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# INSTRUCTION MANUAL

## APH SERIES

## POWER SUPPLY

### AUTOMATIC CROSSOVER

KEPCO INC.
An ISO 9001 Company.

**MODEL**
**APH SERIES**
**POWER SUPPLY**

| ORDER NO. | REV. NO |
|---|---|
| | |

NOTE: This on-line version of the Technical Manual includes only installation and operating instructions. For the complete manual, please contact Kepco.

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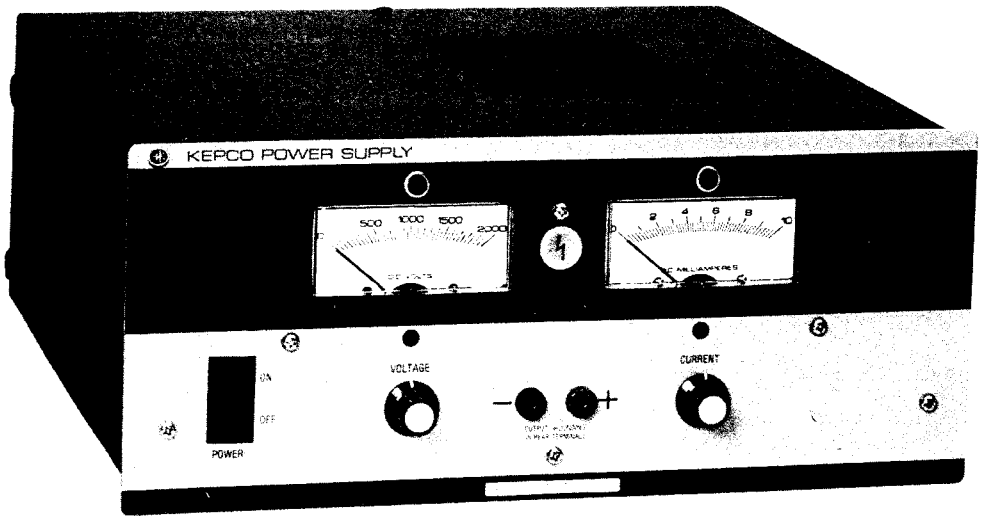
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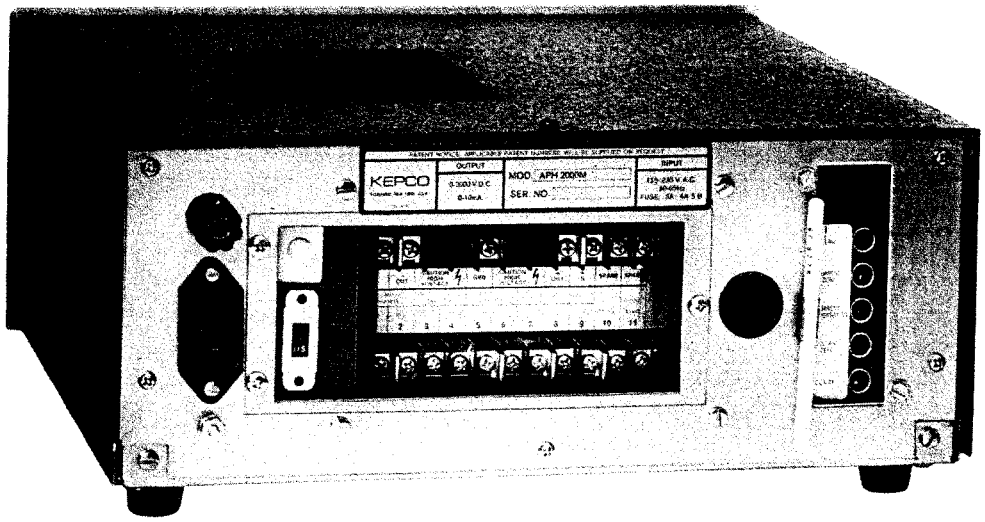




FIG. 1-1 APH POWER SUPPLY, TYPICAL FRONT AND REAR VIEW.

## 1-1 SCOPE OF MANUAL

1-2 This manual contains instructions for the installation, operation and maintenance of the APH High Voltage, Automatic Crossover Power Supplies, manufactured by Kepco, Inc., Flushing, New York, U.S.A.

## 1-3 GENERAL DESCRIPTION

1-4 Kepco Series APH Power Supplies are high voltage, low current, precision-stabilized d-c sources of approximately twenty watts of d-c output power. Their important design features include:

a) AUTOMATIC CROSSOVER BETWEEN VOLTAGE AND CURRENT STABILIZATION MODE OF OPERATION WITH VISUAL FRONT PANEL (LED) MODE INDICATORS.

b) PRECISION, TEN-TURN FRONT PANEL OUTPUT VOLTAGE AND OUTPUT CURRENT CONTROLS.

c) RECESSED FRONT PANEL OUTPUT METERS PERMIT THE SIMULTANEOUS MONITORING OF OUTPUT VOLTAGE AND OUTPUT CURRENT.

d) FRONT AND REAR OUTPUT TERMINALS WITH REMOTE SENSING PROVISION, ALLOW PRECISION STABILIZATION AT A DISTANT LOAD.

e) PROGRAMMING TERMINALS PERMIT ACCESS TO A BUILT-IN, INDEPENDENT PRE-AMPLIFIER, TO THE VOLTAGE CONTROL AND MAIN VOLTAGE AMPLIFIERS AND TO A SEPARATE CURRENT CONTROL AMPLIFIER. A MODE FLAG SIGNAL OUTPUT (TTL COMPATIBLE), AS WELL AS TWO D-C REFERENCE SOURCES (±6.2 volts at 1 mA MAX.) REFERENCED TO COMMON (+ SENSE) ARE PROVIDED.

1-5 The APH Power Supply can, in simplified form, be electrically represented by the fold-out diagram in Section III of this manual (see FIG. 3-15 at the end of Section III). A high voltage, low current d-c source is controlled by a series pass element (vacuum tube), which in turn is controlled by the driver circuit via the voltage channel or the current channel. The driver is connected to three control amplifiers (Main Voltage, Internal Current Control, External Current Control) via the gating circuit, which permits only one amplifier to take control of the APH output.

1-6 Because of the high gain of the control amplifiers and the functioning of the "Exclusive OR Gate," the output characteristics of the APH is that of a true "auto-crossover" power supply (see Section III, FIG. 3-1). The "crossover" resistance ($R_{LX}$) at any instant is given by the straight line on the $E_O$ vs. $I_O$ graph from ($E_O$, $I_O$) = 0 to any other point ($E_O$, $I_O$), where $E_O$ represents the set APH output voltage and $I_O$ the set output current:

$$R_{LX} = E_O/I_O$$

For load resistances ***greater*** than $R_{LX}$, the APH voltage channel is in control, while for load resistances ***smaller*** than $R_L$, the current channel takes control of the APH output.

## 1-7 SPECIFICATIONS, GENERAL

a) A-C INPUT POWER: 105 to 125V a-c ***or*** 210 to 250V a-c (selectable, refer to Section II), 50 to 65 Hz single phase. Approximately 75 Watts.

b) OPERATING TEMPERATURE RANGE: (−)20°C to (+)65°C (without derating of the output).

c) STORAGE TEMPERATURE: (−)40°C to (+) 85°C.

d) COOLING: The Kepco APH Power Supply is designed for adequate convection cooling through the wrap-around, perforated case.

e) ISOLATION: A maximum of 1000 volts (d-c or peak) can be connected between chassis and either output terminal. Common-mode current from output (either side) to ground: <50 μA rms, 500 μA p-p at 115V a-c, 60 Hz.

f) OUTPUT RATINGS AND IMPEDANCES: (See Table 1-1).

| MODEL | D-C OUTPUT RANGE | | OUTPUT IMPEDANCE | |
|---|---|---|---|---|
| | VOLTS | AMPS | D-C OHMS + SERIES L VOLTAGE MODE | D-C OHMS + SHUNT C CURRENT MODE (INT.) |
| APH 500M | 0–500 | 0–0.04 | 0.625Ω + 10 μH | 125 MΩ + 6.0 μF |
| APH 1000M | 0–1000 | 0–0.02 | 2.5Ω + 20 μH | 500 MΩ + 3.0 μF |
| APH 2000M | 0–2000 | 0–0.01 | 10.0Ω + 40 μH | 2000 MΩ + 1.1 μF |

TABLE 1-1 OUTPUT RATINGS AND IMPEDANCES

## 1-8 SPECIFICATIONS, PERFORMANCE

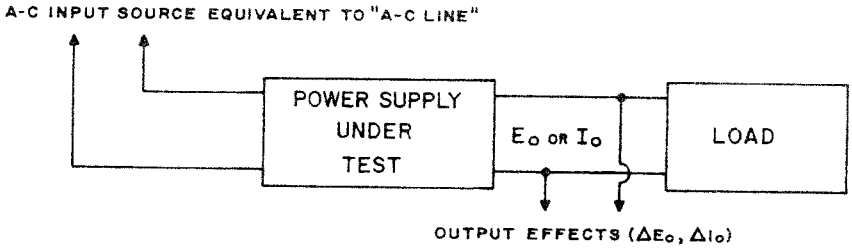
1-9 VOLTAGE CONTROL CHANNEL:

a) OPEN LOOP GAIN, D-C: $>1 \times 10^6$ V/V.
b) OUTPUT EFFECTS AND D-C OFFSETS: See Table 1-2.

NOTE 1: In this instruction manual the traditional terms "line regulation" and "load regulation" are not used. Instead, Kepco follows the NEMA standard for D-C Power Supplies (NEMA STD. PY-1-1972) and speaks of the "Output Effects" caused by changes in the "Influence Quantities." "Output Effects" are expressed either as a percentage change, referred to the maximum specified output voltage ($E_O$) or current ($I_O$), or as an absolute change ($\Delta E_O$, $\Delta I_O$), directly in millivolts or milliamperes or both. The illustration below will clarify the terminology:

INFLUENCE QUANTITIES

1) SOURCE
2) LOAD
3) TEMPERATURE
4) TIME




1) DUE TO SOURCE = SOURCE EFFECT . . . . . (equivalent to LINE REGULATION)
2) DUE TO LOAD = LOAD EFFECT . . . . . (equivalent to LOAD REGULATION)
3) DUE TO TEMPERATURE = TEMPERATURE EFFECT COEFFICIENT . (equivalent to TEMPERATURE COEFFICIENT)
4) DUE TO TIME = DRIFT . . . . . (equivalent to STABILITY)

NOTE 2: The output effects for power supplies used in the operational mode with external input and feedback components cannot be specified directly, since they depend on the value and quality of the external components added by the user. Instead, the d-c errors are specified at the input of the pre-amplifier as a change in "offset voltage" and "offset current" ($\Delta E_{io}$, $\Delta I_{io}$, see Table 1-2). To calculate the "worst case" output effects for ***your*** application, insert the value of the external feedback components and the specified offsets (see Table 1-2) into the ERROR EQUATION and calculate first the output effect of the pre-amplifier:

$$\Delta E_{pa} = \Delta E_{ref} (R_f/R_i) + \Delta E_{io} (1 + R_f/R_i) + \Delta I_{io} R_f,$$

where: $\Delta E_{pa}$ = Pre-Amp Output Voltage Change
$\Delta E_{ref}$ = Change in the Voltage Reference
$\Delta E_{io}$ = Change in Offset Voltage
$\Delta I_{io}$ = Change in Offset Current
$R_f$ = External Feedback Resistor
$R_i$ = External Input Resistor

NOTE: Variations in the value of the feedback and input resistors are considered secondary effects in the Error Equation.

Multiply the output effect of the pre-amplifier ($\Delta E_{pa}$) by the gain of the power amplifier section of your APH Model (APH 500M = 100, APH 1000M = 200, APH 2000M = 400) for the total output effect of the APH ($\Delta E_O$): $\Delta E_O = \Delta E_{pa} \times$ GAIN.

| INFLUENCE QUANTITY | | OUTPUT EFFECTS VOLTAGE MODE (4) | OUTPUT EFFECTS CURRENT MODE (Internal Sensing) | UNCOMMITTED PRE-AMPLIFIER OFFSETS $\Delta E_{io}$ | UNCOMMITTED PRE-AMPLIFIER OFFSETS $\Delta I_{io}$ | INTERNAL VOLTAGE REFERENCE ±6.2V ±5% (Internal) 1 mA max. |
|---|---|---|---|---|---|---|
| SOURCE: 105–125V a-c | | <0.001% | <0.005% or 0.2 μA(1) | <5 μV | <1 nA | <0.0005% |
| LOAD: No load – full load | | <0.005% | <0.01% of $I_o$ max. | NOT APPLICABLE | | |
| TIME: 8-hour [drift] | | <0.01% | <0.01% of $I_o$ max. | <20 μV | <1 nA | <0.005% |
| TEMPERATURE: Per °C | | <0.01% | <0.01% of $I_o$ max. | <20 μV | <2 nA | <0.005% |
| UNPROGRAMMED OUTPUT DEVIATION:(2) (Ripple and noise) | rms | <1.0 mV | <40 μA | NOT APPLICABLE | | |
| | p-p(3) | <5.0 mV | <200 μA | | | |

(1)Whichever is greater.

(2)One terminal must be grounded or connected so that the common mode current does not flow through the load or through a current sensing resistor.

(3)20 Hz to 10 MHz.

(4)Specifications are expressed as a percent-of-setting for the output range 10% to 100%. Below 10% output, the specification limit is the rated percentage of the 10% output setting.

TABLE 1-2 OUTPUT EFFECTS, REFERENCE AND D-C OFFSET SPECIFICATIONS, APH POWER SUPPLIES.

c) DYNAMICS: The time required for the stabilized output voltage to return to the load effect band (or 10 mV, whichever is greater) following a step in load current, is less than 50 microseconds.

1-10 CURRENT CONTROL CHANNEL

a) OUTPUT EFFECTS: See Table 1-2.

b) DYNAMICS: The speed with which the stabilized output current returns to the stabilization band following a step in load voltage (CURRENT RECOVERY) is either governed by the time constant of the load resistance and output shunt capacitance, or by the ratio $I_O/C_S$ ($I_O$ = current setting, $C_S$ = tabulated shunt capacitance, see Table 1-1), whichever is smaller.

## 1-11 MISCELLANEOUS FEATURES

a) VOLTAGE CHANNEL: Fixed feedback resistors (500 k ohm for APH 500M, 1 M ohm for APH 1000M and 2 M ohm for APH 2000M) are connected from the (-) output/sense terminal to the null junction of the main voltage amplifier. The null junction is brought to programming terminal (6) via a 5 K ohm resistor. A 0–5 volt control voltage source, connected from the (+) output/sense terminal (common) to the input (inverting) of the main voltage amplifier will program the output voltage through the rated range for local control. The control voltage is derived from the voltage control amplifier. For remote control, it can be provided via the uncommitted pre-amplifier, or it can be generated from an external source, such as a digitally controlled d-c programming source (see Kepco "SN" Series for example).

b) UNCOMMITTED PRE-AMPLIFIER: The input and output terminals of the UNCOMMITTED PRE-AMPLIFIER are available at the rear barrier-strip terminals. This amplifier may be used for signal processing or for passive resistance programming of the APH voltage or current output.

c) CURRENT CHANNEL: The current control channel may be used as a current limiter or as a continuously adjustable d-c current source (Specified Performance, see Table 1-2). For local control, the internal current control amplifier and a front panel multiturn rheostat control the output current over the full range. For remote control, a separate current control amplifier is provided. Its input is available at the rear barrier-strip. A 0–1 volt d-c control potential will program the output current over the full range. The control signal can be provided via the UNCOMMITTED PRE-AMPLIFIER or it can be generated from an external source, such as a digitally controlled d-c programming source (see Kepco "SN" Series for example).

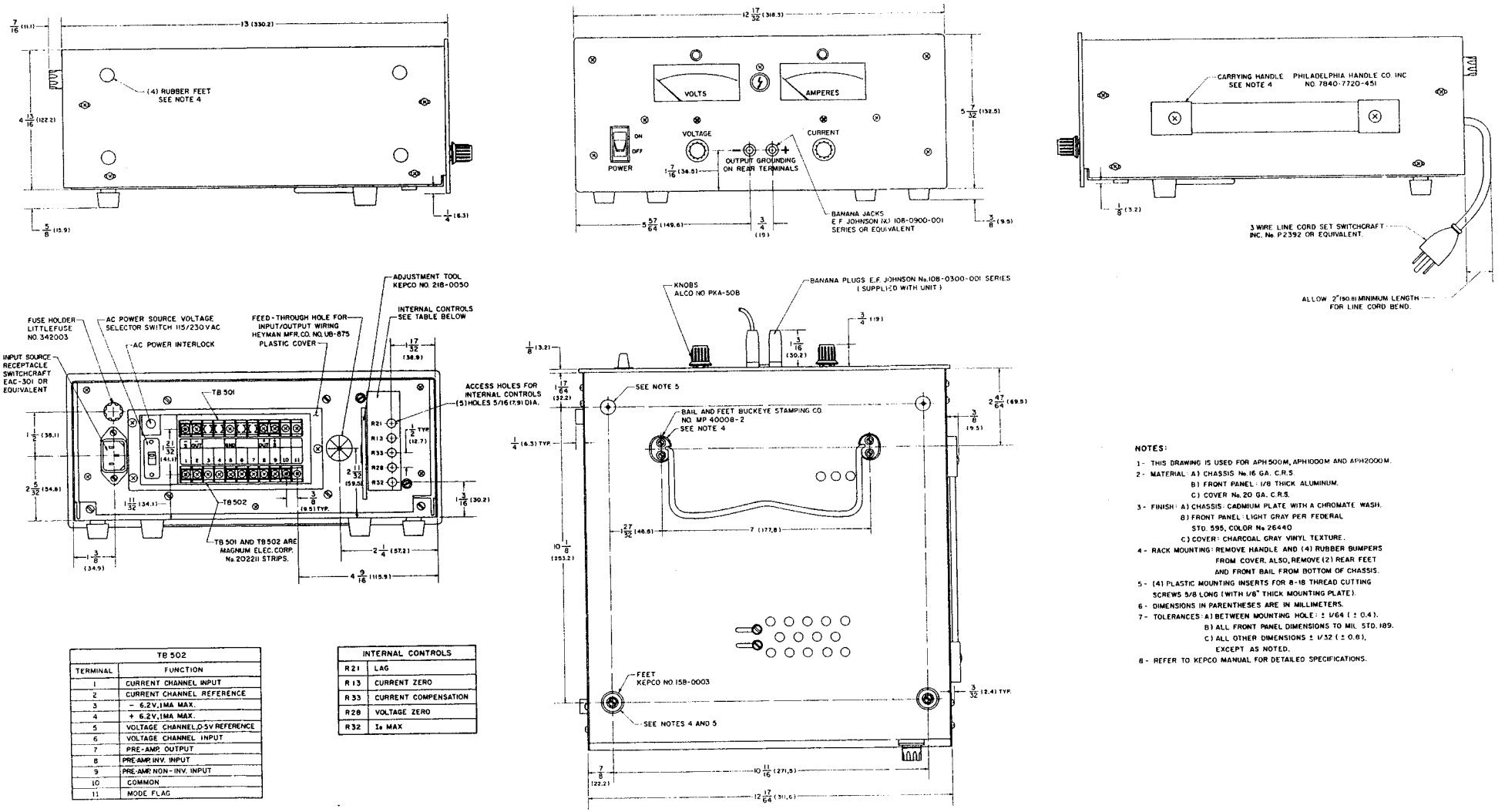
d) REMOTE ERROR SENSING: Provisions are made for a 4-terminal connection to a remote load. The effects of static voltage drops along the load wire (up to 0.5 volt per lead) can thus be eliminated.

e) OFFSET NULLING: The initial (static) part of the main voltage amplifier's offset ($E_{io}$, $I_{io}$) can be zeroed by a built-in multiturn trimmer.

f) REFERENCES: A pair of nominal ±6.2V reference voltage sources [1 mA maximum referenced to the (+) output/sense terminal] are available at the designated terminals on the rear barrier strip.

## 1-12 SPECIFICATIONS, MECHANICAL

Refer to the "Mechanical Outline Drawing," FIG. 1-2.




| TB 502 | |
|---|---|
| TERMINAL | FUNCTION |
| 1 | CURRENT CHANNEL INPUT |
| 2 | CURRENT CHANNEL REFERENCE |
| 3 | - 6.2V, 1MA MAX. |
| 4 | + 6.2V, 1MA MAX. |
| 5 | VOLTAGE CHANNEL, 0-5V REFERENCE |
| 6 | VOLTAGE CHANNEL INPUT |
| 7 | PRE-AMP. OUTPUT |
| 8 | PRE-AMP. INV. INPUT |
| 9 | PRE-AMP. NON-INV. INPUT |
| 10 | COMMON |
| 11 | MODE FLAG |

| INTERNAL CONTROLS | |
|---|---|
| R21 | LAG |
| R13 | CURRENT ZERO |
| R33 | CURRENT COMPENSATION |
| R28 | VOLTAGE ZERO |
| R32 | Io MAX |

NOTES:

1 - THIS DRAWING IS USED FOR APH500M, APH1000M AND APH2000M.
2 - MATERIAL: A) CHASSIS No. 16 GA. C.R.S.
B) FRONT PANEL: 1/8 THICK ALUMINUM.
C) COVER No. 20 GA. C.R.S.
3 - FINISH: A) CHASSIS: CADMIUM PLATE WITH A CHROMATE WASH.
B) FRONT PANEL: LIGHT GRAY PER FEDERAL STD. 595, COLOR No. 26440
C) COVER: CHARCOAL GRAY VINYL TEXTURE.
4 - RACK MOUNTING: REMOVE HANDLE AND (4) RUBBER BUMPERS FROM COVER. ALSO, REMOVE (2) REAR FEET AND FRONT BAIL FROM BOTTOM OF CHASSIS.
5 - (4) PLASTIC MOUNTING INSERTS FOR 8-18 THREAD CUTTING SCREWS 5/8 LONG (WITH 1/8" THICK MOUNTING PLATE).
6 - DIMENSIONS IN PARENTHESES ARE IN MILLIMETERS.
7 - TOLERANCES: A) BETWEEN MOUNTING HOLE: ± 1/64 (± 0.4).
B) ALL FRONT PANEL DIMENSIONS TO MIL STD. 189.
C) ALL OTHER DIMENSIONS ± 1/32 (± 0.8), EXCEPT AS NOTED.
8 - REFER TO KEPCO MANUAL FOR DETAILED SPECIFICATIONS.

FIG. 1-2 MECHANICAL OUTLINE DRAWING.

# SECTION II – INSTALLATION

## 2-1 UNPACKING AND INSPECTION

2-2 This instrument has been thoroughly inspected and tested prior to packing and is ready for operation. After careful unpacking, inspect for shipping damage before attempting to operate. Perform the preliminary functional check as outlined in par. 2-11 below. If any indication of damage is found, file an immediate claim with the responsible transport service.

## 2-3 TERMINATIONS

a) FRONT PANEL: Refer to FIG. 2-1.

b) REAR: Refer to FIG. 2-2.

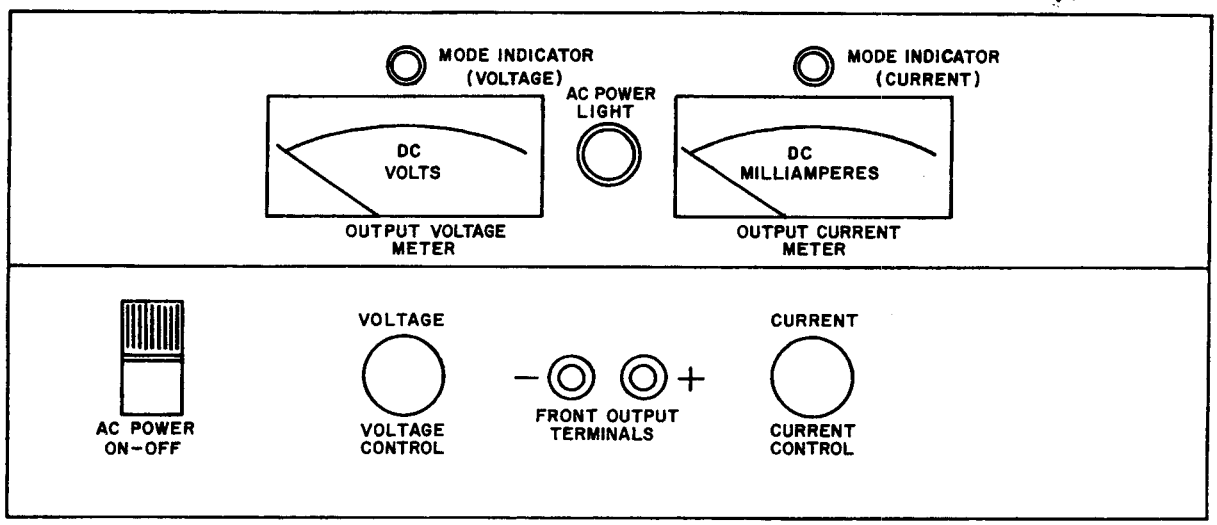



FIG. 2-1 FRONT PANEL, KEPCO APH MODELS.

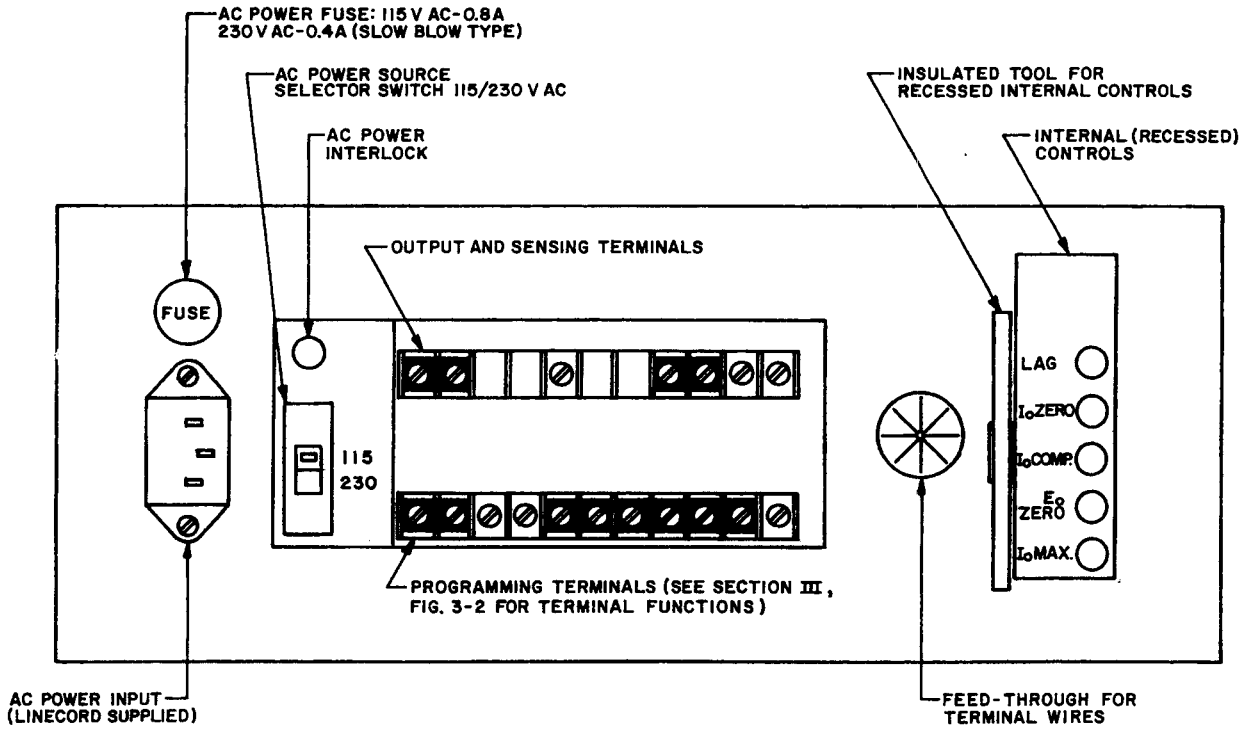



FIG. 2-2 REAR TERMINATIONS, KEPCO APH MODELS.

## 2-4 A-C POWER REQUIREMENTS

2-5 The Kepco APH Power Supply is normally delivered for operation on a single phase, 105 to 125V a-c source, 50 to 65 Hz. For operation on 210 to 250V sources, the a-c source selector switch, as well as the power fuse value, must be changed as follows: (See also FIG. 2-2).

| A-C POWER SOURCE SELECTOR | FUSE VALUE |
|---|---|
| 115V a-c | 0.8 AMP, SLOW BLOW TYPE |
| 230V a-c | 0.4 AMP, SLOW BLOW TYPE |

## 2-6 GROUNDING

**WARNING**

2-7 *A-C SAFETY GROUND.* THE DANGEROUS VOLTAGES PRESENT IN THIS EQUIPMENT MAKE IT IMPERATIVE THAT THE CASE IS KEPT AT GROUND POTENTIAL AT ALL TIMES. If the 3-wire line cord with 3-prong safety plug (supplied with this equipment) is used in combination with a properly grounded outlet, this is taken care of automatically. If an adapter for a nongrounded outlet is used, however, the case must be grounded separately. A separate "GROUND" terminal is provided for this purpose on the rear of the APH. (See Section III, FIG. 3-2.)

2-8 *D-C SIGNAL GROUND.* It is good practice to ground one side of the output at all times. Where the circuit requirements do not permit grounding of the output, additional precautions against dangerous electrical shocks must be taken. Equipment used in conjunction with high voltage power supplies must be able to withstand the operating voltage of the latter. Properly insulated wires are essential. Refer also to Section III, par. 3-3c for more signal grounding details. **Output ripple measurements on a "floating" (ungrounded) power supply output require battery-operated instrumentation. The instrument must be insulated to make inadvertent touch impossible.**

## 2-9 COOLING

2-10 The Kepco Operational Power Supply is designed for adequate convection cooling through the wrap-around perforated case under specified operating conditions. ***Sufficient space around the unit must be allowed for free air circulation.*** If the instrument must be mounted into confined spaces, forced air cooling may be necessary to keep the surrounding air within the specified ambient temperature limits.

## 2-11 FUNCTIONAL CHECK

2-12 A simple operating check, after unpacking and before permanent installation, is advisable to ascertain whether the APH has suffered damage resulting from shipment. Refer to FIG. 2-1 and FIG. 2-2 for the location of the operating controls and the rear terminals.

**WARNING**

*THIS INSTRUMENT IS CAPABLE OF PRODUCING LETHAL VOLTAGES:*

1) REMOVE A-C INPUT POWER FROM THE APH BEFORE REMOVING THE METAL WRAP-AROUND COVER. EXERCISE EXTREME CARE IN MAKING ALL CONNECTIONS TO AND FROM THE FRONT AND REAR TERMINALS.

2) WIRES AND/OR CABLES, CONNECTED FROM THE APH TERMINALS TO EXTERNAL COMPONENTS OR PROGRAMMING DEVICES MUST BE PROPERLY INSULATED AND SECURELY TERMINATED ON BOTH ENDS, TO MAKE ACCIDENTAL TOUCH IMPOSSIBLE. RE-INSTALL REAR PROTECTIVE TERMINAL COVER AFTER ALL CONNECTIONS TO THE APH HAVE BEEN COMPLETED.

3) *THE APH CHASSIS AND COVER MUST BE SAFETY-GROUNDED TO A RELIABLE A-C SOURCE GROUND.* A SAFETY-GROUND MAY BE ESTABLISHED BY USING A GROUNDED A-C POWER OUTLET OR, IF THE LATTER IS NOT AVAILABLE, BY MEANS OF A SEPARATE WIRE, FROM THE PROVIDED "GROUND" TERMINAL TO A RELIABLE A-C SOURCE GROUND POINT.

4) IF POSSIBLE, EITHER THE POSITIVE, OR THE NEGATIVE OUTPUT TERMINAL OF THE APH SHOULD BE SIGNAL GROUNDED. IF FOR ANY REASON, GROUNDING OF THE OUTPUT IS NOT POSSIBLE, ADDITIONAL PRECAUTIONS MUST BE TAKEN TO MAKE INADVERTENT ACCESS TO THE ISOLATED OUTPUT IMPOSSIBLE. ***EXTERNAL PROGRAMMING SOURCES MUST BE ISOLATED FROM THE A-C POWER SOURCE FOR A MINIMUM OF 2000 VOLTS,*** IF THE NEGATIVE OUTPUT IS GROUNDED.

5) ***FOR ANY INTERNAL CONTROL ADJUSTMENTS ON THE APH, USE THE INSULATED TOOL WHICH IS ATTACHED AT THE REAR, OR A SIMILARLY INSULATED SCREWDRIVER.***

2-13 PROCEDURE, FUNCTIONAL CHECK

1) Connect the APH to a grounded a-c power outlet. Turn the front panel VOLTAGE CONTROL rheostat to the maximum counterclockwise position. Set CURRENT CONTROL to its midrange.

2) Turn APH A-C POWER SWITCH "on." The APH uses vacuum tubes as the series pass element. Before full output is available, a warm-up delay of about 25 seconds after turn-on is provided to allow the vacuum tube cathodes to reach proper operating temperature. Ovserve the FRONT PANEL VOLTMETER and turn the VOLTAGE CONTROL potentiometer clockwise. The output voltage of the APH should increase smoothly from zero to the maximum rated d-c output voltage, as the VOLTAGE CONTROL is turned through its range. Turn VOLTAGE CONTROL to zero output volts again and turn APH A-C POWER SWITCH "off."

3) Connect a "short circuit" across the output terminals of the APH Power Supply. Set the front panel VOLTAGE CONTROL to its approximate mid position.

4) Turn the APH Power Supply "on." Allow for a warm-up time of approximately 25 seconds.

5) Turn the front panel CURRENT CONTROL slowly fully clockwise. Observe the front panel OUTPUT CURRENT METER. The APH output current should smoothly increase from zero to the maximum rated value of the APH Power Supply as the front panel OUTPUT CURRENT CONTROL is turned through its range.

6) Turn A-C POWER SWITCH "off." Remove the short circuit from the APH output terminals. This concludes the preliminary check of the APH Power Supply.

## 2-14 INSTALLATION (See "Mechanical Outline Drawing," Section I, FIG. 1-2)

2-15 APH models can be operated directly on the bench, or they can be rack-mounted, using the Kepco RA–24 hardware systems. For rack-mounting, the four bottom feet and the front bail of the APH must be removed.

## 2-16 LOAD CONNECTION (See also Section III, par. 3-3 a,b)

2-17 The load may be connected in either one of the ways illustrated in FIG. 2-3. IMPORTANT NOTE: IF ERROR SENSING IS USED, THE SHORTING LINKS BETWEEN OUTPUT AND SENSING TERMINALS MUST BE COMPLETELY REMOVED. IF ERROR SENSING IS NOT USED, THE LINKS MUST BE CONNECTED AT THE REAR.

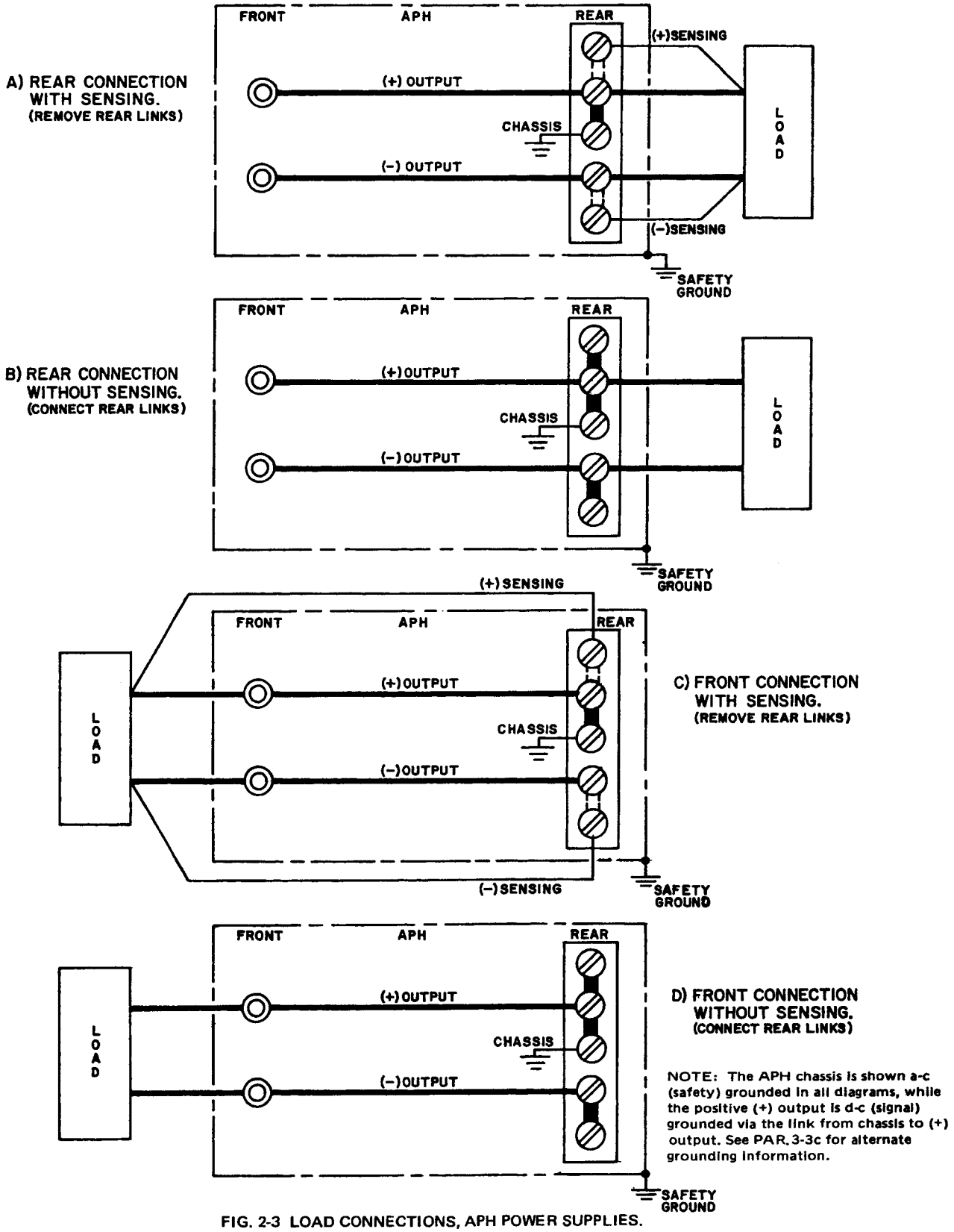



FIG. 2-3 LOAD CONNECTIONS, APH POWER SUPPLIES.

# SECTION III – OPERATION

## 3-1 GENERAL

3-2 Kepco APH Power Supplies are precision stabilized, two channel d-c sources, which can be used in a variety of operating modes:

a) As a precision VOLTAGE OR CURRENT SOURCE, the control channels of the APH are utilized with either local feedback (built-in, 10-turn front panel rheostats), with external feedback (remote control resistance), or programmed with external control voltages. With either control method, the APH output is stabilized and controlled over the full rated range of the APH model. The operating mode ("Voltage Mode" or "Current Mode") is determined by the load resistance and by the magnitude of the set (at the front panel or externally) output quantities. If, in Figure 3-1, "$E_O$" (output voltage) and "$I_O$" (output current) represent the respective settings of the APH output quantities, set by means of front panel or external controls, the "crossover" resistance ($R_{LX}$) is given by Ohm's Law:

$$R_{LX} = E_O/I_O$$

Any load resistance ***smaller*** than $R_{LX}$ (as for example $R_{LI}$ in FIG. 3-1) will transfer the APH into the "Current Mode." With any load resistance ***larger*** than $R_{LX}$ (as for example $R_{LV}$ in FIG. 3-1), the APH will operate in the "Voltage Mode." The prevailing operating mode is indicated by means of front panel mode indicator lamps.

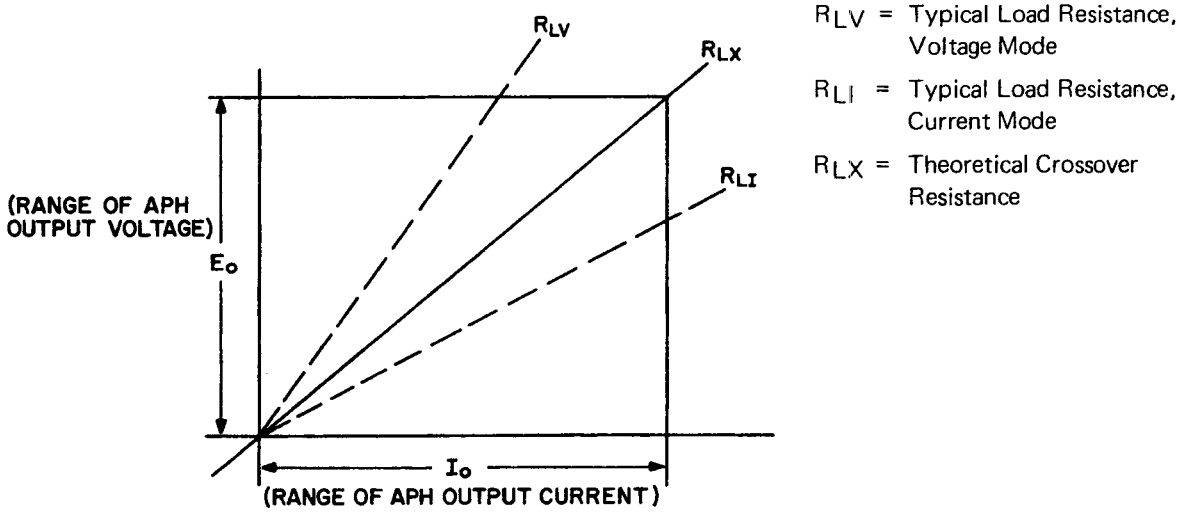



FIG. 3-1 OUTPUT VOLTAGE/CURRENT CHARACTERISTIC, APH.

b) As a unipolar VOLTAGE OR CURRENT AMPLIFIER, the control channels of the APH can be used, with either local or external feedback as the gain control, to amplify external input signals to the maximum rated APH output voltage or current. As a unipolar amplifier, the APH has a potentially high power gain but limited frequency response, largely due to the output capacitor acting as a low pass filter.

3-3 Detailed description of these and other operating modes will be given in the following paragraphs. BEFORE ACTUAL OPERATION, however, the following important general comments on power supply operation should be considered:

a) LOAD CONNECTION (I). The basic interconnection between the APH and the load are shown in SECTION II, FIG. 2-3b,d. The load wire size for the 2-wire connection shown should be as large as practicable to keep the series resistance and inductance low. In addition, the load wire pair should be tightly twisted, to reduce possible "pick-up" from stray magnetic fields. The basic 2-wire connection is useful where the voltage drop in the load wires is of minor consequence, as for example, operation into a constant load or in a constant current operating mode.

b) LOAD CONNECTION (I). The recommended load connection for all applications requiring minimum load effect across a ***remote*** load is shown in SECTION II, FIG. 2-3a,c. A twisted, shielded pair of wires (No. 20 AWG minimum) are connected from the APH "± sensing" terminals to the load. This "remote error sensing" technique will compensate for load wire voltage drops up to 0.5 volts per wire.

NOTE: OBSERVE POLARITIES:
THE ***NEGATIVE*** SENSING WIRE MUST GO TO THE ***NEGATIVE*** LOAD WIRE.
THE ***POSITIVE*** SENSING WIRE MUST GO TO THE ***POSITIVE*** LOAD WIRE.

c) GROUNDING

1) A-C (SAFETY) GROUND (See Section II, par. 2-7).

2) D-C (SIGNAL) GROUND. The ***positive*** side of the APH output is shown grounded in all application diagrams, since it is "common" to both, internal reference source and any external signal input source. If the application requires, the ***negative*** side of the APH output may be signal-grounded or the APH output may be left ungrounded (floating). In the latter case, however, the ripple and noise level will increase somewhat, since the common-mode current (specified in Section I, par. 1-7e) now flows through the load (Voltage Mode) or through the sensing resistor (Current Mode). To reduce the ripple and noise level when operating with an ungrounded (floating) APH output, a capacitor/resistor series combination (0.1 μF, paralleled by 10 MΩ and in series with 10 ohm) may be connected from either APH output to ground. All components must be of high quality. The capacitor must be rated for at least 3 KV. The signal ground point in the APH/load circuit must consist of a ***single point*** only, to which all input source grounds, shields and load grounds are connected. Multiple signal grounds in the APH output/load circuit cause "ground-loop" problems, since noise signals develop across the impedances between the multiple ground points. The exact physical location of the "best" single ground point must be carefully selected for minimum ripple/noise output.

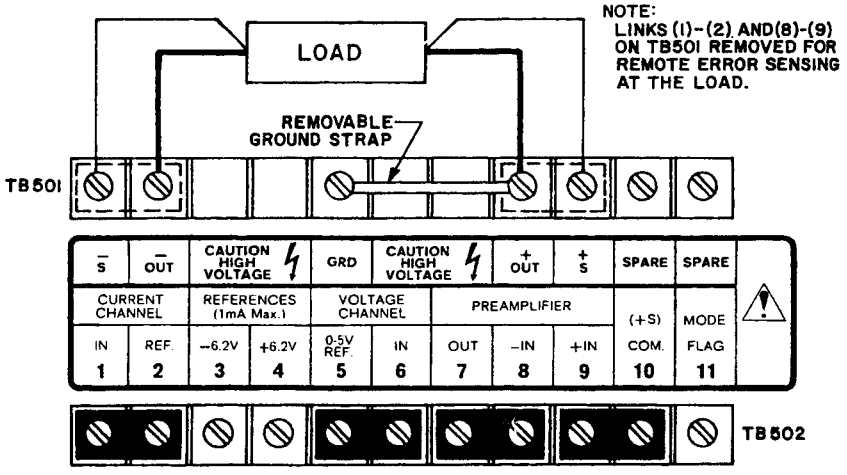



**FIG. 3-2 REAR TERMINAL CONNECTIONS, APH POWER SUPPLY SET-UP FOR STANDARD VOLTAGE MODE OR CURRENT MODE OPERATION WITH LOCAL (FRONT PANEL) CONTROL OF THE OUTPUT.**

**NOTE:** Grounding in FIG. 3-2, as well as in all other connection diagrams is indicated by means of the "ground strap," connected from the "(+) output" to "ground" terminal on TB501. Since the APH chassis is safety grounded by means of the 3-wire line cord, and the "ground" terminal is connected to the APH chassis, this connection serves as the "signal ground" in all diagrams, The ground strap may be removed, however, and the "signal ground" may be established elsewhere in the APH output/load circuit.

## 3-4 STANDARD VOLTAGE MODE OPERATION, LOCAL (FRONT PANEL) CONTROL.

3-5 Once the load is connected to the output terminals of the APH Power Supply and safety, as well as signal grounding rules have been applied as described (refer to par. 3-3c), power supply operation can proceed:

1) Temporarily, disconnect the load and turn the APH front panel VOLTAGE CONTROL and CURRENT CONTROL completely counterclockwise, and then clockwise for one turn. Turn A-C POWER SWITCH "on" (the voltage mode indicator light should be "on" and the output will be present after a delay of approximately 25 seconds. Observe front panel VOLTMETER and adjust VOLTAGE CONTROL to the desired output voltage level. Turn a-c power "off."

2) Apply a short circuit across the output terminals of the APH Power Supply. Turn A-C POWER SWITCH "on" (the current mode indicator light should be "on" after the 25 second delay).

3) Observe front panel CURRENT METER and adjust CURRENT CONTROL to the required load current value, plus 5%. Turn A-C POWER SWITCH "off."

4) Remove the short circuit from the output terminals. Reconnect the load. The power supply is now ready for operation.

## 3-6 STANDARD CURRENT MODE OPERATION, LOCAL (FRONT PANEL) CONTROL.

3-7 Apply all safety and signal grounding rules as described previously. Proceed as follows:

1) ***BEFORE*** connecting the load to the power supply output terminals: Turn A-C POWER switch "on" (the voltage mode indicator light should be "on"). After the time delay, observe the front panel VOLTMETER and adjust the VOLTAGE control to the required compliance (output voltage) level. Turn A-C POWER switch "off" and connect a short circuit to the output terminals of the APH.

2) Turn A-C POWER switch "on." Observe the front panel CURRENT METER and adjust CURRENT CONTROL to the desired value. The current mode indicator light should go "on" (after the time delay) to indicate that the power supply is truly in the current mode of operation. Turn A-C POWER SWITCH "OFF."

3) Remove the short circuit, connect the load and turn A-C POWER switch "on." If the APH does not enter the current mode (as indicated by the front panel indicator), the load resistance ($R_L$) is too high. ***Either*** $R_L$ must be ***decreased, or*** the VOLTAGE CONTROL setting must be ***increased, or*** the CURRENT CONTROL setting must be ***decreased.*** The APH is now ready for operation.

## 3-8 REMOTE CONTROL OF THE APH OUTPUT

3-9 GENERAL. The Voltage Control Channel, as well as the Current Control Channel of the APH Power Supply are accessible for the remote control (PROGRAMMING) of the output voltage and/or the output current respectively. The two control channels can be programmed individually or simultaneously by means of either passive (resistance) or active (voltage/current) control signals. Representative programming examples are described and illustrated in the following paragraphs. These examples constitute only a few of the many possible programming circuit variations. Please consult the Kepco Engineering Application Department for assistance with problems concerning ***your*** specific application. ***Before*** connecting ***any*** programming circuit, please review the previous comments on GROUNDING and LOAD CONNECTIONS (see par. 3-3) as well as the following:

a) DIAGRAMS. Application and test set-up diagrams in this section and in Section V of this manual represent the APH Power Supply by means of the barrier-strip terminal drawing shown in FIG. 3-2 A FOLD-OUT DIAGRAM IS PROVIDED AT THE END OF THIS SECTION (SECTION III) RELATING THE BARRIER-STRIP TERMINALS TO THE ACTUAL CIRCUITRY OF THE APH POWER SUPPLY.

b) EXTERNAL PROGRAMMING RESISTORS. External programming resistors should be high-quality units, with low-temperature coefficients. Resistors should be selected carefully, so that their specifications do not limit the performance of the APH Power Supply. Selection criteria for resistors are:

1) TEMPERATURE COEFFICIENT
2) LEAKAGE (IN VALUES ABOVE 100 k OHM)
3) HUMIDITY EFFECTS
4) DRIFT WITH TIME
5) SELF-HEATING
6) TOLERANCE

For variable resistors (potentiometers or rheostats) similar selection criteria apply. In addition, such specifications as listed below should be carefully considered if the application requires:

1) END RESISTANCE
2) LINEARITY
3) CAPACITIVE AND INDUCTIVE EFFECTS

c) ACTIVE PROGRAMMING SOURCES. External programming sources (Signal Generators, etc.,) or reference sources should have temperature coefficients and drift specifications comparable to (or better than) the APH Power Supply. CAUTION: A-C source operated programming sources must have their output isolated from the case. Older signal generators which do not have isolated outputs, can only be used if their metal case can be connected to the APH "common."

d) EXTERNAL SWITCHES. Switching devices, used for step-voltage or current programming of the APH, should be of the "make before break" type.

e) EXTERNAL LEADS. Shielded (preferably twisted) lead pairs are recommended for all input connections to the APH control channels. The shield should be connected (single-ended) to the chosen signal ground point. Shielded leads should be held as short as practicable. Output leads must be "high voltage" wire, rated at least for the maximum APH output voltage.

**WARNING**

***THIS INSTRUMENT IS CAPABLE OF PRODUCING LETHAL VOLTAGES:***

1) EXERCISE EXTREME CARE IN MAKING ALL CONNECTIONS TO AND FROM THE APH TERMINALS. ***REMOVE A-C POWER FROM THE APH BEFORE MAKING ANY CONNECTIONS!***

2) AN INTERLOCK DEVICE REMOVES THE A-C SOURCE POWER FROM THE APH IF THE REAR COVER IS REMOVED. ***DO NOT BYPASS THE INTERLOCK!***

3) WIRES AND/OR CABLES, CONNECTED FROM THE APH TERMINALS TO EXTERNAL COMPONENTS OR PROGRAMMING DEVICES MUST BE PROPERLY INSULATED AND SECURELY TERMINATED ON BOTH SIDES, TO MAKE ACCIDENTAL TOUCH IMPOSSIBLE. A FEED-THROUGH HOLE IS PROVIDED ON THE APH REAR PANEL TO BRING THE WIRES FROM THE APH REAR TERMINALS TO THE OUTSIDE.

4) ***THE APH CHASSIS AND COVER MUST BE SAFETY-GROUNDED TO A RELIABLE A-C SOURCE GROUND.*** A SAFETY-GROUND MAY BE ESTABLISHED BY USING A GROUNDED A-C POWER OUTLET OR, IF THE LATTER IS NOT AVAILABLE, BY MEANS OF A SEPARATE WIRE, FROM THE PROVIDED "GROUND" TERMINAL TO A RELIABLE A-C SOURCE GROUND POINT.

5) IF POSSIBLE, EITHER THE POSITIVE, OR THE NEGATIVE OUTPUT TERMINAL OF THE APH SHOULD BE SIGNAL GROUNDED. IF FOR ANY REASON, GROUNDING OF THE OUTPUT IS NOT POSSIBLE, ADDITIONAL PRECAUTIONS MUST BE TAKEN TO MAKE ANY ACCESS TO THE ISOLATED OUTPUT IMPOSSIBLE. ***EXTERNAL PROGRAMMING SOURCES MUST BE ISOLATED FROM THE A-C POWER SOURCE FOR A MINIMUM of 2000 VOLTS,*** IF THE NEGATIVE OUTPUT IS GROUNDED.

6) ***FOR ALL INTERNAL CONTROL ADJUSTMENTS ON THE APH, USE ONLY THE INSULATED TOOL WHICH IS ATTACHED AT THE REAR, OR A SIMILARLY INSULATED SCREWDRIVER.***

## PROGRAMMING THE VOLTAGE CONTROL CHANNEL

### 3-10 OUTPUT VOLTAGE CONTROL BY EXTERNAL RESISTANCE

3-11 The basic method of output voltage control in the APH is by means of a 0 to 5 volt control voltage, applied to the MAIN VOLTAGE AMPLIFIER. This amplifier has a fixed gain (100 for APH 500M, 200 for APH 1000M, 400 for APH 2000M) which produces the full output voltage swing for the above control voltage.

For internal control (by means of the front panel VOLTAGE CONTROL), the VOLTAGE CONTROL AMPLIFIER produces the control potential. For external or remote control, the latter is disconnected and an external control potential of 0–5 volt must be substituted and applied to the MAIN VOLTAGE AMPLIFIER. The general method of output voltage control can be expressed by the equation:

$E_o$ = CONTROL VOLTAGE (0–5V) X GAIN (Eq. 1), where:

$E_o$ = APH OUTPUT VOLTAGE

GAIN = 100 (APH 500M)
200 (APH 1000M)
400 (APH 2000M)

3-12 POTENTIOMETER CONTROL. If the APH output voltage is to be controlled by means of a potentiometer, the VOLTAGE CONTROL AMPLIFIER is disconnected and the control voltage is produced by means of the PRE-AMPLIFIER and the built-in REFERENCE potential.

3-13 Since the REFERENCE potential is nominally 6.2 volts, a resistive divider is used across it, consisting of the EXTERNAL VOLTAGE CONTROL and the CAL. rheostat. The CAL. rheostat enables us to adjust the control voltage to exactly 5 volts across the EXTERNAL VOLTAGE control. The wiper of the EXTERNAL VOLTAGE CONTROL potentiometer is now connected to the non-inverting PRE-AMPLIFIER input so that the control voltage is repeated at its output, which is in turn connected to the MAIN VOLTAGE AMPLIFIER INPUT. (See connecting diagram FIG. 3-3 and fold-out diagram FIG. 3-15.)

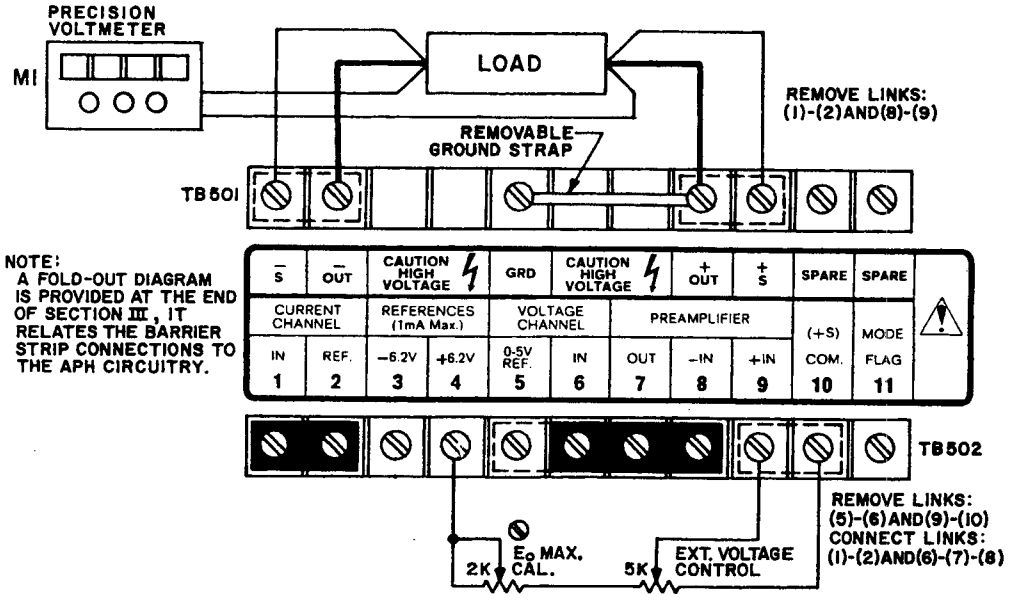



FIG. 3-3 CONNECTIONS FOR REMOTE APH OUTPUT VOLTAGE CONTROL WITH A POTENTIOMETER.

3-14 POTENTIOMETER CONTROL, PROCEDURE

1) Connect the potentiometer (EXTERNAL VOLTAGE CONTROL), the calibrating rheostat ($E_o$ CAL.), the LOAD and the OUTPUT VOLTMETER (M1) to the APH as shown in FIG. 3-3. FOR INTERCONNECTION DETAILS AND PRECAUTIONS, TURN TO THE -"WARNING" PARAGRAPH ON PAGE 3-4.

2) Turn the EXTERNAL VOLTAGE CONTROL to the position yielding minimum output. Turn APH "on."

3) Vary the EXTERNAL VOLTAGE CONTROL through its complete range. The APH output, as read out on M1, should vary from approximately zero to its maximum rated output voltage. Return EXTERNAL VOLTAGE CONTROL to the "initial" position (zero volts output).

3-15 CALIBRATION (Refer to Section II, FIG. 2-2 for the location of all internal controls)

1) Check the OUTPUT VOLTMETER (M1) for zero reading and correct if necessary by adjusting the $E_o$ ZERO control.

2) Set EXTERNAL VOLTAGE CONTROL to its maximum position. Observe OUTPUT VOLTMETER (M1). Calibrate the output voltage to the exact maximum rated voltage of the APH by adjusting the external rheostat ($E_o$ CAL.) to this value.

3) Set EXTERNAL VOLTAGE CONTROL to zero again, recheck the previously calibrated zero point on M1 and correct with the $E_o$ ZERO control if necessary.

4) Set the front panel CURRENT CONTROL to the required output current value or use one of the illustrated programming circuits for remote output current control. (See par. 3-26 to 3-36.)

5) Operation can now proceed. Check output by means of an oscilloscope. (CAUTION: HIGH VOLTAGE PROBE REQUIRED) for dynamic stability and output ripple. Refer to Section III, par. 3-3 if high output ripple is evident. Refer to Section V, par. 5-6a if dynamic instability is encountered.

3-16 TWO-TERMINAL RESISTANCE CONTROL. The APH output voltage can be linearly controlled by means of an external resistance decade, rheostat or any other two terminal resistance network. Identical theoretical considerations as set forth in the previous programming circuit apply (see par's. 3-11, 3-12) except that the 0 to 5 volt control voltage for the MAIN VOLTAGE AMPLIFIER is produced by a different method.

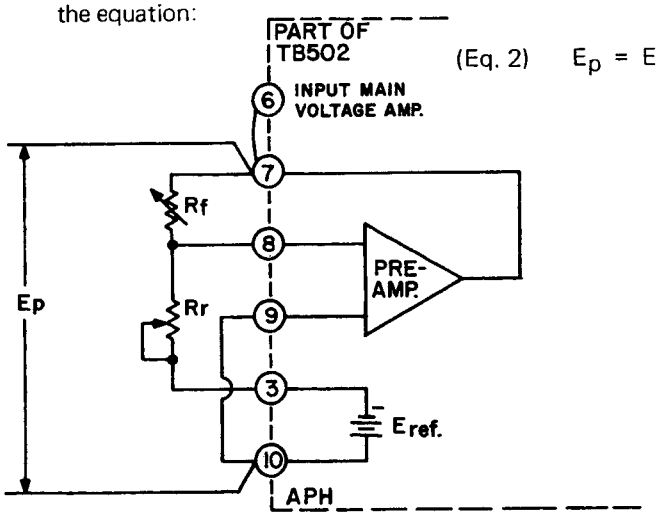
3-17 The APH PREAMPLIFIER is used here in the inverting configuration. Its output voltage can be expressed by the equation:

(Eq. 2) $E_p = E_r/R_r\,(R_f)$, where: $E_p$ = Pre-amp output voltage serving as the control voltage (0–5 volts).

$E_{ref}$ = 6.2V reference voltage (internal).

$R_r$ = reference resistor (external).

$R_f$ = feedback resistor, serving as the External Voltage Control.




GENERATING THE CONTROL VOLTAGE

3-18 The ratio $E_r/R_r$ can be expressed as a control current ($E_r/R_r = I_b$), which with the 6.2 volt reference potential and a 6.2 K reference resistor is selected to be 1 mA. Consequently, Eq. 2 can now be simplified to: $E_o = I_b\,(R_f)$, (Eq. 3), so that for a zero to 5 volt control voltage, a zero to 5 kilohm resistance change is required.

3-19 If the suggested control resistance value ($R_f$ = 5 K ohm) is not available, other values may be substituted, making use of equations (2) and (3). If, for example, control is to be exercised by a 10 Kilohm resistance decade, the required control current ($I_b$) is first found by inserting the known quantities into Eq. 3:

$$0\text{–}5 \text{ volts} = I_b\,(0\text{–}10\ K\Omega) = 0.5 \text{ mA}.$$

$$\text{Since } I_b = E_r/R_r, \text{ and } E_r = 6.2 \text{ volts (nominal)}$$

$$\text{The new } R_r \text{ must be: } \frac{6.2V}{R_r} = 0.5 \text{ mA}, R_r = 12.4\ K\Omega$$

3-20 TWO-TERMINAL RESISTANCE CONTROL, PROCEDURE

1) Connect the selected feedback resistor ($R_f$ = EXTERNAL VOLTAGE CONTROL), the reference resistor ($R_r$). Note: Make part of $R_r$ adjustable for $E_o$ CAL. control), the LOAD and the OUTPUT VOLTMETER (M1) to the APH as shown in FIG. 3-4. NOTE: FOR INTERCONNECTION DETAILS AND PRECAUTIONS, TURN TO THE "WARNING" PARAGRAPH ON PAGE 3-4.

2) Turn the EXTERNAL VOLTAGE CONTROL to its minimum resistance position. Turn APH "on."

3) Vary the EXTERNAL VOLTAGE CONTROL from its minimum to its maximum resistance position. The APH output, as read out on M1, should vary from approximately zero to its maximum rated output voltage. Return EXTERNAL VOLTAGE CONTROL to its minimum resistance position.

3-21 CALIBRATION (Refer to Section II, FIG. 2-2 for the location of all internal controls)

1) Check the OUTPUT VOLTMETER (M1) for "zero" reading and correct if necessary by adjusting the $E_O$ ZERO control.

2) Set EXTERNAL VOLTAGE CONTROL to its maximum resistance position. Observe the OUTPUT VOLTMETER (M1). Calibrate the output voltage to the exact maximum rated APH output voltage by adjusting the external reference resistor ($E_O$ CAL.) to this value.

3) Set EXTERNAL VOLTAGE CONTROL to "zero" again, recheck the previously calibrated zero point on M1 and correct with the $E_O$ ZERO control if necessary.

4) Set the front panel CURRENT CONTROL to the required output current value or use one of the illustrated programming circuits for remote output current control (see par's. 3-26 to 3-36).

5) Operation can now proceed. Check output by means of an oscilloscope. (CAUTION: HIGH VOLTAGE PROBE REQUIRED) for dynamic stability and output ripple. Refer to Section III, par. 3-3 if high output ripple is evident. Refer to Section V, par. 5-6a if dynamic instability is encountered.

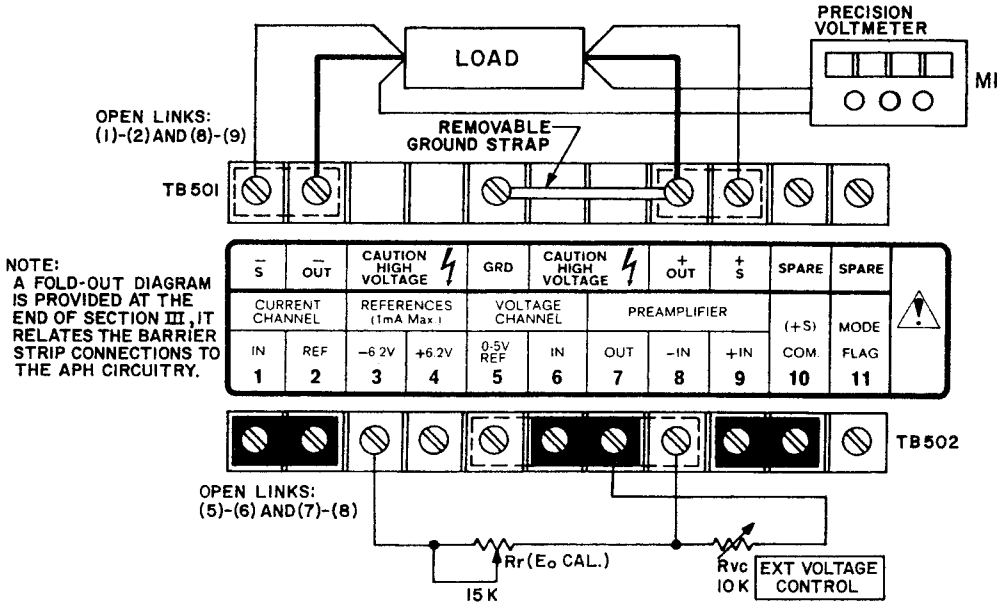



FIG. 3-4 CONNECTIONS FOR APH OUTPUT VOLTAGE CONTROL WITH A TWO-TERMINAL RESISTANCE.

**3-22 OUTPUT VOLTAGE CONTROL BY MEANS OF AN EXTERNAL CONTROL VOLTAGE.** To control the APH output voltage between zero and its maximum rated value, a control potential varying from zero to 5 volts must be applied to the input of the MAIN VOLTAGE AMPLIFIER input (TB502-6) with reference to COMMON (TB502-10). As described in previous paragraphs, the control potential can be developed by the internal VOLTAGE CONTROL amplifier (as in the local or front panel control mode), from the internal reference source in combination with an external potentiometer, or from the internal reference source and a two-terminal resistance. The control potential can also be derived externally, from any stable d-c source, variable in the range from zero to 5 volts. One example of such a source is the Kepco Type "SN" Digital Programmer, which can supply the required control potential and is in turn controlled either manually (by means of a Kepco Manual Program Generator or by switches) or by machine (computer output).

3-23 External control potentials which are able to supply at least 1 mA of control current, may be connected to the MAIN VOLTAGE AMPLIFIER directly, as shown in FIG. 3-5. High impedance control sources which are not able to supply 1 mA, can be connected via the PRE-AMPLIFIER, as shown in FIG. 3-6. All control sources should have their own means of calibration (0V and 5V), if output accuracy is considered important. CAUTION: THE MAXIMUM CONTROL VOLTAGE BETWEEN "COMMON" AND THE MAIN VOLTAGE AMPLIFIER INPUT MUST NOT EXCEED 5 VOLTS ±2%. If control sources with higher output voltage are used which cannot be calibrated to 5 volts maximum output, a resistor in series with the control voltage should be used. The value of this resistor can be calculated by:

$$R_{series} = \frac{E_{control} - 5\ volt}{1\ mA}$$

3-24 OUTPUT VOLTAGE CONTROL BY MEANS AN EXTERNAL CONTROL VOLTAGE, PROCEDURE

1) Connect the EXTERNAL CONTROL VOLTAGE, the LOAD and the OUTPUT VOLTMETER (M1) to the APH as shown in *either* FIG. 3-5 *or* FIG. 3-6 (see par. 3-23).

2) Turn the EXT. CONTROL VOLTAGE to zero. Turn the APH "on."

3) Vary the EXT. CONTROL VOLTAGE from zero to its maximum output position (5 volts, see par. 3-23). The APH output voltage, as read out on M1, should vary from approximately zero to its maximum rated output voltage. Return the EXT. CONTROL VOLTAGE to zero.

3-25 CALIBRATION (Refer to Section II, FIG. 2-2 for the location of all internal controls)

1) Turn the APH A-C POWER SWITCH "on." Transfer the OUTPUT VOLTMETER (M1) to the output of the EXT. CONTROL VOLTAGE and calibrate the "zero" as well as the maximum output (5 volts). Return the OUTPUT VOLTMETER to the previous position.

2) With EXT. CONTROL VOLTAGE at zero, check the OUTPUT VOLTMETER (M1) for a "zero" reading and correct if necessary by adjusting the APH $E_O$ ZERO control.

3) Set the EXT. CONTROL VOLTAGE to its maximum output (5 volts) and check the OUTPUT VOLTMETER (M1). Calibrate the output voltage to the exact maximum rated APH output voltage by adjusting the calibrating control of the EXT. CONTROL VOLTAGE.

4) Set EXT. CONTROL VOLTAGE to zero again and recheck the previously calibrated zero point on M1. Correct if required, using the APH $E_O$ ZERO control.

5) Set the front panel CURRENT CONTROL to the required output current value or use one of the illustrated programming circuits for remote output current control. (see par. 3-26 to 3-36.)

6) Operation can now proceed. Check output by means of an oscilloscope. (CAUTION. HIGH VOLTAGE PROBE REQUIRED) for dynamic stability and output ripple. Refer to Section III, par. 3-3 if high output ripple is evident. Refer to Section V, par. 5-6a if dynamic instability is encountered.

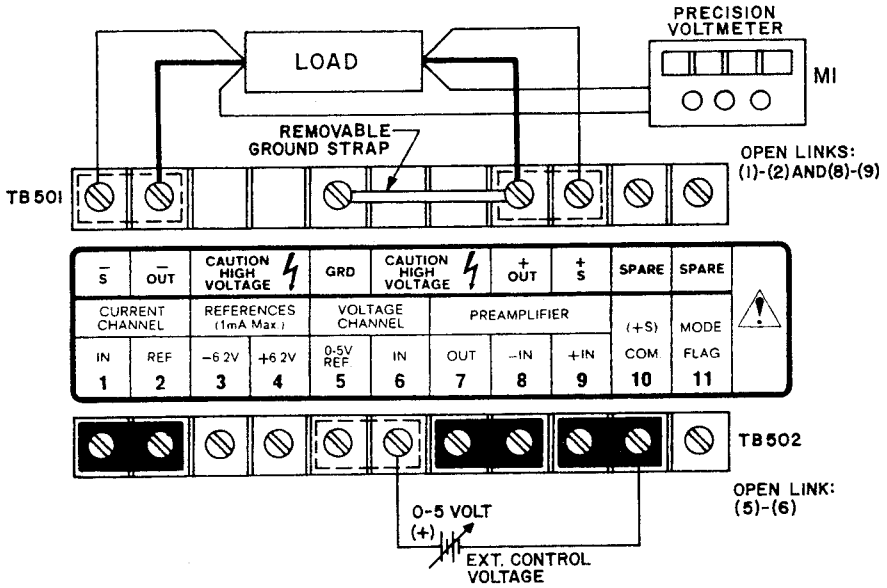



FIG. 3-5 CONNECTIONS FOR APH OUTPUT VOLTAGE CONTROL WITH AN EXTERNAL CONTROL VOLTAGE, HAVING A LOW IMPEDANCE OUTPUT.

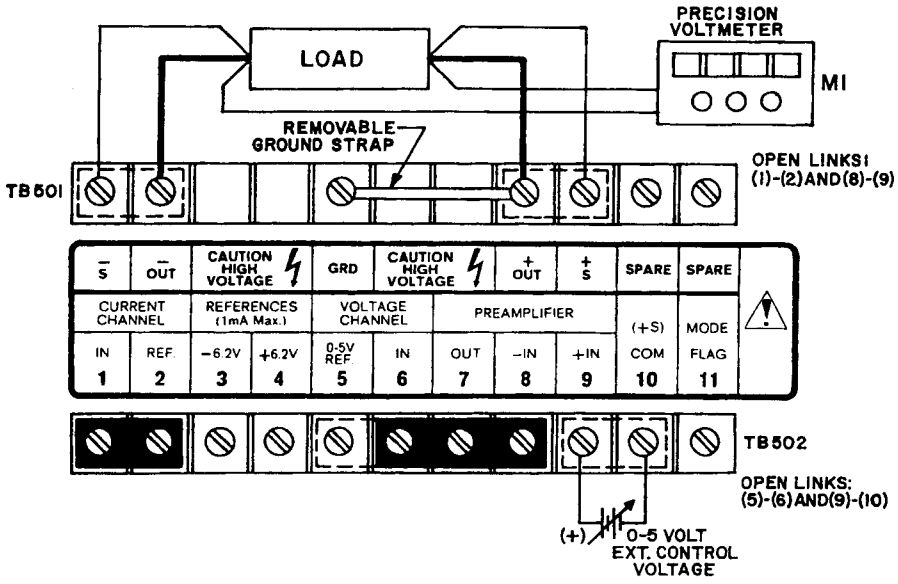



FIG. 3-6 CONNECTION FOR APH OUTPUT VOLTAGE CONTROL WITH AN EXTERNAL CONTROL VOLTAGE HAVING A HIGH IMPEDANCE OUTPUT.

## PROGRAMMING THE CURRENT CONTROL CHANNEL

### 3-26 OUTPUT CURRENT CONTROL BY EXTERNAL RESISTANCE

3-27 POTENTIOMETER CONTROL. Utilizing the EXT. CURRENT CONTROL AMPLIFIER and the (positive) internal reference source ($I_O$ ref.), the APH Power Supply output current can be controlled over the full output range by means of an external potentiometer. The INT. CURRENT CONTROL AMPLIFIER is left in the APH control circuit, serving as a "back-up" current limit. The maximum output current, which can be controlled by the external potentiometer, is determined by the setting of the front panel CURRENT CONTROL.

3-28 The principle of operation can be described with the assistance of the simplified APH schematic diagram at the rear of this section. The current sensing circuit for both the INTERNAL and EXTERNAL CURRENT CONTROL AMPLIFIERS is dimensioned such that a zero to 1 volt control signal at the input to any one of the two current control amplifiers controls the APH output current over the full output range. Only the amplifier with the ***lower*** control potential at any given instant is in control. Normally, the EXT. CURRENT CONTROL AMPLIFIER is biased to the "off" condition by means of the barrier strip terminal link (TB502–1 and 2). The INT. CONTROL AMPLIFIER derives its control potential from the internal reference source (+E ref.) via the $I_O$ MAX. control and the front panel CURRENT CONTROL. For external control, the front panel CURRENT CONTROL sets the INT. CURRENT CONTROL AMPLIFIER to the maximum value to be controlled. As the terminal link (TB502–1 and 2) is now removed, a zero to 1 volt control potential presented at the input of the EXT. CURRENT CONTROL AMPLIFIER will control the APH output current over the full output range.

3-29 The necessary external control potential is derived from the internal reference source $I_O$ ref. (TB502-2) which is connected to the external control potentiometer (EXT. CURRENT CONTROL) in series with a calibrating rheostat ($I_O$ MAX. EXT.). Since the internal amplifier is used "open loop" as a comparator, only the amplifier bias current (in the nanoampere range) flows through the potentiometer arm. Control linearity and absolute accuracy are therefore strictly a function of the potentiometer linearity and the final calibration of the circuit.

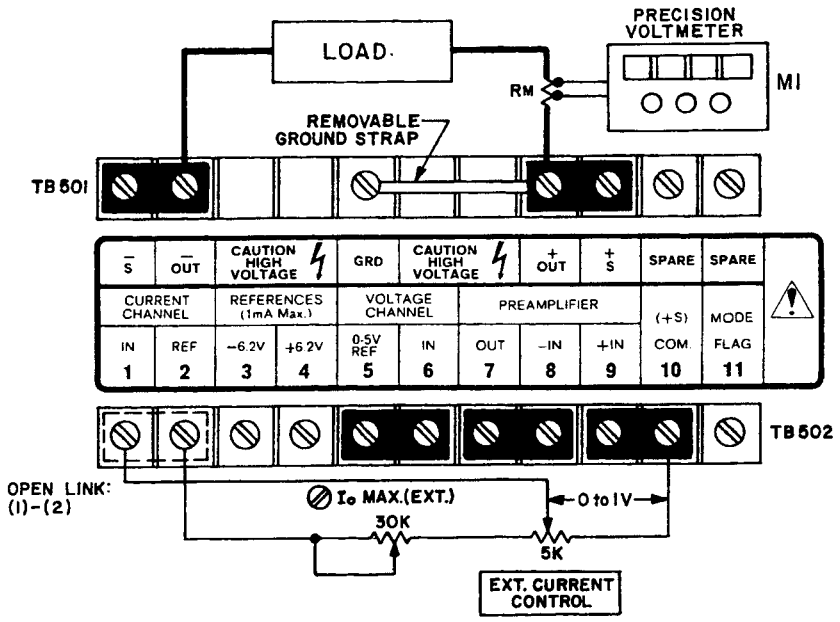



FIG. 3-7 CONNECTIONS FOR APH OUTPUT CURRENT CONTROL WITH AN EXTERNAL POTENTIOMETER.

3-30 OUTPUT CURRENT CONTROL BY AN EXTERNAL POTENTIOMETER, PROCEDURE

1) Refer to FIG. 3-7. Connect all external components as shown. Turn APH "on." Adjust the front panel VOLTAGE CONTROL to the required load compliance voltage. Adjust the EXTERNAL CURRENT CONTROL to the position yielding the minimum output current.

2) Adjust the FRONT PANEL CURRENT CONTROL to its maximum clockwise position.

3) Slowly, turn the EXTERNAL CURRENT CONTROL through its range. The APH output current, as read out on M1, should vary smoothly from approximately zero to its maximum rated output current. Return EXTERNAL CURRENT CONTROL to the position yielding the minimum output current.

**NOTE:** The output current value can be measured directly by means of a suitable milliammeter in series with the load or, as indicated in FIG. 3-7, indirectly by means of the precision voltmeter across a current measuring resistor ($R_M$). $R_M$ should be selected such that a convenient range on the precision voltmeter can be used, e.g., for a 10 milliampere output current, use a 100 ohm resistor to produce one volt full scale. If an electronic voltmeter is used, it should be battery-operated to avoid ground loops.

3-31 CALIBRATION (Refer to SECT. II, FIG. 2-2 for the location of all internal power supply controls)

1) Check the output current meter (M1) for "zero" current reading and correct if necessary by adjusting the internal $I_O$ ZERO control.

2) Set EXTERNAL CURRENT CONTROL to the position yielding the maximum output current. Observe the OUTPUT CURRENT METER. Calibrate the output current to the maximum rated value by adjusting the external rheostat $I_O$ MAX. (EXT.).

3) Repeat (1) above after returning the EXT. CURRENT CONTROL to its "zero" position.

4) Operation can now proceed. Note that the output voltage can be simultaneously remotely controlled (programmed) by one of the circuits described in par's. 3-10 to 3-25.

5) Check output by means of an oscilloscope across the current measuring resistor ($R_M$). Refer to the paragraph on signal grounding (par. 3-3) if high ripple is evident.

3-32 OUTPUT CURRENT CONTROL BY AN EXTERNAL TWO-TERMINAL RESISTANCE. The APH output current can be linearly controlled by a resistance decade, rheostat or any other two terminal resistance network. The preamplifier is used in an identical manner as described in par. 3-17, except that the control potential must be zero to 1 volt. To derive the correct control potential, use is made of the output equation:

$E_p = E_r/R_r\ (R_{cc})$, where: $E_p$ = Pre-amp output voltage, serving as the control voltage ($E_i$).
$E_{ref}$ = 6.2V reference voltage (internal).
$R_r$ = Reference resistor (external).
$R_{cc}$ = Feedback resistor, serving as the two-terminal output current control.

3-33 Once the value of the external CURRENT CONTROL resistor is selected, its value can be inserted into the equation below with the other known values, to calculate the necessary reference resistor. If, for example, a 0–10 K ohm resistance decade is to be used for the EXT. CURRENT CONTROL ($R_{cc}$), $R_r$ can be found by:

$$R_r = \frac{E_r}{E_p}\ (R_{cc}) = \frac{6.2V}{0–1V}\ (0–10\text{ K ohm}) = 62\text{ K ohm.}$$

3-34 OUTPUT CURRENT CONTROL BY AN EXTERNAL TWO-TERMINAL RESISTANCE, PROCEDURE

1) Connect the selected EXT. CURRENT CONTROL resistance, the calculated reference resistor ($R_r$), the LOAD and the OUTPUT CURRENT METER (M1) to the APH as shown in FIG. 3-8. NOTE: $R_r$ should be divided into a fixed component and a calibrating rheostat (50 K and 20 K in the example).

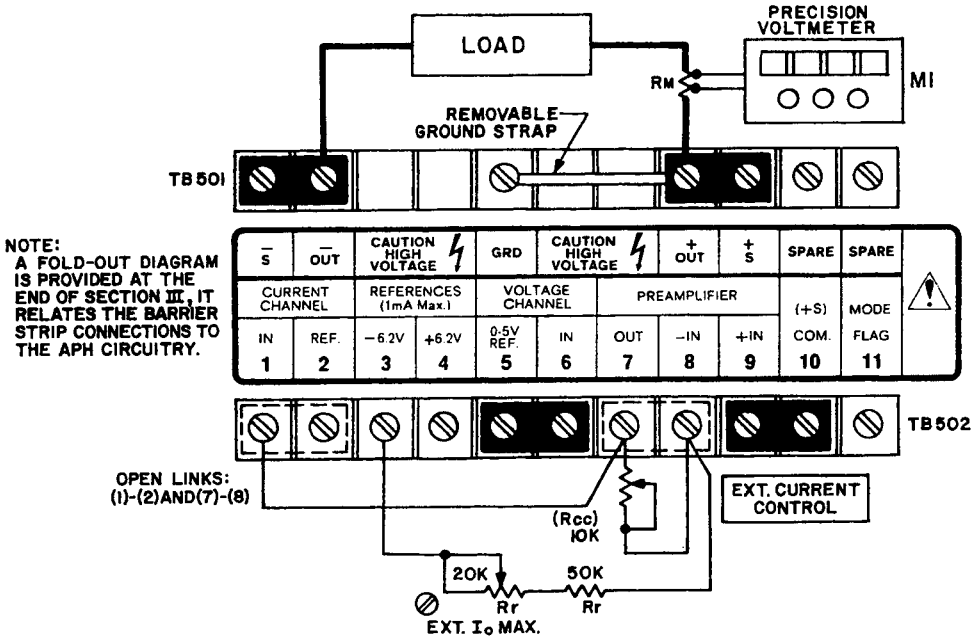



FIG. 3-8 CONNECTIONS FOR APH OUTPUT CURRENT CONTROL WITH A TWO-TERMINAL RESISTANCE.

2) Turn APH "on." Adjust the FRONT PANEL VOLTAGE CONTROL to the required load compliance voltage. Adjust the EXTERNAL CURRENT CONTROL to the position yielding the minimum output current.

3) Slowly, turn the EXTERNAL CURRENT CONTROL through its range. The APH output current, as read out on M1, should vary smoothly from approximately zero to its maximum rated output current. Return EXTERNAL CURRENT CONTROL to the position yielding the minimum output current.

**NOTE:** The output current value can be measured directly by means of a suitable milliammeter in series with the load, or as indicated in FIG. 3-8, indirectly by means of the precision voltmeter across a current measuring resistor ($R_M$). ($R_M$) should be selected such that a convenient range on the precision voltmeter can be used, e.g., for a 10 milliampere output current, use a 100 ohm resistor to produce one volt full scale. If an electronic voltmeter is used, it should be battery-operated to avoid ground loops.

3-35 CALIBRATION (Refer to Section II, FIG. 2-2 for the location of all internal power supply controls)

1) Check the output current meter (M1) for "zero" current reading and correct if necessary by adjusting the internal $I_O$ ZERO control.

2) Set EXTERNAL CURRENT CONTROL to the position yielding the maximum output current. Observe the OUTPUT CURRENT METER. Calibrate the output current to the maximum rated value by adjusting the external rheostat $I_O$ MAX. (EXT.) to this value.

3) Repeat (1) above after returning the EXT. CURRENT CONTROL to its "zero" position.

4) Operation can now proceed. Note that the output voltage can be simultaneously remotely controlled (programmed) by one of the circuits described in par's. 3-10 to 3-25.

5) Check output by means of an oscilloscope across the current measuring resistor ($R_M$). Refer to the paragraph on signal grounding (par. 3-3) if high ripple is evident.

**3-36 OUTPUT CURRENT CONTROL USING AN EXTERNAL SIGNAL VOLTAGE.** To control the APH output current between zero and its maximum rated value, a control potential, varying from zero to 1 volt must be applied to the external $I_O$ CONTROL AMPLIFIER. The internal $I_O$ CONTROL AMPLIFIER remains connected, while the front panel CURRENT CONTROL is set to the maximum output current to be controlled by the EXT. CURRENT CONTROL, thus serving as a "Back-Up Current Limit." As described in previous paragraphs, the necessary control potential may be derived via the internal reference source (REF) across an external potentiometer, or from the internal reference source (REF), and the built-in PREAMPLIFIER, controlled by a two-terminal resistance. The (0—1 volt) control potential can also be generated by an external, stable d-c source, variable in the range from zero to 1 volt. One example of such a source is the Kepco Type "SN" Digital Programmer. The "SN" Programmer can be controlled manually (Kepco Manual Program Generator, switches, etc.,) or by machine (computer output).

3-37 CURRENT CONTROL BY AN EXTERNAL CONTROL VOLTAGE, PROCEDURE

1) This control method is often used in combination with a Kepco SN Digital Programmer, although any stabilized, positive-going d-c source variable from zero to approximately 1 volt can be used.[1] The Kepco Model SN—2, for example, can deliver an input control signal from zero to 1 volt by setting its "ATTENUATOR SELECTOR" to the "1V" position. It has a built-in zeroing control and linearity of ±0.2%. The SN Programmer can be addressed manually (with a Kepco MPG—2 keyboard) or by machine (parallel input, 10 lines).

2) Refer to FIG. 3-9. The Kepco SN—2 is used as the EXTERNAL CURRENT CONTROL, producing the control voltage between the "common" and the current amp input. The required compliance (output) voltage can be adjusted by the front panel VOLTAGE CONTROL potentiometer.

3) Refer to FIG. 3-9. Connect all external components as shown. Turn the Kepco SN—2 "on" and set to zero. Turn APH "on." Set front panel VOLTAGE CONTROL to the required load compliance voltage. Set front panel CURRENT CONTROL to the maximum output current to be controlled by the EXT. CURRENT CONTROL.

4) Increase the programming voltage from the SN from "zero" to 1 volt. The APH output current as read out on M1 should follow proportionately from approximately zero to the maximum rated value. Return programming voltage from the SN to "zero."

**[1] If a *negative* going source or a source of either polarity which cannot be conveniently trimmed to 0—1V is available, the PRE-AMPLIFIER can be used for scaling and/or inverting the available programming source.**

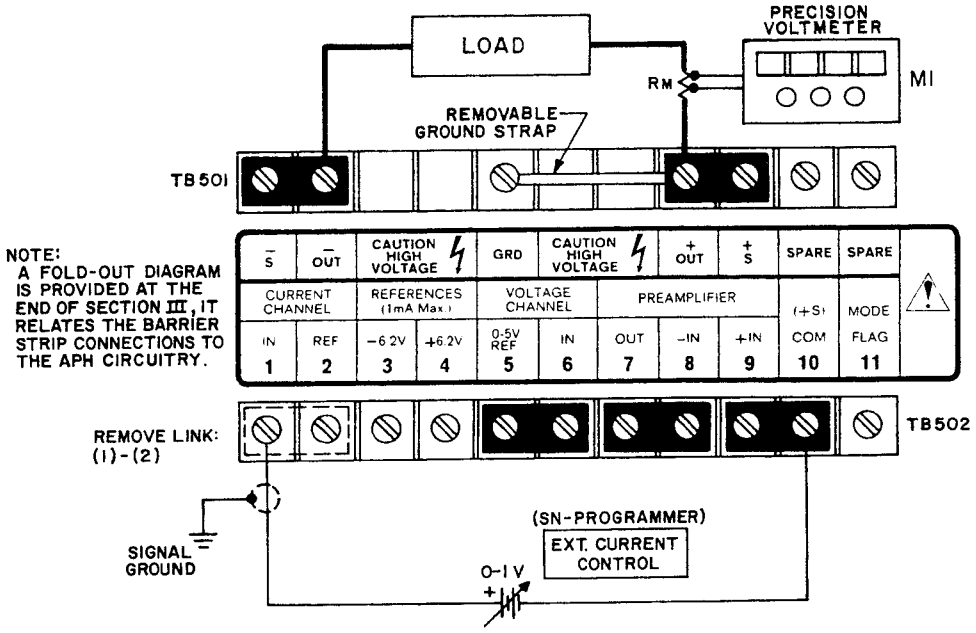



FIG. 3-9 CONNECTIONS FOR APH OUTPUT CURRENT CONTROL WITH AN EXTERNAL VOLTAGE SOURCE.

**NOTE:** The output current value can be measured directly by means of a suitable milliammeter in series with the load or, as indicated in FIG. 3-9 indirectly by means of the precision voltmeter across a current measuring resistor ($R_M$). $R_M$ should be selected such that a convenient range on the precision voltmeter can be used, e.g., for a 10 milliampere output current, use a 100 ohm resistor to produce one volt full scale. If an electronic voltmeter is used, it should be battery-operated to avoid ground loops.

3-38 CALIBRATION

1) Check the OUTPUT CURRENT METER (M1) for "zero" reading. Adjust to zero by means of the SN ZERO CONTROL.

2) Set SN Programmer for 1 volt output. Check M1 and calibrate for the maximum rated APH output current by means of the SN FULL SCALE control (optional control). (SN models with suffix "R" only.)

3) Reset SN Programmer to "zero" and recheck the previously calibrated "zero" point on M1. Correct with the SN ZERO control if necessary.

4) Operation can now proceed. Note that the output voltage can be simultaneously remotely controlled (programmed) by one of the circuits described in par's. 3-10 to 3-25.

5) Check output by means of an oscilloscope across the current measuring resistor ($R_M$). Refer to the paragraph on signal grounding (PAR. 3-3) if high ripple is evident.

## 3-39 SERIES OPERATION OF APH POWER SUPPLIES

3-40 GENERAL. APH Power Supplies can be connected in series with other voltage sources for increased voltage output. ***The total value of the voltage sources to be connected in series with the individual APH supply must be limited to 1000 volts (d-c or peak).***

3-41 Two basic methods of series connection are commonly used: The "Automatic" series connection and the "Master/Slave" or "tracking" configuration. The choice between the two methods should be made according to the application at hand. If individual power supply control is desired, the "Automatic" series connection should be used. If power supply control from a common "Master" supply is desired, the "Master/Slave" connection is best. For ***either*** method, some general rules should be remembered.

1) Series connect supplies ***only*** up to their specified isolation voltage limits (see par. ,3-40).

2) Use error sensing, as shown in the following diagrams to compensate for load wire drops. NOTE: Error sensing ***not*** required if operation is confined to series operation in the current mode.

3) Load wires should be ***as short as practicable.*** Select the wire guage ***as heavy as possible*** and twist tightly. Approximately ***equal length*** of all wire pairs is recommended.

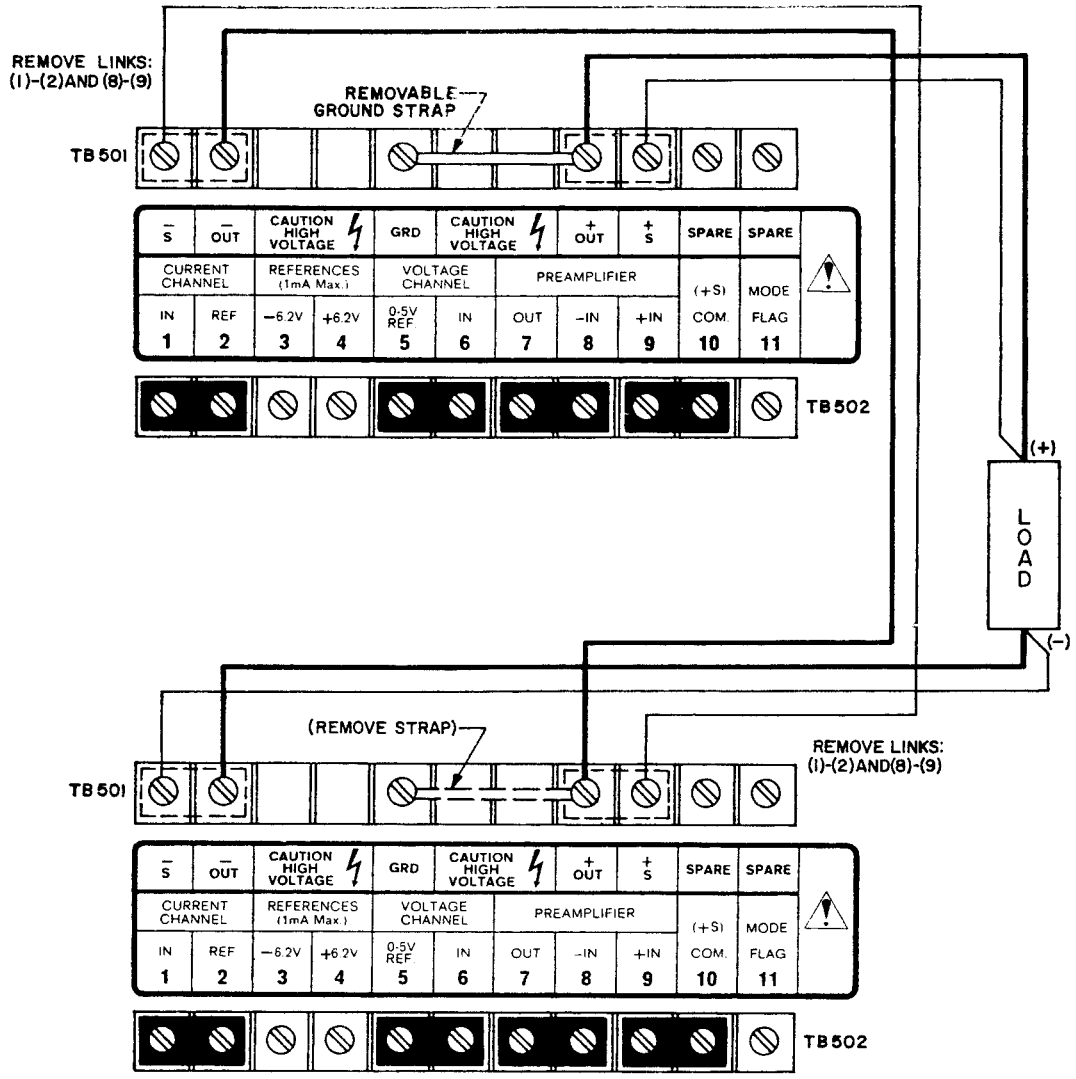



FIG. 3-10 "AUTOMATIC" SERIES CONNECTION OF TWO MODEL APH 500M POWER SUPPLIES.

3-42 PROCEDURE FOR "AUTOMATIC" SERIES CONNECTION (Refer to FIG. 3-10)

1) ***Without*** connecting the power supplies to the load, turn a-c power "on," and adjust the output voltage on each supply to the required level (the ***sum*** of the output voltages will be the voltage applied to the load).

2) Adjust the current control on each power supply to its extreme ***clockwise*** position. Turn a-c power "off."

3) Make all load connections as shown in the diagram (refer to FIG. 3-10). The error sensing connections are ***not*** needed if ***only*** current mode operation is planned.

4) Turn a-c power "on." Wait 25—30 seconds and observe output metering and MODE lights. The output current will be identical on all series connected supplies and all supplies should operate in the voltage mode (VOLTAGE MODE light "on").

5) Turn current control on ***each*** supply ***counterclockwise*** until each supply just transfers into the current mode (CURRENT MODE light "on,") then turn slightly ***clockwise*** again until the VOLTAGE MODE light energizes again. (This adjustment sets the current limit point on each individual power supply.)

6) If current mode operation is desired, leave each current control in a position such that the CURRENT MODE light is just energizing.

Operation can now proceed.

3-43 MASTER/SLAVE SERIES OPERATION. (Refer to FIG. 3-11). In this mode of operation, the total output voltage of all supplies in the series connection is controlled from a common "Master" supply, while the voltage output of the "Slave" supplies "follow" the output voltage of the "Master" in a ratio which can be selected by the user.

3-44 (Refer to FIG. 3-11.) As seen from the illustration, the internal voltage control amplifier of the "Slave" supply is disconnected and its control current is now derived from the output of the "Master" supply, via the "tracking" resistor ($R_t$). The "Slave" output is therefore completely dependent on the "Master" supply output:

$$E_{os} = E_{om} \frac{R_f}{R_t}$$

where: $E_{om}$ = Output Voltage, Master
$E_{os}$ = Output Voltage, Slave
$R_t$ = Tracking Resistor
$R_f$ = Internal (fixed) feedback resistor, Slave ($R_f$ = R44 in APH 500M, and APH 1000M, $R_f$ = R44, R45 in APH 2000M models.)

Note: $R_f$ = 500 KΩ (APH 500M)
$R_f$ = 1 MΩ (APH 1000M)
$R_f$ = 2 MΩ (APH 2000M)

As seen from the equation, the ratio with which the "Slave" supply follows the output of the "Master" is determined by the ratio ($R_f/R_t$). If a 1:1 ratio is desired, for example, the value of the feedback resistor of the "Slave" unit is selected to equal this value. The output of the "Slave" supply will now "follow" that of the "Master" in the 1:1 ratio established. Other ratios can be selected by choosing the value of $R_t$ proportionally. If a single load is connected to the series connection (FIG. 3-11), the total output voltage will equal the sur . of "Master" and "Slave" output voltages. If individual loads are connected to "Master" and "Slave" supplies, all load voltages will equal that of the "Master" supply (for a 1:1 tracking ratio).

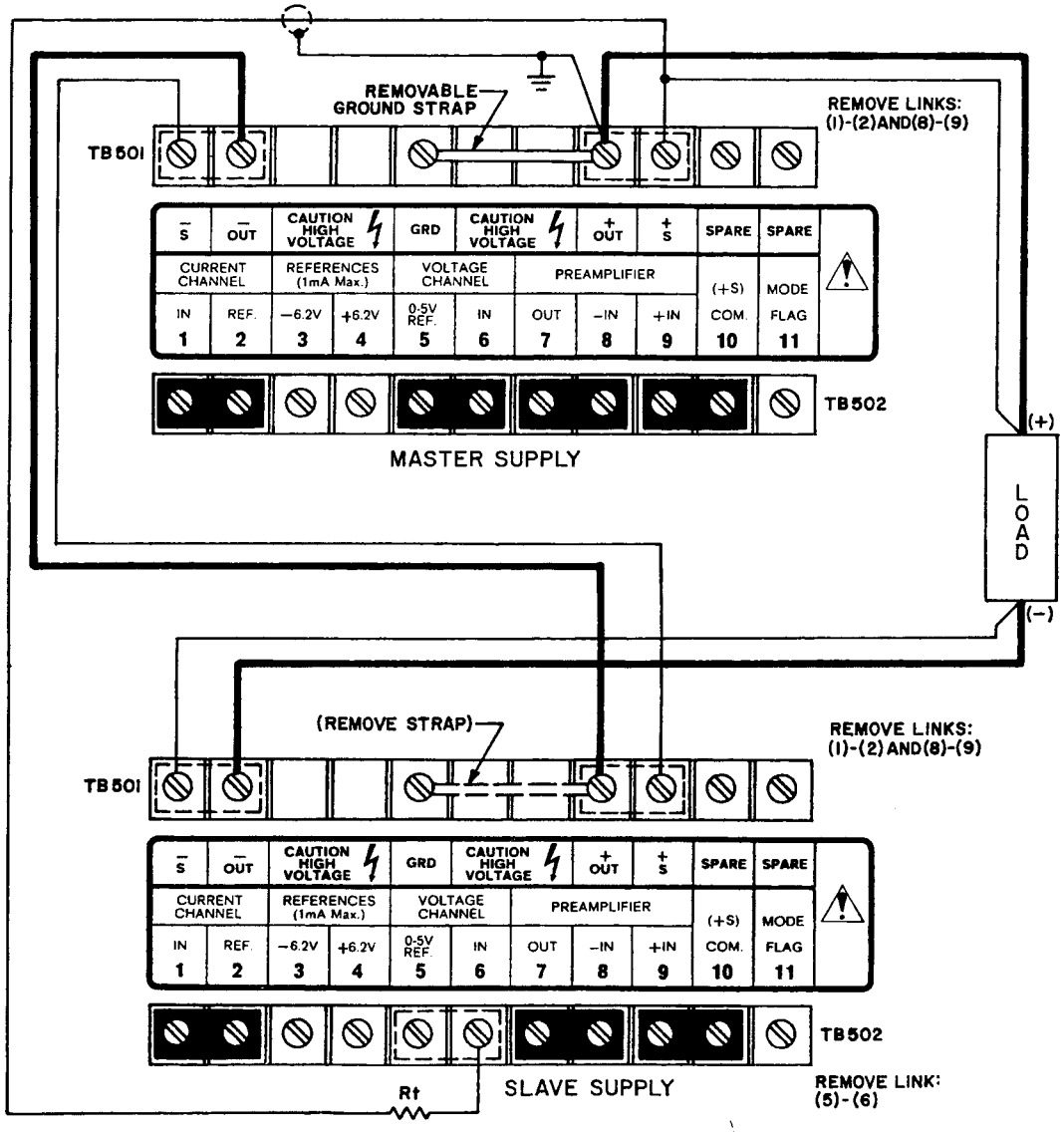



FIG. 3-11 "MASTER/SLAVE" SERIES CONNECTION OF TWO MODEL APH 500M POWER SUPPLIES.

3-45 PROCEDURE FOR "MASTER/SLAVE SERIES CONNECTION

1) Interconnect the power supplies as shown in FIG. 3-11. Turn "Slave" current controls to their maximum ***clockwise*** positions. Turn "Master" ***voltage*** control to its maximum ***counterclockwise***, and the ***current*** control to the maximum ***clockwise*** position.

2) Turn a-c power "on." Wait 25–30 seconds and observe the front panel meters and the mode indicator lights on all series connected supplies. All VOLTAGE MODE lights should be energized, and all front panel meters should read approximately zero.

3) Slowly turn the voltage control of the "Master" ***clockwise,*** until the desired output voltage level is reached. (CAUTION: The ***total*** load voltage is the ***sum*** of "Master" and "Slave" units.)

4) Set the output current limit point by turning the current control on ***all*** series connected supplies ***counterclockwise,*** until each supply just transfers into the current mode (CURRENT MODE light "on,") then turn each slightly ***clockwise*** again, until each VOLTAGE mode light energizes again.

5) If current mode operation is desired, leave the setting of the "Master" current control such that the CURRENT MODE light is energized. While the output current can now be controlled by the "Master" supply, the "Slave" supply will still operate in the voltage mode (VOLTAGE MODE light "on" and deliver additional compliance voltage to the load.)

## 3-46 PARALLEL OPERATION OF KEPCO APH POWER SUPPLIES

3-47 GENERAL. As in the previously described "series" connections, an "Automatic" or a "Master/Slave" connection method can be chosen. The choice between the two methods will depend on the application at hand. For constant loads or small load variations (load changes ***smaller*** than the maximum output range of a ***single*** power supply), the "Automatic" parallel connection can be used. For load changes ***exceeding*** the maximum rating of a ***single*** power supply, the "Master/Slave" method is suitable. For either method, some general rules should be observed:

1) Parallel ***only*** supplies which can be adjusted to the same compliance (output) voltage.

2) Error sensing can be used to compensate for load wire voltage drops.

3) Load wires should be ***as short as practicable.*** Select wire gauge ***as heavy as possible*** and twist wires tightly. Approximately ***equal*** lenghths of wire should be used.

4) ***Common*** a-c power source "turn-off" for all supplies is recommended.

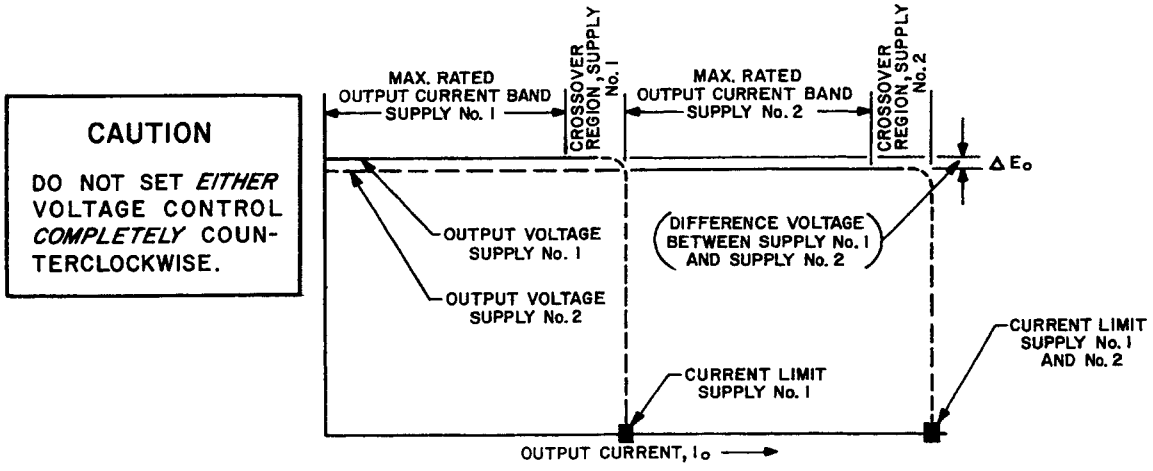



FIG. 3-12 "OUTPUT CHARACTERISTIC GRAPH OF TWO APH POWER SUPPLIES IN PARALLEL.

## 3-48 AUTOMATIC PARALLEL CONNECTION

1) ***Without*** connecting the power supplies to the load or to each other, turn a-c power "on," and adjust the output voltage on each supply to the required compliance voltage.

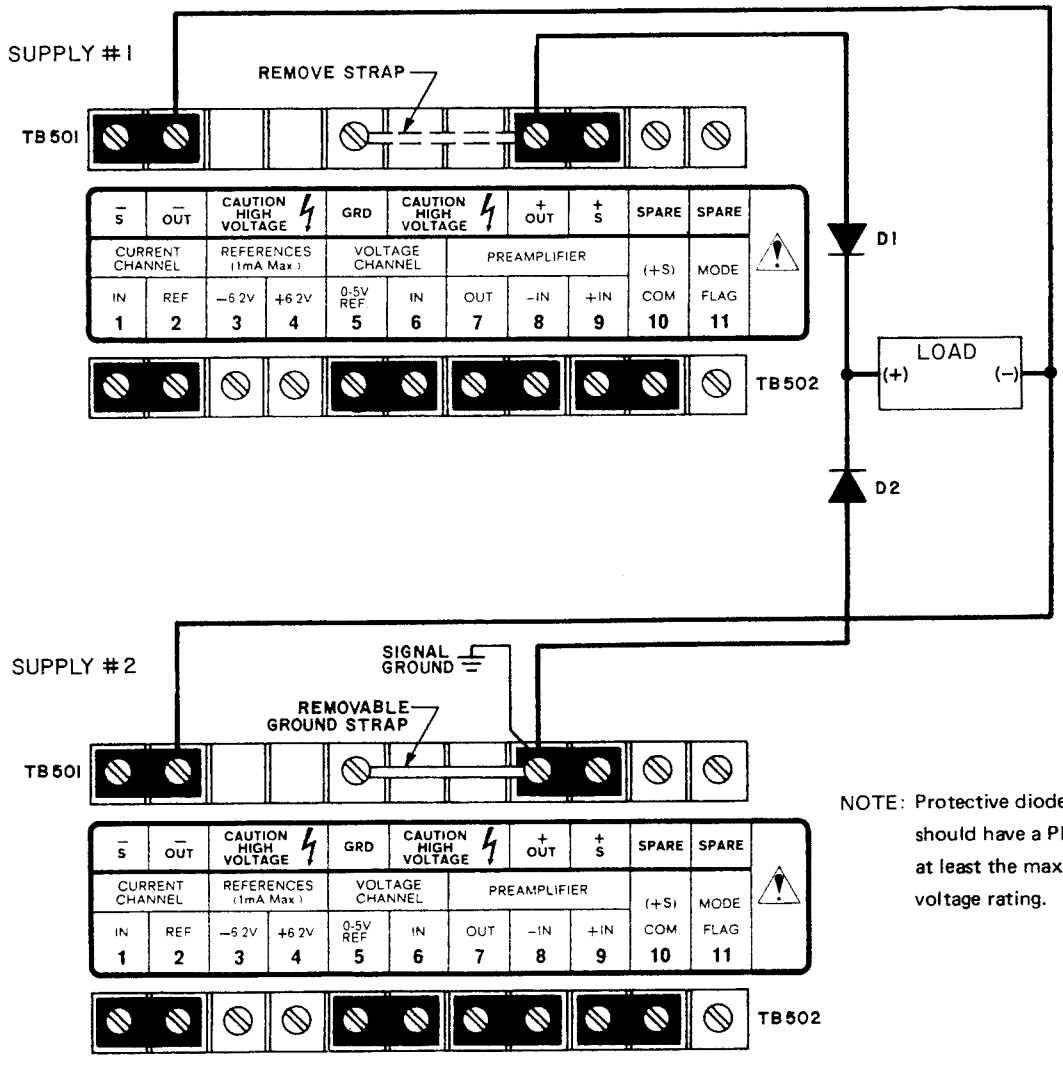
2) Adjust ***both*** "current" controls to their maximum (extreme clockwise) position. Turn a-c power "off."

3) Make all load interconnections as shown in the connection diagram (refer to FIG. 3-13.

4) Turn a-c power "on." Observe output current meters and mode indicator lights on ***both*** units. Since the initial output voltage adjustments were not identical, ***one*** of the power supplies (to be designated SUPPLY #1) will be at a slightly higher output voltage than the other (to be designated SUPPLY #2). Consequently, SUPPLY #1 will deliver its maximum load current and will operate in the current mode, (CURRENT MODE light "on"). The rest of the load current is delivered by SUPPLY #2, which is operating in the voltage mode (VOLTAGE MODE light "on").

5) The "current" control of SUPPLY #1 can now be adjusted, as to equalize the total load current between SUPPLY #1 and SUPPLY #2, and operation can proceed.

**NOTE:** The output graph (refer to FIG. 3-12) shows how the two power supplies operate in the parallel mode. As seen from FIG. 3-12, load variations should be confined to the stabilization region of SUPPLY #2, since there is an initial adjustment error ($\Delta E_O$) between the two supplies. Load variations not confined to this area will include $\Delta E_O$ as an additional Stabilization Error.




NOTE: Protective diodes (D1, D2) should have a PIV rating of at least the maximum APH voltage rating.

FIG. 3-13 CONNECTIONS FOR "AUTOMATIC" PARALLEL OPERATION (TWO SUPPLIES).

3-49 If stabilized output ***current*** (rather than stabilized output ***voltage***) is desired, all previous comments are valid. For stabilized output current from ***both*** power supplies, the "current" control of the supply operating initially in the "voltage" mode (SUPPLY #2) is readjusted (counterclockwise) to such a value that SUPPLY #2 just switches to the "current" mode (observe mode indicator lights).

3-50 MASTER/SLAVE PARALLEL CONNECTION. In this mode of operation, the output is controlled by the designated MASTER supply, while the SLAVE supply follows the MASTER in a ratio determined by resistor selection. Two methods are shown in the following paragraphs, one (Method 1) with the SLAVE pre-amp driving the Main Voltage Amplifier (while the Current Control amplifier is left free to be programmed) and the other (Method 2) with the SLAVE pre-amp driving the Current Control Amplifier (while the Main Voltage Amplifier is left free to be programmed). Method 2 is shown for two applications, one more suitable for operation in the Voltage Mode (FIG. 3-15), the other for optimum performance in the Current Mode (FIG. 3-16).

3-51 MASTER/SLAVE PARALLEL CONNECTION, DRIVING THE SLAVE'S VOLTAGE AMPLIFIER. (Refer to FIG. 3-14.) The two sensing resistors ($R_{S1}$, $R_{S2}$), in series with the positive output lead of both supplies are selected to drop approximately 0.1 to 0.5 volts at the maximum current for each APH unit. The two voltage drops are compared at the input to the SLAVE pre-amp. The differential signal at the pre-amp is amplified and the pre-amp output is connected to the SLAVE Voltage amplifier, which drives the SLAVE output so that the drop across the two resistors is zero. If equal resistors have been chosen for $R_{S1}$ and $R_{S2}$, the slave current into the load will equal the master current. The ratio of their currents will follow the resistors proportionally.

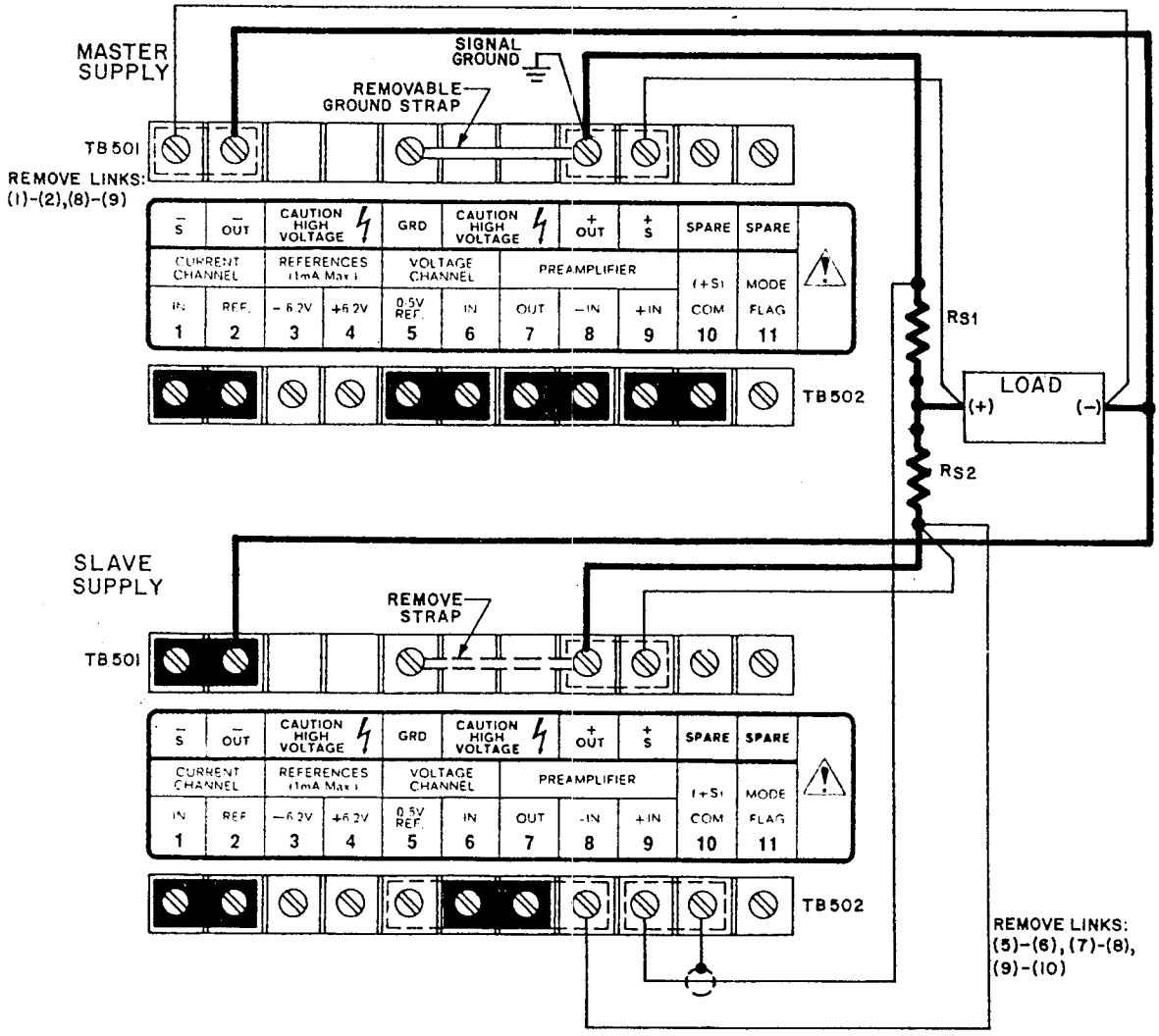



FIG. 3-14 "MASTER/SLAVE" PARALLEL CONNECTION OF TWO APH POWER SUPPLIES (METHOD I)

3-52 PROCEDURE FOR MASTER/SLAVE OPERATION (METHOD I).

1) Connect the supplies, the load and all other external components as shown in FIG. 3-14.
2) Turn A-C power "on". After the 25 second delay, observe APH front panel meters and mode indicator lights. Note: MASTER AND SLAVE "VOLTAGE" MODE LIGHTS WILL BE ON, ALTHOUGH ONLY THE MASTER SUPPLY IS OPERATING IN THE VOLTAGE MODE.
3) Adjust output voltage or output current on the MASTER supply as required. ***All*** adjustments of either voltage or current are made via the MASTER'S controls. The slave has no function except to follow the MASTER.

3-53 MASTER/SLAVE PARALLEL CONNECTION, DRIVING THE SLAVE'S CURRENT CONTROL AMPLIFIER (Refer to FIG. 3-15). A sensing resistor ($R_S$ = 12.5Ω for APH 500M, $R_S$ = 25Ω for APH 1000M, $R_S$ = 50Ω for APH 2000M) is selected to drop 0.5 volt at the maximum APH output current. A resistor divider (R1, R2) is selected to produce a 0–1 volt control voltage from the SLAVE pre-amp into the SLAVE current channel input as a function of the Master's current. Note: The SLAVE pre-amp is connected in the non-inverting configuration, to produce a ***positive*** control signal ($E_p$) from a ***positive*** input signal ($E_i$ = 0.5 volt) from the sensing resistor. The pre-amp output is therefore:

$$E_p = E_i \left(\frac{R1 + R2}{R2}\right)$$

3-54 If other sensing resistors are chosen, "$E_i$" will be different and the divider resistors (R1, R2) should be recalculated by means of the above equation, since the control voltage ($E_p$) into the current channel must always equal 1 volt for full APH output.

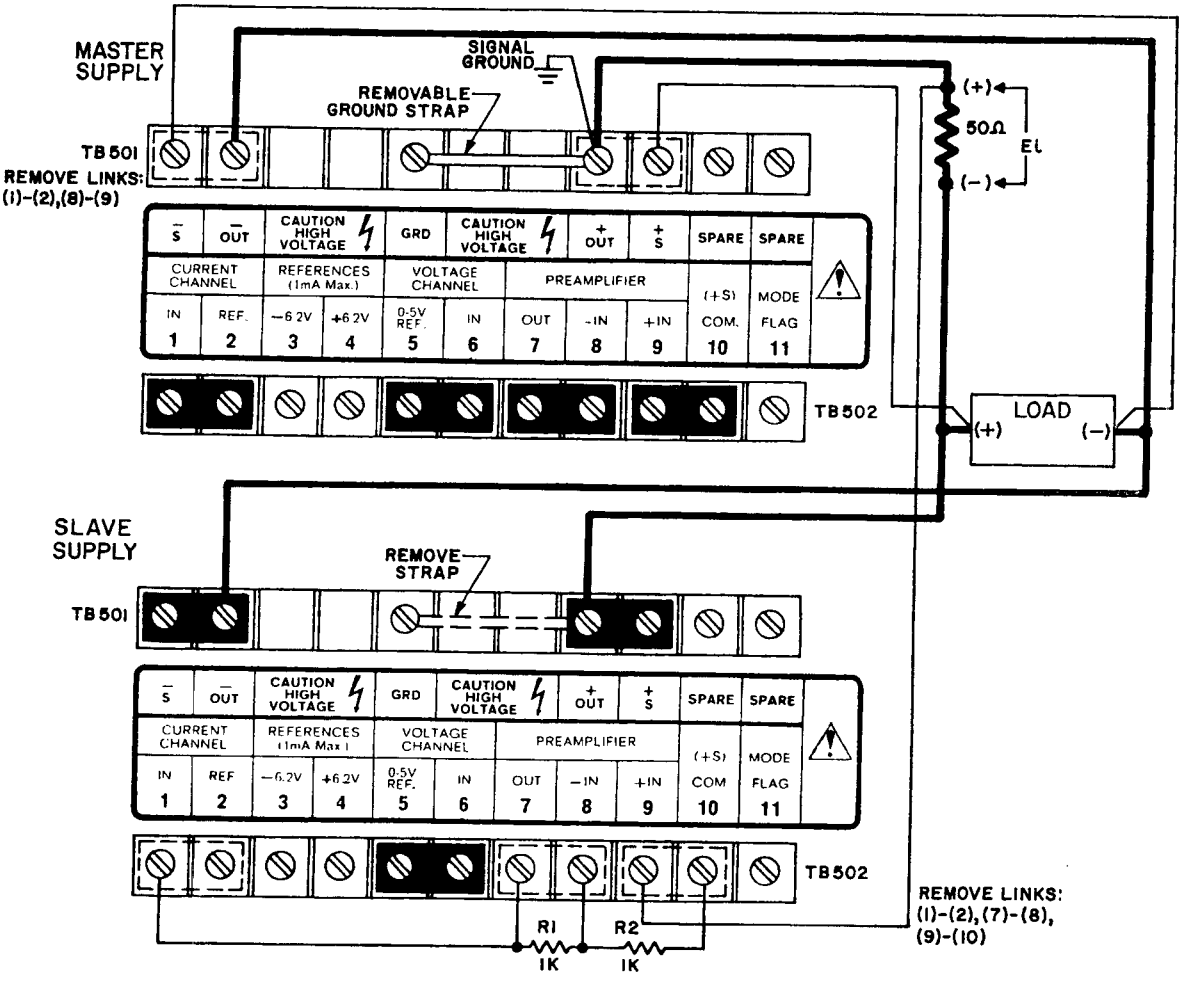



FIG. 3-15 "MASTER/SLAVE" PARALLEL CONNECTION OF TWO APH POWER SUPPLIES (VOLTAGE MODE)

3-55 PROCEDURE FOR "MASTER/SLAVE" OPERATION (METHOD 2, VOLTAGE MODE)

1) Connect the supplies, the load and all other external components as shown in FIG. 3-15. Equal output current sharing between MASTER and SLAVE units may be adjusted by making R1 a rheostat.

3-56 MASTER/SLAVE PARALLEL CONNECTION, DRIVING THE SLAVE'S CURRENT CONTROL AMPLIFIER (Refer to FIG. 3-16). A sensing resistor ($R_S$ = 100Ω for APH 2000M, 50Ω for APH 1000M, 25Ω for APH 500M) is selected to drop 1.0 volt at the maximum APH output current. $R_S$ is connected in series with the positive output terminal of the MASTER supply. The voltage drop thus produced, due to the MASTER'S output current (0–1 volt) is applied via the limiting resistor ($R_{LIMIT}$ = 5KΩ) to the input of the current control amplifier of the SLAVE supply. The SLAVE output current is therefore exactly proportional to that of the MASTER. In the above example, $R_S$ was selected to produce a 1:1 ratio of the MASTER and SLAVE output current, although other ratios can be selected by choosing $R_S$ accordingly (1 volt at the input of the SLAVE current amplifier will produce maximum rated output current.)

3-57 PROCEDURE FOR MASTER/SLAVE OPERATION, METHOD 2, (CURRENT MODE):

1) Connect the supplies, the load and all other external components as shown in FIG. 3-16.
2) Adjust desired output level on the MASTER supply. SLAVE front panel VOLTAGE and CURRENT CONTROLS should be set fully clockwise.

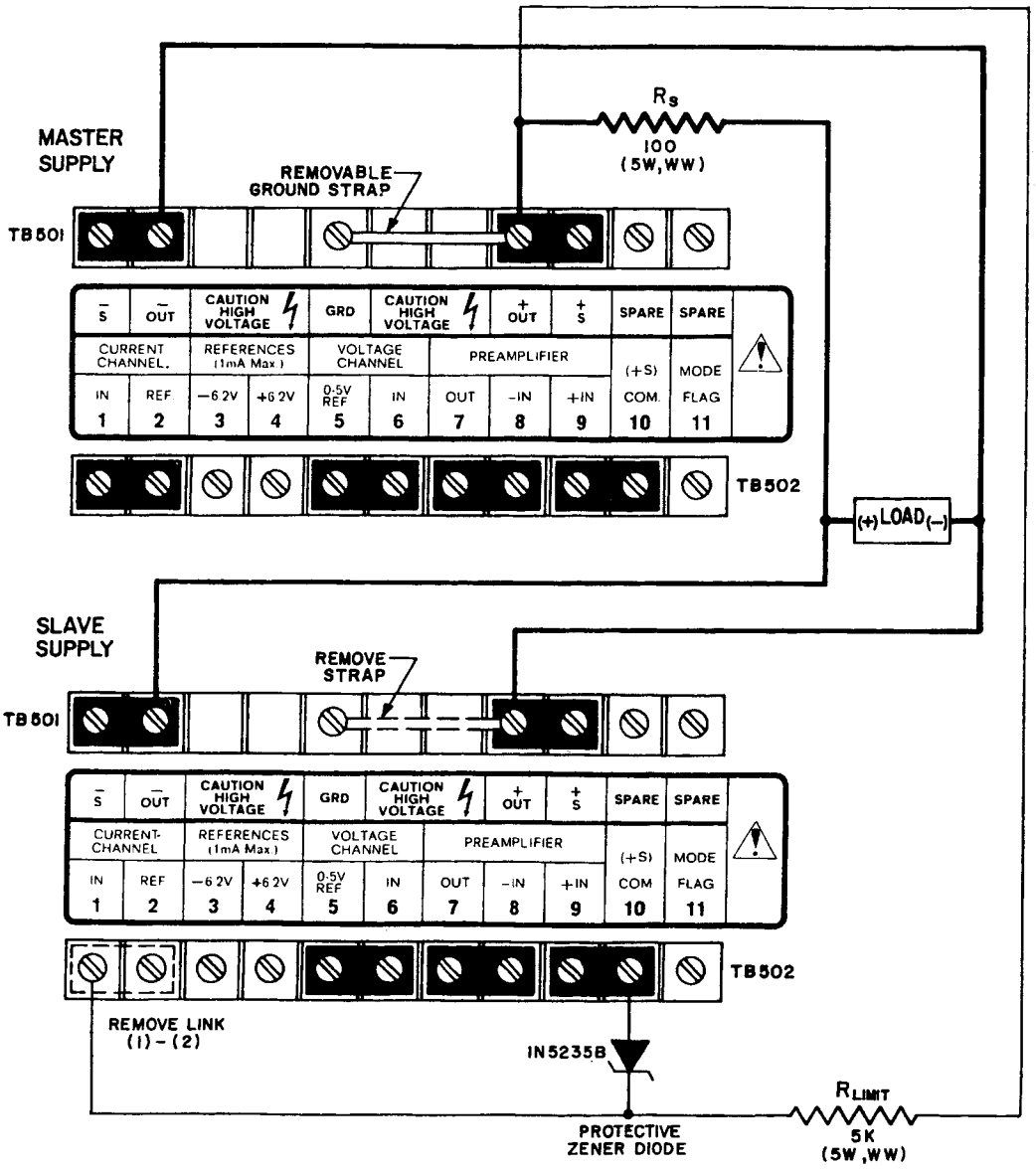



FIG. 3-16 MASTER/SLAVE PARALLEL CONNECTION OF TWO APH POWER SUPPLIES (CURRENT MODE)

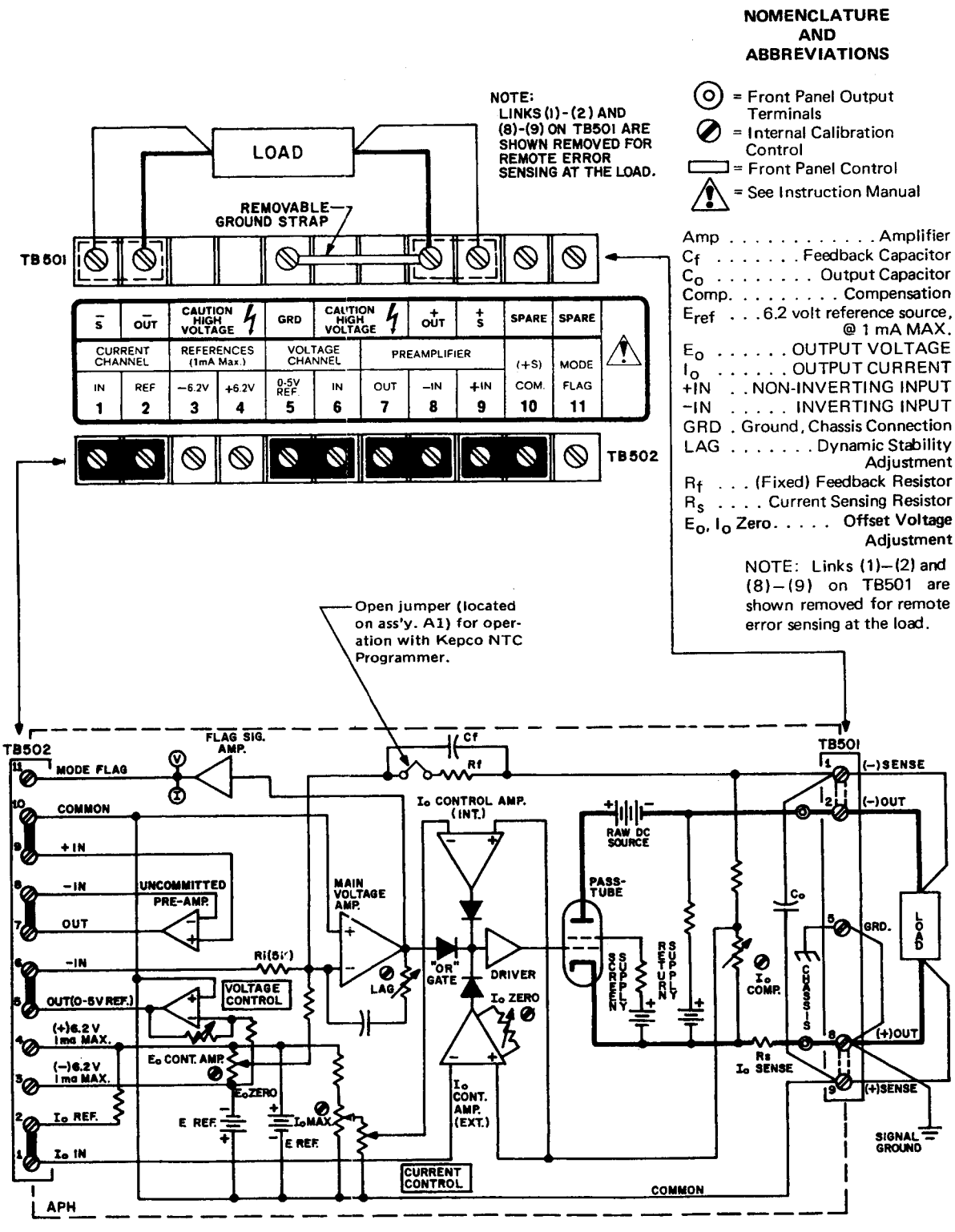



FIG. 3-15 ACTUAL APH REAR TERMINALS(TOP) AND SIMPLIFIED SCHEMATIC DIAGRAM (BELOW)

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