KEPCO

POWER SUPPLIES

APH
AUTOMATIC CROSSOVER

Model APH 500M

Serial No. . . . .

instruction manual

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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:

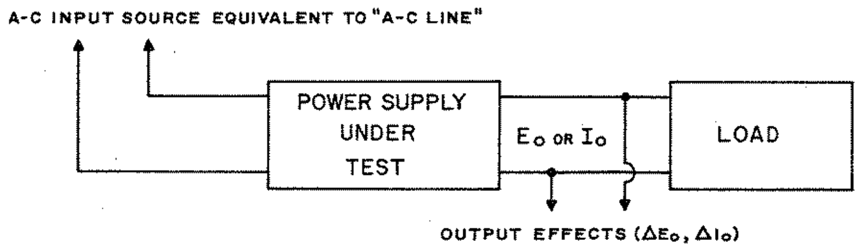
a) OPEN LOOP GAIN, D-C: >1 x 10^6 V/V.

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:
- ΔE_{pa} = Pre-Amp Output Voltage Change
- ΔE_{ref} = Change in the Voltage Reference
- ΔE_{io} = Change in Offset Voltage
- ΔI_{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 (ΔE_{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 (ΔE_O): $\Delta E_O = \Delta E_{pa}$ X GAIN.

INFLUENCE QUANTITY		OUTPUT EFFECTS VOLTAGE MODE (4)	OUTPUT EFFECTS CURRENT MODE (Internal Sensing)	UNCOMMITTED PRE-AMPLIFIER OFFSETS ΔE_{io}	UNCOMMITTED PRE-AMPLIFIER OFFSETS ΔI_{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).

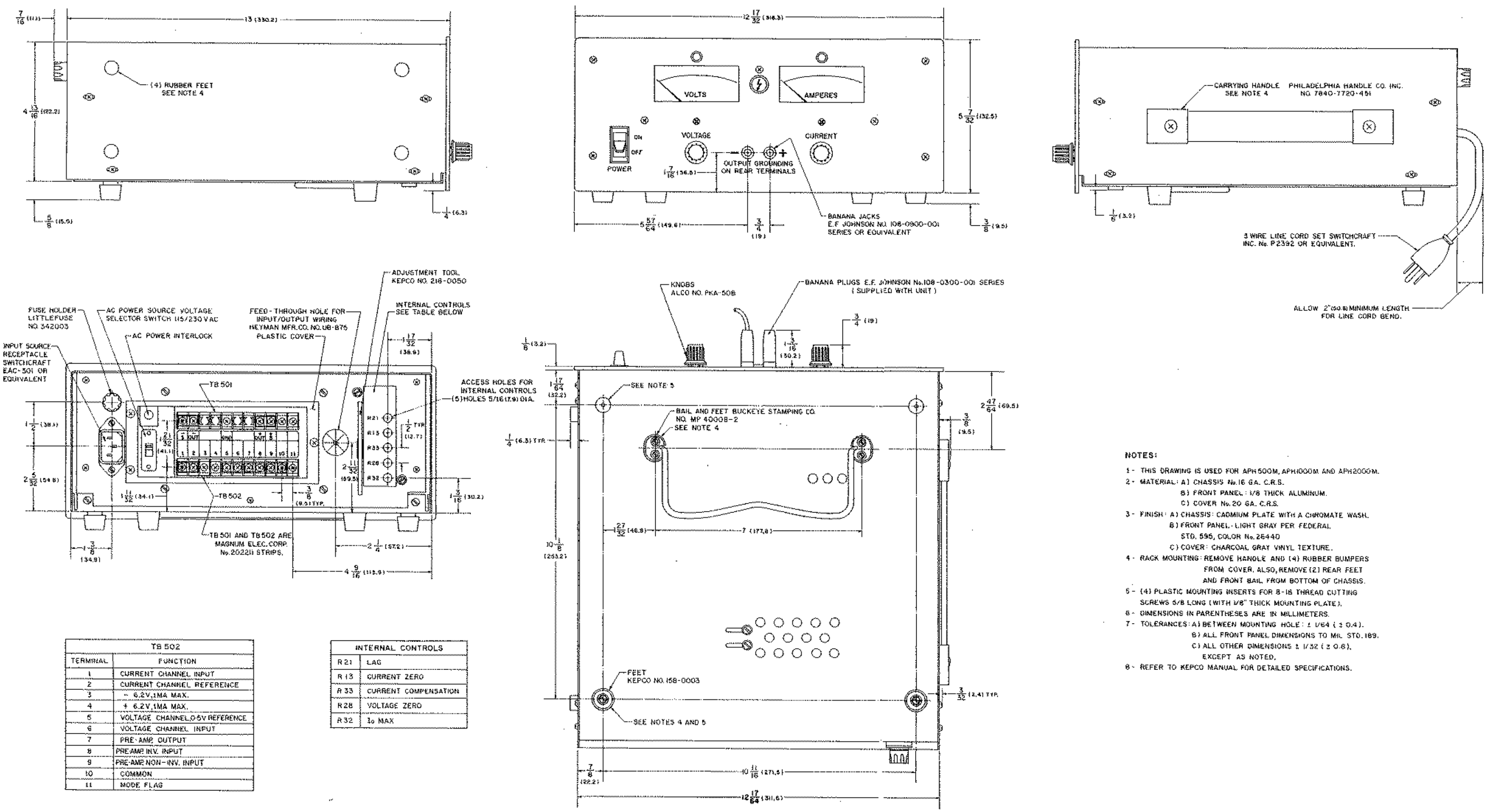
d) REMOTE ERROR SENSING: Provisions are made for a 4-terminal connection to a remote load. The effects of static voltage drops along the load wire (up to 0.5 volt per lead) can thus be eliminated.

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.



NOTES:

1 - THIS DRAWING IS USED FOR APH 500M, 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 3/8 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.

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	PREAMP. INV. INPUT
9	PRE-AMP. NON-INV. INPUT
10	COMMON
11	MODE FLAG

INTERNAL CONTROLS	
R 21	LAG
R 13	CURRENT ZERO
R 33	CURRENT COMPENSATION
R 28	VOLTAGE ZERO
R 32	Io MAX

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.

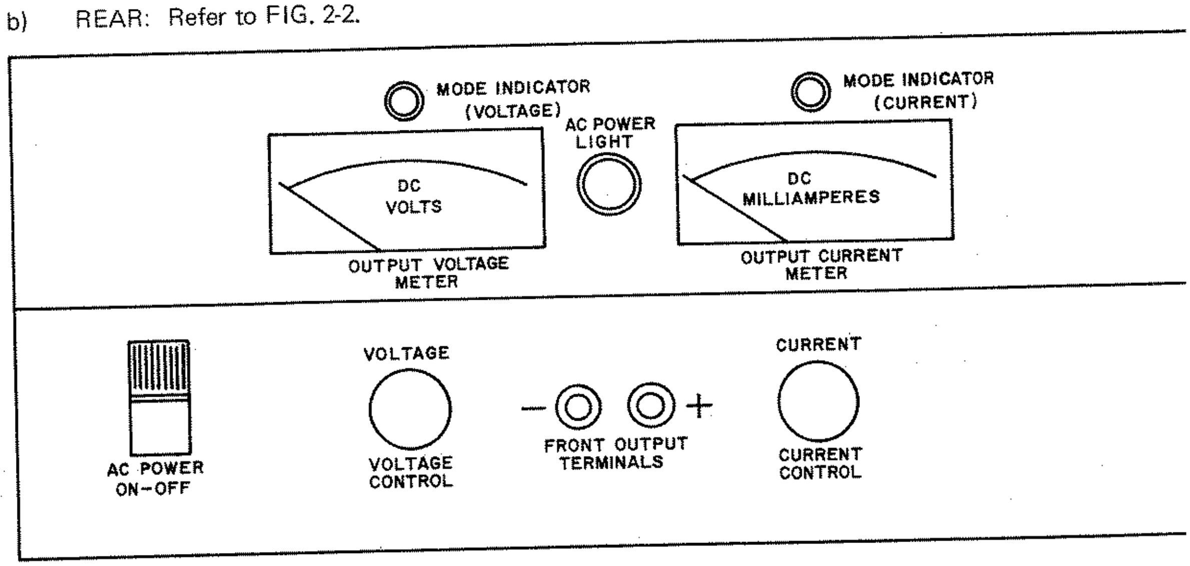


FIG. 2-1 FRONT PANEL, KEPCO APH MODELS.

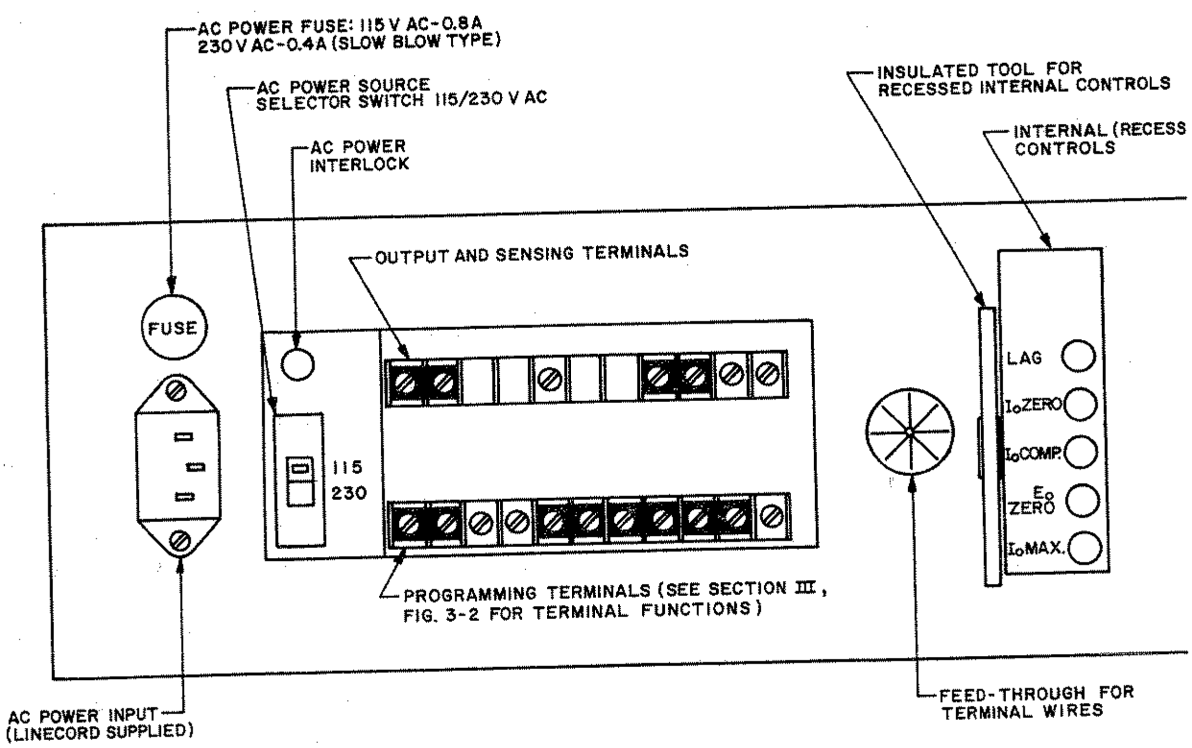


FIG. 2-2 REAR TERMINATIONS, KEPCO APH MODELS.

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.

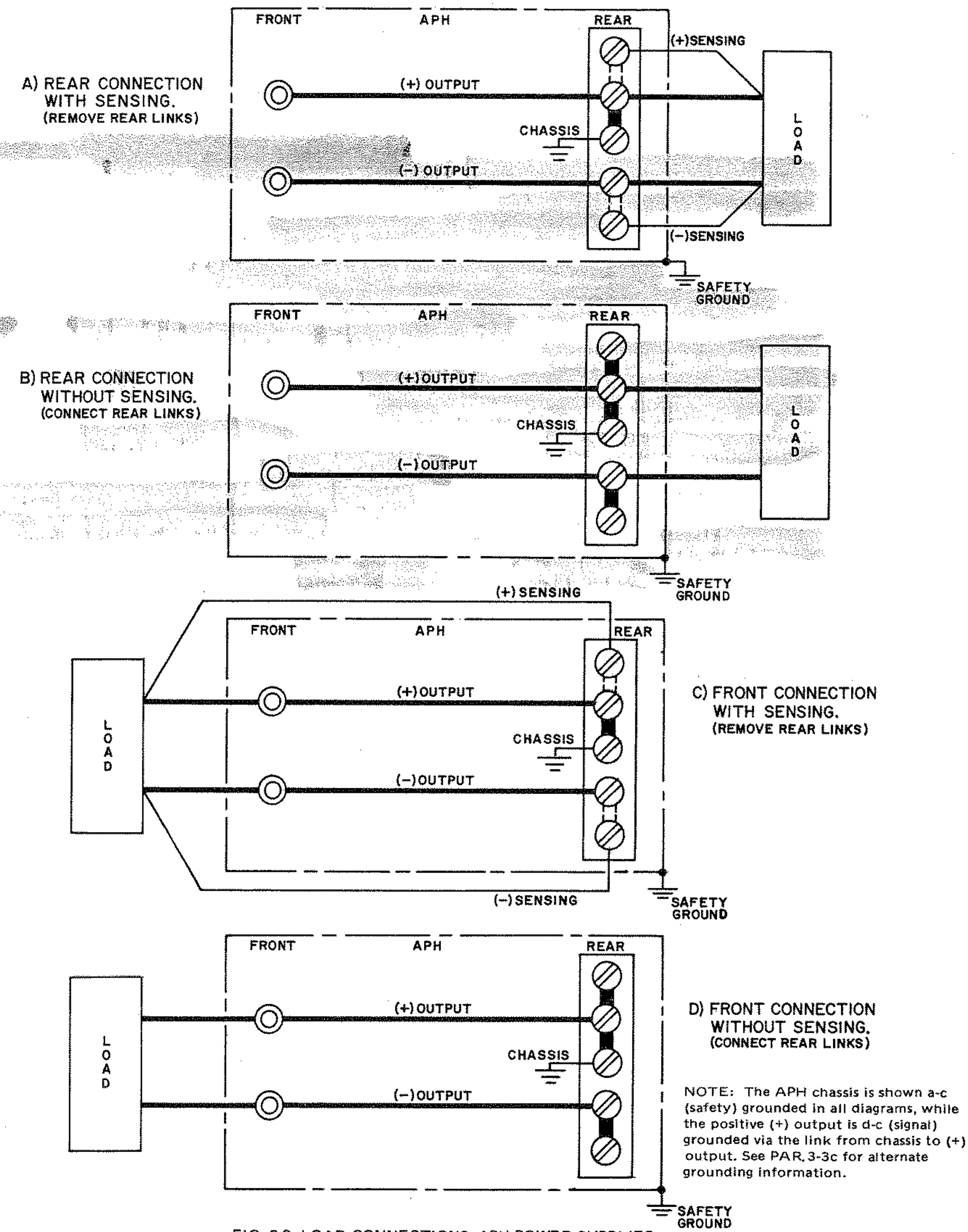


FIG. 2-3 LOAD CONNECTIONS, APH POWER SUPPLIES.

SECTION III – OPERATION

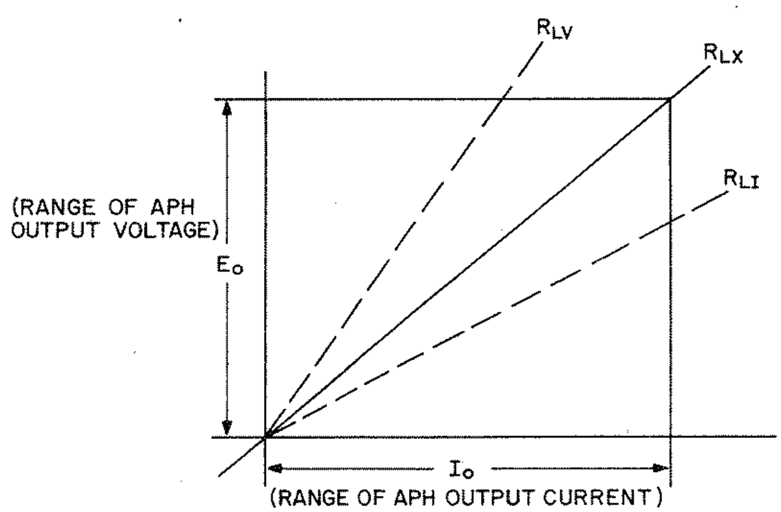
3-1 GENERAL

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.



R_{LV} = Typical Load Resistance, Voltage Mode

R_{LI} = Typical Load Resistance, Current Mode

R_{LX} = Theoretical Crossover Resistance

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.

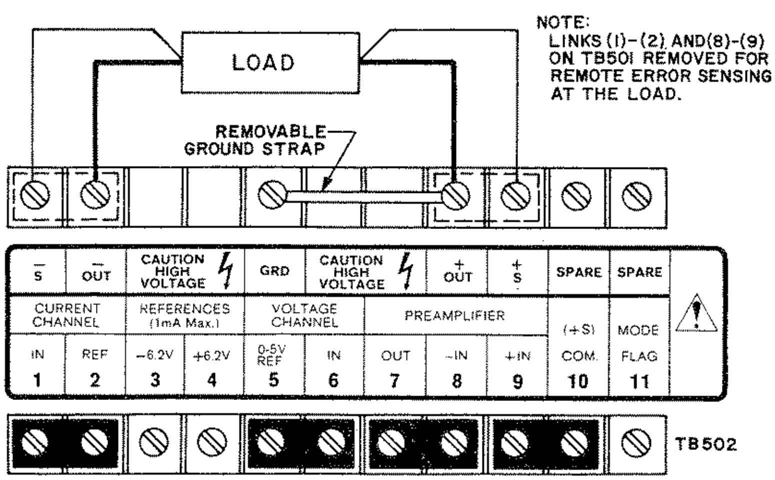


FIG. 3-2 REAR TERMINAL CONNECTIONS, APH POWER SUPPLY SET-UP FOR STANDARD VOLTAGE MODE OR CURRENT MODE OPERATION WITH LOCAL (FRONT PANEL) CONTROL OF THE OUTPUT.

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 sign 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 CURREN CONTROL completely counterclockwise, and then clockwise for one turn. Turn A-C POWER SWITC "on" (the voltage mode indicator light should be "on" and the output will be present after a delay approximately 25 seconds. Observe front panel VOLTMETER and adjust VOLTAGE CONTROL to th 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 SWITC "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 curre 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 no 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 "or (the voltage mode indicator light should be "on"). After the time delay, observe the front pan VOLTMETER and adjust the VOLTAGE control to the required compliance (output voltage) leve 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 CURREN CONTROL to the desired value. The current mode indicator light should go "on" (after the time dela to indicate that the power supply is truly in the current mode of operation. Turn A-C POWER SWITC "OFF."
3) Remove the short circuit, connect the load and turn A-C POWER switch "on." If the APH does no enter the current mode (as indicated by the front panel indicator), the load resistance (R_L) is too hig *Either* R_L must be ***decreased*, *or*** the VOLTAGE CONTROL setting must be ***increased*, *or*** th 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 Suppl are accessible for the remote control (PROGRAMMING) of the output voltage and/or the output curren respectively. The two control channels can be programmed individually or simultaneously by means of eithe passive (resistance) or active (voltage/current) control signals. Representative programming examples ar described and illustrated in the following paragraphs. These examples constitute only a few of the man possible programming circuit variations. Please consult the Kepco Engineering Application Department fo assistance with problems concerning ***your*** specific application. ***Before*** connecting ***any*** programming circui please review the previous comments on GROUNDING and LOAD CONNECTIONS (see par. 3-3) as well a the following:

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

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

$$E_O = \text{CONTROL VOLTAGE (0–5V)} \times \text{GAIN} \quad \text{(Eq. 1), where:}$$

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.)

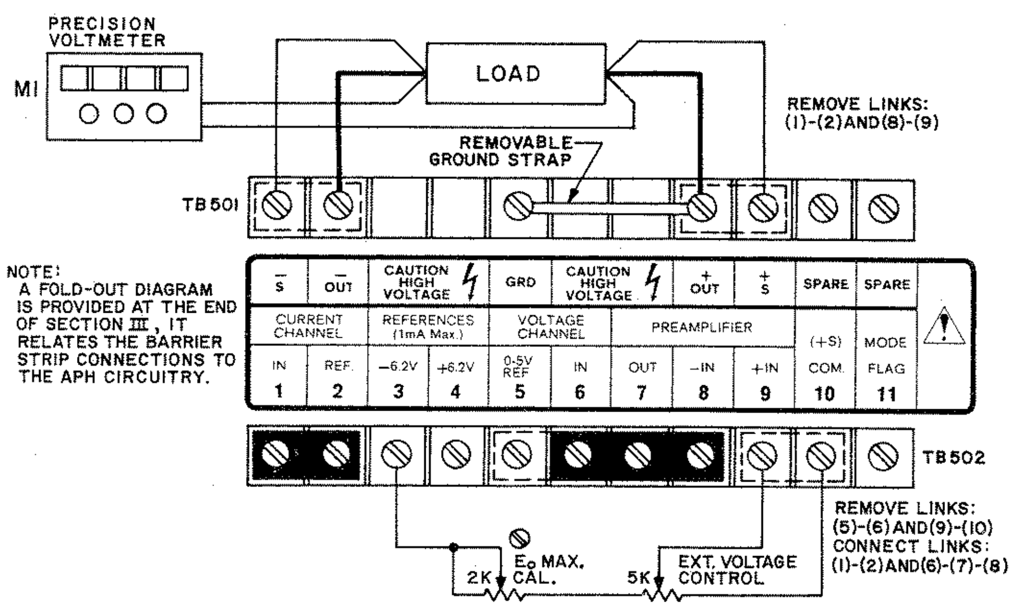


FIG. 3-3 CONNECTIONS FOR REMOTE APH OUTPUT VOLTAGE CONTROL WITH A POTENTIOMETER.

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.)

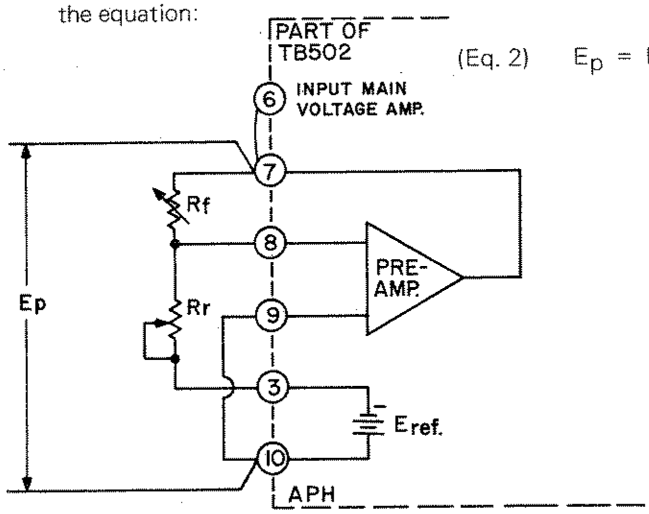
5) Operation can now proceed. Check output by means of an oscilloscope. (CAUTION: HIGH VOLTAGE PROBE REQUIRED) for dynamic stability and output ripple. Refer to Section III, par. 3-3 if high output ripple is evident. Refer to Section V, par. 5-6a if dynamic instability is encountered.

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.

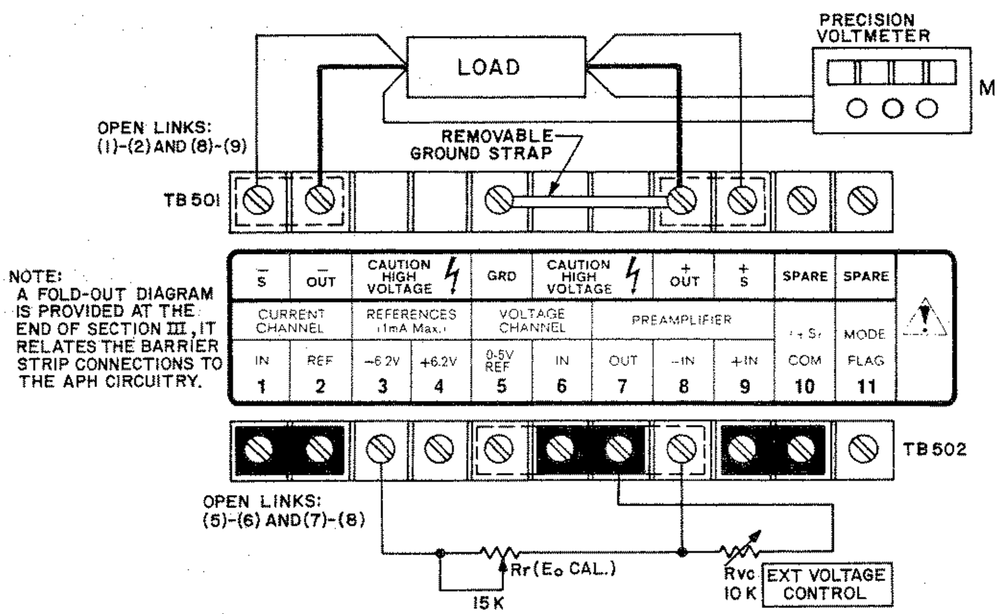


FIG. 3-4 CONNECTIONS FOR APH OUTPUT VOLTAGE CONTROL WITH A TWO-TERMINAL RESISTANCE.

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:

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

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_0 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_0 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.

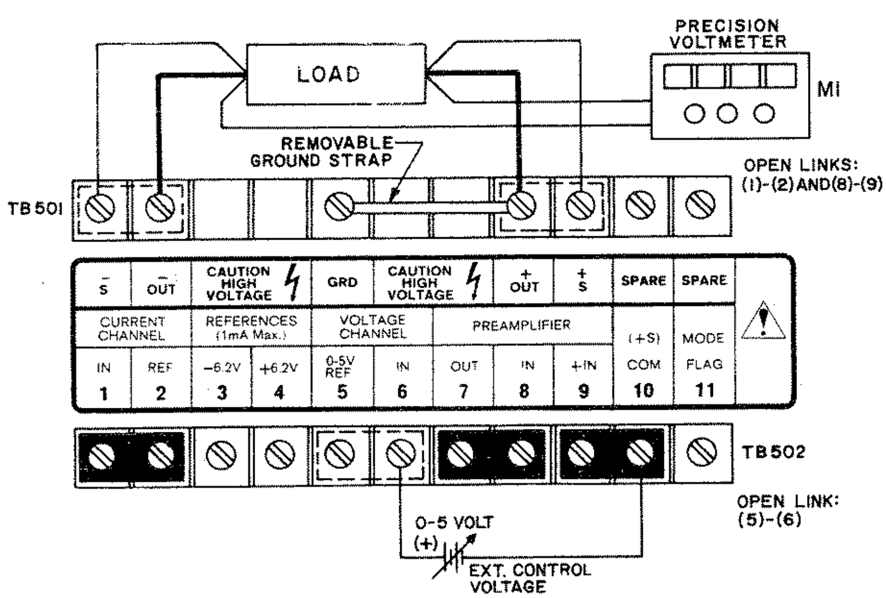


FIG 3-5 CONNECTIONS FOR APH OUTPUT VOLTAGE CONTROL WITH AN EXTERNAL CONTROL VOLTAGE, HAVING A LOW IMPEDANCE OUTPUT.

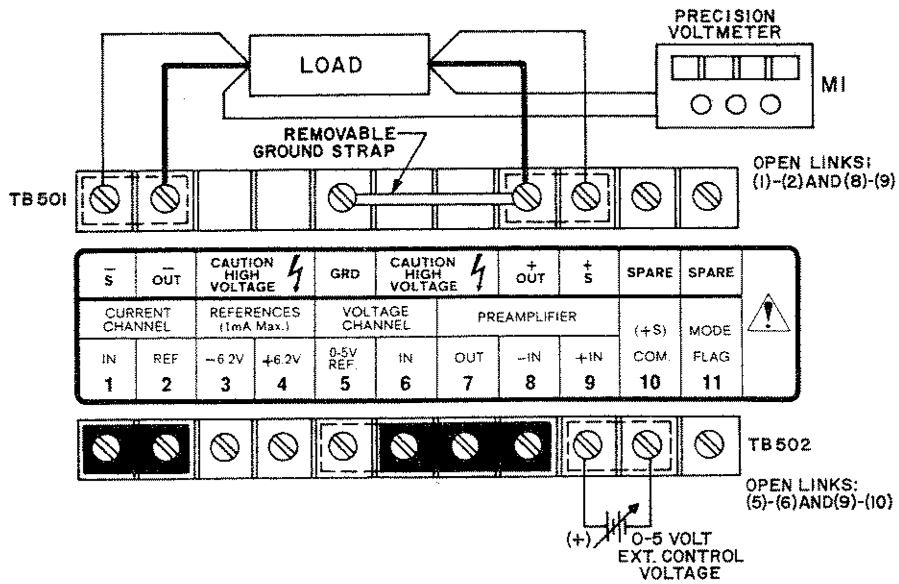


FIG. 3-6 CONNECTION FOR APH OUTPUT VOLTAGE CONTROL WITH AN EXTERNAL CONTROL VOLTAGE HAVING A HIGH IMPEDANCE OUTPUT.

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 a 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

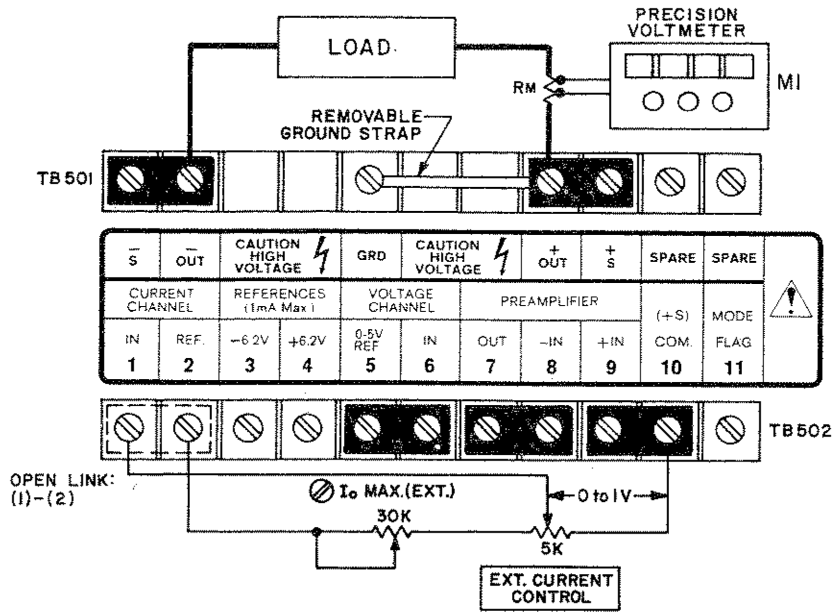


FIG. 3-7 CONNECTIONS FOR APH OUTPUT CURRENT CONTROL WITH AN EXTERNAL POTENTIOMETER.

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).

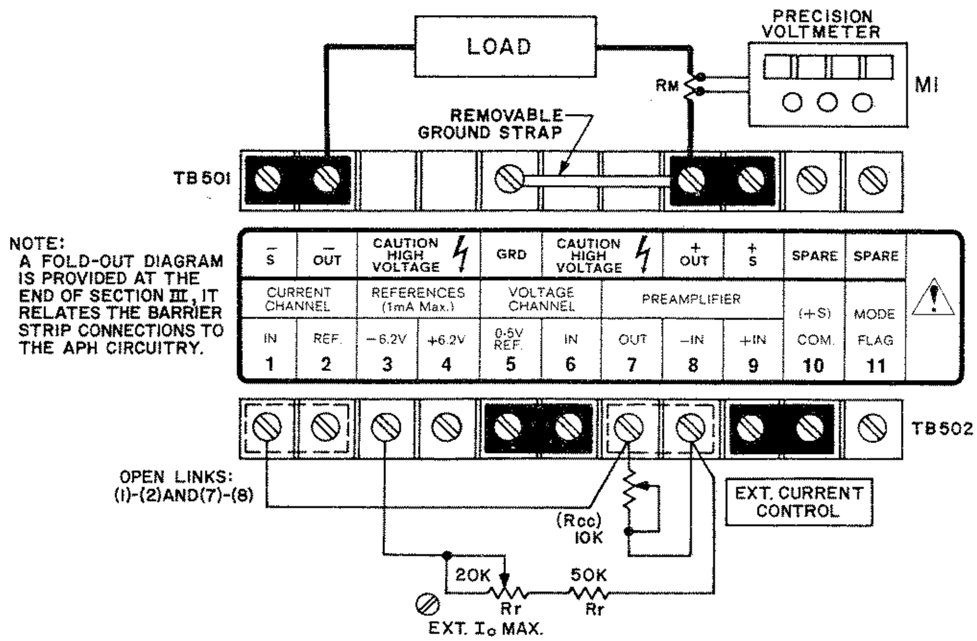


FIG. 3-8 CONNECTIONS FOR APH OUTPUT CURRENT CONTROL WITH A TWO-TERMINAL RESISTANCE.

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 "IV" 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.

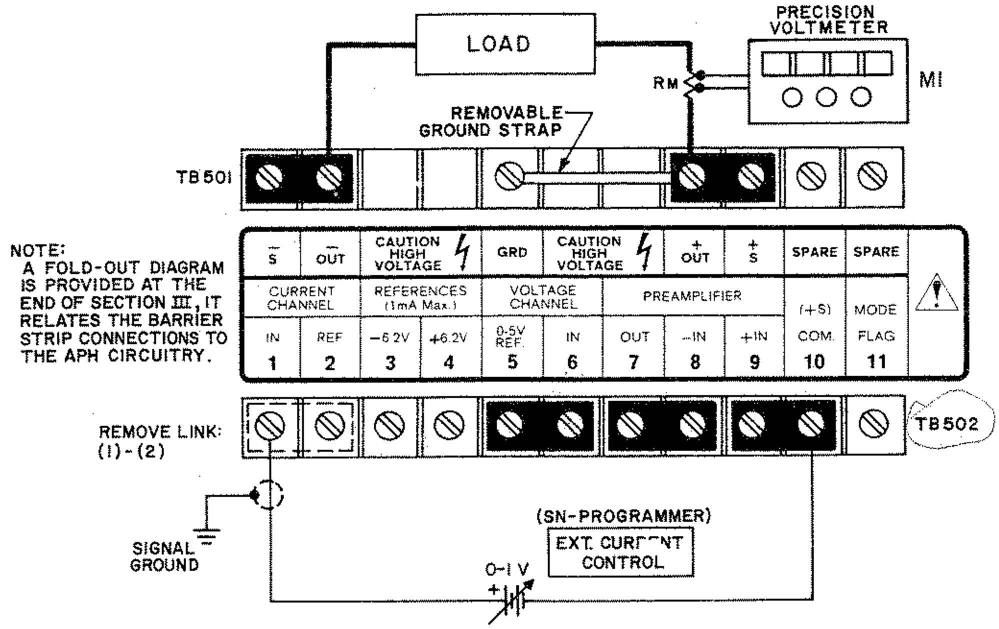


FIG. 3-9 CONNECTIONS FOR APH OUTPUT CURRENT CONTROL WITH AN EXTERNAL VOLTAGE SOURCE.

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

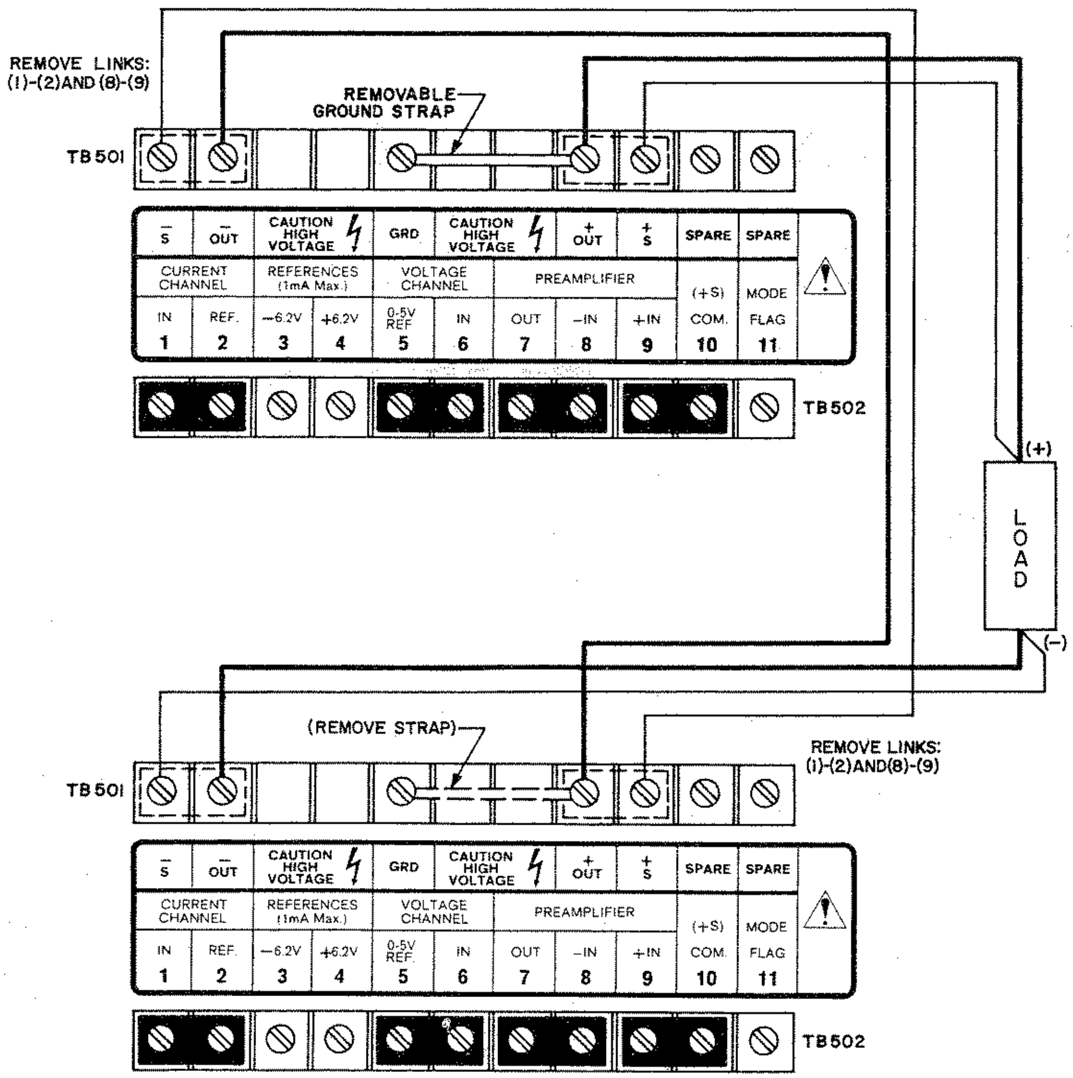


FIG. 3-10 "AUTOMATIC" SERIES CONNECTION OF TWO MODEL APH 500M POWER SUPPLIES.

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).

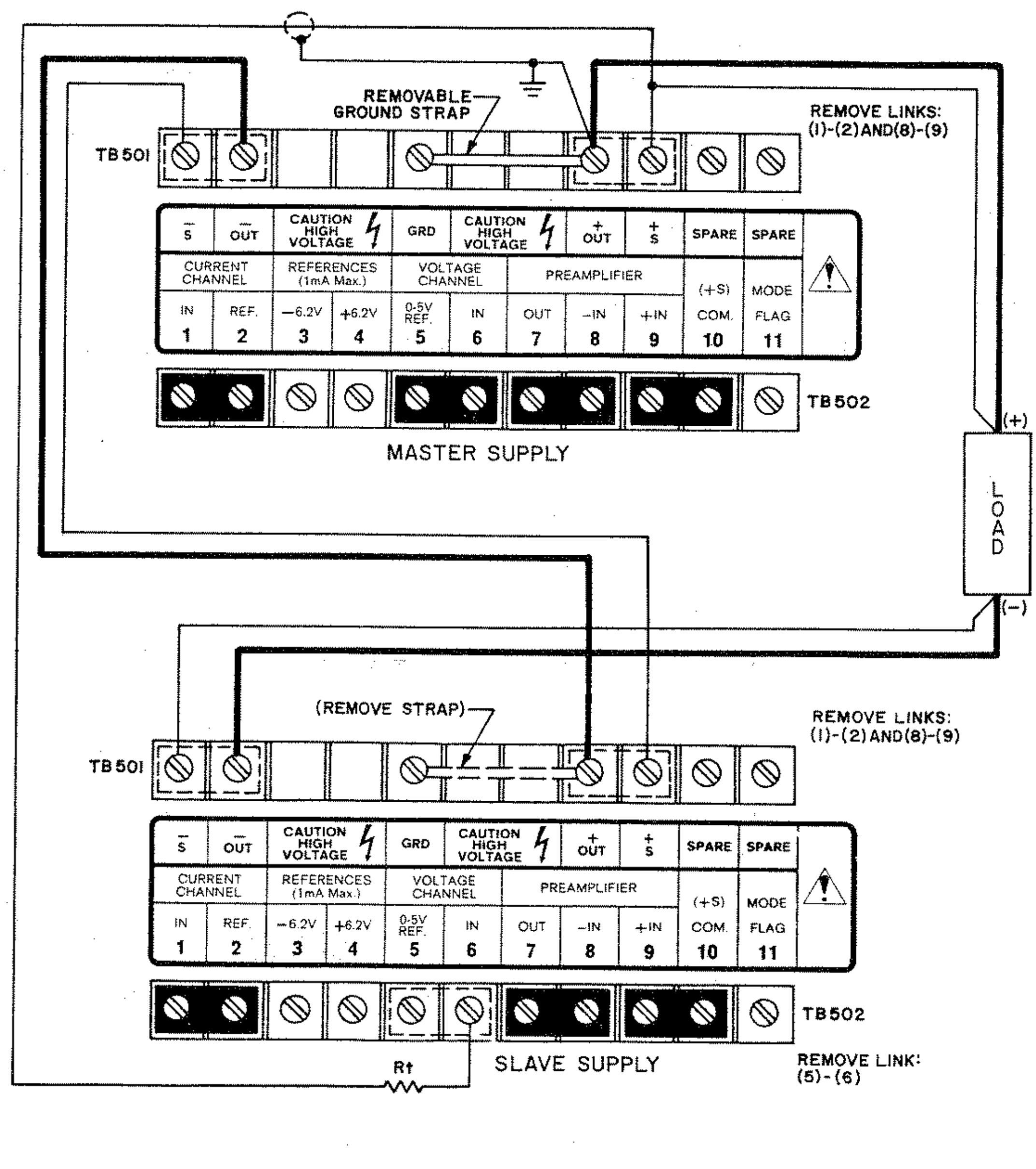


FIG. 3-11 "MASTER/SLAVE" SERIES CONNECTION OF TWO MODEL APH 500M POWER SUPPLIES.

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.

CAUTION

DO NOT SET *EITHER* VOLTAGE CONTROL *COMPLETELY* COUNTERCLOCKWISE.

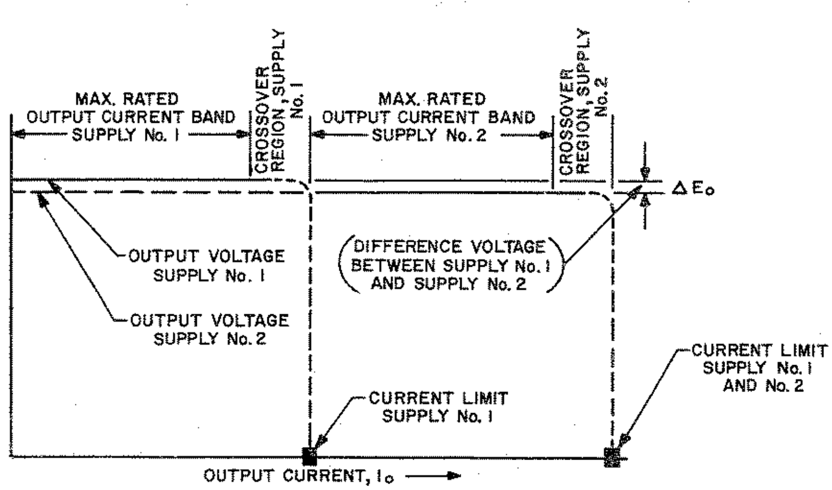
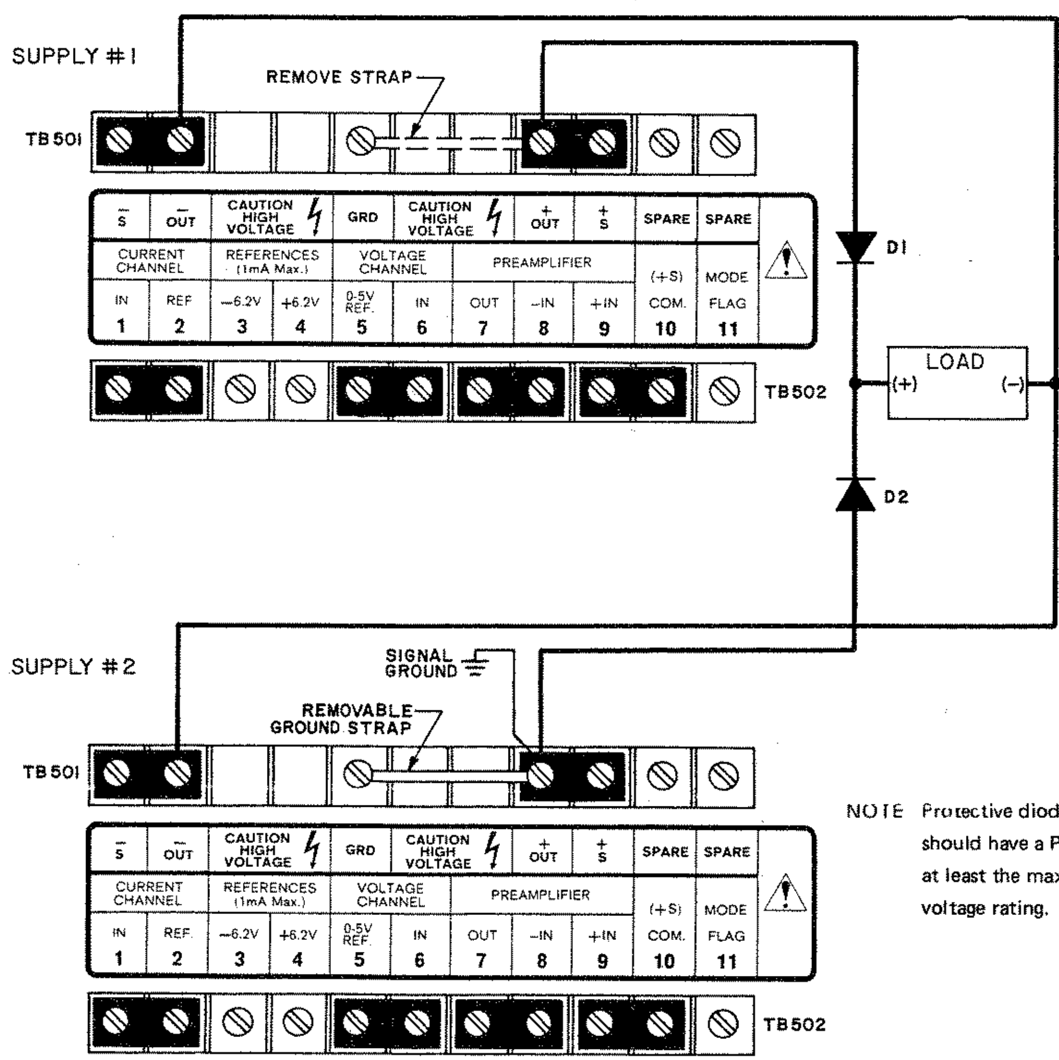


FIG. 3-12 "OUTPUT CHARACTERISTIC GRAPH OF TWO APH POWER SUPPLIES IN PARALLEL.

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 (ΔE_O) between the two supplies. Load variations not confined to this area will include ΔE_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.

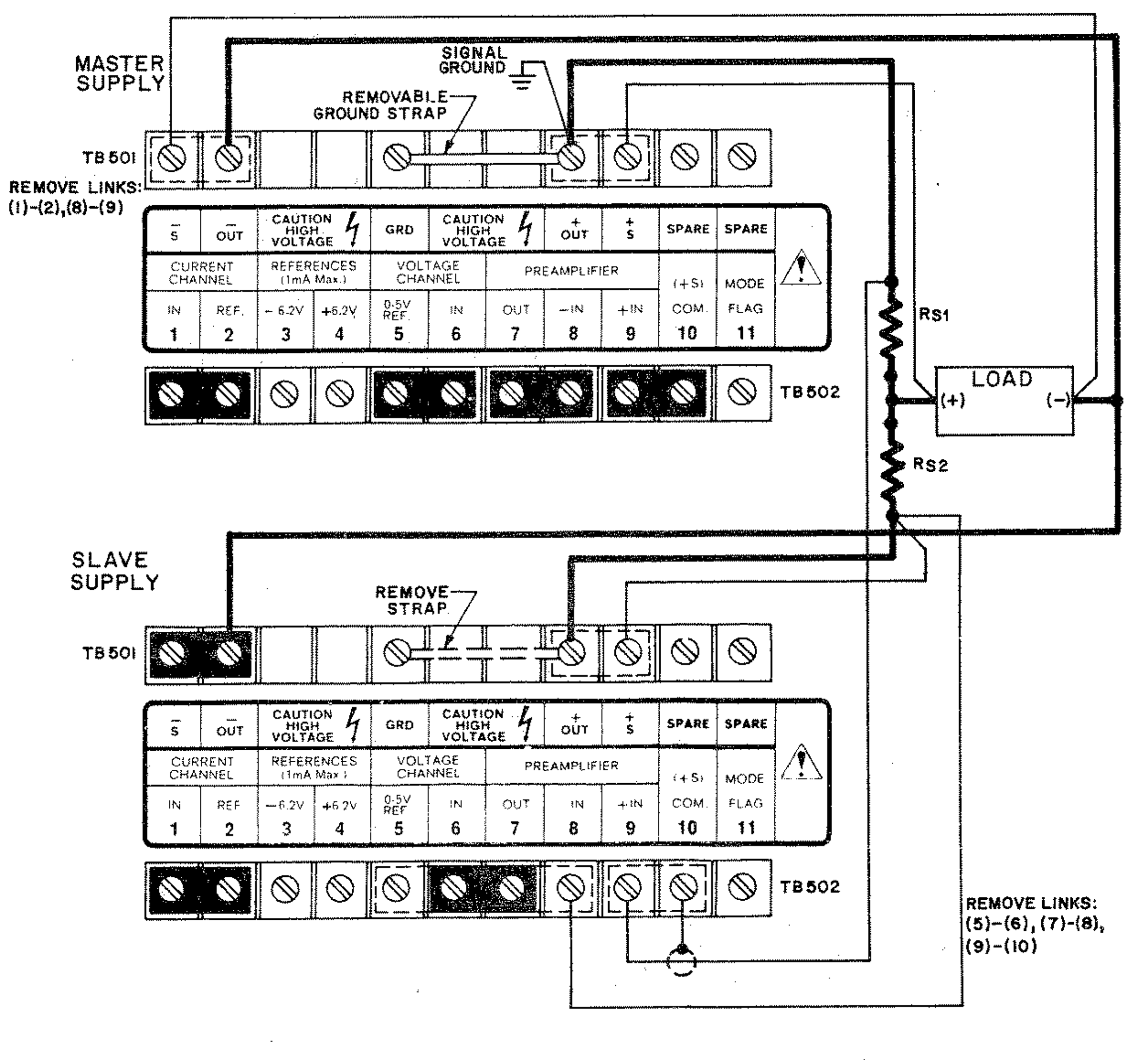


FIG. 3-14 "MASTER/SLAVE" PARALLEL CONNECTION OF TWO APH POWER SUPPLIES (METHOD I)

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.

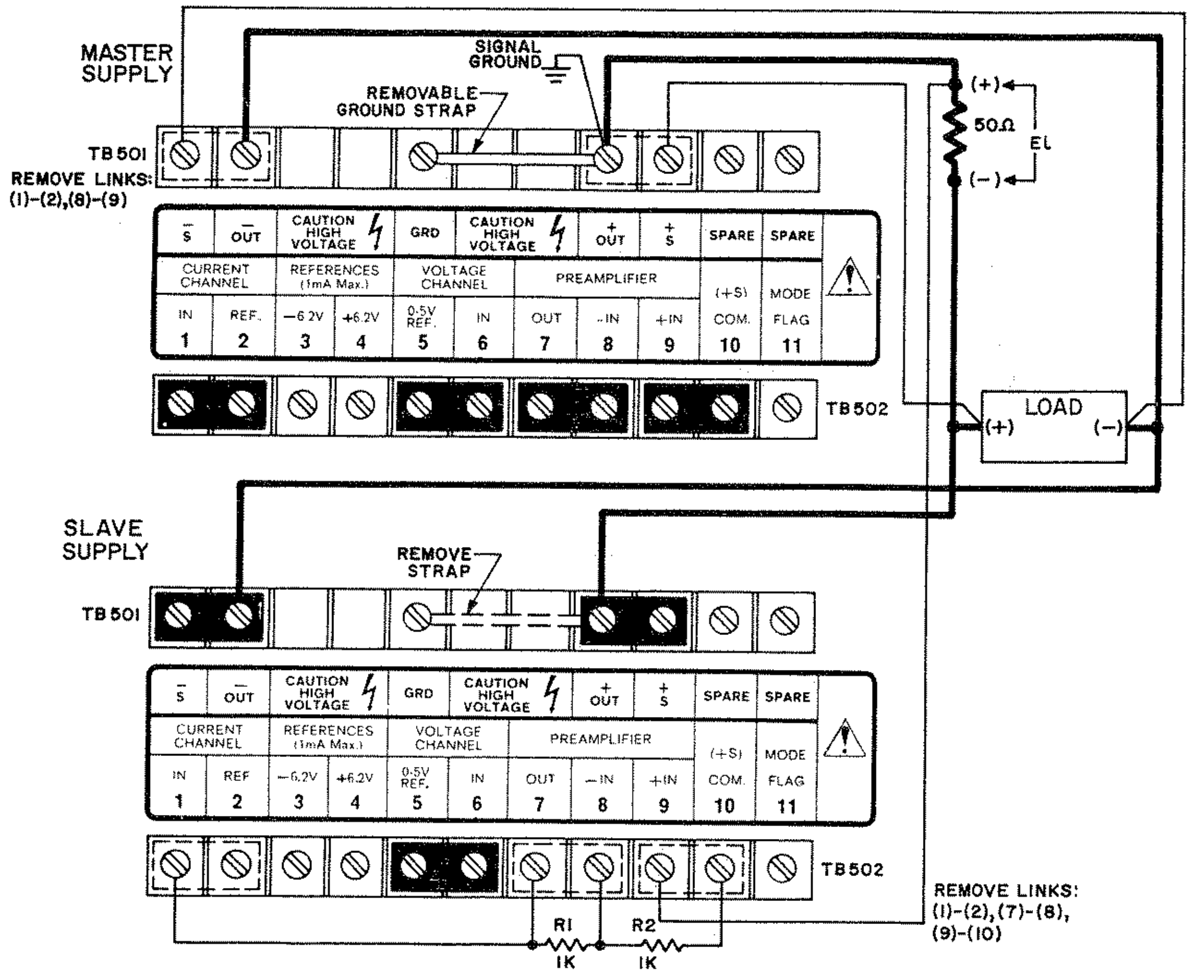


FIG. 3-15 "MASTER/SLAVE" PARALLEL CONNECTION OF TWO APH POWER SUPPLIES (VOLTAGE MODE

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.

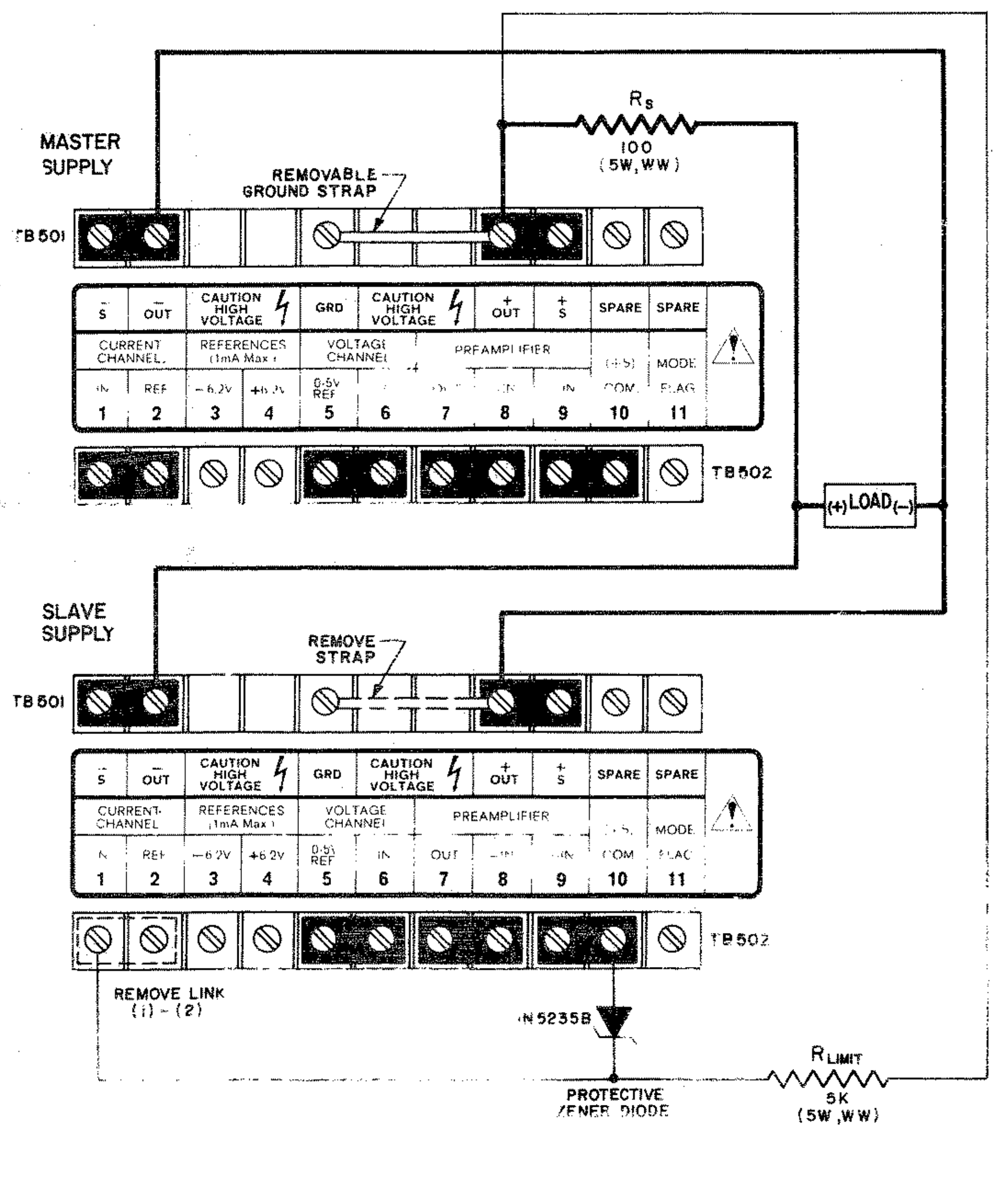


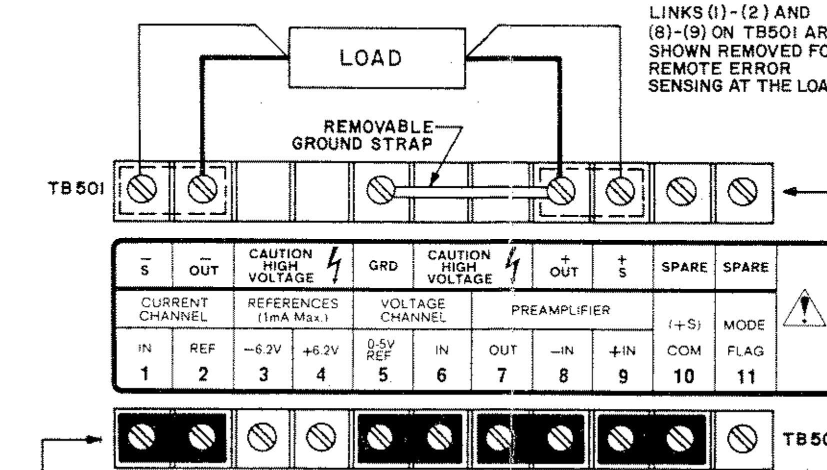
FIG. 3-16 MASTER/SLAVE PARALLEL CONNECTION OF TWO APH POWER SUPPLIES (CURRENT MODE)

NOMENCLATURE AND ABBREVIATIONS

(O) = Front Panel Output Terminals
⊘ = Internal Calibration Control
▭ = Front Panel Control
⚠ = See Instruction Manual

Amp . . . . Amplifier
C_f . . . . Feedback Capacitor
C_o . . . . Output Capacitor
Comp. . . . . Compensation
E_{ref} . . . 6.2 volt reference source, @ 1 mA MAX.
E_o . . . . . . OUTPUT VOLTAGE
I_o . . . . . . OUTPUT CURRENT
+IN . . NON-INVERTING INPUT
–IN . . . . . INVERTING INPUT
GRD . Ground, Chassis Connection
LAG . . . . Dynamic Stability Adjustment
R_f . . . (Fixed) Feedback Resistor
R_s . . . . Current Sensing Resistor
E_o, I_o Zero. . . . . **Offset Voltage Adjustment**

NOTE: Links (1)–(2) and (8)–(9) on TB501 are shown removed for remote error sensing at the load.



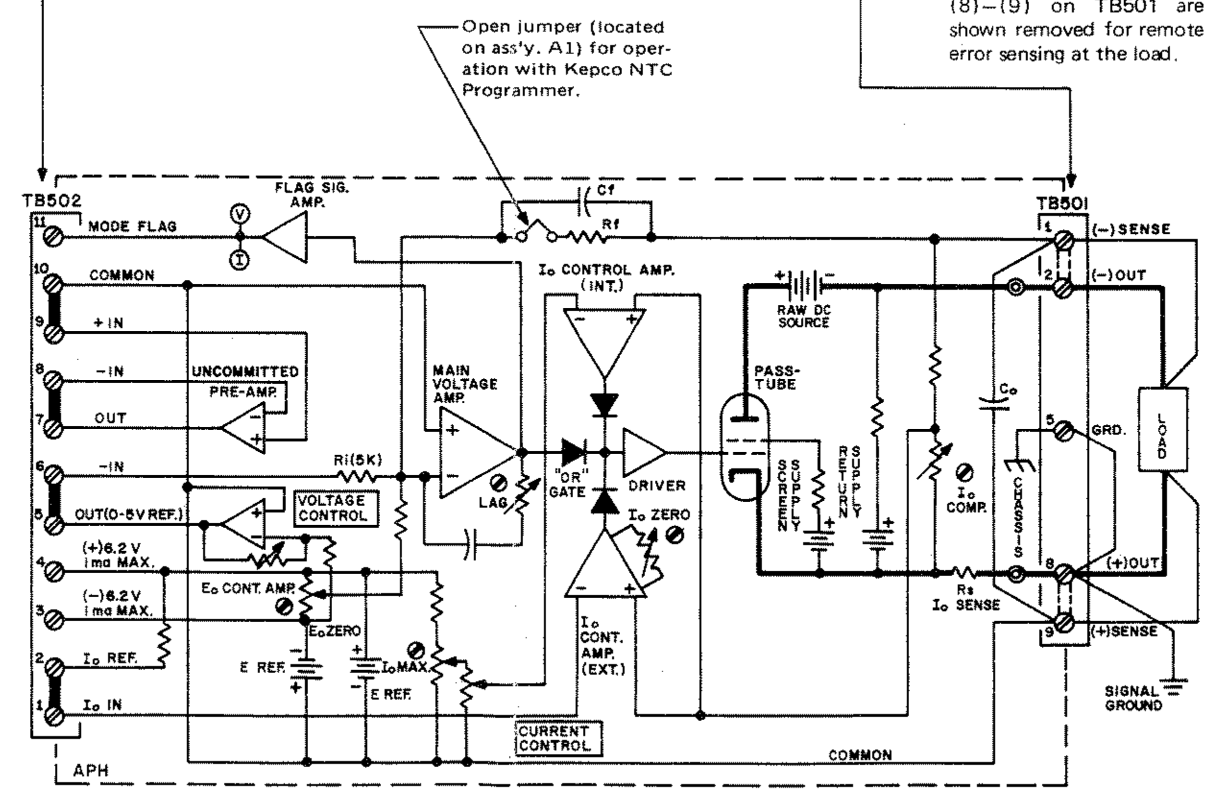


FIG. 3-15 ACTUAL APH REAR TERMINALS (TOP) AND SIMPLIFIED SCHEMATIC DIAGRAM (BELOW)

SECTION IV – THEORY OF OPERATION

4-1 SIMPLIFIED DIAGRAM DISCUSSION (Refer to FIG. 4-1)

4-2 The POWER TRANSFORMER has six (6) secondary windings which are used to produce the a-c filament voltage for the SERIES PASS TUBE and the d-c operating potentials for the MAIN D-C SUPPLY, the DRIVER SUPPLY, the SCREEN SUPPLY, the RETURN SUPPLY and the AMPLIFIER SUPPLY. The MAIN D-C SUPPLY is connected in series with the SERIES PASS TUBE, the CURRENT SENSING RESISTOR and the (±) OUTPUT terminals. The output level of the APH is controlled by varying the series impedance of the PASS TUBE. The necessary drive to affect this control is provided by the DRIVER STAGE, which in turn receives its drive either from the MAIN VOLTAGE AMPLIFIER or from one of the CURRENT CONTROL AMPLIFIERS.

NOMENCLATURE AND ABBREVIATIONS

(◎) = Front Panel Output Terminals
(⊘) = Internal Calibration Control
▭ = Front Panel Control
⚠ = See Instruction Manual

Amp . . . . Amplifier
C_f . . . . Feedback Capacitor
C_o . . . . Output Capacitor
Comp. . . . . Compensation
E_{ref} . . . 6.2 volt reference source, @ 1 mA MAX.
E_o . . . . . . OUTPUT VOLTAGE
I_o . . . . . . OUTPUT CURRENT
+IN . . NON-INVERTING INPUT
−IN . . . . . INVERTING INPUT
GRD . Ground, Chassis Connection
LAG . . . . Dynamic Stability Adjustment
R_f . . . (Fixed) Feedback Resistor
R_s . . . . Current Sensing Resistor
Zero . . Offset Voltage Adjustment

NOTE: Links (1)–(2) and (8)–(9) on TB501 are shown removed for remote error sensing at the load.

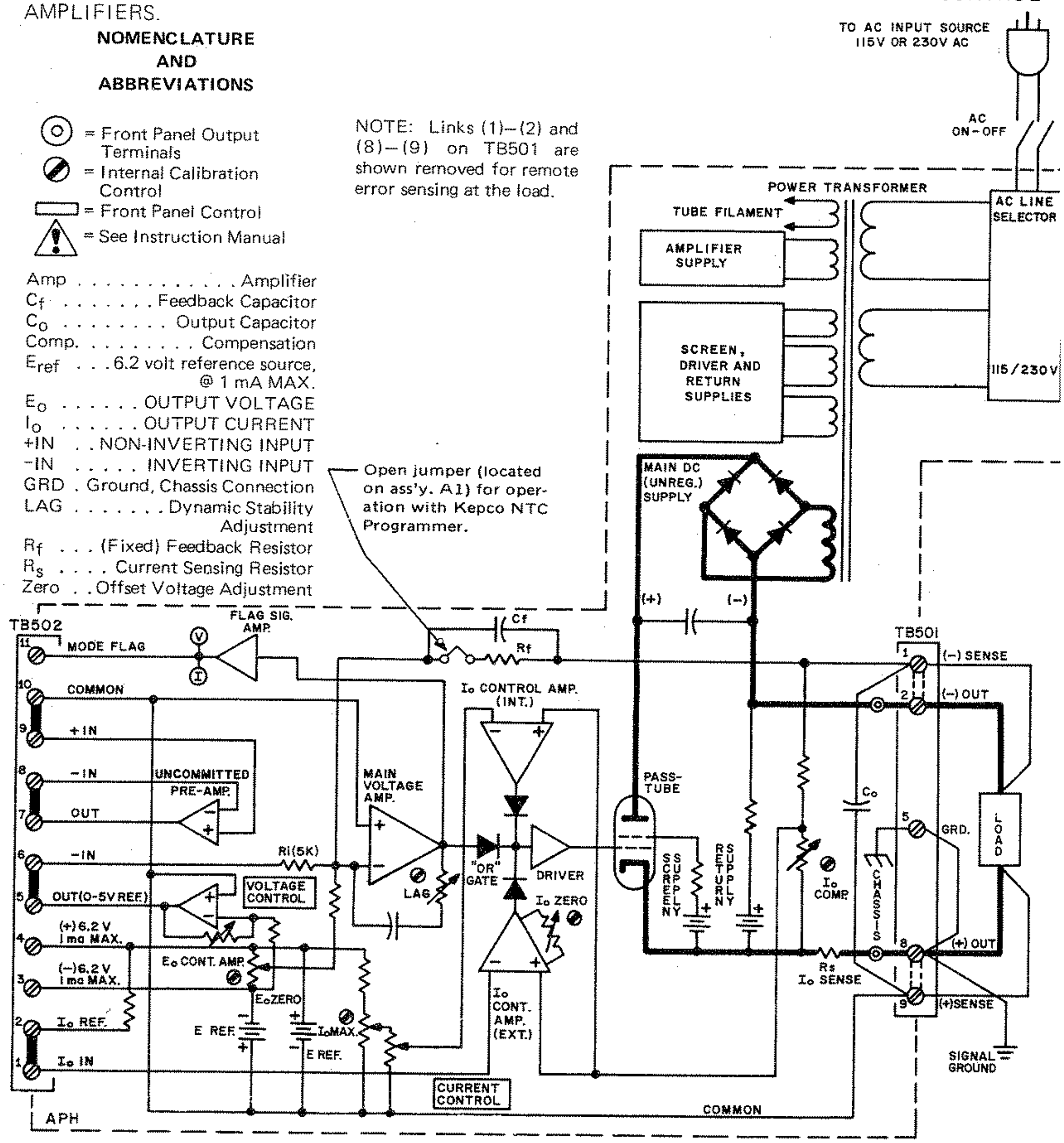


FIG. 4-1 SIMPLIFIED DIAGRAM, KEPCO APH POWER SUPPLY. REAR LINK CONNECTION PATTERN SHOWN IS FOR LOCAL (FRONT PANEL) OUTPUT CONTROL AND ERROR SENSING AT THE LOAD.

4-3 If the APH is used in the local (front panel controlled) operating modes, with the rear links connected as shown in FIG. 4-1, it functions as a d-c source delivering stabilized output voltage or stabilized output current to the load. The operating mode ("voltage" or "current" is determined by the load resistance and by the setting of the front panel OUTPUT VOLTAGE CONTROL and the front panel OUTPUT CURRENT CONTROL. If, in FIG. 4-2, "E_o" (voltage) and "I_o" (current) represent the respective settings of the output controls, the "crossover" resistance (R_{LX}) is given by Ohm's Law:

$$R_{LX} = E_o/I_o.$$

4-4 Any load resistance, ***smaller*** than R_{LX} (as, for example, R_{LI} in FIG. 4-2) will transfer the APH into the "Current Mode." With any load resistance ***larger*** than R_{LX} (as, for example, R_{LV} in FIG. 4-2), the APH will operate in the "Voltage Mode."

4-5 Operating as a d-c source (as shown in FIG. 4-1, the APH output voltage and current are constantly monitored and compared to the internal temperature-compensated REFERENCE SOURCE (E_{ref}). The VOLTAGE and CURRENT CONTROL AMPLIFIERS operate as "Error-Signal Amplifiers," and at balance, the settings of the output controls and the value of the load resistance establish a given operating point on the output characteristic, as described previously. A change in either output control setting, or an external influence on the set output quantities (change in load, variations in a-c source voltage) are interpreted by the APH sensing circuits as "Error Signals." Depending on the prevailing operating mode of the APH, the "error signal" is amplified by one of the control amplifiers. The amplified error signal is presented to the OR—GATE, which only passes the most positive signal, so that only ***one*** of the amplifiers can be in control at any one time. Once the amplified error signal is passed by the OR—GATE, it becomes a "control signal" which, amplified by the DRIVER STAGE, is applied to the control grid of the SERIES PASS TUBE.(1) The SERIES PASS TUBE changes its series impedance in response to the control signal from the DRIVER STAGE. The control signal was derived from the "error signal" and is, therefore, proportional to the original output variation of the APH. The resulting series impedance change in the SERIES PASS TUBE is, therefore, exactly inversely proportional to the original output variation, so that the APH output is returned to the original value and thereby stabilized.

4-6 If the APH is controlled remotely (programmed) in the voltage mode, the INVERTING INPUT of the MAIN VOLTAGE AMPLIFIER can be addressed directly, or via the output of the PREAMPLIFIER. Both operating methods are illustrated and described in Section III of this manual. (Refer for example to FIG. 3-3.
The output of the APH is "unipolar," varying in a single direction. The current control channel in this application is used as a "current limiter" by setting the CURRENT CONTROL to the maximum desired output current.

4-7 The current control channel has a second amplifier (I_o CONTROL AMP. EXT.) provided for remote control (programming) of the output current. The amplifier for internal control (I_o CONTROL AMP. INT.) is left in the circuit and serves, together with the front panel CURRENT CONTROL as a back-up current limit. Directions for remote control of the output current are given in Section III of this manual.

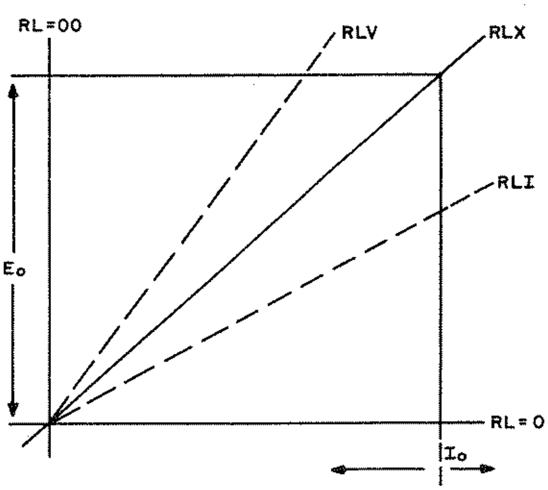


FIG. 4-2 "CROSSOVER" CHARACTERISTICS, APH POWER SUPPLY.

(1)At turn-on, the signal from the DRIVER STAGE is delayed for approximately 25 seconds by a delay circuit

4-8 CIRCUIT DESCRIPTION (Refer to Main Schematic, FIG. 6-6)

4-9 For the purpose of analysis, the circuitry of the APH Power Supply may be divided into several sections which are subsequently described below. Refer to the main schematic diagram, FIG. 6-6.

a) A-C INPUT CIRCUIT (Refer to FIG. 4-3). The a-c input power is introduced via the 3-wire line cord (detachable) with a 3-prong safety plug. The line cord ground wire (green), is directly connected to the metal chassis of the APH, providing automatic grounding of the APH case and chassis if a properly grounded a-c power outlet is used. The input fuse (F201) protects the APH from overloads reflected into the a-c input circuitry. The "hot" side of the a-c power line is connected to the transformer (T201) via the A-C POWER "ON-OFF" switch and the INTERLOCK switch (S401). The INTERLOCK switch serves to disconnect the a-c power from the APH if the protective rear cover is removed. The interlock function can be defeated by pulling the activating button completely outward. The POWER TRANSFORMER (T201) is equipped with dual primary windings, which are either operated in parallel (115V a-c nominal source voltage) or in series (230V a-c nominal source voltage). The APH can be readily connected for either source voltage by setting the A-C LINE SELECTOR SWITCH to the prevailing source voltage (see Section II of this manual). Once the APH is connected to the a-c source and the A-C POWER SWITCH (S201) is closed, the primary of the MAIN TRANSFORMER (T201) and the front panel A-C POWER LIGHT are energized. The output voltage is delayed for approximately 25 seconds to permit the warm-up of the filament on the SERIES PASS TUBE. Any interruption of a-c source voltage will necessitate a new 25 second delay cycle.

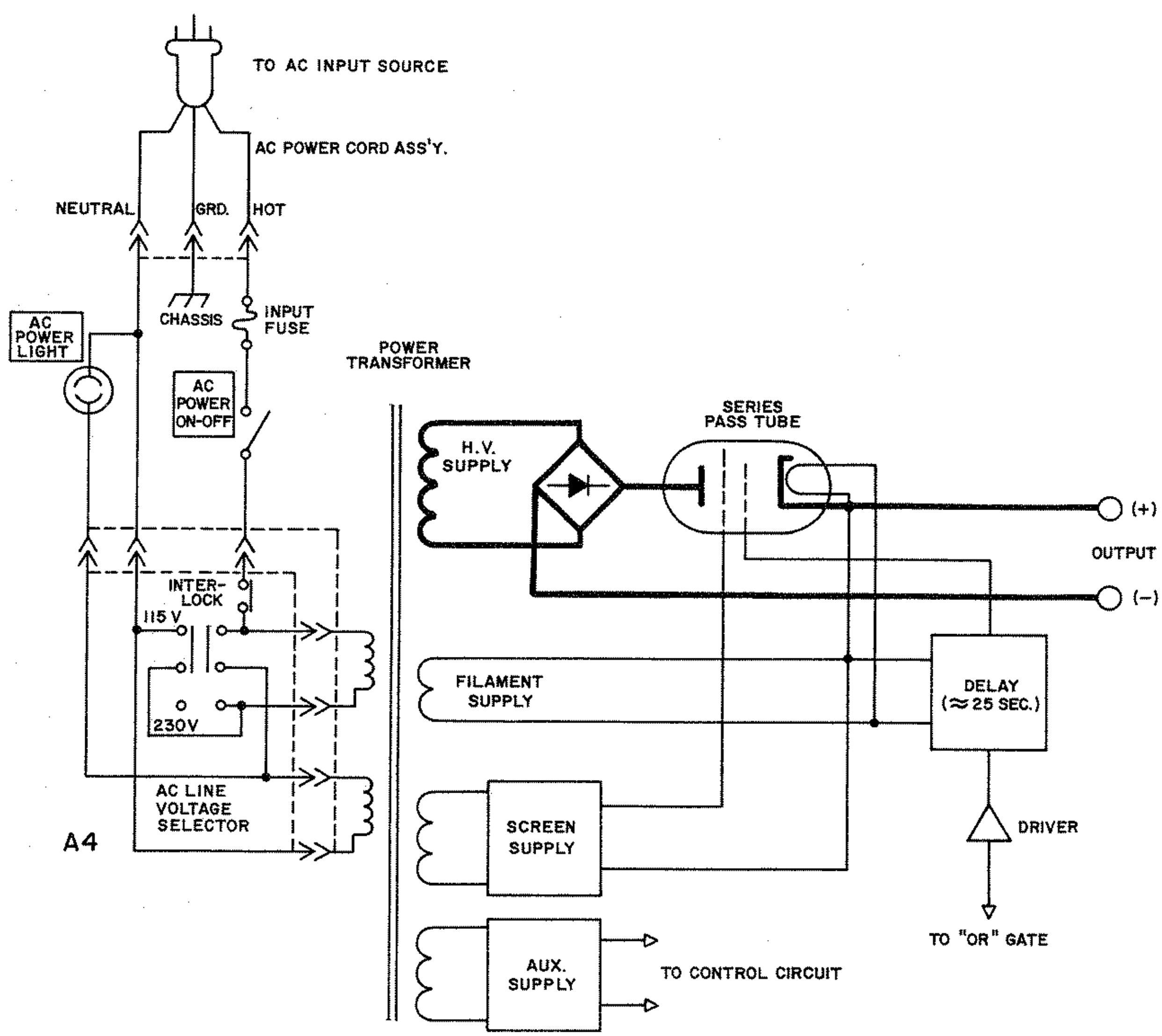


FIG. 4-3 SIMPLIFIED A-C INPUT CIRCUIT, APH POWER SUPPLY.

b) MAIN D-C SUPPLY. The main d-c supply is derived from a secondary winding on the POWER TRANSFORMER (T201). Rectified by the bridge rectifier (CR601 to CR604) and filtered by C201, the main d-c supply delivers the output power via the Series Pass Tube (V301).

c) SERIES PASS TUBE CIRCUIT. The SERIES PASS TUBE (V301) is electrically in series with the (unregulated) main d-c supply and the external load connected to the ±Output terminals on TB501 (or at the front panel output jacks [J101 and J102]). The APH output is stabilized for variations in the unregulated d-c main supply or for changing external load conditions by controlling the series conductance of the pass tube. The necessary control grid signal to affect the change in conductance is supplied by the DRIVER stage (Q2). The DRIVER stage, in turn, receives its control signals either from the MAIN VOLTAGE AMPLIFIER (IC-4), the (INTERNAL) CURRENT CONTROL AMPLIFIER (½ IC-2), or the (EXTERNAL) CURRENT CONTROL AMPLIFIER (IC-3).

d) VOLTAGE CONTROL CHANNEL. If the APH is used as a stabilized d-c voltage source, the Main Voltage Amplifier (IC-4) serves as a comparator. The output voltage is sensed (via the feedback resistors R44, R45) [1] at the ± sense terminals on TB501, and compared with a reference voltage (via Main Voltage Amplifier input resistor [R22]) at the inverting input of IC-4. The reference potential may be applied (as a control voltage) to the (inverting) MAIN VOLTAGE AMPLIFIER INPUT TERMINAL (TB502-6) via the output of the VOLTAGE CONTROL AMPLIFIER (½ IC-5), or via the output of the PREAMPLIFIER (½ IC-5), or it may be applied directly. A condition of balance at the inverting input of the MAIN VOLTAGE AMPLIFIER may be expressed by the equation:

$$\frac{E_o}{R_f} = \frac{E_i}{R_i}$$

where:

E_o = Output Voltage
E_i = Reference (control) Voltage
R_f = Built-in Feedback Resistors
R_i = Built-in Input Resistor

A change in any of the quantities in the balance equation will produce an "error signal" at the input of the MAIN VOLTAGE AMPLIFIER. This amplifier is a high-gain integrated circuit "op-amp," which produces a control signal at the OR—GATE (CR7, CR8, CR9), thereby providing the base drive for the driver transistor Q2. The drive from Q2 is phased and proportioned to influence the conductance of the SERIES PASS TUBE in such a way as to compensate exactly for the original change in the quantities of the balance equation.

e) The (inverting) MAIN VOLTAGE AMPLIFIER INPUT is made available at the rear barrier-strip (TB502-6) and may be used for programming with voltage signals. The MAIN VOLTAGE AMPLIFIER (IC-4) is stabilized by means of a lag network (C9, R21) which can be used to optimize dynamic performance. With zero volts applied at the Voltage Mode Amplifier Input, the output voltage may be zeroed by use of the internal VOLTAGE ZERO CONTROL (R28).

f) PREAMPLIFIER STAGE. An uncommitted preamplifier (½ IC-5) is provided, which can be used for a variety of programming tasks. The output, as well as both inputs, are available at the rear barrier-strip (TB502-7, TB502-8, TB502-9).

g) VOLTAGE CONTROL AMPLIFIER. The Voltage CONTROL AMPLIFIER (½ IC-5) provides an analog output voltage signal, proportional to the VOLTAGE CONTROL (R101) setting, of approximately 0 to 5 volts (1 mA maximum). It provides the necessary interface for local control of the MAIN VOLTAGE AMPLIFIER (IC-4) via the (inverting) MAIN VOLTAGE AMPLIFIER INPUT (TB502-6). The OUTPUT of the VOLTAGE CONTROL AMPLIFIER is available on the rear barrier-strip (TB502-5).

h) CURRENT CONTROL CHANNEL (Internal Control). The (INTERNAL) CURRENT CONTROL AMPLIFIER (½ IC-2) compares the voltage drop across the CURRENT SENSING RESISTOR (R305) to a control potential, derived from the positive zener source (CR23) and established across the CURRENT CONTROL potentiometer (R102). The maximum output current (with the CURRENT CONTROL fully clockwise) is established with the internal I_o MAX control (R32). Variations in output current flow (and consequent changes in the voltage drop across R305) or changes in the control potential (as adjusted by means of the CURRENT CONTROL) result in an error signal across the differential input of the (INTERNAL) CURRENT CONTROL AMPLIFIER (½ IC-2). The amplified error signal from this half of IC-2 pass the gate diode (CR8) as a control signal, taking control away from the MAIN VOLTAGE AMPLIFIER (IC-4) and transferring the APH into the "current mode" of operation.

[1] Model APH 2000M. Single resistor (R44) on other models.

i) CURRENT CONTROL CHANNEL (External Control). The (EXTERNAL) CURRENT CONTROL AMPLIFIER (IC-3) compares the voltage drop across the CURRENT SENSING RESISTOR (R305) to a control potential via the external CURRENT CONTROL AMPLIFIER INPUT, available on the rear barrier-strip (TB502-1). An EXTERNAL CURRENT REFERENCE is provided from the positive zener source (CR23) via R30 at the rear barrier-strip (TB502-2). Remote programming of the CURRENT CONTROL CHANNEL may be accomplished by use of an external current control potentiometer or by means of an externally applied control signal. During remote programming of the current channel, the (EXTERNAL) CURRENT CONTROL AMPLIFIER compares the potential across the CURRENT SENSING RESISTOR (R305) against the externally provided control potential. The amplified error signal passes via the gate diode (CR-9). Zeroing of the current control channel during application of a zero control signal may be accomplished by adjustment of the I_O zero control (R13).

NOTE: Since the front panel CURRENT CONTROL is not disconnected for remote current programming, it may be used as a "back-up" current limit control. It should be set to a higher value than the maximum output current value adjustable by the external control, since the control with the lower setting acts as the active current control.

j) In the current mode of operation, the MAIN VOLTAGE AMPLIFIER FEEDBACK RESISTORS represent a shunt load parallel with the external load, resulting in a "error current" in parallel with the actual load current. A compensating circuit, consisting of a voltage divider (R47, R306, R33) is used in the APH output circuit, providing a proportional compensating voltage, opposing the direction of the error current. An "I_O COMPENSATION" CONTROL (R33) is provided to adjust the compensation to exact proportionality with the error current, thus minimizing the output effects for load changes in the current mode of operation. A signal from the voltage divider is also applied to the AMMETER BUFFER AMPLIFIER (½ IC-2). The AMMETER BUFFER AMPLIFIER acts as a high impedance non-inverting, unity gain interface which prevents the current passing through the MAIN VOLTAGE AMPLIFIER FEEDBACK RESISTORS from influencing the reading of the current meter (M102).

k) The purpose of the DELAY CIRCUIT IS: (1) To provide sufficient warm-up time for the filament of the SERIES PASS TUBE before the anode voltage is applied and d-c output is taken from the APH; (2) To prevent output "overshoot" at turn-on or turn-off.

The operating voltage for the DELAY CIRCUIT is derived from the filament winding for the SERIES PASS TUBE (V301), rectified by CR308 and filtered by C304. The delay time (approximately 25 seconds) is provided by the time constant of R309, C306 in conjunction with the programmable unijunction transistor for (Q301) and resistors R307, R308.

Prior to a-c power turn-on, the SERIES PASS TUBE is held at cut-off by means of a large negative potential from the DRIVER (Q2) collector supply, while the MAIN VOLTAGE AMPLIFIER is biased off (via the N.C. contact of K301).

Approximately 25 seconds following a-c power turn-on, Q301 generates a pulse, turning the SCR (CR312) "on," which in turn energizes the relay (K301). Now, the N.C. contact of K301 opens, returning the MAIN VOLTAGE AMPLIFIER (IC-4) to its operating state and the N.O. contact of K301 applies the drive signal from Q2 (via CR30) to the control grid of the SERIES PASS TUBE (V301). Turn-on overshoot is then avoided and the APH output is available.

At a-c power turn-off, the relay (K301) de-energizes immediately, its N.O. contact removing the drive signal (from Q2) from the control grid of the SERIES PASS TUBE (V301), while its N.C. contact disables the MAIN VOLTAGE AMPLIFIER (IC-4). The DRIVER collector supply voltage maintains the SERIES PASS TUBE (V301) at cut-off and no turn-off overshoot will occur.

l) MODE INDICATOR LIGHTS and MODE FLAG. A pair of LED mode indicators on the front panel indicate either voltage mode or current mode of operation. The voltage mode indicator (DS103) and current mode indicator (DS102) are driven from transistors (Q4) and (Q3) respectively. Signals for the VOLTAGE INDICATOR DRIVER (Q4) are derived from the output of the MAIN VOLTAGE AMPLIFIER (IC-4) via R18, R19 and CR16. When the APH is operating in voltage mode, the voltage indicator driver will be placed into saturation causing the voltage MODE INDICATOR (DS103) to display and causing the current mode driver (Q3) to cut-off. Operation in current mode (either internal or remote control) will cause the voltage indicator driver to cut off, allowing the current indicator driver to turn on and hence, the current mode indicator will energize. The MODE FLAG transistor (Q5) derives its signal from the output of the current indicator driver (Q3) via R40 and CR27. The MODE FLAG TRANSISTOR (Q5) inverts the input information from the current indicator driver and presents a TTL compatible FLAG (with respect to common) at the MODE FLAG terminal on the rear barrier strip (TB502-11). Voltage mode of operation is represented by a logic level "0," and current mode of operation is represented by a logic level "1".

m) AUXILIARY D-C VOLTAGE SOURCES

1) SCREEN SUPPLY. The d-c voltage for the screen grid of the SERIES PASS TUBE is derived from a secondary winding on the POWER TRANSFORMER (T201). The supply has full wave bridge rectification (CR301 to CR304) and capacitive filtering (C302), and is connected from the cathode to the screen of the series PASS TUBE (V301). The filter capacitor (C302) is provided with a "bleeder" resistor (R301).

2) RETURN SUPPLY. The return supply provides a small circulating current through the SERIES PASS TUBE (V301) to maintain feedback control at zero volts output. The supply is derived from a secondary winding on the POWER TRANSFORMEP (T201). The full-wave bridge rectifier consists of four (4) diodes (CR605—CR608) and the filter capacitor (C602). The supply is connected between the cathode of V301 and (via resistors R602--R604) to the (-) output terminal.

3) AMPLIFIER POWER SUPPLY. This d-c source is derived from a secondary winding of POWER TRANSFORMER (T201), rectified by the full wave bridge (CR306) and capacitor filtered (C308). The dual d-c voltage (±13.6 volts) is stabilized by the differential amplifier [VOLTAGE REGULATOR AMPLIFIER] (IC-1) with series transistor (Q1) and filtered by C2 and C3. The zener diodes at the output of the regulator circuit (CR1, CR2, CR3) provide additional stabilization and divide the supply into the required auxiliary potentials. The two reference potentials (±6.2V) at 1 milliampere, available at the rear barrier-strip (TB502-3, TB502-4) are derived via series resistors (R27, R29) by means of temperature compensated zener diodes (CR23, CR24).

4) THE DRIVER TRANSISTOR COLLECTOR SUPPLY is derived from a secondary winding on the POWER TRANSFORMER (T201), rectified by the full wave bridge (CR305) and filtered by the capacitor (C307). The supply provides the necessary operating potentials for the control grid of the SERIES PASS TUBE (V301) via R304 and the driver transistor (Q2).

5) The FILAMENT SUPPLY is derived from a secondary winding on the POWER TRANSFORMER (T201) and provides the heater voltage for the series PASS TUBE (V301) and the operating potential for the delay circuit via the full wave bridge rectifier (CR308) and the filter capacitor (C303).

SECTION V — MAINTENANCE

5-1 GENERAL

5-2 This section covers maintenance procedures, calibration, and test measurements of the Kepco APH Power Supplies. Conservative rating of components and the noncongested layout should keep maintenance problems to a minimum. If trouble does develop, however, the easily removed wrap-around cover and the plug-in feature of the circuit boards provide exceptional accessibliity to all components of the supply.

5-3 COVER REMOVAL

5-4 The wrap-around cover and the main printed circuit board (A1) may be easily removed by following the directions given in FIG. 5-1 below.

WARNING

THIS INSTRUMENT IS CAPABLE OF PRODUCING LETHAL VOLTAGES:

1) ***WHENEVER POSSIBLE, RETURN THIS INSTRUMENT TO THE FACTORY IF SERVICE IS NEEDED.*** IF EMERGENCY REPAIRS MUST BE PERFORMED, PROCEED WITH EXTREME CAUTION:

2) ***WHENEVER POSSIBLE, REMOVE THE A-C POWER COMPLETELY FROM THE APH, BEFORE OPENING THE COVER.*** NORMALLY POWER REMOVAL IS AUTOMATIC, BY MEANS OF THE REAR TERMINAL INTERLOCK. IF NECESSARY THE INTERLOCK FUNCTION CAN BE DEFEATED BY PULLING THE ACTIVATING SHAFT COMPLETELY OUT.

3) IF THE APH MUST BE OPERATED WITH OPEN COVER OR DEFEATED INTERLOCK FUNCTION, MAKE CERTAIN OF THE FOLLOWING:

   A) SET UP APH IN A DRY, UNCLUTTERED AREA WHICH HAS AN INSULATED FLOOR.

   B) ***GROUND THE CHASSIS AND THE POSITIVE OUTPUT SIDE OF THE APH TO A GOOD A-C GROUND POINT.*** THIS WILL HELP GREATLY IN REDUCING THE SHOCK HAZARD, SINCE ALL AMPLIFIER AND AUXILIARY VOLTAGES ARE NOW CLOSE TO GROUND POTENTIAL.

   C) TOUCH WIRING AND CIRCUITRY WITH INSULATED ROD OR TOOL ONLY. ***REMOVE A-C POWER BEFORE REMOVING ANY COMPONENT.***

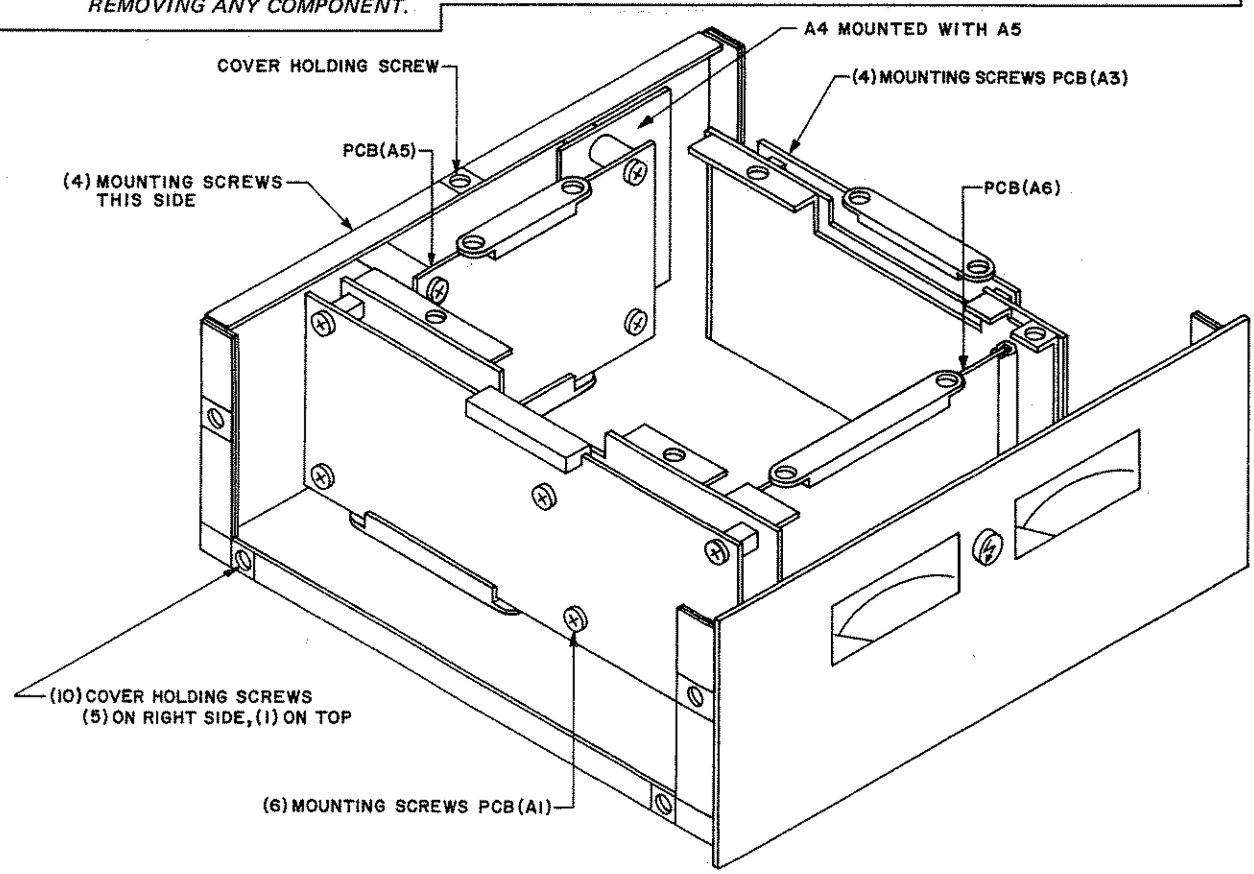


FIG. 5-1 COVER REMOVAL.

5-5 INTERNAL ADJUSTMENTS PROCEDURES

5-6 All available internal controls are located recessed from the rear panel of the APH. (See Section II, FIG. 2-2.) ***All controls should be adjusted only with the insulated tool,*** provided on the rear chassis of the APH. (See Section II, FIG. 2-2). Most adjustment procedures for the internal controls have been provided throughout the text in Section III of this manual. A summary of ***all*** procedures is presented below:

NOTE: Refer to Section II, FIG. 2-2, for the location of all internal APH controls.

a) LAG NETWORK ADJUSTMENTS. An a-c stability control in the form of a lag network has been provided in this power supply (LAG, see FIG. 2-2 for location). This network has been factory-adjusted for maximum amplifier stability when operating into a resistive load. Readjustment is indicated if components affecting the a-c characteristics of the amplifier must be replaced, or if the load connected to the power supply contains excessive capacity or inductance causing instability. Dynamic instability is usually indicated by high frequency oscillation observed with an oscilloscope across the power supply load. In such cases, the lag network should be adjusted so that stable operation is resumed. If in extreme cases adjustment of the lag network should not prove sufficient, twisted load and error-sensing wire pairs, or decoupling capacity directly across the load may provide a solution to the problem.

b) I_O ZERO ADJUSTMENT. An offset voltage zeroing adjustment is provided for the (EXTERNAL) CURRENT CONTROL AMPLIFIER. When externally programming the APH output current, this control is used to establish the I_O "zero" point (see for example Section III, par. 3-26 through par. 3-35).

c) I_O COMP ADJUSTMENT. The fixed feedback resistance of the APH MAIN VOLTAGE AMPLIFIER constitutes an internal shunt load in the current mode of operation. The shunt current thus flowing through the feedback resistance, if not compensated, produces an error proportional to the ratio of the feedback and the load resistance. The compensating circuit, provided in the APH, is factory adjusted for the best current stabilization with the built-in feedback resistor (R_f). If the feedback resistors must be replaced, the compensating circuit may be readjusted for optimum output current stabilization using the test set-up shown in Section V, fig. 5-3 for example, and following the procedure described below.

1) Set up the test circuit shown in Section V, FIG. 5-3 . Select the LOAD as required and connect a switch across the load. **(NOTE: The single pole switch is used to short-circuit the LOAD. It must be rated for the maximum compliance voltage appearing across the LOAD.)** Follow the turn-on procedure as described in Section II, par. 2-13. Set required compliance (load voltage) with the front panel VOLTAGE CONTROL.

2) Read and record the voltage drop (V_{RM}) across the measuring resistor (R_M). Close the LOAD switch and note the ***change*** in the voltage drop (ΔV_{RM}) across R_M. Current stability as a ***percentage*** can be expressed by: $\Delta V_{RM}/V_{RM} \times 100\%$.

3) Locate the CURRENT COMPENSATION CONTROL and adjust by observing the output meter (M1) while opening and closing the load switch. Adjust for minimum ***change*** (ΔV_{RM} MINIMUM) across the measuring resistor (R_M).

4) Turn APH "off," remove the measuring circuit components and reconnect the LOAD. This concludes the compensation adjustment.

d) E_O ZERO CONTROL. The E_O ZERO control is associated with the MAIN VOLTAGE AMPLIFIER. When operating in the "Voltage Mode," this control is used to establish the E_O "zero" point (see for example Section III, par. 3-10 through 3-23).

e) I_O MAX CONTROL. This adjustment determines the absolute maximum of the output current for local (front panel) control and serves as a calibration for the range of the front panel ***Current Control.*** The I_O MAX control is factory-set, so that the front panel control covers an output current range of 1—105% of the maximum rated output current. Readjustment of the I_O MAX control is needed only if a component in the (internal) current control circuitry must be replaced. A convenient way to make the adjustment is as follows:

a) BEFORE turning the a-c power "on," place a short circuit across the output terminals of the APH Power Supply. Turn VOLTAGE CONTROL fully clockwise, turn CURRENT CONTROL fully counterclockwise.

b) Turn a-c power "on." Turn APH CURRENT CONTROL slowly clockwise and observe front panel CURRENT meter. The meter should indicate 105% of the maximum rated output current with the APH CURRENT control in the maximum clockwise position. If it does ***not***, proceed to "C".

c) Locate the I_O MAX control and adjust front panel current meter reading to 105% of the rated output current. DO NOT ADJUST TO MORE THAN 105% I_O max. Although this might be possible (due to component tolerances), malfunction of the power supply may be caused by exceeding the rated maximum output current value. This concludes the adjustment.

5-7 TROUBLE SHOOTING

5-8 Modern, high performance power supplies have reached a state of sophistication requiring a thorough understanding of the problems involved in repairing complex, solid-state circuitry. Servicing beyond simple parts replacement should consequently be atempted only by personnel thoroughly familiar with solid-state component techniques and with experience in closed-loop circuitry.

5-9 Trouble shooting charts showing resistance and voltage readings are of very limited usefulness with feedback amplifiers and are not included here. Instead, a detailed circuit description (Section IV), parts location diagrams, simplified functional schematics, and a main schematic with all significant voltage readings (Section VI) are presented in this manual.

5-10 The following basic steps in case of a power supply malfunction may be found helpful:

a) NO OUTPUT.

1) If power supply does not function at all, check obvious points first. Check a-c input source connections, a-c input source voltage and frequency. (Normally the power supply is connected for 115V a-c service.) Check fuse and replace if open.

2) Operate the power supply as a voltage source, as for example, described in Section II, par. 2-13.

3) Check if the CURRENT CONTROL has been inadvertently misadjusted. Turn CURRENT CONTROL to approximately one-half its maximum ***clockwise*** position.

4) Remove the APH cabinet cover and check mating of the PC connectors with the PC boards. Check for correct jumper connections on the barrier-strip at the rear of the APH. (See Section III, FIG. 3-2.)

5) Check indicated voltage readings on the main schematic, check transistors and vacuum tube and start circuit analysis with the help of Section IV.

b) HIGH OUTPUT.. Checks as listed in par. 5-10a (4 and 5) are also applicable for this condition. In addition, check the following:

1) Remove the driver transistor (Q2, located on the main amplifier Assembly A1, see Section VI, FIG. 6-3 for location). The output should now go to approximately zero.

2) If it does, the series pass tubes and the high voltage d-c main supply sections are most likely not at fault.

3) Check driver transistor (Q2) and concentrate trouble shooting on the main amplifier board (A1). Check IC's and Q1, and look for burned components. Replace if necessary.

4) If output does not go to zero after Q2 is removed, check series pass tube with a tube tester. Replace if defective. Check assembly A3 for burned or discolored components and replace if necessary.

c) POOR PERFORMANCE:

1) Excessive output variations are often due to incorrectly connected loads or faulty measurement techniques. Perform measurements only as directed in Section V and follow the connection diagrams.

2) High frequency oscillations at the output are often due to an improperly adjusted lag network (see Section V, par. 5-6a) or to loads with large inductive or capacitive components and/or long load wires. Tightly twisted load wires of sufficient diameter, kept as short as possible, are often the solution to the problem. In extreme cases, connect an additional output capacitor across the remote load. NOTE: THE EXTERNAL LOAD CAPACITOR MUST BE RATED FOR THE MAXIMUM APH OUTPUT VOLTAGE.

3) High ripple at the output or the load may be caused by ground loops or long load wires passing through magnetic fields. Grounding of one side of the output and careful lead dressing are often helpful. (Refer to Section III, par. 3-3c) for more signal grounding information.

d) KEPCO Field Engineering Offices or the KEPCO Applications Engineering Department are always available for consultation or direct help in difficult service or applications problems.

5-11 POWER SUPPLY PERFORMANCE MEASUREMENTS

5-12 GENERAL. Measurements to verify the performance specifications are a frequent requirement of "Incoming Inspection" departments, a part of a routine maintenance program, or part of repair procedures. Some power supply measurements (OUTPUT IMPEDANCE, DRIFT, TEMPERATURE COEFFICIENT, etc.,) require specialized test equipment and/or a controlled environment, and are therefore not described here. For information on these measurements, consult the Kepco Engineering Test Department. The measurements described in the following paragraphs require only a minimum of equipment, and are generally sufficient to verify the most important d-c performance specifications.

5-13 REQUIRED INSTRUMENTATION

a) STABILIZED A-C INPUT SOURCE, with provisions for "stepping" and monitoring the voltage over the specified a-c input range (105 to 125V *or* 210 to 250V). A variable AUTOTRANSFORMER is generally adequate if it can deliver the required a-c input current.

b) RESISTOR LOAD, variable, capable of dissipating the full d-c output power of the unit under test and equipped with "on-off" and "shorting" switch (S1 in FIG'S 5-2, 5-3, must be rated for the maximum APH output voltage).

c) D-C VOLTAGE MONITOR, digital or differential voltmeter, able to resolve at least 1 microvolt.

CAUTION: Large transient voltage spikes may be produced by opening and closing the load switch (current mode measurements). The precision voltmeter (M1) must, therefore, be protected by a surge-suppressor such as a metal-oxide varistor, Kepco Part No. 125-0012.

d) OSCILLOSCOPE, vertical sensitivity at least 10 mV/div and with a minimum bandwidth of 10 megahertz (high voltage probe required).

5-14 OUTPUT EFFECT MEASUREMENTS, VOLTAGE CONTROL CHANNEL. The output effects due to a-c input source changes in the ***voltage mode*** can be measured with the circuit shown in FIG. 5-2. These output effects ("SOURCE EFFECT", "LOAD EFFECT") are defined as ***the amount of output voltage change resulting from specified variations in the a-c source voltage, or from a change in load resistance*** (see Section I, Table 1-2). The output effects can be expressed as an absolute change (ΔE_O) or as a percentage of the total output voltage (E_O):

$$\%\ \text{OUTPUT EFFECT} = \frac{\Delta E_O}{E_O} \times 100\% \quad \text{(Eq. 5-1)},$$

where: ΔE_O = Change in output voltage
E_O = Total output voltage

5-15 PROCEDURE (Refer to FIG. 5-2)

1) Connect the APH Power Supply to a metered a-c input source, such as described in par. 5-13a.

2) To measure the SOURCE EFFECT, vary the a-c source voltage over the specified range (105 to 125V *or* 210 to 250V) and note the deviation (ΔE_O) on the PRECISION VOLTMETER (M1).

3) To measure the LOAD EFFECT, open and close the load switch (S1) and note the deviation (ΔE_O) on the PRECISION VOLTMETER (M1).

4) From the results of the two previous measurements, calculate the output effects by means of equation (5-1).

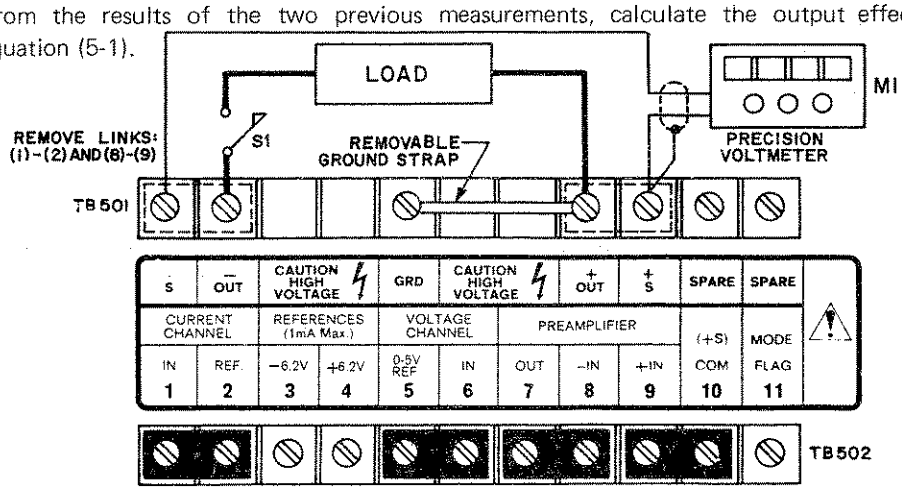


FIG. 5-2 OUTPUT EFFECT MEASUREMENTS, VOLTAGE CONTROL CHANNEL (TEST CIRCUIT).

5-16 OUTPUT EFFECT MEASUREMENTS, CURRENT CONTROL CHANNEL. The output effects due to a-c source or d-c load variations in the *current mode* can be measured with the circuit shown in FIG. 5-3. These output effects ("SOURCE" and "LOAD" EFFECT) are defined as *the amount of output current change resulting from the specified variation in a-c source voltage, or from a change in load resistance. (See Section I, Table 1-2.) The output effects can be expressed as an absolute change (ΔI_O), or as a percentage of the total output current (I_O):*

$$\% \text{ OUTPUT EFFECT} = \frac{\Delta I_O}{I_O} (100\%) \quad \text{(Eq. 5-2)},$$

where: ΔI_O = Change in output current
I_O = Total output current

5-17 PROCEDURE (Refer to FIG. 5-3)

1) Connect the APH Power Supply to a metered a-c input source such as described in par. 5-13a.
2) To measure the SOURCE EFFECT, vary the a-c source voltage over the specified range (105 to 125V *or* 210 to 250V) and note the deviation ($\Delta V / RM = \Delta I_O$) on the voltmeter (M1 across R_M).
3) To measure the LOAD EFFECT, close the load switch (S1) and note the deviation ($\Delta V / R_M$) on the voltmeter (M1 across R_M).
4) From the results of the two previous measurements, calculate the output effects by means of equation (5-2). Note: $\Delta I_O = \Delta V/R_M$.

CAUTION: Large transient voltages may appear across R_M as S1 is opened or closed. M1 must, therefore, be protected by a surge-suppressor. S1 must be a high voltage switching device, rated for the maximum compliance (load) voltage of the APH.

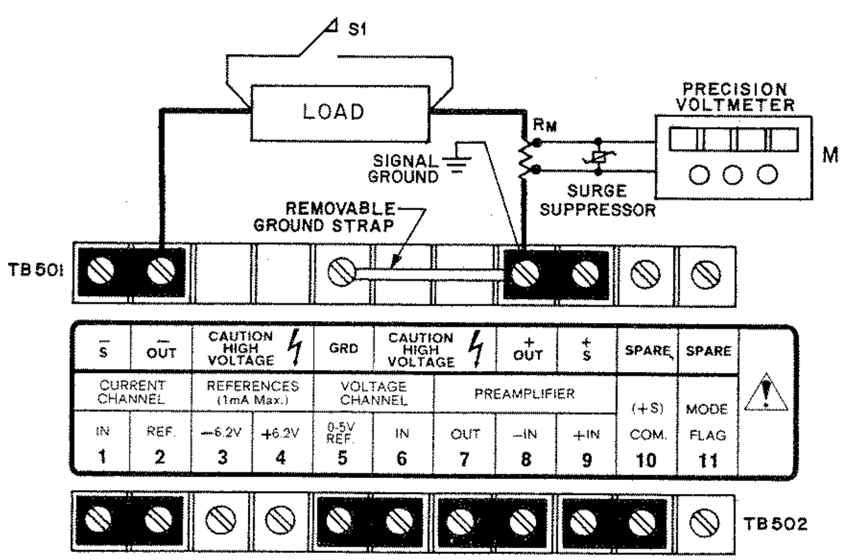


FIG. 5-3 OUTPUT EFFECT MEASUREMENTS, CURRENT CONTROL CHANNEL (TEST CIRCUIT).

SECTION VI—ELECTRICAL PARTS LIST AND DIAGRAMS

6-1 GENERAL

6-2 This section contains the main schematic, the parts location diagrams, and a list of all replaceable electrical parts. All components are listed in alpha-numerical order of their reference designations. Consult your Kepco Representative for replacement of parts not listed here.

6-3 ORDERING INFORMATION

6-4 To order a replacement part or to inquire about parts not listed in the parts list, address order or inquiry either to your authorized Kepco Sales Representative or to:

KEPCO, INC.
131-38 Sanford Avenue
Flushing, N.Y. 11352

6-5 Specify the following information for each part:

a) Model and complete serial number of instrument.
b) Kepco part number.
c) Circuit reference designator.
d) Description.

6-6 To order a part not listed in the parts list, give a complete description and include its function and location.

NOTE: KEPCO DOES NOT STOCK OR SELL COMPLETE POWER SUPPLY SUBASSEMBLIES AS DESCRIBED HERE AND ELSEWHERE IN THIS INSTRUCTION MANUAL. SOME OF THE REASONS ARE LISTED BELOW:

1) Replacement of a complete subassembly is a comparatively rare necessity.
2) Kepco's subassemblies are readily serviceable, since most of them are of the "plug-in" type.
3) All active componets are socket mounted, making replacement extremely easy.
4) The nature of a closed-loop power supply system requires that subassembly replacement is followed by careful measurement of the total power supply performance. In addition, depending on the function of the subassembly, extensive alignment may be required to restore power supply performance to specified values.

IF REPAIRS INVOLVING SUBASSEMBLY REPLACEMENTS ARE REQUIRED, PLEASE CONSULT YOUR LOCAL KEPCO REPRESENTATIVE OR THE KEPCO SALES ENGINEERING DEPARTMENT IN FLUSHING, NEW YORK, N.Y.

ABBREVIATIONS USED IN KEPCO PARTS LISTS

A) Reference Designators:

A = Assembly
B = Blower (Fan)
C = Capacitor
CB = Circuit Breaker
CR = Diode
DS = Device, Signaling (Lamp)
F = Fuse
FX = Fuse Holder
IC = Integrated Circuit
J = Jack
K = Relay
L = Inductor
LC = Light-Coupled Device
M = Meter
P = Plug
Q = Transistor
R = Resistor
S = Switch
T = Transformer
TB = Terminal Block
V = Vacuum Tube
X = Socket

B) Descriptive Abbreviations

A = Ampere
a-c = Alternating Current
AMP = Amplifier
AX = Axial
CAP = Capacitor
CER = Ceramic
CT = Center-Tap
°C = Degree Centigrade
d-c = Direct Current
DPDT = Double Pole, Double Throw
DPST = Double Pole, Single Throw
ELECT = Electrolytic
F = Farad
FILM = Polyester Film
FLAM = Flammable
FP = Flame-Proof
°F = Degree Fahrenheit
FXD = Fixed
Ge = Germanium
H = Henry
Hz = Hertz
IC = Integrated Circuit
K = Kilo (10^3)
m = Milli (10^{-3})
M = Mega (10^6)
MFR = Manufacturer
MET = Metal
n = Nano (10^{-9})
NC = Normally Closed
NO = Normally Open
p = Pico (10^{-12})
PC = Printed Circuit
POT = Potentiometer
PIV = Peak Inverse Voltage
p-p = Peak to Peak
ppm = Parts Per Million
PWR = Power
RAD = Radial
RECT = Rectifier
RECY = Recovery
REG = Regulated
RES = Resistor
RMS = Root Mean Square
Si = Silicon
S-End = Single Ended
SPDT = Single Pole, Double Throw
SPST = Single Pole, Single Throw
Stud Mt = Stud Mounted
TAN = Tantalum
TSTR = Transistor
μ = Micro (μ) (10^{-6})
V = Volt
W = Watt
WW = Wire Wound

KEPCO® REPLACEMENT PARTS LIST

APH 500M, CONTROL CIRCUIT ASSEMBLY (A1) **Code 2-2676**

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C1	1	Capacitor,Ceramic,Disc 100 pF, ±10%, 500V	Radio Materials Corp. Type JK	117-0754	1
C2,3	2	Capacitor,Elect.,Axial Leads 100 μF, ±20%, 25V	Sangamo Type 556	117-0459	1
C5,7	2	Capacitor,Mylar,Axial Leads 0.02 μF, ±10%, 200V	Sprague Type 192P	117-0377	1
C6	1	Capacitor,Mylar,Axial Leads 0.0022 μF, ±10%, 200V	Sprague Type 192P	117-0659	1
C8	1	Capacitor,Mylar,Axial Leads 0.1 μF, ±20%, 200V	Sprague Type 192P	117-0186	1
C9,10,11	3	Capacitor,Mylar,Axial Leads 0.05 μF, ±20%, 200V	Sprague Type 192P	117-0315	1
C12,13	2	Capacitor,Mylar,Axial Leads 0.25 μF, ±20%, 200V	TRW Type X663F	117-0378	1
C16	1	Capacitor,Fixed,Polyester Film 0.25 μF, ±20%, 1 kV d-c	TRW Type 663UW	117-0066	1
CR1,2,3,16	4	Zener Diode,Axial Leads 6.8V ±5%, 500 mW	Motorola IN5235B	121-0080	1
CR4,6,7,8, 9,10,11,12 13,14,15,17 18,19,20,21 22,25,27	19	Switching Diode, 75V PIV, 400 mW	American Power Devices 1N4148	124-0437	2
CR5	1	Rectifier Diode,Axial Leads 400V PIV, 1A	Semicon Inc. Type SI–4	124-0028	1
CR23,24	2	Zener Diode (Reference) 5.6–6.2V, 7.5 mA	IRC 1N821	121-0041	1
CR26	1	Zener Diode,Axial Leads 4.3V ±5%, 500 mW	Motorola 1N5229B	121-0059	1
IC-1,3	2	I.C. Operational Amplifier Type 741	Motorola MC1741P	250-0025	1
IC-4	1	I.C. Operational Amplifier Type 307	Texas Instruments SN72307P	250-0039	1
IC-2,5	2	I.C. Operational Amplifier Type 558 (Dual)	Signetics N5558	250-0040	1
Q1	1	Transistor,Silicon,NPN Small Signal, TO–5	RCA 2N3053	119-0059	1
Q2	1	Transistor,Silicon,PNP Small Signal, Plastic, TO–106	Fairchild 2N4888	119-0085	1
Q3,4,5	3	Transistor,Silicon,NPN Small Signal, Plastic, TO–18	Texas Instruments 2N5450	119-0093	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

KEPCO. REPLACEMENT PARTS LIST

APH 500M, CONTROL CIRCUIT ASSEMBLY (A1)

Code 2-2676

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
R1	1	Resistor,Fixed,Molded 470 Ω, 2W, 10%	Allen Bradley HB4715	115-0373	1
R2,3	2	Resistor,Fixed,Precision,M.F. 10 KΩ, 1/8 W, 1%	Dale Type MFF–1/8	115-2174	1
R4	1	Resistor,Fixed,Precision,M.F. 562 Ω, 1/4 W, 1%	Dale Type MFF–1/4	115-1897	1
R5,8,14, 17,24,25	6	Resistor,Fixed,Precision,M.F. 1 KΩ, 1/4 W, 1%	Dale Type MFF–1/4	115-1822	2
R6,9,11, 19,38	5	Resistor,Fixed,Molded 1 KΩ, 1/4 W, 10%	Allen Bradley CB1021	115-2238	1
R10	1	Resistor,Fixed,Molded 2 KΩ, 1/2 W, 5%	Allen Bradley EB2025	115-0520	1
R12	1	Resistor,Fixed,Molded 47 KΩ, 1/4 W, 10%	Allen Bradley CB4731	115-2237	1
R13	1	Resistor,Variable,Cermet 10 KΩ, 3/4 W, 10%	Bourns Type 3009P	115-2481	1
R16	1	Resistor,Fixed,Molded 39 KΩ, 1/4 W, 10%	Allen Bradley CB3931	115-2469	1
R15,41	2	Resistor,Fixed,Molded 2.4 KΩ, 1/2 W, 5%	Allen Bradley EB2425	115-0795	1
R18	1	Resistor,Fixed,Molded 10 KΩ, 1/4 W, 10%	Allen Bradley CB1-41	115-2211	1
R20	1	Resistor,Fixed,Molded 330 Ω, 1/2 W, 5%	Allen Bradley EB2035	115-1086	1
R21,32	2	Resistor,Variable,Cermet 20 KΩ, 3/4 W, 10%	Bourns Type 3009P	115-2393	1
R22	1	Resistor,Precision,W.W.,20 ppm 5 KΩ, 1 W, 1%	Tepro TS-1W	115-2604	1
R23	1	Resistor,Fixed,Precision,M.F. 2.67 MΩ, 1/2 W, 1%	Dale Type MFF–1/2	115-2313	1
R26	1	Resistor,Fixed,Precision,W.W. 5.7 KΩ, 1 W, 1%	Tepro Type TS1-W	115-1301	1
R27,29	2	Resistor,Fixed,Precision,M.F. 750 Ω, 1/4 W, 1%	Dale Type MFF–1/4	115-1803	1
R28	1	Resistor,Variable,W.W. 20 KΩ, 1 W, 5%	Bourns Type 3067Y	115-2363	1
R30	1	Resistor,Fixed,Precision,M.F. 6.98 KΩ, 1/4 W, 1%	Dale Type MFF–1/4	115-1901	1
R31	1	Resistor,Fixed,Precision,M.F. 9.09 KΩ, 1/4 W, 1%	Dale Type MFF–1/4	115-1998	1
R33	1	Resistor,Variable,Cermet 100 Ω, 3/4 W, 10%	Bourns Type 3009P	115-2396	1
R35	1	Resistor,Fixed,Molded 330 Ω, 1/2 W, 10%	Allen Bradley CB3311	115-0804	1
R36,37	2	Resistor,Fixed,Molded 82 Ω, 1/2 W, 5%	TRW Type GB–1/4	115-1243	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES.
KEPCO, INC.

APH 500M, CONTROL CIRCUIT ASSEMBLY (A1)

Code 2-2676

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
R39,42	2	Resistor,Fixed,Molded 2.4 KΩ, 1/4 W, 5%	Allen Bradley CB2425	115-2394	1
R40	1	Resistor,Fixed,Molded 22 KΩ, 1/4 W, 10%	Allen Bradley CB2231	115-2458	1
R43	1	Resistor,Fixed,Molded 10 Ω, 1/2 W, 10%	Allen Bradley CB1031	115-0502	1
R44	1	Resistor,Fixed,Precision,W.W. 500 K, 2 W, 1%	Marstan Type MAW12	115-2410	1
R46	1	Resistor,Fixed,Precision,W.W. 1 KΩ, 5 W, 5%	Tepro TS-5W	115-0512	1
R47	1	Resistor,Fixed,Thick Film 20 MΩ, 1 W, 2%	KDI Pyrofilm Corp. PVC 70 20MΩ 2%	115-2618	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

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KEPCO® REPLACEMENT PARTS LIST

APH 500M, MAIN CHASSIS ASSEMBLY (A2) WITH FRONT PANEL Code 2-2676

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
FRONT PANEL ASSEMBLY CONTAINS:					
DS101	1	H.V. Pilot Light Assembly 125V a-c	Industrial Devices 1000 Series	152-0095	1
DS102,103	2	Mode Indicator Lights LED, red, 1.8V @ 10 mA	Little Fuse 971-660X-02 WRN	152-0096	2
M101	1	Voltmeter,0–500V d-c 500 μA (F.S.) ±2%, 135 Ω nom.	Modutech "2W" series (Special Item)	135-0502	1
M102	1	Milliammeter,0–40 mA d-c 1V (F.S.) ±2%, 1000 Ω/V	Modutech "2W" series (Special Item)	135-0502	1
R101,102	2	Resistor,Variable,W.W.,10-turn 5 KΩ, 2 W, ±5%, 20 ppm	Bourns Type 3540S	115-2603	1
R103	1	Resistor,Fixed,Precision,M.F. 1 MΩ, 1/2 W, 1/2%	Dale Type MFS–1/2	115-2605	1
S101	1	Switch,SPST,Toggle 125V a-c/15 A, 250V a-c/10 A	Carling TA 201-PB-B	127-0323	1
RC101	1	R-C Network 0.1 mF,400V,20% & 100Ω, 1/2 W, 10%	Sprague Type 288P	245-0003	1
MAIN CHASSIS ASSEMBLY CONTAINS:					
C201,C202	2	Capacitor,Paper,Can 6 μF, ±10%, 1 kV	General Electric Type 23F	117-0740	[illegible]
F201	1	Fuse,Slow Blow Type 0.8 A/125V	Bussman MDL-8/10	141-0027	5
R201	1	Resistor,Fixed,Power,Axial 680 K, 2 W, 20%	TRW MVX–2	115-1281	1
T201	1	Transformer,Power	Kepco Magnetics 100-2062	100-2032	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

KEPCO® REPLACEMENT PARTS LIST

APH 500M AUXILIARY SUPPLIES AND PASS TUBE ASSEMBLY (A3) — Code 2-2676

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C301	1	Capacitor,Ceramic,Disk 0.05 μF, ±20%, 500V	Sprague Type 36C	117-0163	1
C302	1	Capacitor,Elect.,Axial Leads 60 μF, +50% - 10%, 175V	Sangamo Type 052	117-0466	1
C303	1	Capacitor,Tantalum,Axial Leads 1 μF, +50 - 10%, 50V	Sprague Type 162D	117-0815	1
C304	1	Capacitor,Elect.,Axial Leads 290 μF, +75% - 10%, 12V	Mallory Cap. TTX-291 Type	117-0647	1
C305	1	Capacitor,Ceramic,Disc. 0.005 μF, ±20%, 500V	Radio Materials Corp. Type SM	117-0061	1
C306	1	Capacitor,Mylar,Axial Leads 150 μF, +75 - 10%, 15V	Sangamo Type 556	117-0677	1
C307	1	Capacitor,Elect.,Axial Leads 40 μF, +75% - 10%, 75V	Sangamo Type 052	117-0788	1
C308	1	Capacitor,Elect.,Axial Leads 200 μF, +75% - 10%, 50V	Sprague Type 38D	117-0651	1
CR301,302 303,304	4	Rectifier Diode,Axial Lead 400V PIV, 1 A	Semocon Inc. Type SI–4	124-0028	1
CR305,306,308	3	Rectifier Bridge,Rad. Leads 200 V PIV, 1 A	Varo VE-28	124-0346	1
CR307	1	Zener Diode,Axial Leads 6.8V ±5%, 500 mW	Motorola 1N5235B	121-0080	1
CR309,313	2	Rectifier,Diode, Axial Leads (P.I.V. 100V, 1.5 A)	Semicon Inc. Type SI-1	124-0133	1
CR310	1	Rectifier,Diode,Axial Leads 2000V PIV, 0.5 A	Semicon Inc. HV-20	124-0299	1
CR311	1	Diode,Switching (75 P.I.V., 400 mW	American Power Devices 1N4148	124-0437	1
CR312	1	Thyristor (SCR) 50V PIV, 4 A rms	Motorola 2N4441	124-0349	1
K301	1	Relay,Dry Reed 6V, N.O. & N.C. Contact	Douglas-Randall GLP-1A1B	140-0093	1
Q301	1	Transistor,Silicon,PUT Small Signal, Plastic, TO-98	General Electric 2N6027	119-0111	1
Q302	1	Transistor,Silicon,PNP Small Signal, TO-5	Fairchild 2N4355	119-0076	1
R301	1	Resistor,Fixed,Molded 150 KΩ, 1/2 W, 5%	Allen Bradley EB1545	115-0243	1
R302	1	Resistor,Fixed,Molded 3.9 KΩ, 1/2 W, 10%	Allen Bradley EB3921	115-0921	1
R303	1	Resistor,Fixed,Molded 1 KΩ, 1/2 W, 10%	Allen Bradley EB1021	115-0547	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

KEPCO. REPLACEMENT PARTS LIST

APH 500M, AUXILIARY SUPPLIES AND PASS TUBE ASSEMBLY (A3)

Code 2-2676

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
R304	1	Resistor,Fixed,Precision,M.F. 100 KΩ, 1/2 W, 1%	Dale Type MFF--1/2	115-2004	1
R305	1	Resistor,Fixed,Precision,W.W. 25 Ω, 3W, 1%, 20 ppm	Tepro TS-5W	115-2606	1
R306	1	Resistor,Fixed,Precision,W.W. 950 Ω, 5 W. 1%, 20 ppm	Tepro TS-5W	115-2619	1
R307	1	Resistor,Fixed,Precision,M.F. 18.2 KΩ, 1%, 1/8 W	Dale MFF-1/8	115-2275	1
R308	1	Resistor,Fixed,Precision,M.F. 30.1 KΩ, 1%, 1/8 W	Dale MFF-1/8	115-2571	1
R309	1	Resistor,Fixed,Precision,M.F. 150 KΩ, 1/8 W, 1%	Dale MFF-1/8	115-2597	1
R310	1	Resistor,Fixed,Molded 47 Ω, 1/4 W, 10%	IRC GBT-1/4	115-2273	1
R311	1	Resistor,Fixed,Molded 120 Ω, 1/4 W, 10%	IRC GBT-1/4	115-2232	1
R312	1	Resistor,Fixed,Molded 10 KΩ, 10%, 1/4 W	Allen Bradley CB1031	115-2211	1
R313	1	Resistor,Fixed,Molded 5.6 KΩ, 10%, 1/4 W	Allen Bradley CB5631	115-2491	1
RV301	1	Varistor,Metal Oxide	General Electric VP 130-A10	125-0012	1
V301	1	Vacuum Tube Beam Power Pentode	General Electric 8068	126-0096	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

KEPCO. REPLACEMENT PARTS LIST

APH 500M A-C INPUT SELECTOR SWITCH ASSEMBLY (A4)

Code 2-2676

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
S401	1	Interlock Switch SPDT, 125V a-c/10 A	Cherry Electrical Products E69-30A	127-0324	1
S402	1	Slide-Switch DPDT	Switchcraft 46206 LFH	127-0294	1

MODEL APH 500M, REAR TERMINAL BOARD ASSEMBLY (A5)

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO.	KEPCO PART NO.	REC. SPARE PART QTY.
C501,502	2	Capacitor,Elect.,Tantalum 140 μF, - 15%, +75%, 6V	General Electric Type 62F	117-0849	1
CR501,503	2	Diode (Double Diced), Ax.Leads (Special)	Semicon Inc. Type HVP	124-0178	1
CR502	1	Diode,H.V.,Axial Leads 2 kV PIV, 150 mA	Semicon Inc. HB–20	124-0299	1

MODEL APH 500M, H.V. RECTIFIER ASSEMBLY (A6)

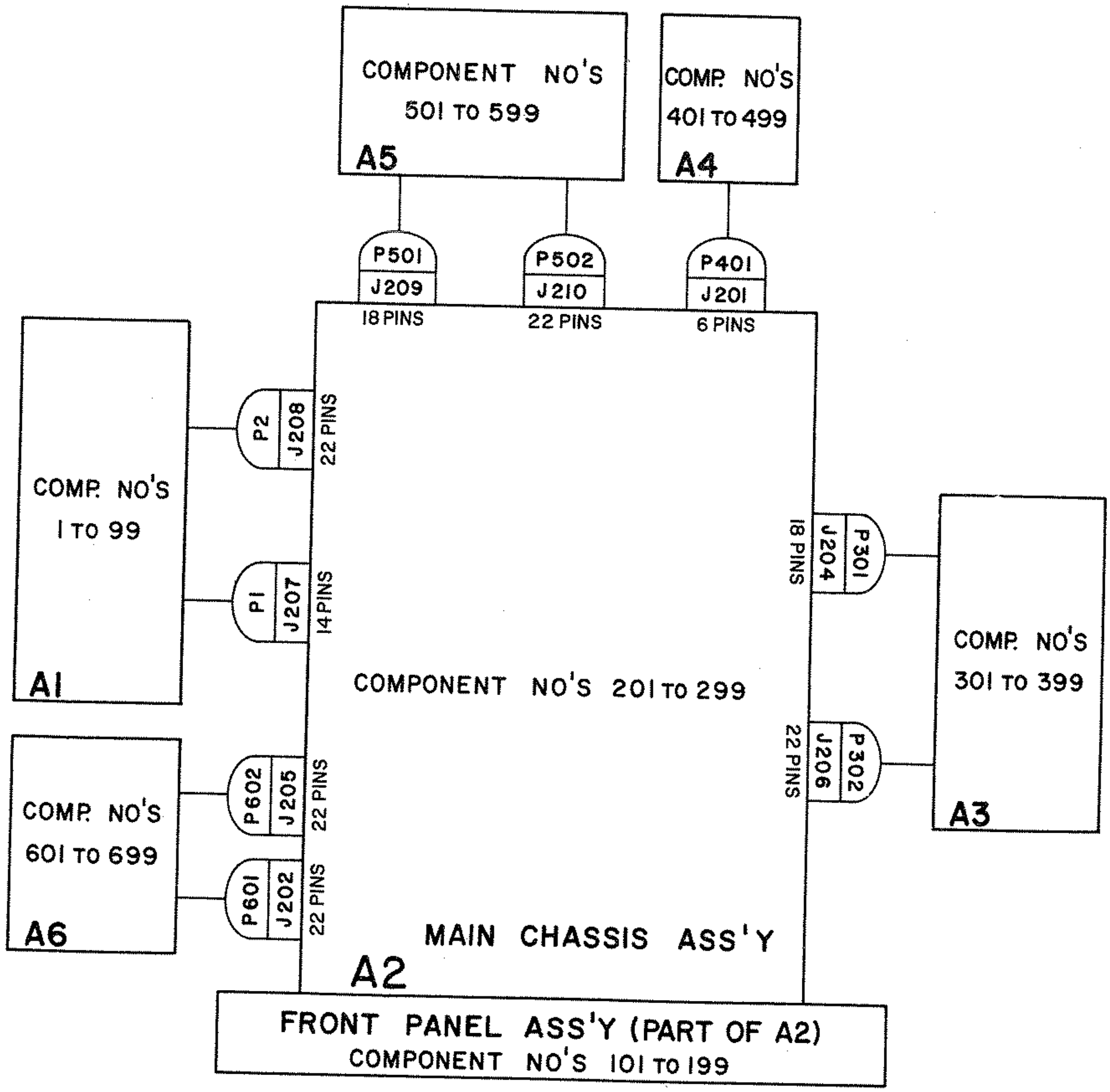
REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO.	KEPCO PART NO.	REC. SPARE PART QTY.
C601	1	Capacitor,Ceramic,Disk 680 pF, ±20%, 6 KV	Centralab DD-60-681	117-0721	1
C602	1	Capacitor,Mylar,Axial Leads 0.25 μF, ±20%, 1 KV	TRW Type 663 UW	117-0066	1
CR601,602,603, 604,605,606, 607,608	8	Rectifier Diode,Axial Leads 2 kV PIV, 150 mA	Semicon Inc. HV–20	124-0299	1
R601	1	Resistor,Fixed,Molded 100 KΩ, 2 W, 10%	Allen Bradley HB 1041	115-0197	1
R602,603,604	3	Resistor,Fixed,Power,W.W. 250 KΩ, 10 W, 3%	Tepro Type TS-10W	115-1254	1

MISCELLANEOUS

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO.	KEPCO PART NO.	REC. SPARE PART QTY.
J101	1	Banana Jack, Black	E.F. Johnson 108-0903-001	173-0017	1
J102	1	Banana Jack, Red	E.F. Johnson 109-0902-001	173-0016	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.



INTERFACE	TOTAL PINS	UNUSED PINS
J201/P401	6	NONE
J202/P602	22	No. 2 to 6, 8 to 16, 18 to 21
J204/P301	18	No. 3, 6 to 11, 14, 15, 17
J205/P602	22	No. 3 to 10, 12 to 21
J206/P302	22	No. 5, 7 to 13, 16, 18, 20
J207/P1	14	No. 10, 12
J208/P	22	
J209/P501	18	No. 3, 6, 9, 11, 13, 15, 17
J210/P502	22	No. 4 to 8, 10 to 17, 21, 22

FIG. 6-1 APH PLUG-IN DIAGRAM

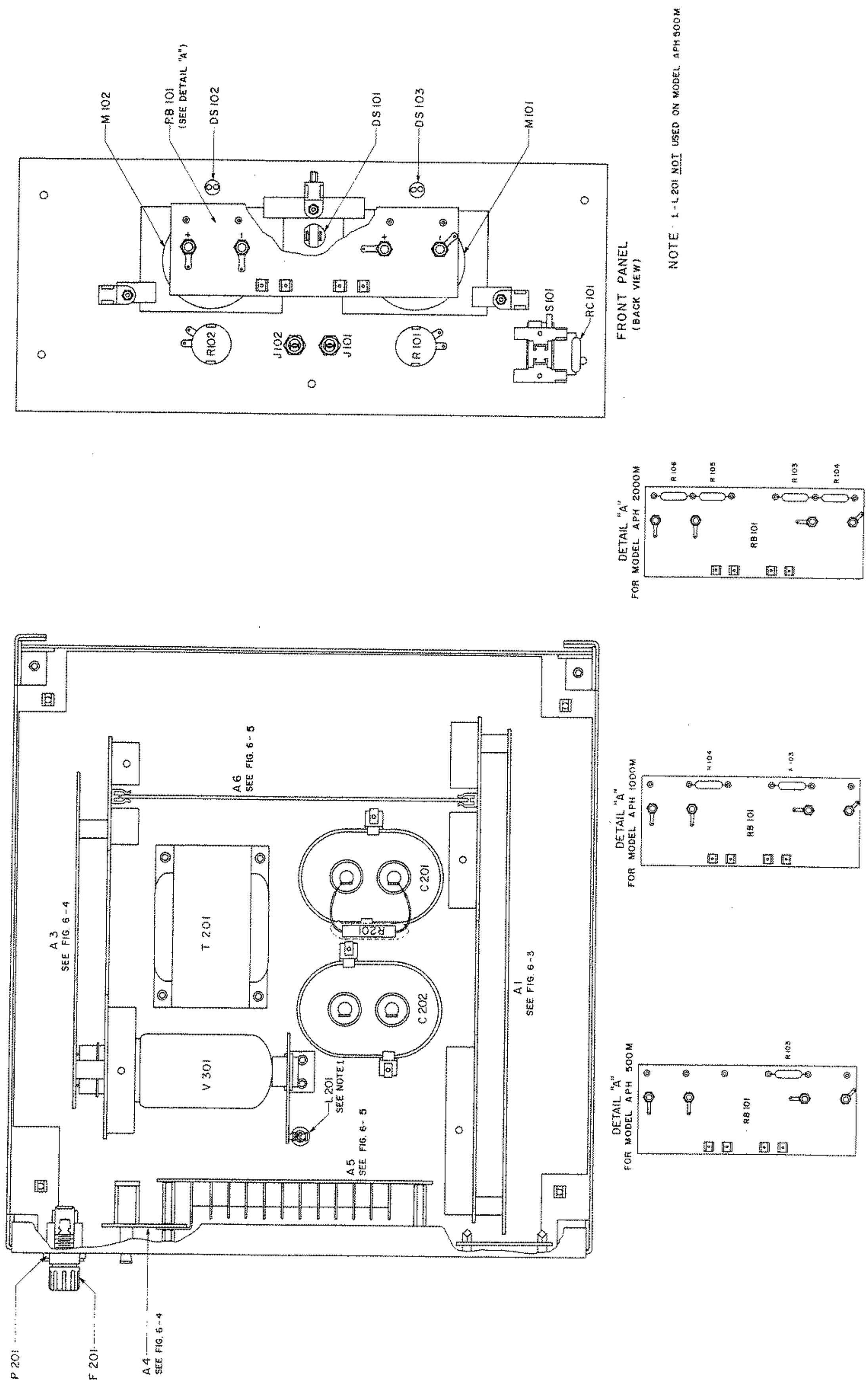
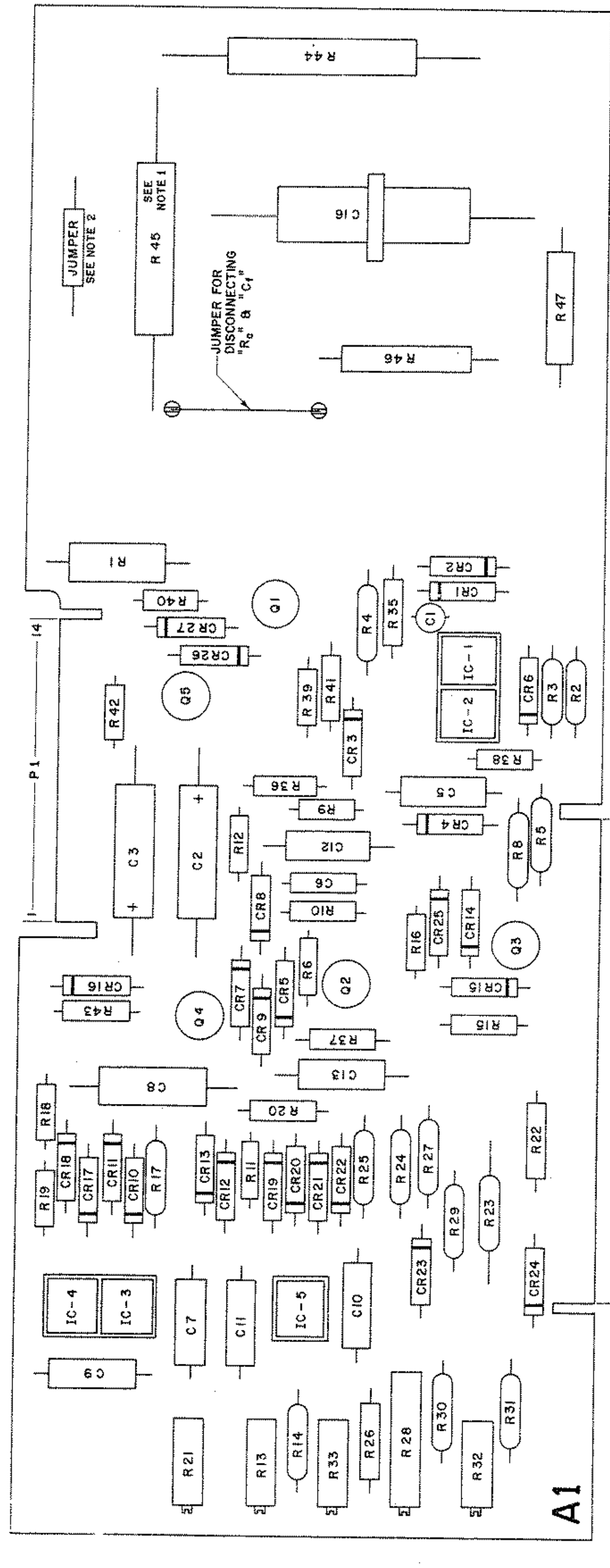
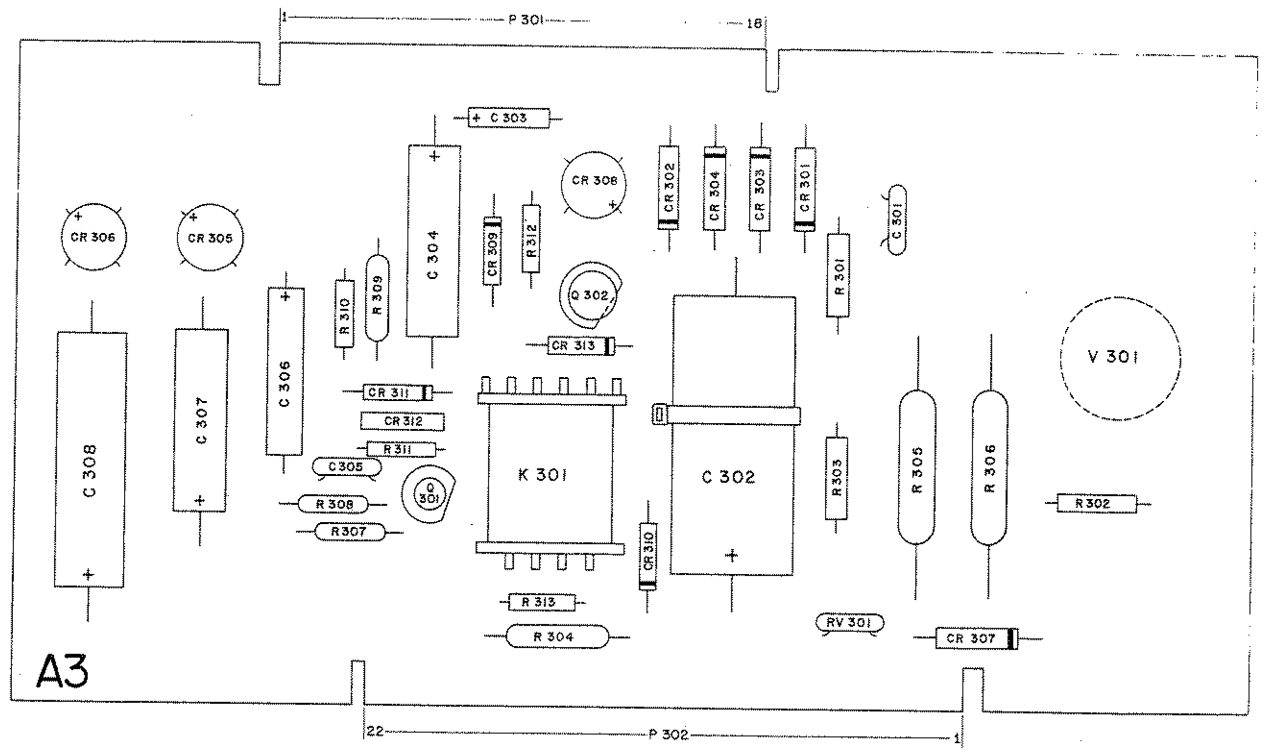


FIG. 6-2 COMPONENT LOCATION, MAIN CHASSIS ASSEMBLY A2.



NOTES:
1. R 45 USED ONLY ON APH 2000M.
2. JUMPER NOT USED ON APH 2000M.

FIG. 6-3 COMPONENT LOCATION, CONTROL ASSEMBLY A1



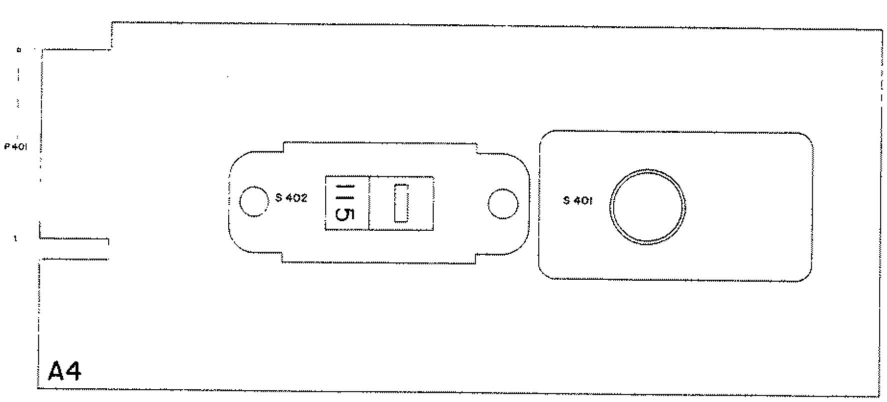


FIG. 6-4 COMPONENT LOCATION, AUXILIARY ASSEMBLIES A3, A4.

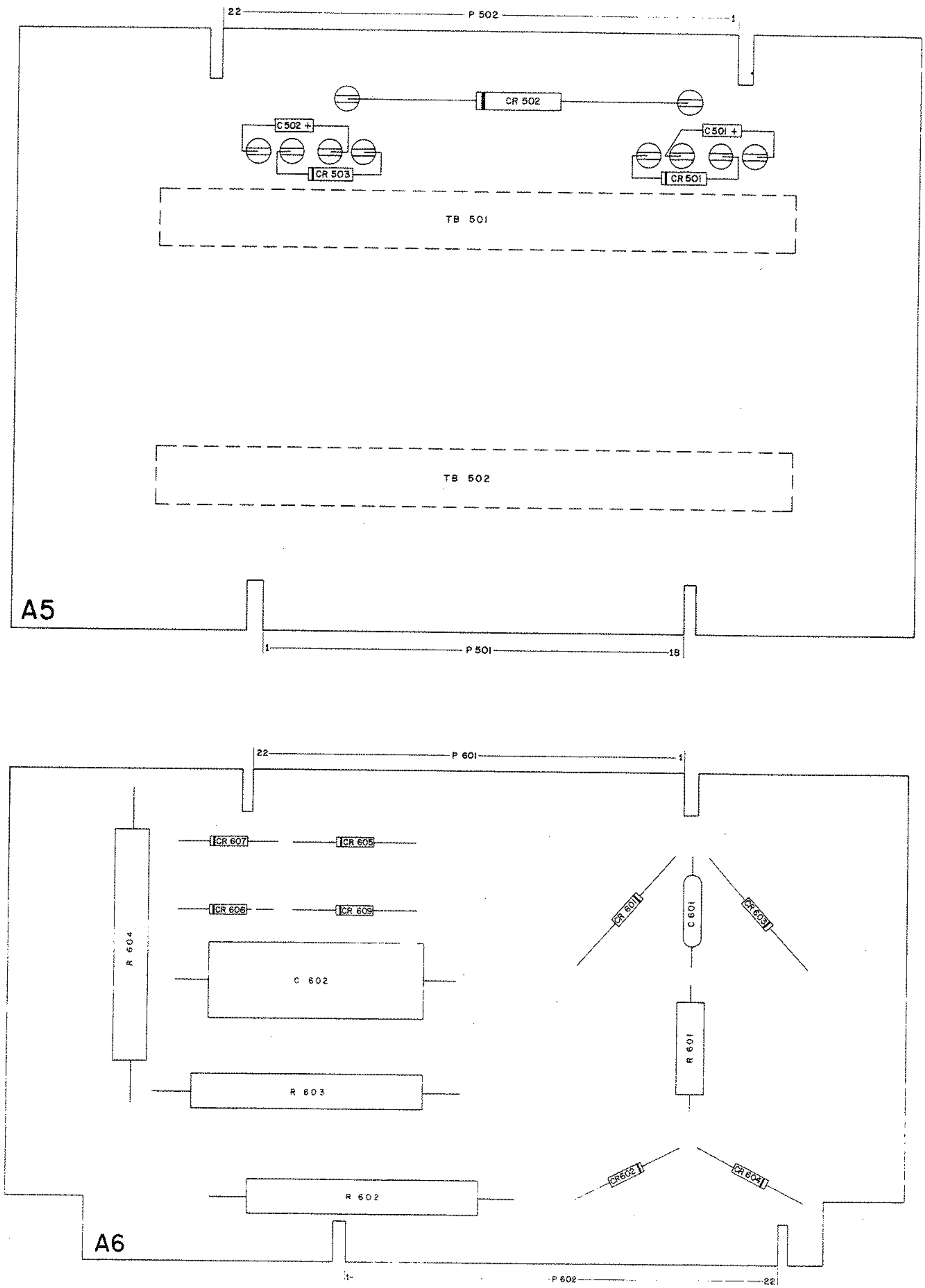


FIG. 6-5 COMPONENT LOCATION, AUXILIARY ASSEMBLIES A5, A6.

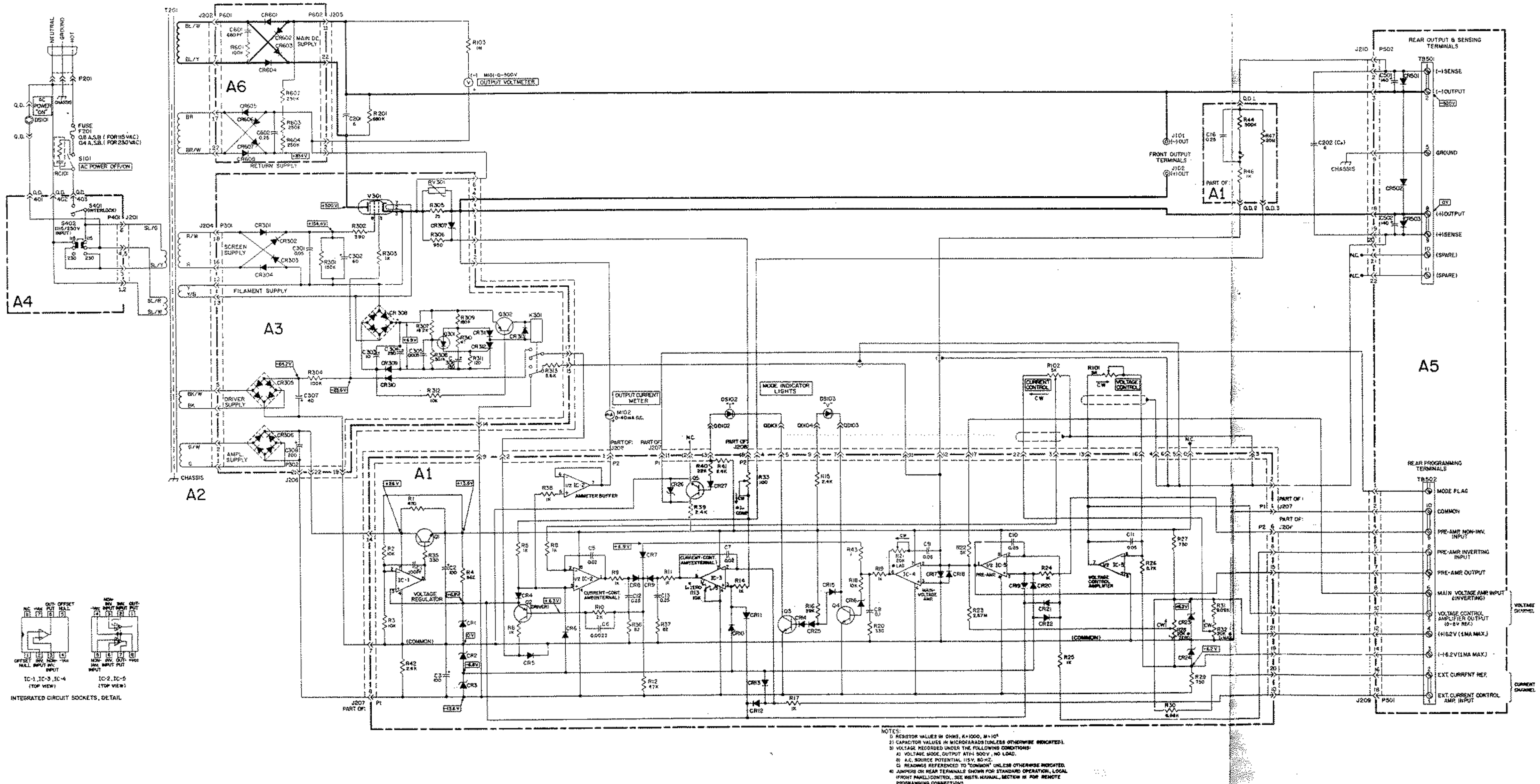


FIG. 6-6 MAIN SCHEMATIC DIAGRAM, MODEL APH 500M.