mode, Output Oscillates (sawtooth)	Q5 defective
VII. In Voltage Mode, Regulation and ripple slightly outside the specification	Q13 defective
VIII. No crossover from voltage mode to current mode	Q14 or Q15 shorted.

Table 5-1. Troubleshooting Data (Sheet 2 of 2)

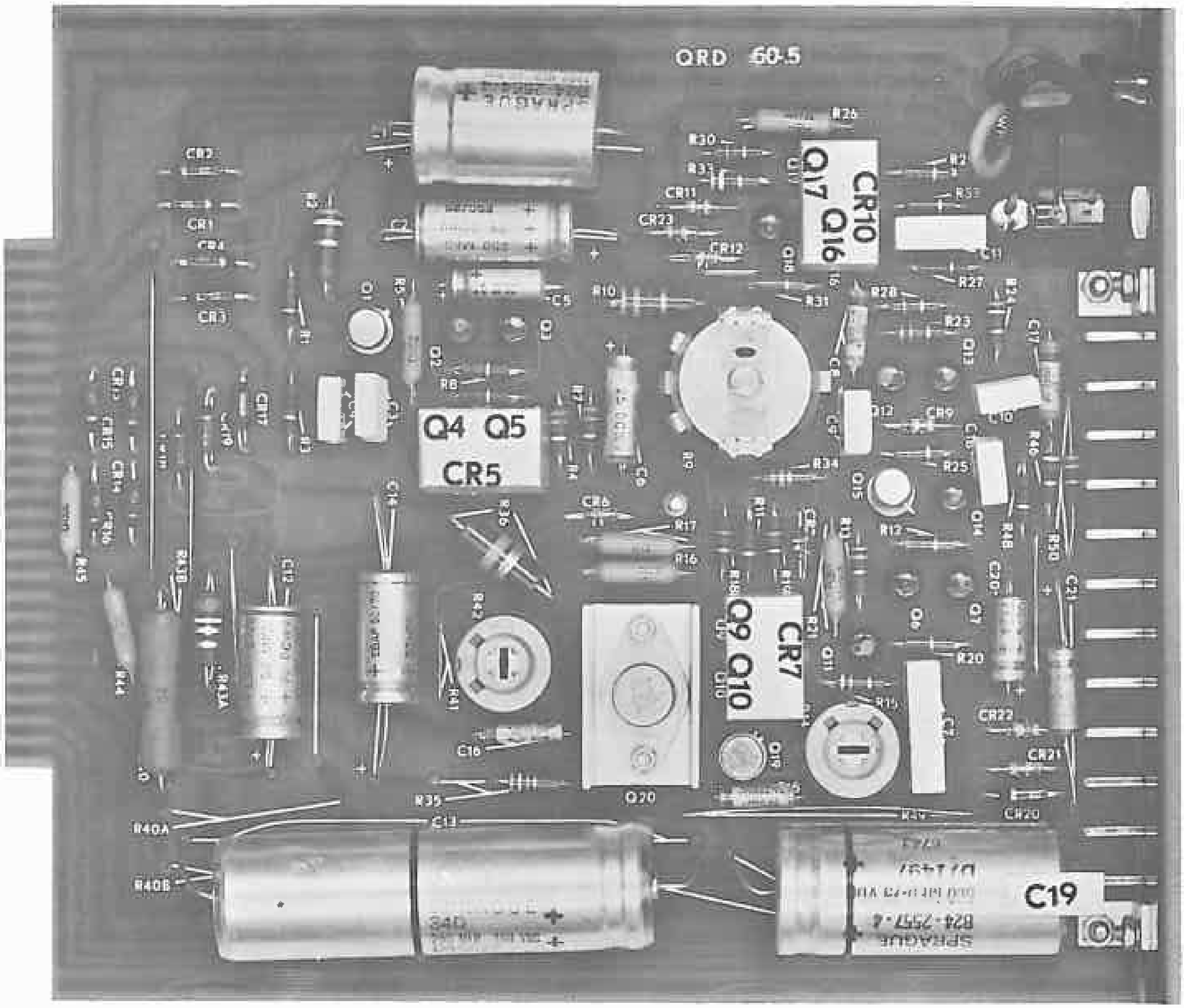


Figure 5-1. Component Board

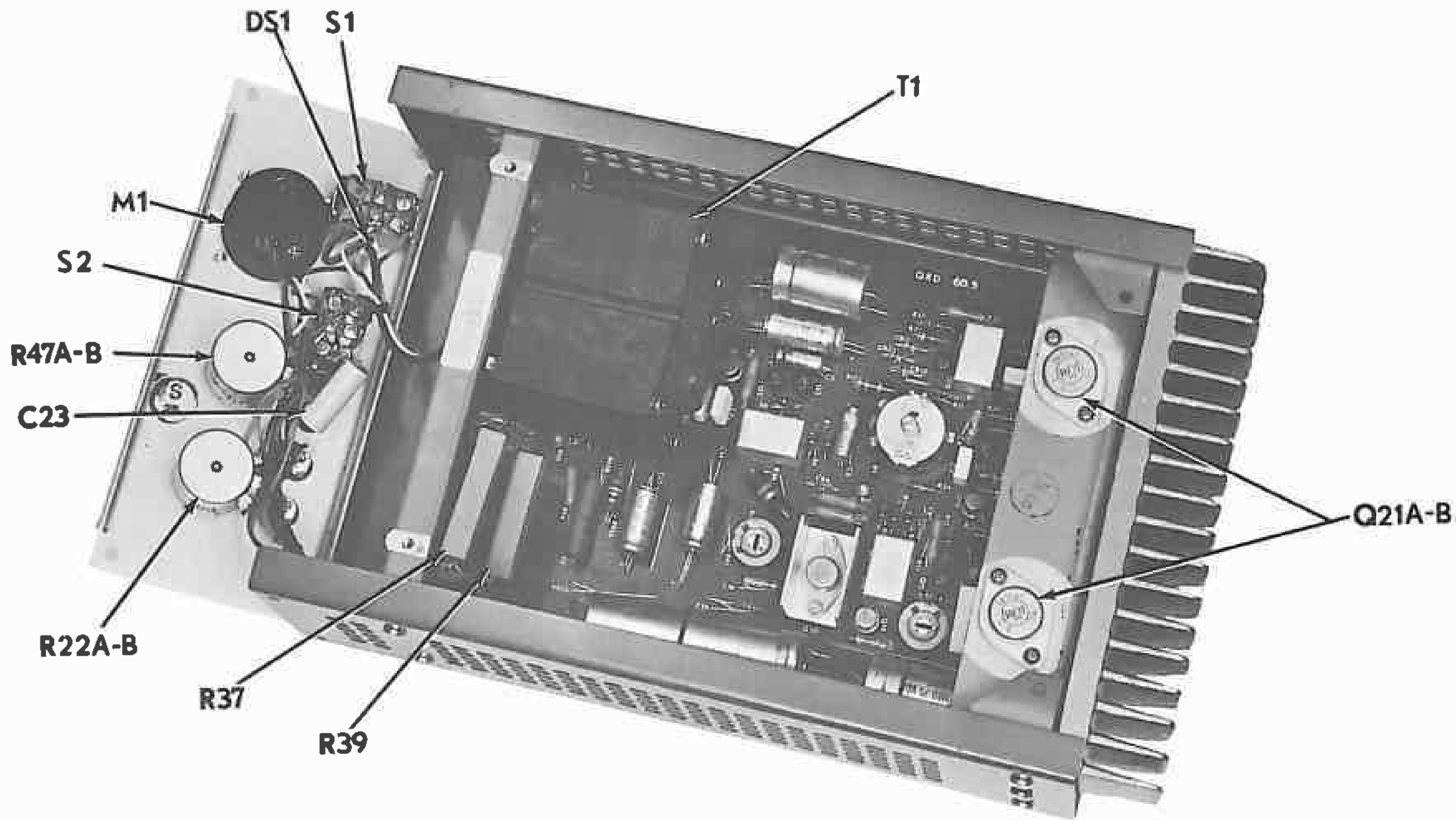
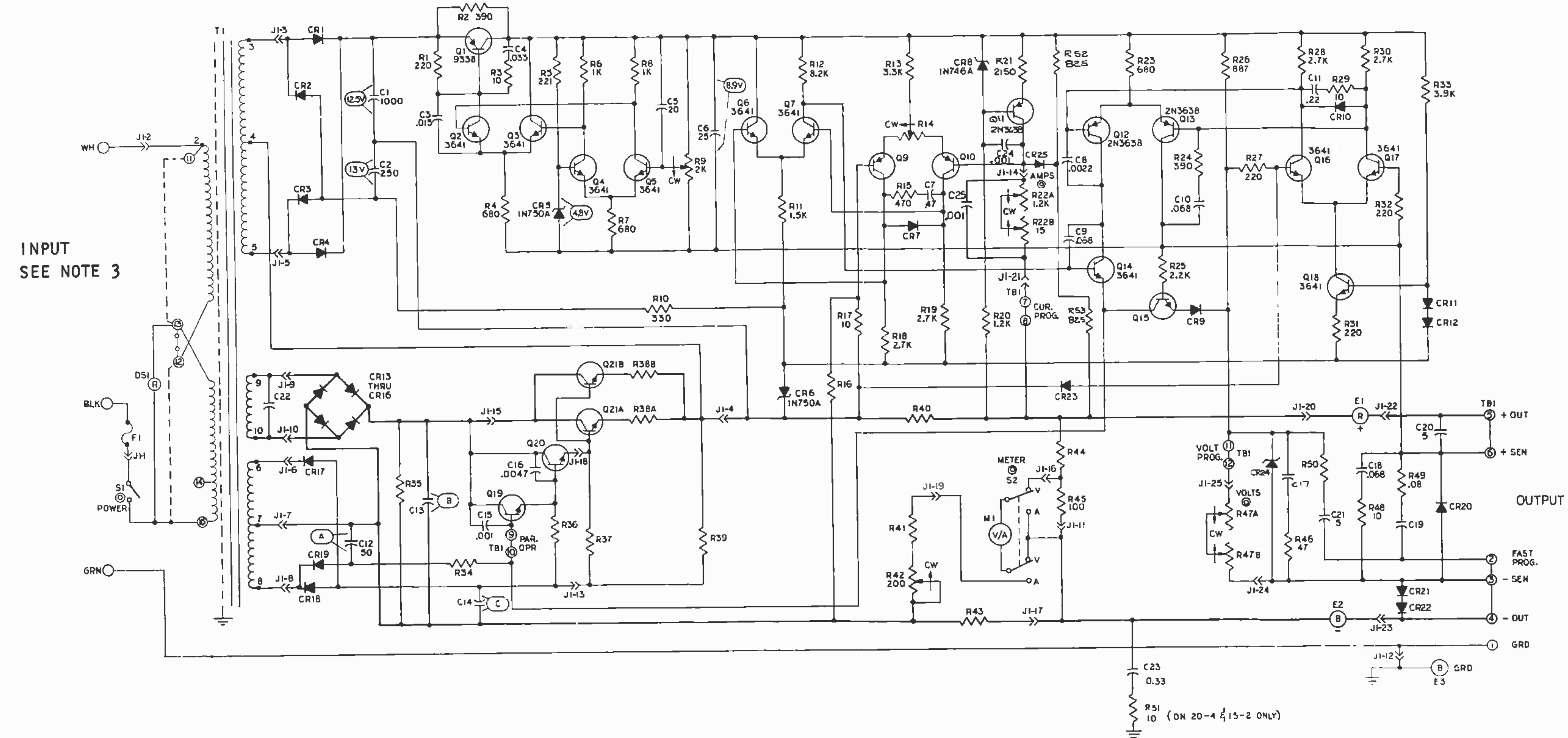
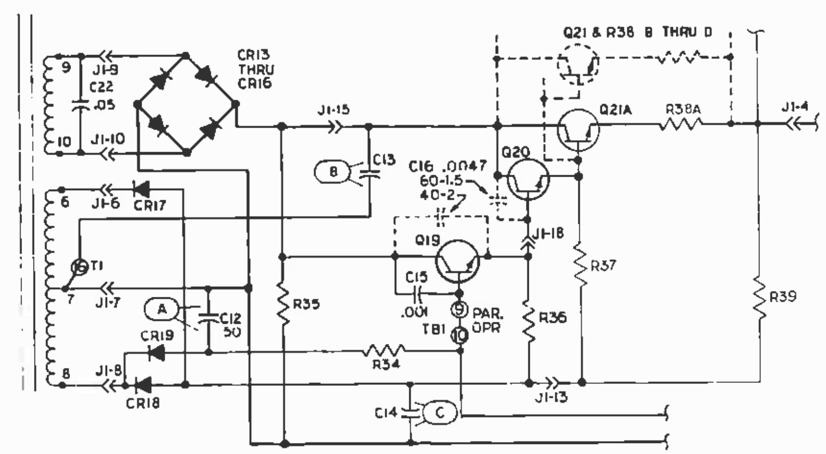
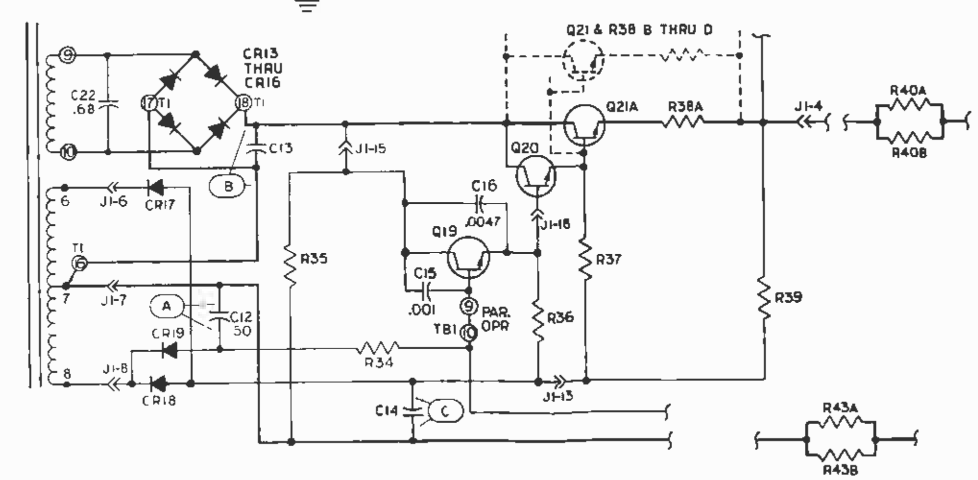


Figure 5-2. Typical Partial Disassembly





POWER CIRCUIT MODELS QRD40-2 & 60-1.5



POWER CIRCUIT MODEL QRD20-4

MODEL	VOLTAGE A	B	C
15-2	21	31	19
30-1	42	53	39
40-.75	49	71	46
60-.5	69	98	67
20-4	25	36	22
40-2	49	66	46
60-1.5	69	88	67

NOTES:
1. ALL VOLTAGES MEASURED AT NO LOAD, FULL OUTPUT VOLTAGE AND NOMINAL INPUT.
2. ◉ DENOTES FRONT-PANEL CONTROL.
3. SEE FIG. 2-3 FOR INPUT-CONNECTION DETAILS.

Figure 5-3 Schematic Diagram

		QRD MODELS						
		15-2	30-1	40-.75	60-.5	20-4	40-2	60-1.5
A	(ohms)	1500	3000	4000	6000	2000	4000	6000
B	(Vdc)	15 ± .052	30 ± .105	40 ± .140	60 ± .210	20 ± .070	40 ± .140	60 ± .210
C	(Vdc)	0.15	0.3	0.4	0.6	0.2	0.4	0.6
D	(mA)	5	3	3	3	5	5	5
E	(A)	2.0	1.0	0.75	0.5	4.0	2.0	1.5
F	(A)	2.2	1.1	0.825	0.55	4.4	2.2	1.65

Table 5-2. Calibration Data

locking compound to R9.

i. Set PWR switch to off, disconnect resistance box, and reinsert link between terminals 11 and 12.

j. Set PWR switch to ON, and rotate coarse VOLTS control fully clockwise. Voltmeter should indicate at least the maximum voltage specified in row B. Turn coarse VOLTS control to midpoint.

k. Turn fine VOLTS control from stop-to-stop. Range of output control is specified in row C, Table 5-2.

l. Set PWR switch to off, and disconnect voltmeters from output terminals.

m. Rotate coarse AMPS control fully counterclockwise, and connect a 10-mA ammeter in series with the equivalent of full load and across the output terminals.

n. Set PWR switch to ON, and adjust potentiometer R14 to obtain current between 0 and that specified in row D, Table 5-2. Apply locking compound to R14.

o. Switch test ammeter's range to one compatible with unit's rated output, and set METER switch to A position.

p. Rotate coarse AMPS control until test ammeter indicates rated output current, row E, Table 5-2.

q. Adjust potentiometer R42 until ammeter indicates current equal to that indicated on test ammeter. Apply locking compound to R42.

r. Turn fine and coarse AMPS controls fully clockwise, and increase load until unit starts current limiting, i.e., output current is held constant, while voltage varies. Current limit value should be greater than that specified in row F, Table 5-2. Set PWR switch to off, and disconnect external ammeter and load.

5-11. PERFORMANCE TESTING.

5-12. If it is desired to check unit performance following repair and calibration, refer to para 2-19, Specification Verification.

SECTION VI
REPLACEMENT PARTS LIST

6-1. GENERAL.

6-2. This section provides a replacement parts list for the QRD Series. The list is keyed to both the parts-locating photographs (Figure 5-1, and 5-2) and the schematic diagram (Figure 5-3).

6-3. TABLE HEADINGS DEFINED.

6-3.1 Circuit Symbol

This is an alpha numeric identification of the component as called out on the unit drawings.

6-3.2 Sorensen P/N

This number should be used when ordering parts directly from:

Sorensen Company
Replacement Parts Dept.
676 Island Pond Road
Manchester, N. H. 03103

6-3.3 MANUFACTURER TYPE.

This is the basic group or series under which the part is listed by a manufacturer. The coded identification of representative manufacturers is listed below, alphabetically.

AB	Allen Bradley Company
AX	Aerovox Corp.
CB	Centralab, Div. of Globe Union Inc.
CH	Cutler-Hammer Inc.
CS	Clarostat Manufacturing Co., Inc.
FC	Fairchild Semiconductor
GE	General Electric Co.
HA	Hughes Aircraft Co.
EL	Electra Manufacturing Co.
ID	Industrial Devices, Inc.
IRC	International Resistance Co.
ITT	International Telephone
LF	Littlefuse Co.
MA	Motorola Semiconductor Products
OM	Ohmite Manufacturing Co.
RCA	Radio Corporation of America
SE	Semicon, Inc.
SM	Semitech, Inc.
SP	Sprague Electric Company
SR	Sorensen Co.
ST	Solitron Devices, Incorporated
UN	Unitrode Semiconductor Corporation
WL	Ward Leonard Electric Co.

TABLE 6-1
REPLACEMENT PARTS LIST

CIRCUIT SYMBOL	QRD MODELS 15-2	20-4	30-1	40-.75	40-2	60-.5	60-1.5	DESCRIPTION	SORENSEN PART NUMBER	MANUFACTURER, TYPE
								Capacitors (µF unless noted)		
C1	X	X	X	X	X	X	X	1000, 15V	24-2554-4	SP, 45D
C2	X	X	X	X	X	X	X	200, 25V	24-2472	
C3	X	X	X	X	X	X	X	0.015, 250V	24-2015-3	SE, MMK
C4	X	X	X	X	X	X	X	0.033, 250V	24-2015-7	SE, MMK
C5	X	X	X	X	X	X	X	20, 12V	24-2276-10	SP, TE1130
C6	X	X	X	X	X	X	X	25, 25V	24-2552-1	AX, EBAP
C7	X	X	X	X	X	X	X	0.47, 250V	24-2015-21	SE, MMK
C8	X	X	X	X	X	X	X	0.0022, 200V	24-2409-3	AX, V146XR
C9	X	X	X	X	X	X	X	0.068, 200V	24-2015-11	SE, MMK
C10	X	X	X	X	X	X	X	0.068, 200V	24-2015-11	SE, MMK
C11	X	X	X	X	X	X	X	0.22, 250V	24-2015-17	SE, MMK
C12	X	X	X	X	X	X	X	50, 70V	24-2553-4	AX, EBAP
C13	X							2500, 30V	24-2449-3	SP, 34D
		X						4700, 40V	24-2460-2	SP, 32D
			X	X				1000, 75V	24-2457-3	SP, 39D
					X			1650, 75V	24-2525-6	SP, 32D
						X		250, 100V	24-2463-2	SP, 34D
							X	1200, 150V	24-2466-2	SP, 36D
C14	X	X						250, 25V	24-2552-3	AX, EBAP
			X	X				100, 50V	24-2556-2	SP, 45D
					X		X	200, 75V	24-2557-3	SP, 45D
						X		50, 70V	24-2553-4	AX, EBAP
C15	X	X	X	X	X	X	X	0.001, 200V	24-2409-1	AX, V146XR
C16	X	X	X	X	X	X	X	0.0047, 200V	24-2409-5	AX, V146XR
C17	X	X						0.0047, 200V	24-2409-5	AX, V146XR
			X					0.0033, 200V	24-2409-4	AX, V146XR
				X	X			0.0022, 200V	24-2409-3	AX, V146XR
						X	X	0.0015, 200V	24-2409-2	AX, V146XR
C18	X	X	X	X	X	X	X	0.068, 200V	24-2015-11	SE, MMK
C19	X							650, 25V	24-2555-6	SP, 45D
		X						2500, 30V	24-2449-3	SP, 34D
			X	X		X		500, 75V	24-2557-4	SP, 45D
					X			1500, 50V	24-2556-6	SP, 45D
							X	1000, 75V	24-2557-5	SP, 45D
C20	X	X	X	X	X	X	X	5, 70V	24-2553-1	AX, EBAP
C21	X	X	X	X	X	X	X	5, 70V	24-2553-1	AX, EBAP
C22	X							0.22, 200V	24-2409-15	AX, V146XR
		X						0.68, 200V	24-2409-18	AX, V146XR
			X	X	X	X	X	0.05, 600V	24-2010	CB, DD503
C23	X	X	X	X	X	X	X	0.33, 200V	24-2409-16	AX, V146XR
C24	X	X	X	X	X	X	X	0.001, 1kV	235-7421P14	RMC
C25	X	X	X	X	X	X	X	0.001, 1kV	235-7421P14	RMC
								Diodes		
CR1	X	X	X	X	X	X	X	RG-118	587565-1	UN
CR2	X	X	X	X	X	X	X	RG-118	587565-1	UN
CR3	X	X	X	X	X	X	X	RG-118	587565-1	UN
CR4	X	X	X	X	X	X	X	RG-118	587565-1	UN
CR5	X	X	X	X	X	X	X	1N750A, Zener	26-211	MA
CR6	X	X	X	X	X	X	X	1N750A, Zener	26-211	MA
CR7	X	X	X	X	X	X	X	RD 5637/9119	26-1017	SR
CR8	X	X	X	X	X	X	X	1N5226B, Zener	588101-3	MA
CR9	X	X	X	X	X	X	X	RD 5637/9119	26-1017	SR
CR10	X	X	X	X	X	X	X	RD 5637/9119	26-1017	SR
CR11	X	X	X	X	X	X	X	RD 5637/9119	26-1017	SR
CR12	X	X	X	X	X	X	X	RD 5637/9119	26-1017	SR
CR13	X		X					3S11	587566-1	SEM
		X						1N4720	26-1006-2	MA
				X		X		RG-119	587565-2	UN
					X			3A100	26-1026-4	ST
							X	3S12	587566-2	SEM

TABLE 6-1
REPLACEMENT PARTS LIST

CIRCUIT SYMBOL	QRD MODELS 15-2	20-4	30-1	40-.75	40-2	60-.5	60-1.5	DESCRIPTION	SORENSEN PART NUMBER	MANUFACTURER, TYPE
								Diodes (cont'd.)		
CR 14	X		X					3S11	587566-1	SEM
		X						1N4720	26-1006-2	MA
				X		X		RG-119	587565-2	UN
					X			3A100	26-1026-4	ST
							X	3S12	587566-2	SEM
CR15	X		X					3S11	587566-1	SEM
		X						1N4720	26-1006-2	MA
				X		X		RG-119	587565-2	UN
					X			3A100	26-1026-4	ST
							X	3S12	587566-2	SEM
CR12	X		X					3S11	587566-1	SEM
		X						1N4720	26-1006-2	MA
				X		X		RG-119	587565-2	UN
					X			3A100	26-1026-4	ST
							X	3S12	587566-2	SEM
CR17	X	X						RG-118	587565-1	UN
			X	X	X	X	X	RG-119	587565-2	UN
CR18	X	X						RG-118	587565-1	UN
			X	X	X	X	X	RG-119	587565-2	UN
CR19	X	X	X	X	X	X	X	RG-119	587565-2	UN
CR20	X	X	X	X	X	X	X	RG-118	587565-1	UN
CR21	X	X	X	X	X	X	X	RD-5637/9119	26-1017	SR
CR22	X	X	X	X	X	X	X	RD 5637/9119	26-1017	SR
CR23	X	X	X	X	X	X	X	RD 5637/9119	26-1017	SR
CR24	X							1N4747A, Zener	588102-13	MA
		X						1N4750A, Zener	588102-14	MA
			X					1N4754A, Zener	588102-15	MA
				X	X			1N4757A, Zener	588102-19	MA
						X	X	1N4761A, Zener	588102-20	MA
CR25	X	X	X	X	X	X	X	1N4148A	322-7220P1	ITT
DS1	X	X	X	X	X	X	X	Lamp Assembly	43-344	ID, 2120A1
F1	X		X	X		X		Fuse, 1.5A, 250V, 3AG	42-407	LF, 31201.5
		X			X		X	Fuse, 3.0A, 250V, 3AG	42-409	LF, 312003
XF1	X	X	X	X	X	X	X	Holder, Fuse, 3AG	42-459	LF, 342012
M1	X							Meter, V-A, 0-15V, 0-3A	94-823-4	SR
		X						Meter, V-A, 0-25V, 0-5A	94-393-9	SR
			X					Meter, V-A, 0-30V, 0-1.5A	94-823-3	SR
				X				Meter, V-A, 0-50V, 0-1A	94-823-2	SR
					X			Meter, V-A, 0-50V, 0-2.5A	94-393-10	SR
						X		Meter, V-A, 0-60V, 0-.6A	94-823-1	SR
							X	Meter, V-A, 0-80V, 0-2A	94-393-8	SR
								Transistors		
Q1	X	X	X	X	X	X	X	RT-9338	18-146	SR
Q2	X	X	X	X	X	X	X	PN3641	18-144	FC
Q3	X	X	X	X	X	X	X	PN3641	18-144	FC
Q4	X	X	X	X	X	X	X	PN3641	18-144	FC
Q5	X	X	X	X	X	X	X	PN3641	18-144	FC
Q6	X	X	X	X	X	X	X	PN3641	18-144	FC
Q7	X	X	X	X	X	X	X	PN3641	18-144	FC
Q9 & 10	X	X	X	X	X	X	X	Transistor, PNP, Dual	18-176	SR
Q11	X	X	X	X	X	X	X	2N3638	18-143	FC
Q12	X	X	X	X	X	X	X	2N3638	18-143	FC
Q13	X	X	X	X	X	X	X	2N3638	18-143	FC
Q14	X	X	X	X	X	X	X	PN3641	18-144	FC
Q15	X	X						2N697	18-115	GE
			X					2N3019	386-7316P1	
				X	X			2N697 (Selected)	18-161-3	SR
						X	X	40321	18-165	RCA

TABLE 6-1
REPLACEMENT PARTS LIST

CIRCUIT SYMBOL	QRD MODELS 15-2	20-4	30-1	40-.75	40-2	60-.5	60-1.5	DESCRIPTION	SORENSEN PART NUMBER	MANUFACTURER, TYPE
								Transistors (Cont'd.)		
Q16	X	X	X	X	X	X	X	PN3641	18-144	FC
Q17	X	X	X	X	X	X	X	PN3641	18-144	FC
Q18	X	X	X	X	X	X	X	PN3641	18-144	FC
Q19	X	X						2N697	18-115	GE
			X					2N3019	386-7316P1	
				X	X			2N697 (Selected)	18-161-3	SR
						X	X	40321	18-165	RCA
Q20	X	X	X					2N3441	386-7249P5	
				X	X			2N3441	386-7249P5	
						X	X	40313	18-164	RCA
Q21	X	X	X					2N3055	18-151	RCA
				X	X			2N3055 (Selected)	18-178-1	SR
						X	X	2N3442	18-163	RCA
								Resistors (ohms, 1/2W, ±10% unless noted)		
R1	X	X	X	X	X	X	X	220	280-1145P50	AB, EB
R2	X	X	X	X	X	X	X	390, 1W	280-1180P59	AB, GB
R3	X	X	X	X	X	X	X	10	280-1145P2	AB, EB
R4	X	X	X	X	X	X	X	680	280-1145P68	AB, EB
R5	X	X	X	X	X	X	X	221, 1%	28-1188	IRC, CEC-TO
R6	X	X	X	X	X	X	X	1K	280-1145P74	AB, EB
R7	X	X	X	X	X	X	X	680	280-1145P68	AB, EB
R8	X	X	X	X	X	X	X	1K	280-1145P74	AB, EB
R9	X	X	X	X	X	X	X	2K, 1W, 25T	167456-8	Bourns 3252-W
R10	X	X	X	X	X	X	X	330, 1W	280-1180P56	AB, GB
R11	X	X	X	X	X	X	X	1.5K	280-1145P80	AB, EB
R12	X	X	X	X	X	X	X	8.2K	27-1163	AB, EB
R13	X	X	X	X	X	X	X	3.3K	280-1145P91	AB, EB
R14	X	X			X			50, 1W, 25T	167456-3	Bourns 3252-W
			X	X		X	X	100, 2W, POT.	29-523	CS, 39
R15	X	X	X	X	X	X	X	470	280-1145P62	AB, EB
R16	X		X			X		150K, 1%	28-1264	IRC, CEC-TO
		X			X			499K, 1%	28-1266	IRC, CEC-TO
				X				187K, 1%	28-1265	IRC, CEC-TO
							X	604K, 1%	28-1267	IRC, CEC-TO
R17	X	X	X	X	X	X	X	10, 1%	28-1257	IRC, CEC-TO
R18	X	X	X	X	X	X	X	2.7K	280-1145P89	AB, EB
R19	X	X	X	X	X	X	X	2.7K	280-1145P89	AB, EB
R20	X	X	X	X	X	X	X	1.2K	280-1145P77	AB, EB
R21	X	X	X	X	X	X	X	2.15K, 1%	28-1249	IRC, CEC-TO
R22	X	X	X	X	X	X	X	1.2K/15 2N, DUAL POT.	29-521	CS, 43
R23	X	X	X	X	X	X	X	680	280-1145P68	AB, EB
R24	X	X	X	X	X	X	X	390	280-1145P59	AB, EB
R25	X	X	X	X	X	X	X	2.2K	280-1145P86	AB, EB
R26	X	X	X	X	X	X	X	887, 1%	28-1216	IRC, CEC-TO
R27	X	X	X	X	X	X	X	220	280-1145P50	AB, EB
R28	X	X	X	X	X	X	X	2.7K	280-1145P89	AB, EB
R29	X	X	X	X	X	X	X	10	280-1145P2	AB, EB
R30	X	X	X	X	X	X	X	2.7K	280-1145P89	AB, EB
R31	X	X	X	X	X	X	X	220	280-1145P50	AB, EB
R32	X	X	X	X	X	X	X	220	280-1145P50	AB, EB
R33	X	X	X	X	X	X	X	3.9K	280-1145P95	AB, EB
R34	X							15K	280-1145P116	AB, EB
		X						18K	280-1145P119	AB, EB
			X					33K	280-1145P128	AB, EB
				X	X			39K	280-1145P131	AB, EB
						X	X	56K	280-1145P137	AB, EB

TABLE 6-1
REPLACEMENT PARTS LIST

CIRCUIT SYMBOL	ORD MODELS 15-2	20-4	30-1	40-.75	40-2	60-.5	60-1.5	DESCRIPTION	SORENSEN PART NUMBER	MANUFACTURER, TYPE
								Resistors (Cont'd.)		
R35	X							3.9	280-1145P95	AB, EB
		X						1.5K, 5W	27-499-10	CS, C5GL
			X					6.8K	280-1145P104	AB, EB
				X				22K	280-1145P122	AB, EB
					X			5.1K, 2W	280-1147P99	AB, HB
						X		39K	280-1145P131	AB, EB
							X	8.2K, 2W	27-392	AB, HB
R36	X	X						3.3K, 1W, 5%	280-1180P91	AB, GB
			X					6.8K, 1W	280-1180P104	AB, GB
				X	X			8.2K, 2W	27-392	AB, HB
						X	X	12K, 2W	280-1147P113	AB, HB
R37	X							820, 2W	27-388	AB, HB
		X						450, 5W	27-466	CS, C5GL
			X					1.5K, 5W	27-499-10	CS, C5GL
				X		X		2.5K, 10W	27-599-8	IRC, C10GL
					X			1K, 10W	27-599-9	IRC, C10GL
							X	1.5K, 25W	27-719	WL, 25F1500
R38	2	4						1, 2W	28-1253	IRC, BWH
			2		4			2, 2W	28-1254	IRC, BWH
				2			4	3, 2W	28-1255	IRC, 3WH
						2		3.9, 2W	28-1256	IRC, BWH
R39	X							300, 5W	27-457	CS, C5GL
		X			X			400, 25W	27-717	WL, 25F400
			X					600, 10W	27-599-10	IRC, C10GL
				X				1K, 10W	27-599-9	IRC, C10GL
						X		2.5K, 10W	27-599-8	IRC, C10GL
							X	1K, 25W	27-727	WL, 25F1000
R40	X	2			X			0.5, 7W	28-1268-1	SP, 226E
			X					1, 7W	28-1268-3	SP, 226E
				X				1.33, 7W	28-1268-4	SP, 226E
						X		2, 7W	28-1268-5	SP, 226E
							X	0.67, 7W	28-1268-2	SP, 226E
R41	X		X					180	280-1145P47	AB, EB
		X			X			430	280-1145P60	AB, EB
							X	270	280-1145P53	AB, EB
R42	X	X	X	X	X	X	X	200, 1/2W, Var.	167877-11	Bourns 3386-P
R43	X							0.12, 3W	27-397-3	WL, 3X
		2	X	X	X	X	X	0.24, 2W	28-1252	IRC, BWC
R44	X							7.5K, 1%	28-1258	IRC, CEC-TO
			X					15K, 1%	28-1260	IRC, CEC-TO
				X	X			24.9K, 1%	28-1261	IRC, CEC-TO
						X		30.1K, 1%	28-1262	IRC, CEC-TO
							X	40.2K, 1%	28-1263	IRC, CEC-TO
		X						12.4K, 1%	28-1259	IRC, CEC-TO
R45	X	X	X	X	X	X	X	110, 2%	586250-28	
R46	X	X	X	X	X	X	X	47, 1/4W	280-1171P26	AB, CB
R47	X							1.5K/15, 2W, DUAL POT.	29-401	CS, 43
		X						2K/20, 2W, DUAL POT.	29-402	CS, 43
			X					3K/30, 2W, DUAL POT.	29-403	CS, 43
				X	X			4K/40, 2W, DUAL POT.	29-404	CS, 43
						X	X	6K/60, 2W, DUAL POT.	29-520	CS, 43
R48	X	X	X	X	X	X	X	10, 1/4W	280-1171P2	AB, CB
R49	X	X	X	X	X	X	X	0.08, #21 CUPRON	21-033	SR
R50	X	X	X	X		X		3.3K	280-1145P91	AB, EB
					X		X	6.8K	280-1145P104	AB, EB
R51	X	X						10	280-1145P2	AB, EB
R52	X	X	X	X	X	X	X	825, 1/8W, 1%	586250-70	EL, MF4
R53	X	X	X	X	X	X	X	82.5, 1/8W, 1%	586250-22	EL, MF4
R54	X	X	X	X	X	X	X	1.1K, 2%	585326-117	
R55	X	X	X	X	X	X	X	1.1K, 2%	585326-117	

TABLE 6-1
REPLACEMENT PARTS LIST

CIRCUIT SYMBOL	QRD MODELS 15-2	20-4	30-1	40-.75	40-2	60-.5	60-1.5	DESCRIPTION	SORENSEN PART NUMBER	MANUFACTURER, TYPE
S1	x	x	x	x	x	x	x	Switch, DPST, 10A, 250 Vac	45-112	CH, 7561K5
S2	x	x	x	x	x	x	x	Switch, DPDT, 10A, 250 Vac	45-121	CH, 7565K6
T1	x							Transformer	126-2998	SR
		x							126-3002	SR
			x						126-2999	SR
				x					126-3000	SR
					x				126-3003	SR
						x			126-3001	SR
							x		126-3004	SR
								<u>Miscellaneous</u>		
	x	x	x	x	x	x	x	Schematic	E200-4088	SR
	x							Panel, Front	73-2216-4	SR
		x							73-2217-3	SR
			x						73-2216-3	SR
				x					73-2216-2	SR
					x				73-2217-2	SR
						x			73-2216-1	SR
							x		73-2217-1	SR
	x		x	x		x		Case Side (2 Req'd)	73-2209	SR
		x			x		x		73-2210	SR
	x	x	x	x	x	x	x	Cover, Top	73-2211	SR
	x	x	x	x	x	x	x	Cover, Bottom	73-2211	SR
	x	x	x	x	x	x	x	Knob (2 Req'd)	42-278	
	x							PCB Ass'y	190-3801-1	SR
		x							190-3801-5	SR
			x						190-3801-2	SR
				x					190-3801-3	SR
					x				190-3801-6	SR
						x			190-3801-4	SR
							x		190-3801-7	SR

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