Instruction Manual
for

Model 828
AC/DC V-A Source

Warranty

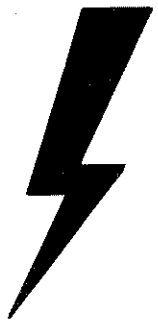
All CLARKE-HESS instruments are warranted against defects in materials and workmanship. This warranty applies for one year from the date of delivery of the instruments. The CLARKE-HESS Communication Research Corp. will repair or replace instruments that prove to be defective during the warranty period. For such repair or replacement the instrument must be returned to CLARKE-HESS and, in our opinion, the instrument must not have been subjected to unreasonable usage or to internal reworking. No other warranty is expressed or implied.

CLARKE-HESS assumes no liability for secondary damages or charges.

CAUTION

FOR YOUR SAFETY

THE INSTALLATION, OPERATION AND MAINTENANCE OF THIS EQUIPMENT SHOULD BE PERFORMED BY QUALIFIED PERSONS ONLY.



WARNING:

The Equipment Herein Described Contains High Voltage

Exercise due care during operation and servicing.
Read safety summary on reverse of this page.

SAFETY SUMMARY

The following safety precautions must be observed at all times during operation, service, and repair of this product. Failure to comply with these precautions, or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the product. CLARKE-HESS assumes no liabality for failure to comply with these requirements.

GROUND THE CHASSIS

To minimize shock hazard and to allow the equipment to perform optimally, the chassis and cabinet must be connected to an electrical ground. All equipment is provided with a ground terminal on the rear, or with a three-connector ac power cable. The ground terminal must be connected to an electrical ground by suitable cabling. For its location refer to the wiring diagram for the chassis or cabinet. The power cable must be plugged into an approved three-contact electrical outlet.

DO NOT OPERATE IN AN EXPLOSIVE ATMOSPHERE

Do not operate the product in the presence of flammable gases or fumes. Operation of any electrical equipment in such an environment constitutes a definite safety hazard.

DO NOT OPERATE IN WET OR DAMP AREAS

Do not operate the product in wet or damp areas. Operation of any electrical equipment in such an environment constitutes a definite safety hazard.

KEEP AWAY FROM LIVE CIRCUITS

Operating personnel must not remove covers. Replacement of components and internal adjustments must be made by qualified maintenance persons. Disconnect power cable when replacing components. Under certain conditions, dangerous voltages may exist even with the power cable removed. To avoid injuries always disconnect power and discharge circuits by grounding before touching them.

DO NOT SERVICE OR ADJUST ALONE

Do not attempt internal service or adjustment unless another person capable of rendering first aid and resuscitation is present.

DO NOT SUBSTITUTE PARTS OR MODIFY EQUIPMENT

Because of the danger of introducing additional hazards, do not install substitute parts or perform an unauthorized modification to the equipment. The product may be returned to RFL for service and repair to ensure that safety features are maintained.

DANGEROUS-PROCEDURE WARNINGS

Throughout this manual, warnings identify potentially dangerous procedures. Instructions contained therein must be followed.

Table of Contents

List of Illustrations

List of Tables

DESCRIPTION

The Model 828 AC/DC V-A Source (figure 1) is a compact, self-regulating voltage and current source, capable of meeting the calibration needs of most measuring instruments and suitable for use in the laboratory, on the production line, or in the field.

Three sets of interlocking pushbutton switches permit output mode and range selection. Mode selection provides either dc output or one of three internally generated ac frequencies. If desired, an external 50-440 Hz signal source may also be used to determine the output frequency. There are four voltage ranges and five current ranges, and the output can be set to a percentage of the selected range value by a set of thumbwheel switches.

The marked value of all ranges can be exceeded by 100%, except the 1000V range which is limited to 1100V maximum, and the 10A range, which is limited to 5 amperes maximum (7 amperes on special order).

Two pushbutton switches on the front panel apply and remove the output signal from the output terminals. Pressing the OPERATE switch applies the output signal to the terminals and lights a green indicator lamp; pressing the DE-ENERGIZE switch removes the signal and lights a red indicator lamp. The red lamp will also light whenever the internal protection circuitry automatically removes the output signal from the front panel terminals.

A three-position toggle switch allows selection between normal, run up, or percent deviation operation of the Model 828. In the NORMAL position, the output present at the output terminals is exactly the value set by the thumbwheel switches and the range selector. In the RUN UP position, a rotary control permits the operator to vary the output from zero to 102% of the value set by the thumbwheel switches; this allows analog meters to be examined for frictional problems in their movements. In the % DEV position, a calibrated control varies the output between 98 and 102% of the value set by the thumbwheel switches and provides a direct reading of the percent error of the device under test.

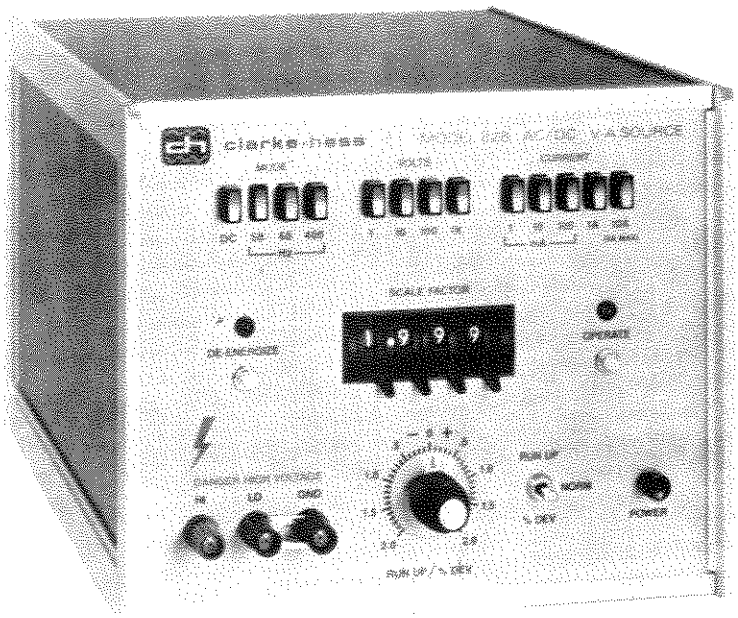


Figure 1. Model 828 AC/DC V-A Source.

SPECIFICATIONS

NOTE

The Model 828 AC/DC V-A Source may be operated between 0°C and +50°C (+32°F to +122°F). All accuracy specifications apply when operated between +18°C and +28°C (+28°F and +82°F).

OUTPUT SPECIFICATIONS

Voltage Source:
Full Scale Ranges: Four; 1, 10, 100, and 1000 V.
Overrange Limits: 1100 volts on 1000 V range; 200% of full-scale value on all other ranges.
Stability: ±0.05%/8 hours; within rated accuracy for 6 months.
Voltage Burden: 5 VA on 1 V range; 10 VA on all other ranges.

Current Source:
Full Scale Ranges: Five: 1, 10, and 100 mA; 1 and 10 A
Overrange Limits: 5 amps on 10A range; 200% of full-scale value on all other ranges.
Compliance: 1 volt on 10 A range; 5 volts on all other ranges.

ACCURACY:

Output Mode	Accuracy
Dc Voltage	±(0.05% of setting + 0.05% of range)
Ac Voltage	±(0.05% of setting + 0.1% of range)
Current	±(0.1% of setting + 0.1% of range)

GENERAL:

Total Harmonic Distortion: Less than 0.3% at full-scale.

Ripple (Dc Operation Only): Less than 1% rms at full-scale with 1 megohm load.

Internal Frequency Source:
Frequencies: 50, 60, and 400 Hz.
Accuracy:
50 and 400 Hz: ±1%
50 Hz: ±0.5%

External Frequency Input:
Frequency Limits: 50 to 440 Hz.
Input Voltage: 3 volts maximum.

% Deviation Control:
Range: ±2% of setting, adjustable via front panel control.
Accuracy: ±1/2 division (0.05%).

Warm-Up Time: Less than 3 minutes at room temperature.

Operating Temperature: +18°C to+28°C (+65°F to+82°F) for rated accuracy; the Model 828 may be operated from 0°C to +18°C (+32°F to +65°F) and +28°C and +50°C (+82°F to +122°F) at derated specifications.

Input Power Requirements:
Standard:
115 V Operation: 104 to 127 volts, 47 to 63 Hz, 45 watts
230 V Operation: 207 to 253 volts, 47 to 63 Hz, 45 watts
Optional:
100 V Operation: 90 to 110 volts, 47 to 63 Hz, 45 watts
200 V Operation: 180 to 220 volts, 47 to 63 Hz, 45 watts

Dimensions:
Height: 7½ inches (19 cm)
Width: 8½ inches (21.6 cm)
Depth: 13 inches (33 cm)

Weight: 25 lbs (11.3 kg)

PRINCIPLES OF OPERATION

The organization of the circuits and the principles of operation of the Model 828 are outlined in its block diagram (fig. 2).

At the left of figure 2, a system clock generates a signal whose frequency is approximately 350 kHz, although the exact value of frequency is not consequential in determining the level of output signal. The clock signal is counted in a 3½-decade counter, the output of which immediately sets the output of the flip-flop following it whenever the counter makes a transition from 1999 to 0000. Thus, the output of the counter is of a constant frequency of about 175 Hz.

The desired level of output signal, within the full-scale range, is set by the operator who uses the 3½-decade thumbwheel switch on the front panel, and the setting of that switch adjusts a digital comparator which tests for coincidence between the target count established by the thumbwheel switch and the output of the counter. When coincidence is reached, a pulse from the comparator resets the flip-flop so that the output pulse of the latter has a duty cycle proportional to the setting of the thumbwheel switch. This output is amplified from the 0-5 volt level of the digital section to the 0-30-volt range required by a variable current source.

The current source is derived from a precision zener diode and referenced to the 30-volt regulated supply in the instrument. This current is modulated according to the duty cycle established in the digital section, so that the current is either summed in a following integrator, or diverted to ground.

The integrator is a capacitor whose value has been increased by electronic means. It is charged by the command current described in the foregoing, and it is discharged by a current sink of value proportional to the required output voltage or current. When the charging and discharging currents are equal, equilibrium is established. The voltage across the integrating capacitor is first buffered and then used to pro-

duce an electronic gain control by controlling the output of an oscillator through a light-modulated resistive attenuator.

The state-variable oscillator provides either 50, 60, or 400 Hz for ac output signals. A switch selects a squarewave signal of approximately 175 Hz when dc output is required, and the same switch provides for selection of an ac source of different frequency, when needed.

The controlled output of the optical attenuator provides the input signal to a wideband preamplifier and power amplifier. These drive the output transformer which has several secondary windings. Note that the turn-on delay circuit serves to interface the power amplifier to the output transformer resulting in reduction of turn-on/off transients. The range-selecting pushbuttons select appropriate voltage attenuators or current shunts to adjust the current sink at the integrator so that the output signal is properly scaled. The standardized, full-scale signal to the differential amplifier and current sink is 0.25 volt for either full-scale current or full-scale voltage (when the thumbwheel switch is set to 1.000).

The runup control varies the current supplied by the "constant-current" source over the full current range, according to its setting, and the percent-deviation control varies the same current by a small, but controlled amount.

The functions of the instrument are completed with circuits for detecting excessive compliance voltage in the current mode, excessive load current in the voltage mode, and for manual control of these factors.

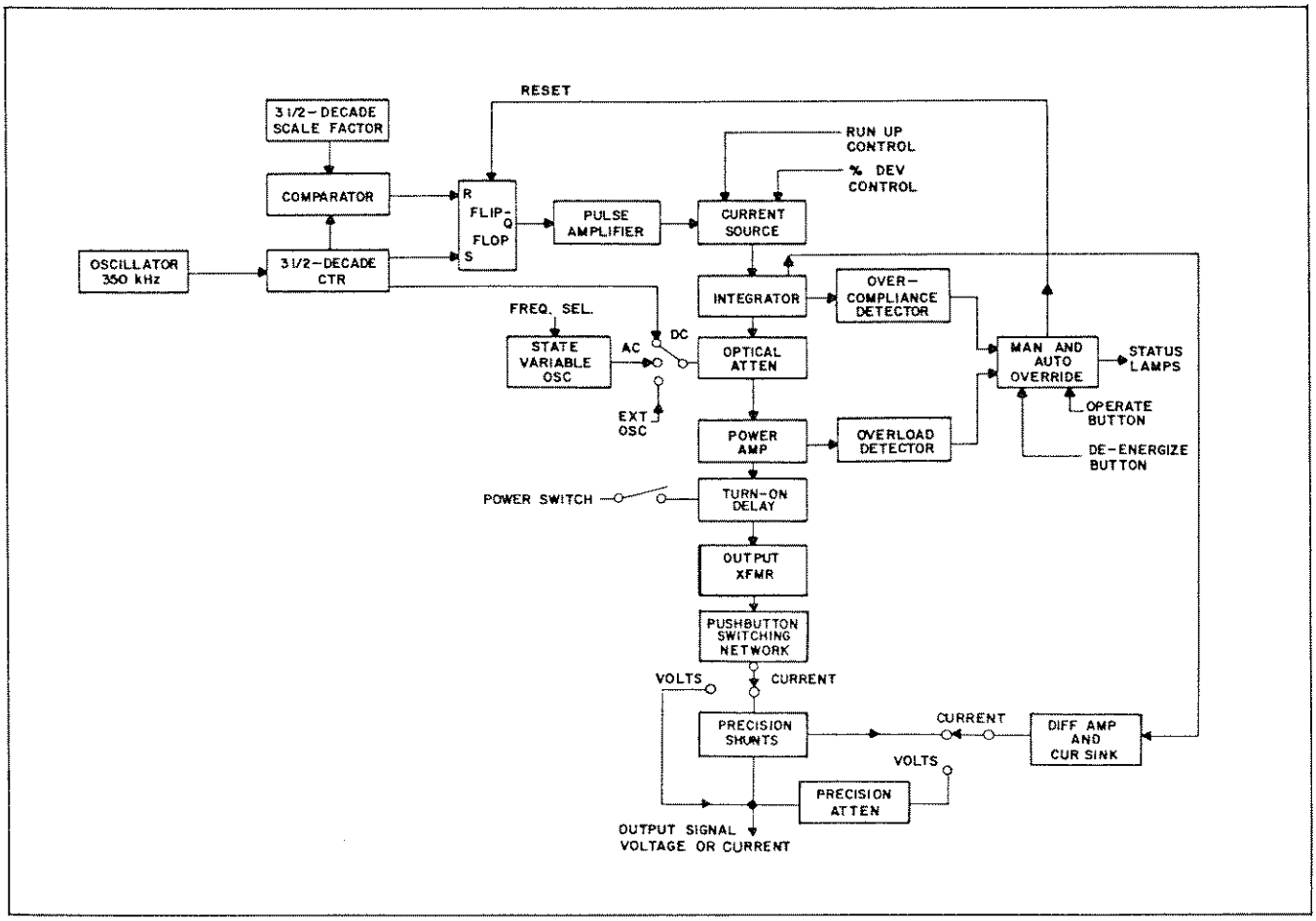


Figure 2. Block diagram of circuit, Model 828.

OPERATING INSTRUCTIONS

CONTROLS AND INDICATORS

Front Panel

All front panel controls and indicators are shown in figure 3 and described in Table 1.

Table 1
Front Panel Controls and Indicators

Item Number (fig. 3)	Name	Function
1	MODE switches	Allows operator to set the output signal to dc, 50 Hz, 60 Hz, or 400 Hz.
2	VOLTAGE switches	Allows operator to select desired voltage range.
3	CURRENT switches	Allows operator to select desired current range.
4	SCALE FACTOR switches	Allows operator to set the output signal level to a percentage of the range selected by the VOLTAGE and CURRENT switches, within the limits established for that range.
5	OPERATE switch and indicator	Applies output signal to output terminals; OPERATE indicator lights when signal is applied.
6	POWER switch	Applies ac input voltage to Model 828.
7	RUN UP/NORM/% DEV switch	Selects Model 828 operating mode: **RUN UP** - RUN UP control is enabled. **% DEV** - % DEV control is enabled. **NORM** - RUN UP and % DEV controls are disabled; output signal will be the value set by range and thumbwheel switches.
8	RUN UP control	Allows operator to vary output signal from zero to 102% of value set by range and thumbwheel switches.
9	% DEV control	Allows operator to vary output signal from 98 to 102% of the value set by range and thumbwheel switches.
10	Output terminals	Binding posts for connection of output signal to device under test.
11	DE-ENERGIZE switch and indicator	Removes output signal from front panel output terminals; DE-ENERGIZE indicator lights when signal is applied.

Rear Panel

All rear panel controls and indicators are shown in figure 4 and described in Table 2.

Table 2
Rear Panel Controls and Indicators

Item Number (fig. 4)	Name	Function
1	EXTERNAL CONNECTIONS connector	Permits an external frequency source to be connected to the Model 828.
2	Access door (not on units with Serial Numbers below 1140)	Allows access to input fuse and input voltage selector switch.
3	EXTERNAL INPUT/ NORMAL switch	Allows operator to select between internal or external frequency source.
4	Ac input receptacle	Mating connector for power cordset.

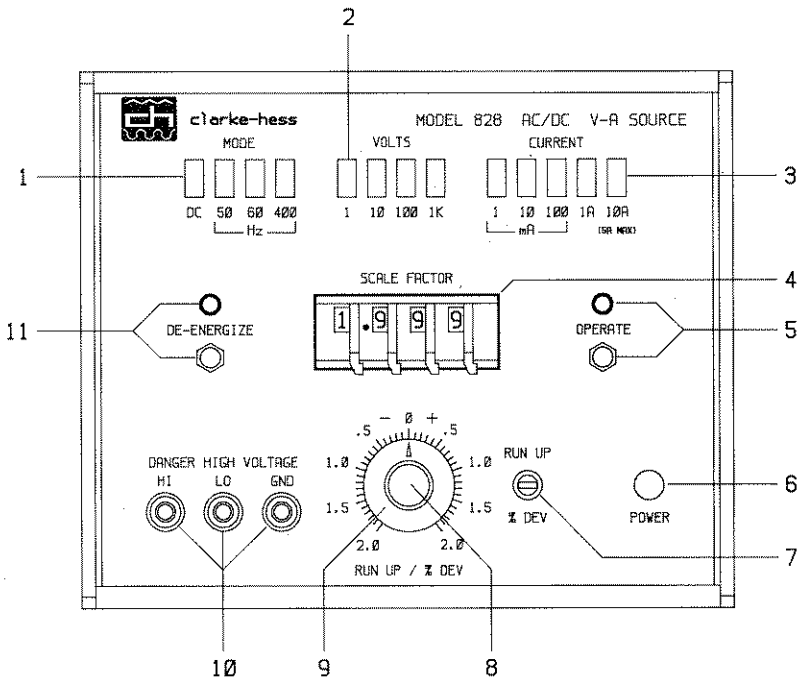


Figure 3. Front-panel controls of Model 828.

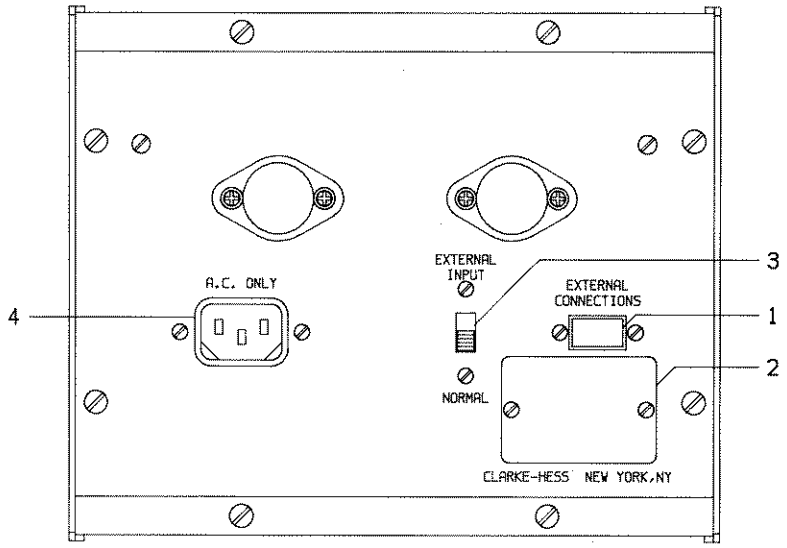


Figure 4. Back-panel connections and controls, Model 828.

INITIAL SET UP

General

The initial set-up procedure prepares the Model 828 for operation, and should be performed upon receipt of the unit. Refer to figures 3 and 4 to locate the controls and indicators described in the procedure.

CAUTION

Before starting the initial set-up procedure, check the rear panel to determine the supply voltage the Model 828 is set to accept. One of the four boxes below the ac input connector will be marked to indicate the supply voltage. If the indicated voltage does not match the supply voltage the unit will be connected to, the Voltage Selection procedure must be performed. Damage to the unit may result if operated at a supply voltage that does not match the indicated voltage.

Voltage Selection

To change the input supply voltage setting to match the available power, proceed as follows:

WARNING

TO AVOID ELECTRICAL SHOCK, MAKE SURE INPUT POWER CORD IS DISCONNECTED FROM THE REAR PANEL CONNECTOR BEFORE PERFORMING VOLTAGE SELECTION PROCEDURE.

1 Disconnect power cordset form rear panel ac input connector.

2. Note unit serial number, as indicated on rear panel.

   For units with serial numbers up to 1139, perform steps 3 and 4.

   For units with serial numbers 1140 and above, go to step 5.

3. Remove top and bottom covers by removing four screws securing covers to rear panel and sliding covers back and off.

4. If unit chassis has solid left side panel, remove as follows:
   a. Remove two screws securing left side panel to rear panel.
   b. Remove two screws securing left side panel to trim rails at front of chassis.
   c. Lift left side panel out of position.

   Once side panel is lifted out of position, go to step 6.

5. Using flat screwdriver, remove two screws securing access door to rear panel. Lift panel out of place.

6. Compare setting of voltage selection switch S22 to the available supply voltage. For voltages between 90 and 125 Vac, place S22 in the 115V position. If the Model 828 will be operated at voltages between 180 and 250 Vac, place S22 in the 230V position.

CAUTION

Replacement fuses must be slow-blow types of the proper current rating and rated for 250 Vac.

7. Check the current rating of input fuse F1. If S22 has been placed in the 115V position, F1 must be rate for 1 ampere; if S22 is in the 230V position, F1 must be rated for 0.5 amperes. Ordering information for replacement fuses can be found in Table 5, Replaceable Parts.

8. If the Model 828 was set at the factory for operation on input power ranges of either 90 to 110 or 180 to 220 Vac, connections were made to terminals 1, 2, 4, and 5 of power transformer T2; if the Model 828 was set for operation at 105 to 120 or 210 to 250 Vac, connections were made to terminals 1, 3, 4, and 6. (See figure 5.)

   If the connections to power transformer T2 must be changed, perform steps 8a through 8e.

   If connections do not have to be changed, go to step 9.

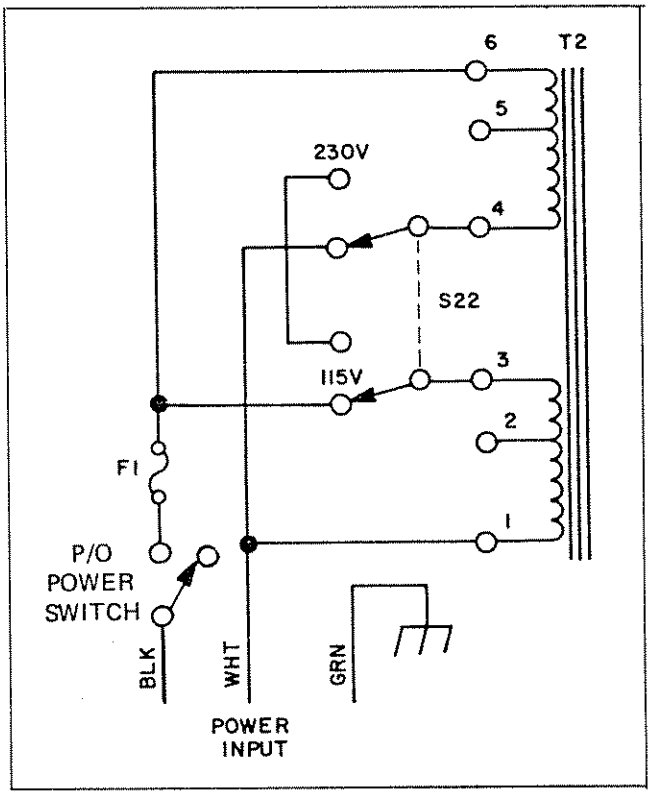


Figure 5. Simplified schematic of primary-power connections, Model 828.

NOTE

The top and bottom covers of the unit must be removed, along with the left side panel of the chassis (if solid) before connections to power transformer T2 can be changed. If covers and panel are still in place, perform steps 3 and 4 above before proceeding.

a. Pull connector J13 out of connector P13 on the lower circuit board.

b. Remove the four screws and nuts securing T2 to the chassis and slide T2 out the side of the case.

c. Change the wiring of T2 as required.

d. Slide T2 back into position and secure with four screws and nuts.

e. Insert connector J13 into connector P13.

9 If solid left side panel was removed from chassis, place in position and secure with four screws (two to rear panel and one to each trim rail at front of chassis).

10. If top and bottom covers were removed from unit, place into position and secure with two screws to rear panel.
Once covers are in place, go to step 12.

11. If access door on rear panel was removed, place in position on rear panel. Using flat screwdriver, install two screws to hold access door in place.

12. Connect power cordset to ac input connector on rear panel.

External Connections

EXTERNAL CONNECTIONS connector J14 on the rear panel is provided for connecting external oscillators and accessory items to the Model 828. J14 is a 9-pin D-Subminiature female connector with the following terminal assignments:

External Oscillator - Pin 9 (high to pin 5 (common)

Accessory Items - Pin 1 to pin 6

CAUTION

External signal inputs must be between 50 and 440 Hz, at an amplitude of 2.5 to 3.5 Vrms. Damage to the unit may result if these limits are exceeded.

NOTE

Pins 2, 3, 4, 7, and 8 of J14 are spares; do not make connections to these pins.

OPERATION

CAUTION

The Model 828 operates at high voltages, and high voltages are present at its output terminals in certain operating modes.

Shock hazard can be minimized during operation by pressing the DE-ENERGIZE button on the front panel whenever making connections or making adjustments to either the Model 828 or the item under test.

Warm-Up

The Model 828 should be allowed to warm up before each use. This will stabilize all internal circuitry, producing accurate test results. Refer to figures 3 and 4 for the location of all controls and indicators described in the procedure.

NOTE

The Model 828 is not functioning properly if any step in the warm-up procedure cannot be performed or if any indication shown in **boldface** type is not obtained. Refer to the Calibration and Maintenance section of this manual for further information.

1. Set front panel controls as follows:
MODE selector - DC
VOLTS - selector - 1
RUN UP/NORM/DEVIATE switch - NORM
RUN UP/% DEV control - 0 (center)
SCALE FACTOR switches - 0.000

2. Connect female end of power cord to mating ac input receptacle on rear panel.

WARNING

MAKE SURE THE VOLTAGE PRESENT AT THE AC RECEPTACLE MATCHES THE VOLTAGE SETTING OF THE MODEL 828. DAMAGE TO THE EQUIPMENT OR SERIOUS INJURY MAY RESULT IF THE VOLTAGES DO NOT MATCH.

3. Connect male end of power cord to a grounded ac receptacle.

NOTE

The use of extension cords to supply power to the Model 828 should be avoided whenever possible. If an extension cord must be used, do not use a two-wire (ungrounded) cord; use a three-wire (grounded) cord.

4. Apply power to the Model 828 by pressing the red POWER switch.
   The red DE-ENERGIZE indicator will light.
5. Activate the Model 828 output by pressing the white OPERATE switch.
   The red DE-ENERGIZE indicator will go out and the green OPERATE indicator will light.
6. Allow at least three minutes warm-up time. At the end of three minutes, the Model 828 is ready for use.

Basic Operating Procedure

The following procedure is designed to help the operator quickly learn the functions of all controls and output signals. This basic procedure uses a general-purpose multimeter as the device under test.

NOTE

The warm-up procedure must be performed before attempting the basic operating procedure.

1. De-activate the Model 828 output by pressing the white DE-ENERGIZE switch.
   The green OPERATE indicator will go out and the red DE-ENERGIZE indicator will light.
2. Select the desired frequency, voltage, and current ranges by pressing the appropriate push-buttons.
3. Connect device to be tested to the Model 828 output terminals, observing proper polarity.
4. Re-activate the Model 828 output by pressing the white OPERATE switch.
   The red DE-ENERGIZE indicator will go out and the green OPERATE indicator will light.
5. Adjust Model 828 output level to the desired output, either by adjusting the SCALE FACTOR switches until the number indicated multiplied by the range selected equals the desired output, or by adjusting the SCALE FACTOR switches until the device under test indicates the desired output.

NOTE

If an overload condition exists, the OPERATE indicator will go out and the DE-ENERGIZE indicator will light. This function can be tested by shorting the output terminals together while operating in the voltage mode, or by disconnecting the device under test from the output terminals while operating in the current mode.

6. Check analog meters for smooth operation as follows:
   a. Adjust range and SCALE FACTOR controls until a full-scale indication is obtained on the meter under test.
   b. Turn RUN-UP control fully counter clockwise.
   c. Place RUN-UP/NORM/% DEV switch in RUN-UP position.
   d. While watching meter under test, slowly turn RUN-UP control clockwise, increasing Model 828 output until full-scale reading is obtained.
7. Check accuracy of device under test as follows:
   a. Place RUN-UP/NORM/% DEV switch in % DEV position.
   b. Turn % DEV control back and forth until the device under test indication matches the value set by the range and SCALE FACTOR controls.
   c. Note position of pointer on % DEV control. This is a direct indication of the device under test's percent error.
8. Deactivate the Model 828 output by pressing the white DE-ENERGIZE switch.
   The green OPERATE indicator will go out and the red DE-ENERGIZE indicator will light.
9. Disconnect device under test from Model 828 output terminals.

Errors at Low Output Voltage

The sensing leads for output voltage or current are connected directly to the output binding posts, at the end of the post behind the front panel. The resistance of the post, therefore, stands between the sensing point and the output plane of the post that is available to the user. For current measurements this resistance is of no consequence since it is only part of the overall lead resistance in series with the device under test. When the instrument is used in its voltage mode, this resistance may also be disregarded when the current is so low that the error introduced is negligible. This is generally true when the output voltage is one volt, or more.

On its lowest voltage range, the Model 828 is capable of delivering a current as great as 5 amperes, and the voltage drop caused by the passage of this current through the resistance of the binding posts can produce a significant error. To illustrate this point, assume that the instrument is set to deliver an output of 100 mV, and that the load is 5 amperes. Assume, also, that the resistance of each binding post is approximately 0.00025 ohm from the sensing point to the plane of connection. This, then will introduce a drop of 1.25 mV through each binding post, 2.5 mV for two posts. The output voltage available, thus, between the two posts is 97.5 mV, an error of 2.5% with respect to the expected output.

When operating at low output voltages with high current, the error, calculated as described, may be corrected by raising the selected output voltage by the amount calculated so that, after the resistive drop through the binding posts, the output voltage at the plane of connection is approximately at the desired value.

A second cause of error when operating at low voltage and high current is the resistance between the connecting wire lead and the binding post. In theory, at least, there is only a line contact between a round connecting wire and the connecting plane of the binding post. This resistance, which is probably about 0.0005 ohm, can be reduced considerably by using a spade lug at the end of the wire connected to the binding post. This practice is recommended.

CALIBRATION and MAINTENANCE

CAUTION

The Model 828 operates at high voltages, and high voltages are present at its output terminals in certain operating modes.

Shock hazard can be minimized during operation by pressing the DE-ENERGIZE button on the front panel whenever making connections or making adjustments to either the Model 828 or the item under test.

CALIBRATION

The following procedure may be used for calibrating the Model 828 AC/DC VA Source.

Equipment Required

(a) Fluke Model 887AV AC/DC Differential Voltmeter, or equal

(b) Oscilloscope

(c) Frequency Counter

(d) Instruction Manual for Model 828

(e) A 5-ohm 25-watt resistor

Setup

The top, bottom, and side covers of the Model 828 can be easily removed to gain access to the internal components. For calibration, the top cover needs to be removed.

NOTE

For best calibration results, it is recommended that the top cover be replaced with a sheet of transparent plastic, with holes drilled in it for passing the adjustment tool through. This will help maintain the temperature stability of the Model 828 during calibration by reducing the effect of external air currents.

Before calibration the Model 828 must be warmed up (with power on and in the de-energized condition) for at least 30 minutes with all covers in place.

Calibration Procedure

WARNING

THE MODEL 828 AC/DC V-A SOURCE CONTAINS HIGH VOLTAGE. READ THE SAFETY SUMMARY ON PAGE iv OF THIS MANUAL BEFORE ATTEMPTING CALIBRATION.

The following procedure is to be used when calibrating the Model 828 AC/DC V-A Source. Refer to figures 7 through 9 to locate all internal adjustments and test points.

1. Turn COMPLIANCE potentiometer R21 and OVRLD potentiometer R102 fully counterclockwise.
2. Press white DE-ENERGIZE button on front panel.
   The green OPERATE indicator will go out and the red DE-ENERGIZE indicator will light.
3. Set front panel controls as follows:
   MODE selector - DC
   RANGE selector - 10 VOLTS
   SCALE FACTOR - 1.999
   RUN UP/NORM/% DEV switch - NORM
4. Adjust the offset voltage on transistor Q5 as follows:
   a. Set oscilloscope to its most sensitive range.
   b. Connect oscilloscope between TP3 and front panel LO input terminal.
   c. Adjust OFFSET Q5 potentiometer R92 for minimum indication on oscilloscope.
   d. Disconnect oscilloscope from TP3 and LO terminal.
5. Adjust dc voltage output as follows:
   a. Set voltmeter for dc measurements and connect across front panel HI and LO output terminals.
   b. Set front panel SCALE FACTOR controls to 0.999.
   c. Adjust COARSE DC potentiometer R44 and FINE DC potentiometer R24 until voltmeter reads 9.99 Vdc.
   d. Set front panel SCALE FACTOR controls to 0.009.
   e. Adjust OFFSET 14 potentiometer R42 until voltmeter reads 0.09 Vdc.
   f. Repeat steps 5b through 5e until proper voltmeter indications are obtained without readjusting potentiometers.
6. Adjust ac voltage output as follows:
   a. Set voltmeter for ac measurements.
   b. Set front panel SCALE FACTOR controls to 0.999 and press 50 HZ MODE selector.
   c. Adjust AC ADJ potentiometer R43 until voltmeter reads 9.99 Vac.
   d. Disconnect voltmeter from front panel output terminals and replace with frequency counter.
   e. Press front panel 60 HZ MODE selector.
   f. Adjust FREQ ADJ potentiometer R55 until frequency counter indication is between 59.9 and 60.1 Hz; if counter is set for period measurements, adjust R55 for an indication between 16.655 and 16.683 milliseconds.
   g. Disconnect frequency counter from front panel output terminals.
7. Adjust overload detection point as follows:
   a. Press white DE-ENERGIZE switch on front panel.
      The green OPERATE indicator will go out and the red DE-ENERGIZE indicator will light.
   b. Set front panel controls as follows:
      MODE selector - 60 HZ
      VOLTS selector - 10
      SCALE FACTOR switches - 0.999
   c. Connect a 5-ohm, 25-watt resistor across the front panel HI and LO output terminals and press the white OPERATE switch.
      The red DE-ENERGIZE indicator will go out and the green OPERATE indicator will light.
   d. Slowly turn OVERLOAD potentiometer R102 clockwise until the green OPERATE indicator goes out.
      The red DE-ENERGIZE indicator will light as soon as the green OPERATE indicator goes out.
   e. Disconnect the 5-ohm resistor from the front panel output terminals.
8. Adjust compliance control as follows:
   a. Set front panel controls as follows
      MODE selector - 50 HZ
      CURRENT selector - 10 A
      SCALE FACTOR switches - 0.500
   b. Press the white OPERATE switch on the front panel.
      The red DE-ENERGIZE indicator will go out and the green OPERATE indicator will light.
   c. Wait 15 seconds, then slowly turn COMPLIANCE potentiometer R21 clockwise until green OPERATE indicator goes out.
      The red DE-ENERGIZE indicator will light as soon as the green OPERATE indicator goes out.
9. Adjust percent deviation control as follows:
   a. Set front panel controls as follows:
      MODE selector - DC
      VOLTS selector - 10 V
      SCALE FACTOR switches - 0.999

b. Press the white OPERATE switch on the front panel.
The red DE-ENERGIZE indicator will go out and the green OPERATE indicator will light.

c. Set voltmeter for ac measurements and select the range that will provide the highest resolution possible for a 10-volt reading

d. Connect voltmeter across front panel HI and LO output terminals. Note and record exact voltmeter indication.

e. Place front panel RUN UP/NORM/% DEV switch in % DEV position.

f. Rotate front panel % DEV control until voltmeter indication is exactly the same as the reading noted in step 8d.

g. Note position of pointer on % DEV control; if pointer does not line up exactly with the zero mark on the front panel, loosen the setscrews on the % DEV control (outer knob) and align the pointer and the zero mark ***without moving the control.*** Once the pointer and zero mark are aligned, retighten the setscrews.

Calibration is now completed.

MAINTENANCE AND REPAIR

WARNING

THE MODEL 828 AC/DC V-A SOURCE CONTAINS HIGH VOLTAGE. READ THE SAFETY SUMMARY ON PAGE iv OF THIS MANUAL BEFORE ATTEMPTING MAINTENANCE OR REPAIR.

Under normal conditions, maintenance of the Model 828 is limited to periodic recalibration to insure continued accuracy; a six-month calibration cycle is recommended.

If the Model 828 does not function properly during normal use, the problem may be either a defective component or an improperly adjusted control. Make sure the fault lies in the Model 828 before attempting repair.

Tables 3 and 4 are provided as an aid to troubleshooting; Table 3 shows waveforms and voltage levels at selected points in the unit, and Table 4 gives the terminal assignments for selected components. Figure 10 is the schematic for all signal circuits, and figure 11 is the schematic for the power supply section.

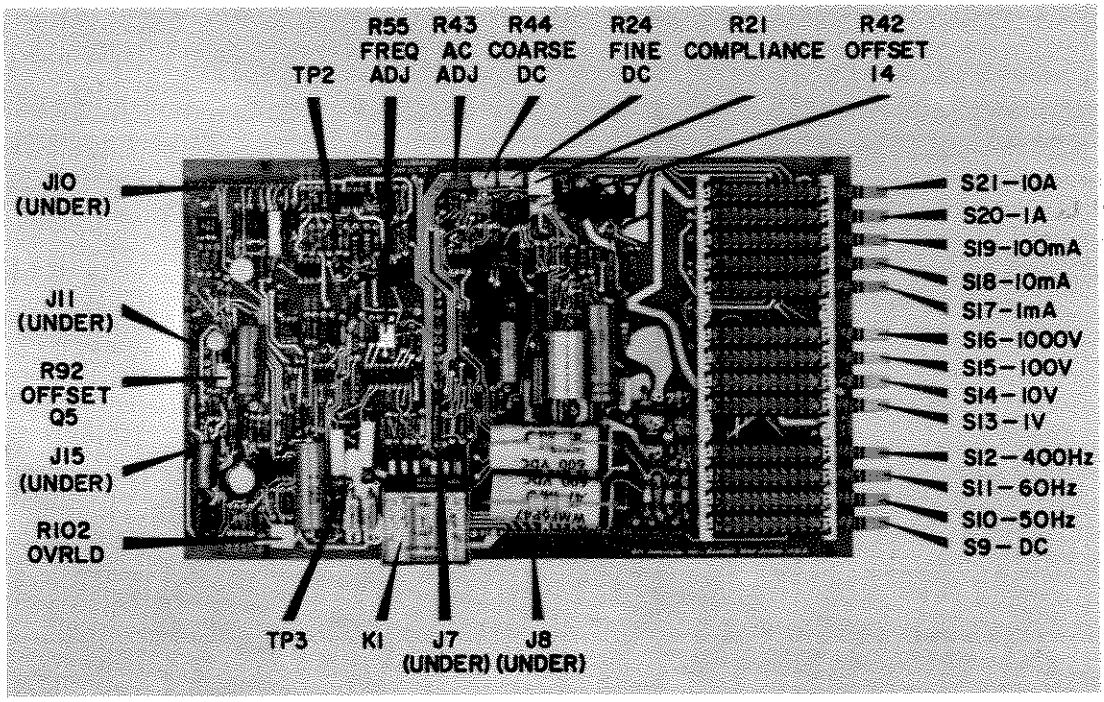


Figure 7. Controls and Adjustments, Main Circuit Board.

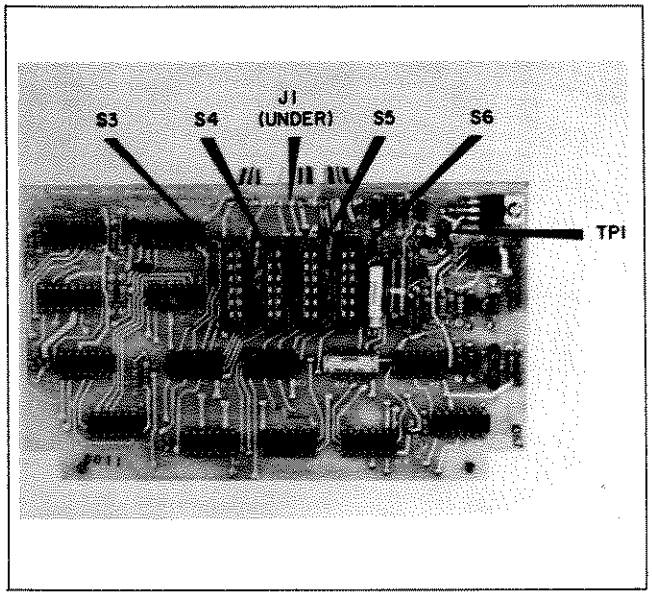


Figure 8. Controls and Adjustments, Digital Circuit Board.

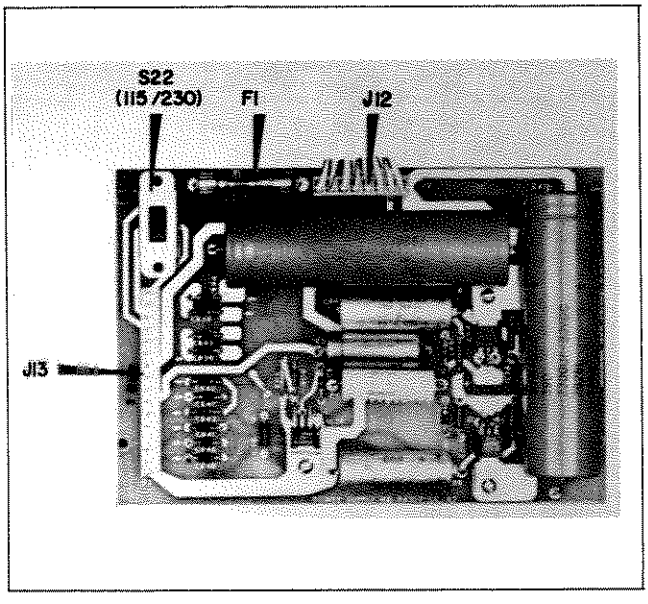
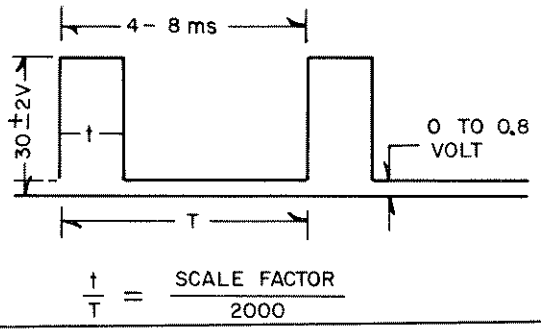
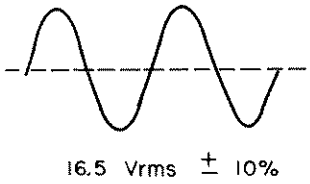


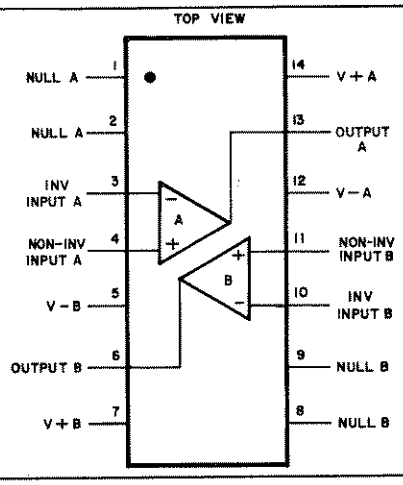
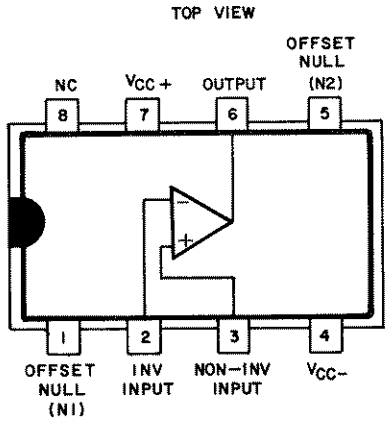
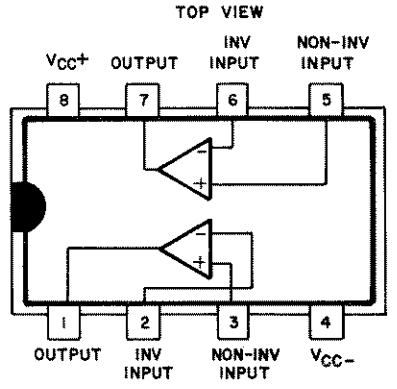
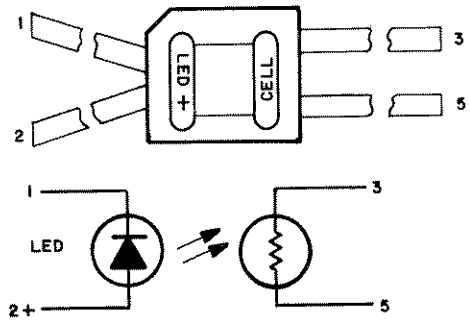
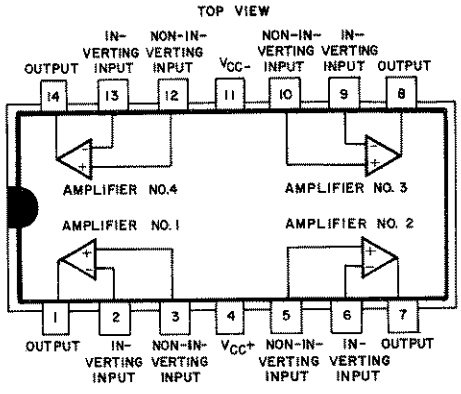
Figure 9. Location of Components on Power Supply Board.

TABLE 3
WAVEFORMS AND VOLTAGES AT SELECTED POINTS

TEST POINT (1)	MODE	RANGE	SCALE FACTOR	OBSERVATION
TP1	ANY	ANY	ANY	
TP2	ANY	ANY	ANY	13 – 18 Vdc
TP3	ANY AC	ANY	1.999	
TP3	DE-ENERGIZED			Less than 10 mVdc
TP3	DC	ANY	1.999	
J10-5	ANY AC	ANY	ANY	Sinewave of frequency selected, 1.75 - 2.25 V, 60 Hz: ±0.5%; Other freq.: ±1%
IC14	ANY	ANY	1.000	Voltage from IC14A-4 to IC14B-11 equals 0.25 Vdc ±0.1%. Use ungrounded meter.

(1) All measurements are made with respect to signal ground unless otherwise noted.

TABLE 4
COMPONENT TERMINAL CONNECTIONS

CIRCUIT SYMBOL	DESCRIPTION	CIRCUIT SYMBOL	DESCRIPTION
IC14	Dual Opamp Prec. Monolithics OP-10CY 	IC21	Opamp TL081 CP 
IC15 IC17 IC20	Dual Opamp TL082 CP 	IC22	Photo Coupled Resistor Vactec VTL5C3 
IC16	Quad Opamp TL084 CN 		

THEORY OF OPERATION

This description of the circuits of the Model 828 is based upon the circuit schematic shown in figures 10 and 11. Organization of the major sections of the circuit will be clarified by reference to the block diagram in figure 2.

OUTPUT SIGNAL LEVEL

The Model 828 uses a closed-loop system in which the desired output signal level is entered digitally by using a 3½-digit thumbwheel switch which is identified as SCALE FACTOR on the front panel.

A module-2000 counter, which used decade counters IC4, IC5, IC6, and J-K flip-flop IC7A is continuously driven by an oscillator using IC1D, IC1E, and IC1F. When the counter rolls over from 1999 to 0000, flip-flop IC7B is set. The count is continuously compared in a four-decade comparator, IC8 through IC11, with the input command from the SCALE FACTOR switches.

When coincidence is sensed, IC7B is reset. Its Q output, at pin 11, will thus have a duty cycle, with respect to the period of the oscillator, which is proportional to the input command. Transistor Q2 serves as a buffer and amplifier to raise the excursion of the signal at IC7B-11 to extend from zero to 30 volts.

CONSTANT-CURRENT SOURCE

The output signal at the collector of Q2 serves to modulate the output of a constant-current source, provided by Q3, IC20A, IC19, R58, and R64. When the signal is high, the current passes through CR9, and when it is low the current is diverted through CR1 to ground.

The modulated output of the constant-current source is an extremely accurate and proportional representation of the digital command set on the SCALE FACTOR switches, and the current will be compared with a feedback current which is proportional to the output signal. The feedback current is produced by a circuit that is simultaneously a differential amplifier, a full-wave rectifier, and a current sink. The circuit includes IC14A, IC14B, IC15A, IC15B, Q11, and Q12. The difference between these two currents is the error signal, and this will be integrated until the loop reduces the error to zero.

INTEGRATOR

The integrator is C20, whose value is electronically multiplied, by IC20B and IC21, so as to appear much larger than its physical value at frequencies that represent harmonics of the output signal. The error current is thereby converted to an almost pure-dc voltage which controls the amplitude of the input signal to an output power amplifier.

OUTPUT AMPLIFIER

The frequency of the input signal to the power amplifier is selected by the MODE switches on the front panel. For 50, 60, or 400 Hz, a state-variable oscillator, using IC16A, -B, -C, and -D, IC17B, and IC18, supplies the input signal. For output signals of other frequencies, an external oscillator, connected through J14 and S23, may be used. For dc output signals, the input of the amplifier is a squarewave derived from the digital section and taken at J1-7. The squarewave is subsequently rectified to obtain a dc output signal.

The amplitude of the power amplifier's input signal is controlled by IC22 which modulates the level in accordance with the error current passing through it.

IC17A is a preamplifier for the wideband power amplifier. Diodes CR11-CR14, and CR16-CR19 provide instantaneous short-circuit protection for the amplifier.

OVERLOAD PROTECTION

If the amplifier is overloaded longer than 0.5 second, then an overload circuit using R101, R102, and IC27 triggers IC23 and IC7B so that an output signal of zero is artificially commanded. The same circuit controls the OPERATE and DE-ENERGIZE lamps on the front panel. This circuit also senses when the limits of compliance have been exceeded, when in the current ranges, and similiarly de-energizes the instrument.

IC23 also processes both the OPERATE and the DE-ENERGIZE commands received through the front panel, powers the associated lamps, and controls the integrator's reset circuit through IC29.

OUTPUT TRANSFORMER

All output signals pass through the output transformer, T1. When the switch for the most-significant digit is set to one, primary taps on T1 are switched, by Q9 and K1, so as to allow the power amplifier driving it to operate with minimum distortion. Secondary winding 10-11 provides distortion-cancelling feedback for the power amplifier, where its signal is injected at the connection between R97 and C30.

For the dc mode, the low-voltage secondaries are connected to full-wave center-tapped rectifier circuits. The two higher voltage secondaries are connected to full-wave-bridge rectifiers to reduce the maximum secondary voltage required. In addition, when not in use, the two halves of the 1000-volt winding, 6-7 and 8-9, are arranged in a voltage-bucking connection so that their net output is zero. All rectifiers are followed by capacitors with appropriate bleeder resistors.

SWITCHING

Switches S9 through S21 select the mode and scale of the output signal and connect the circuit accordingly. On the voltage scales, R15-R19 serve as precision attenuators which standardize the output voltages to a level that can be processed by the differential feedback amplifier, IC14. Similarly, on current ranges precision shunts, R116-R119 and R124, convert the currents to a voltage level suitable for the inputs of IC14.

RUN UP and % DEVIATION

The front panel has dual, concentric potentiometers to provide the RUN UP and % DEV functions.

RUN UP potentiometer R63 attenuates the precision reference voltage from IC19 to the command-current source so that it makes the output swing between zero and 2% above the output level commanded.

The % DEV control, R60, operates similarly except that its range is restricted to ±2% by a precision voltage divider network formed from resistors R59, R61, and R62.

TURN-ON DELAY

This circuit is used to reduce output transients during power-on and power-off. Part of this function is implemented by IC1, which is a timer that delays turning on relay K1 for approximately 10 seconds, at power on. In the energized state, the contacts of K1 connect the output of the power amplifier circuitry to the input of output transformer T1, through which all outputs pass. The ten-second delay is sufficient to allow all internal dc power supplies to rise to their steady-state values and for the power amplifier to stabilize.

In series with the relay contact is a contact on the DPDT, POWER on/off switch which serves to remove, at power off, the connection from the power amplifier to the output transformer instantaneously before the dc power supplies drop off significantly, thereby reducing the turn-off transient.

In addition, during power turn-on, transistor Q1 saturates and serves to disable the OPERATE function for the 10-second delay described above. At the end of this time interval, the unit is fully operational.

POWER SUPPLY

The power supply is of conventional design, and it is powered through transformer T2,. A split primary, connected to the power source through S22, allows operation from nominal 115/230-volt 47-63-Hz input. Operation from nominal 100/200-volt power is available by rewiring the two primaries of T2 as described in the section on installation.

Table 5
Replaceable Parts

Circuit Symbol (See figs. 10 and 11)	Description	Part Number
	Model 828 AC/DC V-A Source - Assembly No. 94200	
	CAPACITORS	
C1	Capacitor, mica, 0.0013μF, 2%, 500V, Electro-Motive DM-19 or equiv.	16214
C2, 4, 8,-13, 17-19, 24, 28, 31, 39, 60, 63-65	Capacitor, ceramic, 0.1μF, GMV, 50V, Centralab CY20C104P or equiv.	1007 1366
C3, 66	Capacitor, mica, 100pF,10%, 100V, Electro-Motive DM-10 or equiv.	1080 328
C5	Capacitor, mica, 470pF, 10%, 300V, Electro-Motive DM-15 or equiv.	1080 272
C6	Capacitor, electrolytic, 50μF, +75 -10%, 25V Sprague 30D506G025CC2 or equiv.	13819
C7	Capacitor, ceramic, 0.02μF, +80 -20%, 25V, Tusonix 5835-000-Y5U-203Z or equiv.	1007 754
C14, 15	Capacitor, polystyrene, 0.315μF, 2%, 100V, Wesco 32P or equiv.	5115 58
C16	Capacitor, tantalum, 3.3μF, 20%, 35V, Kemet T322C335M035AS or equiv.	1007 1260
C20	Capacitor, electrolytic, 100μF, 20%, 25V, Nichicon TKB1E101M or equiv.	1007 1556
C21	Capacitor, mica, 51pF, 5%, 500V, Electro-Motive DM-15 or equiv.	16516
C22	Capacitor, tantalum, 10μF, 10%, 20V, Kemet T322C106K020AS or equiv.	1007 955
C23	Capacitor, ceramic, 1μF, +80 -20%, 50V, Sprague 2C37Z5U105Z050B or equiv.	1007 1153
C25	Capacitor, ceramic, 0.001μF, 10%, 100V, Kemet CK12BX102-K or equiv.	1007 1360
C26, 30	Capacitor, electrolytic, 50μF, +75 -10%, 50V, Sprague 39D506G050EE4 or equiv.	1007 793
C27	Capacitor, electrolytic, 25μF, +150 -10%, 50V, Cornell-Dubilier BR25-50 or equiv.	1007 207
C29	Capacitor, mica, 560pF, 2%, 500V, Electro-Motive DM-19 or equiv.	16636
C32, 48, 49	Capacitor, electrolytic, 100μF, +150 -10%, 50V, Cornell-Dubilier BR100-50 or equiv.	1007 209
C33	Capacitor, mica, 0.002μF, 2%, 500V, Electro-Motive DM-19 or equiv.	16222
C34	Capacitor, electrolytic, 1000μF, +50 -10%, 16V, Nippon Series SL or equiv.	1007 1446
C35, 37, 51-56, 58	Capacitor, tantalum, 1μF, 20%, 35V, Kemet T322B105M035AS or equiv.	1007 496
C32, 38	Not Used.	
C40	Capacitor, tantalum, 4.7μF, 20%, 20V, Kemet T322B475M020AS or equiv.	1007 711
C41, 42	Capacitor, polyester, 0.47μF, 10%, 600V, Cornell-Dubilier WMF-6P47 or equiv.	1007 1333
C43	Capacitor, electrolytic, 15μF, +50 -10%, 250V, Sprague 39D156F250EJ4 or equiv.	1007 1443
C44	Capacitor, electrolytic, 1000μF, +50 -20%, 25V, Siemens B41010-1000/25/82009 or equiv.	1007830
C45	Capacitor, electrolytic, 18,000μF, +75 -10%, 3V, Sprague 39D189G003JT4 or equiv.	1007 1444
C46, 47	Capacitor, electrolytic, 2300μF, +75 -10%, 50V, Sprague 39D238G050JT4 or equiv.	1007 868
	NOTE On units modified at the factory for 7-ampere maximum output, there will be an additional 2300μF, capacitor placed in parallel with C46 and C47.	
C50	Capacitor, electrolytic, 470μF, +100 -10%, 40V, Stettner-Trush EG470-40 or equiv.	1007 1399
C57	Capacitor, mylar, 0.39μF, 2%, 100V, Wesco 32M or equiv.	1007 444
C59	Capacitor, tantalum, 15μF, 20%, 20V, Kemet T322D156M020AS, or equiv.	1007 716

Table 5
Replaceable Parts - continued

Circuit Symbol (See figs. 10 and 11)	Description	Part Number
	RESISTORS	
R1, 34, 38	Resistor, metal film, 1K, 1%, ¼WW, Type RN¼	0410 1288
R2, 108, 126	Resistor, metal film, 301 ohm, 1%, ¼W, Type RN¼	0410 1238
R3, 6, 10, 11, 27, 64, 82, 87	Resistor, metal film, 3.32K, 1%, ¼W, Type RN¼	0410 1353
R4, 13, 26	Resistor, metal film, 3.32K, 1%, ¼W, Type RN¼	0410 1338
R5, 12, 25	Resistor, metal film, 2.21K, 1%, ¼W, Type RN¼	0410 1321
R7, 8, 84, 94, 125	Not Used.	
R9	Resistor, composition, 1K, 5%, 2W, Allen-Bradley HB Series or equiv.	1009 118
R14, 28	Resistor, metal film, 1.82K, 1%, ¼W, Type RN¼	0410 1313
R15-19	Resistor, metal film attenuator network	94274
R20	Resistor, metal film, 332 ohm, 1%, ¼W, Type RN¼	0410 1242
R21	Resistor, variable, single-turn cermet, 2M, 20%, ½W, Beckman Helipot 72PR2M or equiv.	94295
R22	Resistor, composition, 1.2M, 5%, 1W, Allen-Bradley CB Series or equiv.	1009 860
R23, 40	Resistor, metal film, 12.1K, 1%, ⅛W, T-10 temp. coeff., Dale Electronics Type PTF 56 or equiv.	1510 2069
R24, 92	Resistor, variable, 18-turn cermet, 50 ohm, 20%, ½W, Beckman Helipot 68WR50 or equiv.	94297
R29	Resistor, metal film, 6.81K, 1%, ¼W, Type RN¼	0410 1368
R30, 41, 101	Resistor, metal film, 100 ohm, 1%, ¼W, Type RN¼	0410 1192
R31, 32, 115	Resistor, metal film, 5.11K, 1%, ¼W, Type RN¼	0410 1356
R33, 39, 78	Resistor, metal film, 221 ohm, 1%, ½W, Type RN½	0410 2225
R35, 37	Resistor, metal film, 2K, 1%, ⅛W, T-10 temp. coeff., Dale Electronics Type PTF 56 or equiv.	1510 2066
R36	Resistor, metal film, 18.2K, 1%, ⅛W, Type RN60C	1510 1638
R42	Resistor, variable, 18-turn cermet, 10K, 10%, ½W, Beckman Helipot 68WR10K or equiv.	48548
R43	Resistor, variable, 18-turn cermet, 5K, 10%, ½W, Beckman Helipot 68WR5K, or equiv.	94271
R44	Resistor, variable, 18-turn cermet, 500 ohm, 10%, ½W, Beckman Helipot 68WR500 or equiv.	94296
R45, 46	Resistor, metal film, 3.01K, 1%, ¼W, Type RN¼	0410 1334
R47, 50, 73, 75, 77	Resistor, metal film, 100K, 1%, ¼W, Type RN¼	0410 1480
R48, 51	Resistor, metal film, 14.3K, 1%, ¼W, Type RN¼	0410 1399
R49, 52	Resistor, metal film, 499K, 1%, ¼W, Type RN¼	0410 1547
R53	Resistor, composition, 1M, 5%, 1W, Allen-Bradley CB Series or equiv.	1009 798
R54, 56	Resistor, metal film, 20K, 1%, ¼W, Type RN¼	0410 1413
R55	Resistor, variable, 18-turn cermet, 2K, 10%, ½W, Beckman Helipot 68WR2K or equiv.	90392
R57	Resistor, composition, 22M, 5%, 1W, Allen-Bradley CB Series or equiv.	1009 880
R58	Resistor, metal film, 2.43K, 1%, ⅛W, T-10 temp. coeff., Dale Electronics Type PTF 56 or equiv.	1510 2067

Table 5
Replaceable Parts - continued

Circuit Symbol (See figs. 10 and 11)	Description	Part Number
R59	Resistor, metal film, 4.75K, 0.25%, ⅛W, T-10, temp. coeff., Dale Electronics Type PTF 56 or equiv.	1510 2068
R60, 63	Resistor, variable, dual wirewound, 20K, 10%, linear taper, concentric shafts	94279
R61, 62	Resistor, metal film, 97.6 ohm, 0.25%, ⅛W, T-10 temp. coeff., Dale Electronics Type PTF 56 or equiv.	1510 2064
R65	Resistor, composition, 820K, 5%, 1W, Allen-Bradley CB Series or equiv.	1009 868
R66-68, 72, 90, 107	Resistor, metal film, 10K, 1%, ¼W, Type RN¼	0410 1384
R69	Resistor, metal film, 75K, 1%, ¼W, Type RN¼	0410 1468
R70	Resistor, metal film, 18.2K, 1%, ¼W, Type RN¼	0410 1409
R71	Resistor, metal film, 1.21K, 1%, ¼W, Type RN¼	0410 1296
R74	Resistor, metal film, 182K, 1%, ½W, Type RN½	0410 2217
R76	Resistor, metal film, 9.09K, 1%, ¼W, Type RN¼	0410 1380
R79	Resistor, metal film, 8.25K, 1%, ¼W, Type RN¼	0410 1376
R80	Resistor, metal film, 47.5K, 1%, ¼W, Type RN¼	0410 1449
R81, 83	Resistor, composition, 10 ohm 5%, ¼W, Allen-Bradley CB Series or equiv.	1009 823
R85	Resistor, metal film, 365 ohm, 1%, ¼W, Type RN¼	0410 1246
R86, 127, 128	Resistor, metal film, 182 ohm, 1%, ¼W, Type RN¼	0410 1217
R88	Resistor, metal film, 511 ohm, 1%, ¼W, Type RN¼	0410 1260
R89	Resistor, metal film, 4.75K, 1%, ⅛W, Type RN60E	1510 2032
R91	Resistor, metal film, 953 ohm, 1%, ¼W, Type RN¼	0410 1286
R93	Resistor, metal film, 4.87KK, 1%, ¼W, Type RN¼	0410 1354
R95	Resistor, metal film, 100K, 1%, ½W, Type RN½	0410 2480
R96	Resistor, metal film, 4.99K, 1%, ¼W, Type RN¼	0410 1355
R97	Resistor, metal film, 1.65K, 1%, ¼W, Type RN¼	0410 1309
R98	Resistor, composition, 200 ohm, 5%, 1W, Allen-Bradley GB Series or equiv.	1009 75
R99, 100	Resistor, metal film, 1%, ½W, Type RN½ value dependent upon maximum output current: For 5 amperes maximum, 3.01K For 7 amperes maximum, 1.5K	 0410 2334 0410 2305
R102	Resistor, variable, single-turn cermet, 1K, 10%, ½W, Beckman Helipot 72PR1K or equiv.	45343
R103, 104, 123 (2 in parallel)	Resistor, wirewound, 3 ohm, 5%, 3¼W, Ohmite 4342 Style 995-3A or equiv.	1100 667
R105	Resistor, metal film, 274 ohm, 1%, ¼W, Type RN¼	0410 1234
R106	Resistor, metal film, 475K, 1%, ¼W, Type RN¼	0410 1545
R109, 110	Resistor, metal film, 390K, 5%, 2W, Corning Series FP42 or equiv.	1510 1076
R111	Resistor, wirewound, 12.5K, 5%, 6.5W, Clarostat VC5E or equiv.	1100 731
R112	Resistor, wirewound, 180 ohm, 5%, 3¼W. Ohmite 4398 Style 995-3A or equiv.	1100 464
R113	Resistor, composition, 6.8 ohm, 5%, 1W, Allen-Bradley GB Series or equiv.	1009 690
R114	Resistor, metal film, 26.1K, 1%, ¼W, Type RN¼	0410 1424
R116	Resistor, wirewound 4-wire shunt, 0.25 ohm, 0.05%, 3W, Dale Electronics RLS-2B or equiv.	1600 272
R117	Resistor, wirewound 2-wire shunt, 2.5 ohm, 0.05%, 3W, Dale Electronics RS-2B or equiv.	1780 479

Table 5
Replaceable Parts - continued

Circuit Symbol (See figs. 10 and 11)	Description	Part Number
R118	Resistor, wirewound 2-wire shunt, 25 ohm, 0.05%, 3W, Dale Electronics RS-2B or equiv.	1780 480
R119	Resistor, wirewound 2-wire shunt, 250 ohm, 0.05%, 3W, Dale Electronics RS-2B or equiv.	1780 481
R120	Resistor, composition 10 ohm, 5%, ½W, Allen-Bradley EB Series or equiv.	1009 238
R121	Resistor, metal film, 200 ohm, 1%, ¼W, Type RN¼	0410 1221
R122	Resistor, metal film, 2K, 1%, ¼W, Type RN¼	0410 1317
R124	Resistor, wirewound 4-wire shunt, 0.025 ohm, 0.05%, 3W, Dale Electronics RLS-2B or equiv.	1600 271
R129	Resistor, metal film, 332 ohm, 1%, ½W, Type RN½	0410 2242
R130	Resistor, metal film, 150 ohm, 1%, ¼W, Type RN¼	0410 1209
	SEMICONDUCTORS	
CR1, 3-16, 19, 20, 25, 53-59, 69, 72	Diode, silicon, 1N914B or 1N4448	26482
CR2	Diode, silicon, type dependent upon maximum output current: For 5 amperes maximum, same as CR1 For 7 amperes maximum, Schottky; Aertech Industries A2S811 or equiv.	49489
CR17, 18	Diode, Zener, 5.1V, 5%, 1W, 1N4733A	29759
CR22, 51, 52	Diode, Zener, 13V, 5%, 1W, 1N4743A	30725
CR23, 40-43, 46-48, 60, 61	Diode, silicon, 1N4003	30769
CR26-29	Rectifier, high-voltage, Semicon HV-30F or equiv.	94286
CR30-33	Diode, avalanche, 1N4005	26935
CR34, 35	Diode, silicon, 100 PIV, 3A, Semtech 3XM1 or equiv.	94287
CR36, 37	Power rectifier, fast-recovery, 50V, 5A, Motorola MR820 or equiv.	94037
CR38, 39, 44, 45	Diode, silicon, type dependent upon maximum output current: For 5 amperes maximum, same as CR23 For 7 amperes maximum, Motorola MR502 or equiv.	90912
DS1	Light-emitting diode, red, Dialight 559-0101-001 or equiv.	91114
DS2	Light-emitting diode, green, Dialight 559-0201-001 or equiv.	91116
IC1-3	Hex inverter, National Semiconductor DM74LS04N or equiv.	0610 78
UC4-6	Decade counter, National Semiconductor DM74LS90N or equiv.	0610 82
IC7	Dual J-K flip-flop, National Semiconductor DM74LS76N or equiv.	0610 80
IC8-11	BCD comparator, National Semiconductor DM74LS85N or equiv.	0610 81
IC12, 13	Triple 3-input NAND gate, National Semiconductor DM74LS10N or equiv.	0610 79
IC14	Operational amplifier, dual, Precision Monolithics OP-10CY or equiv.	0620 171
IC15, 17, 20	Operational amplifier, dual, JFET input, Texas Instruments TL082CP or equiv.	0620 155
IC16	Operational amplifier, JFET input, Texas Instruments TL084CN or equiv.	0620 151
IC18, 29	Photon-coupled bilateral analog FET, General Electric H11F3 or equiv.	94289
IC19	Voltage reference, National Semiconductor LM399H or equiv.	0620 172
IC21	Operational amplifier, JFET input, Texas Instruments TL081CP or equiv.	0620 160
IC22	Photo-coupled resistor, Vatec Inc. VTL5C3 or equiv.	94288
IC23	Timer, National Semiconductor LM555CN or equiv.	0620 108
IC24	Voltage regulator, 5-volt positive, Motorola MC7805CP or equiv.	0620 77
IC25	Voltage regulator, 15-volt positive, National Semiconductor LM342P-15 or equiv.	0620 175

Table 5
Replaceable Parts - continued

Circuit Symbol (See figs. 10 and 11)	Description	Part Number
IC26	Voltage regulator, 15-volt negative, National Semiconductor LM320MLP-15 or equiv.	0620 174
IC27	Optical isolator, 6-pin DIP package, Litronix IL-1 or equiv.	41083
IC28	Voltage regulator, 30-volt positive, Fairchild μA78GU1C or equiv.	0620 135
Q1	Not Used.	
Q2	Transistor, VMOS FET, TO-237 case, Siliconix VN10KM or equiv.	0715 13
Q3	Transistor, PNP Darlington, TO-92 case, Motorola MPS-A64 or equiv.	26902
Q4	Transistor, NPN, 2N2222A, plastic package	37445
Q5	Transistor, NPN, Motorola 2N2060 or equiv.	94292
Q6	Transistor, silicon, 100 Vceo, Motorola PTC198 or equiv.	92672
Q7	Transistor, NPN Darlington, 2N6385	94291
Q8	Transistor, PNP Darlington, 2N6650	94290
Q9, 11, 12	Transistor, NPN Darlington, TO-92 case, 2N6426	46531
Q13	Transistor, PNP, Motorola MPS-A92 or equiv.	42559
	MISCELLANEOUS COMPONENTS	
F1	Fuse, 3AG slow-blow, 250V, current rating dependent upon voltage setting: For 100 and 115V settings, 1 amp; Littelfuse 313 001 or equiv. For 200 and 230V settings, ½ amp; Littelfuse 313.500 or equiv.	 6645 6723
K1	Relay, DPDT, 2A contacts, 12.5K coil, AMF/Potter & Brumfield R40-E1-Y2-V1.2K 24 VDC or equiv.	41028
RZ1	Resistor network, 13 4.7K 2% resistors, 1.5W total, CTS of Berne 760-1-4. 7K or equiv.	38836
S1	Switch, pushbutton, DPDT snap action, C & K Components 8261ZE (w/7527 red cap) or equiv.	90238
S2	Switch, toggle, DPDT, externally wired for SP3T use, C & K Components 7211-P3-Y1-Z-Q-E or equiv.	94285
S3-6	Switch assembly, thumbwheel, Digitran 28-R-62 or equiv.	94276
S7, 8	Switch, momentary pushbutton, C & K Components 8121 (w/7089-1 white cap) or equiv.	26133
S9-21	Switch, pushbutton, 13-station, 8P2T/station, ITT Schadow 601532 or equiv.	94268
S22	Switch, slide, DPDT, Switchcraft 275-11A1101A or equiv.	45534
S23	Switch, slide, DPDT, 125V, 3A, H. H. Smith 518 or equiv.	9267
T1	Transformer, output	94278
T2	Transformer, power, 115/230V primary, 50/60 Hz	94277
	Transient Reducer - Assembly No. HB-95790	
C1	Capacitor, tantalum, 1μF, 10%, 20V, Kemet T362A105K020AS or equiv.	1007 1461
C2	Capacitor, ceramic, 0.01μF, 10%, 100V, Kemet C320C103K1R5EA or equiv.	1007 13190
CR1, 2	Diode, silicon, 1N4003	30769
IC1	Timer, National Semiconductor LM555CN or equiv.	0620 108
K1	Relay, SPDT, 600 ohm coil, 10A contacts, Cornell-Dubilier 613-12R or equiv.	90237
R1	Resistor, metal film, 1K, 1%, ¼W, Type RN¼	0410 1288
R2	Resistor, metal film, 4.75K, 1%, ¼W, Type RN¼	0410 1353
R3	Resistor, composition, 10M, 5%, ¼W, Allen-Bradley CB Series or equiv.	1009 811
R4	Resistor, metal film, 100 ohm, 1%, ¼W, Type RN¼	0410 1192
Q1	Transistor, NPN, 2N2222A, plastic package	37445