INSTRUCTION MANUAL

OPS GROUP IXB
OPERATIONAL POWER SUPPLIES

KEPCO INC.
An ISO 9001 Company.

MODEL
OPS GROUP IXB
POWER MODULE

ORDER NO.	REV. NO

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

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THE POWER SUPPLIER™

KEPCO, INC. ● 131-38 SANFORD AVENUE ● FLUSHING, NY. 11352 U.S.A. ● TEL (718) 461-7000 ● FAX (718) 767-1102
email: hq@kepcopower.com ● World Wide Web: http://www.kepcopower.com

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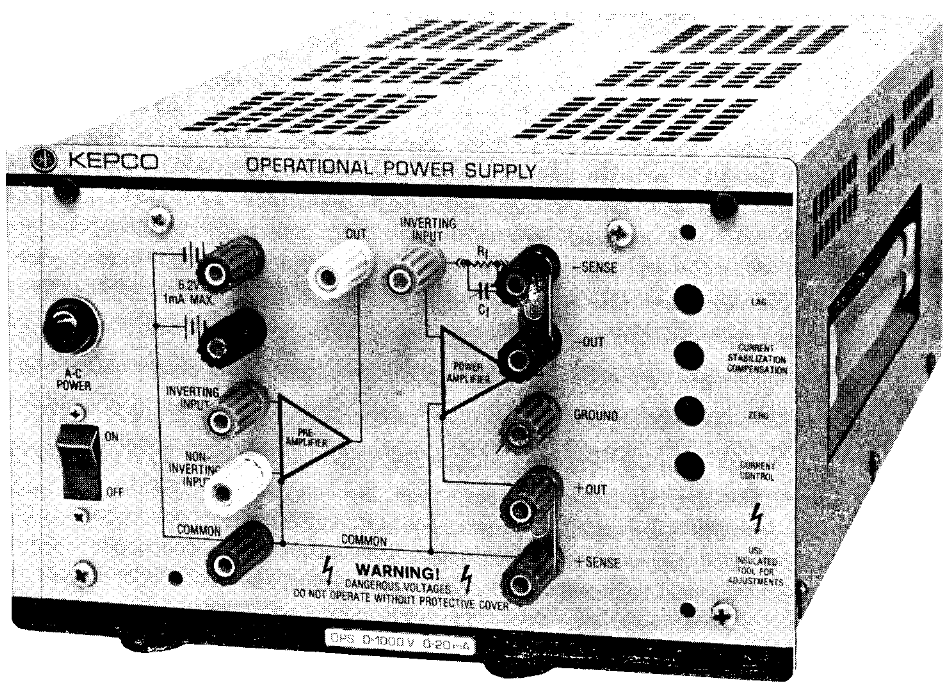


FIG. 1-1 KEPCO GROUP IX OPERATIONAL POWER SUPPLY, TYPICAL FRONT VIEW.

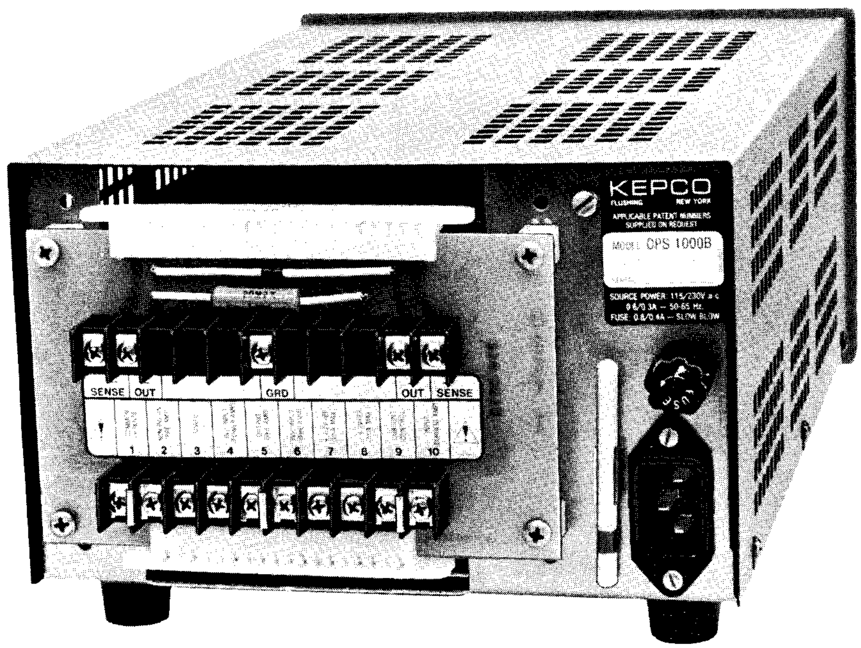


FIG. 1-2 KEPCO GROUP IX OPERATIONAL POWER SUPPLY, TYPICAL REAR VIEW.

SECTION I – INTRODUCTION

1-1 SCOPE OF MANUAL

1-2 This manual contains instructions for the installation, operation, and maintenance of the OPS GROUP IX Operational Power Supplies, manufactured by Kepco, Inc., Flushing, New York.

1-3 GENERAL DESCRIPTION

1-4 Kepco OPS GROUP IX Operational Power Supplies are a-c source powered devices which can be utilized as d-c high voltage/low current sources or, operationally programmed, as unipolar power amplifiers. Integrated circuits in the OPS "front end" contribute very low offsets and allow accurate tracking of all input signals. The OPS GROUP IX Operational Power Supplies feature sharp crossover between the voltage and current operating modes, ensuring accurate limiting over the full output current range and completely short circuit proof operation. Low output shunt capacitance permits rapid voltage programming in the voltage mode and fast load voltage recovery in the current mode of operation.

1-5 The OPS circuitry, in its simplest form, can be represented by one of the simplified operating diagrams in Section III of this manual. A high voltage/low current d-c source is controlled by series pass elements (vacuum tubes), which, in turn, are driven by two high gain wide-band control systems. These control systems consist of two independently programmable channels, operating into a common driver stage. The driver stage is coupled to the series pass tubes via an "exclusive OR" gate, so that only one channel is in control of the OPS output at any time.

1-6 Due to the high d-c gain of the control amplifiers, the OPS output characteristic approaches that of a true "autocrossover" power supply. The crossover load resistance (R_L) at any instant is given by the straight line from zero to the operating point E_O, I_O where E_O represents the OPS output voltage and I_O is the setting of the output current:

$$R_L = E_O/I_O.$$

For load resistances ***greater*** than R_L, the OPS voltage channel is in control, while for load resistances ***smaller*** than R_L the current channel is in control of the OPS 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 Operational Power Supply is designed for adequate convection cooling through the wrap-around, perforated case.

e) ISOLATION: A maximum of 1000 volts (d-c or p-p) can be connected between chassis and either output terminal. Common-mode current from output (either side) to ground: $<30\ \mu A$ rms, $300\ \mu A$ p-p at 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 (EXT.)
OPS 500B	0–500	0–0.04	2.2Ω + 10 mH	125 MΩ + 0.04 μF
OPS 1000B	0–1000	0–0.02	9.0Ω + 10 mH	250 MΩ + 0.02 μF
OPS 2000B	0–2000	0–0.01	34.0Ω + 10 mH	500 MΩ + 0.01 μF

TABLE 1-1 OUTPUT RATINGS AND IMPEDANCES.

1-8 SPECIFICATIONS, PERFORMANCE

1-9 VOLTAGE CHANNEL:

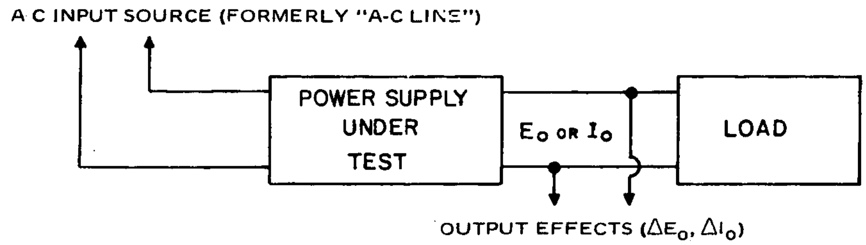
a) OPEN LOOP GAIN, D-C: >1 x 10^6 V/V.

b) D-C OFFSETS: See Table 1-2.

NOTE 1: In this instruction manual the traditional terms "line regulation" and "load regulation" are no longer used. Instead, Kepco will follow the NEMA standards for D-C Power Supplies and speak 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 (ΔE_O, ΔI_O), directly in millivolts or milliamperes or both. The illustration below will clarify the NEMA Standard. Reference: NEMA Standard 3PY-1972.

INFLUENCE QUANTITIES

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



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

NOTE 2: The output effects for operational power supplies cannot be specified directly, since they depend on the value and quality of the external feedback components added by the user. Instead, the d-c errors are specified at the input of the OPS voltage amplifier as a change in "offset voltage" and "offset current" (ΔE_{io}, ΔI_{io}). 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 the total output effect:

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

where:
- ΔE_o = Total 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. See Section IV of this manual for the derivation of the Error Equation.

INFLUENCE QUANTITY	VOLTAGE CONTROL CHANNEL OFFSET VOLTAGE ΔE_{io}	OFFSET CURRENT ΔI_{io}	CURRENT CONTROL CHANNEL OUTPUT EFFECTS	REFERENCE ±6.2V ±5% NOMINAL
SOURCE: 105–125V a-c	<10 µV	<1 nA	<10 µA	<0.0005%
LOAD: No load – full load	<10 µV[1]	<1 nA	<10 µA	–
TIME: 8-hour [drift]	<20 µV	<1 nA	<0.01% of I_o max	<0.005%
TEMPERATURE: Per °C	<20 µV	<0.5 nA	<0.01% of I_o max	<0.005%
UNPROGRAMMED OUTPUT DEVIATION:[3] (Ripple and noise) rms	<0.01% of E_o max or 35 mV[2]		<50 µA	–
p-p[4]	<0.1% of E_o max or 150 mV[2]		<250 µA	–

[1] ΔE_{io} for load in current stabilization mode is ΔE_o/open-loop gain. ΔE_o is the compliance voltage change.
[2] Whichever is greater.
[3] 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.
[4] 20 Hz to 10 MHz.

TABLE 1-2 D-C OFFSET SPECIFICATIONS.

c) DYNAMICS:
1) SLEWING RATE (Fastest rate of change obtainable): >1 volt per microsecond.
2) PROGRAMMING TIME CONSTANT [Measured in the linear operating region, as the exponential response to an input step function. The time to reach 63% of the rated output voltage with a 1000 ohms per volt feedback resistor (R_f) and the feedback capacitor (C_f) adjusted for critical damping]. The programming time constant is approximately equal to the product "$R_f C_f$." The internal feedback capacitor (C_f) is adjustable in the range from 400 to 3900 pF
3) LOAD REACTANCE: Maximum capacitive loading: 0.001 microfarad. For inductive loads, series diodes in the output leads are required to protect the OPS from the back EMF generated by the load.

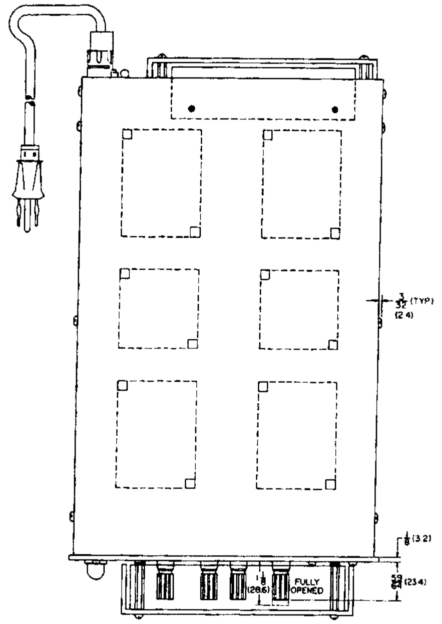
1-10 CURRENT CONTROL CHANNEL
a) OUTPUT EFFECTS: See Table 1-2.
b) DYNAMICS: The speed with which the stabilized output current returns to the stabilization band following a step in load voltage (CURRENT RECOVERY) is either governed by the time constant of the load/feedback resistance and feedback capacitance, or by the ratio I_o/C_s (I_o = current setting, C_s = tabulated shunt capacitance, see Table 1-1), whichever is smaller.

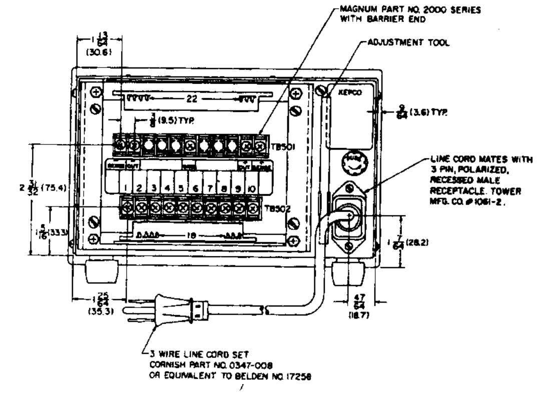
1-11 MISCELLANEOUS FEATURES

a) VOLTAGE CHANNEL: Fixed feedback resistors (500 k ohm for OPS 500B, 1 M ohm for OPS 1000B and 2 M ohm for OPS 2000B) are connected from the (–) output/sense terminal to the null junction of the voltage mode amplifier A 0–1 milliampere control current source, connected from the (+) output/sense terminal (common) to the null junction, of the voltage mode amplifier will program the output voltage through the rated range. The control current may be derived from the built-in (+6.2V) reference, it can be provided via the preamplifier or it can be generated from an external source, such as a function generator.
b) UNCOMMITTED PREAMPLIFIER: The input and output terminals of a unipolar "preamplifier" are made available at the rear barrier-strip terminals. This amplifier may be used for signal processing or for passive resistance programming of the OPS voltage output.
c) CURRENT CHANNEL: The output current is controlled by a built-in multiturn rheostat (accessible through the rear panel). 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). Its input is available at the rear barrier-strip terminals and may be disconnected from the internal reference source to be programmed by an external potentiometer or an external control voltage.
d) REMOTE ERROR SENSING: Provisions are made for a 4-terminal connection to a remote load. Static voltage drops along the load wire (up to 0.5 volt per lead) can thus be illuminated.
e) OFFSET NULLING: The initial (static) part of the voltage mode 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.

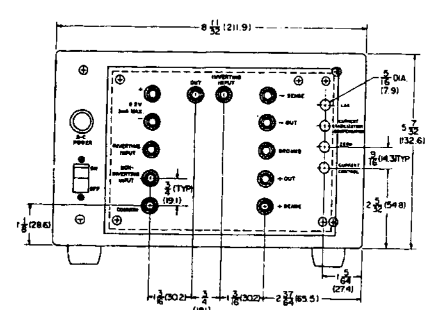
1-12 SPECIFICATIONS, MECHANICAL

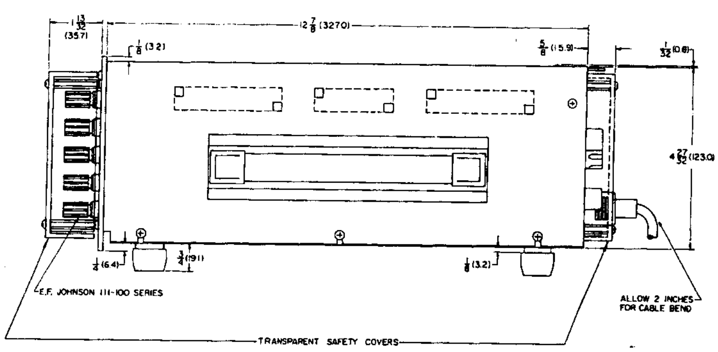
Refer to the "Mechanical Outline Drawing," FIG. 1-2.

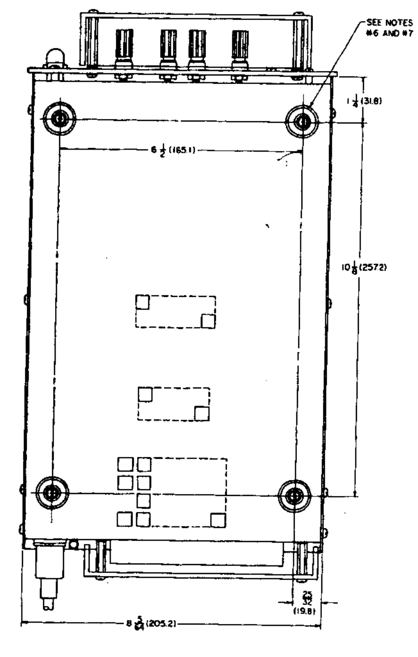




TB502	
TERMINAL	FUNCTION
1	COMMON (+SENSE)
2	NON INV.-IN. (PRE AMP.)
3	N. C.
4	INV. INPUT (POWER AMP.)
5	OUTPUT (PRE AMP.)
6	INV. INPUT (PRE AMP.)
7	+6.2 V REF. (1mA MAX.)
8	−6.2V REF (1mA MAX.)
9	CURRENT CONTROL
10	INPUT (CURRENT AMP.)







NOTES:

1. THIS DRAWING IS USED FOR OPS500B, OPS1000B AND OPS2000B.
2. MATERIAL: A) CHASSIS: 16 GAUGE C.R.S. (0.059).
   B) FRONT PANEL: 1/8" THICK ALUMINUM.
   C) COVER: 20 GAUGE C.R.S. (0.0359).
3. FINISH: A) CHASSIS: CADMIUM PLATED WITH CHROMATE WASH.
   B) FRONT PANEL: LIGHT GREY PER FEDERAL STD. 595 COLOR NO. 26440.
   C) COVER: CHARCOAL GREY VINYL TEXTURE.
4. FUSE DATA: 115 V AC, 0.8A SLO BLO. 230 V AC, 0.4A SLO BLO.
5. REFER TO KEPCO MANUAL FOR DETAILED SPECIFICATIONS.
6. REMOVE (4) FEET FOR RACK MOUNTING.
7. (4) PLASTIC MOUNTING INSERTS (UNDER FEET) FOR 8-18 THREAD CUTTING SCREWS 5/8" LONG (WITH 1/8" THICK MOUNTING PLATE).
8. DIMENSIONS WITHIN PARENTHESES ARE IN MILLIMETERS.
9. TOLERANCES: A) BETWEEN MOUNTING HOLES ±1/64 (±0.4).
   B) ALL FRONT PANEL DIMENSIONS TO MIL STD 189.
   C) ALL OTHER DIMENSIONS ±1/32 (±0.8), EXCEPT AS NOTED.

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 operational 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.

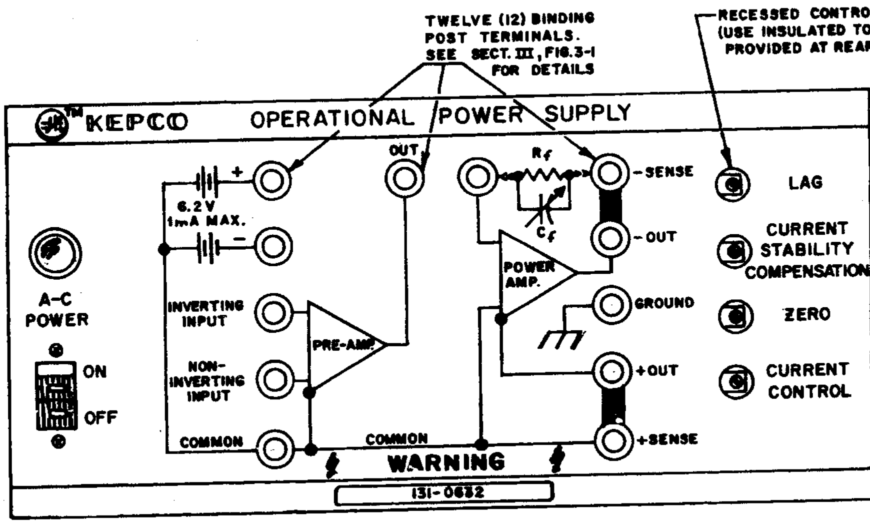


FIG. 2-1 FRONT PANEL, OPS GROUP IX MODELS.

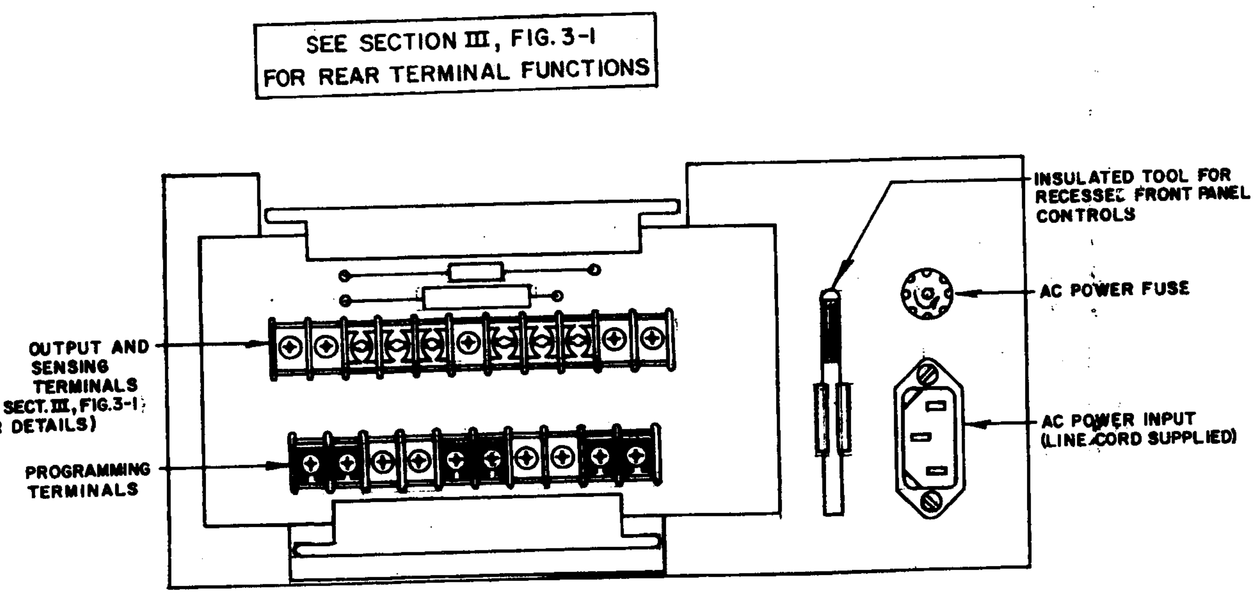


FIG. 2-2 REAR TERMINATIONS, OPS GROUP IX MODELS.

2-4 A-C POWER REQUIREMENTS

2-5 The Kepco OPS Power Supply is normally delivered for operation on a single pahse, 105 to 125V a-c source, 50 to 65Hz. For operation on 210 to 250V sources the jumper connections on the main transformer (T201), as well as the power fuse value, must be changed as shown in FIG. 2-3.

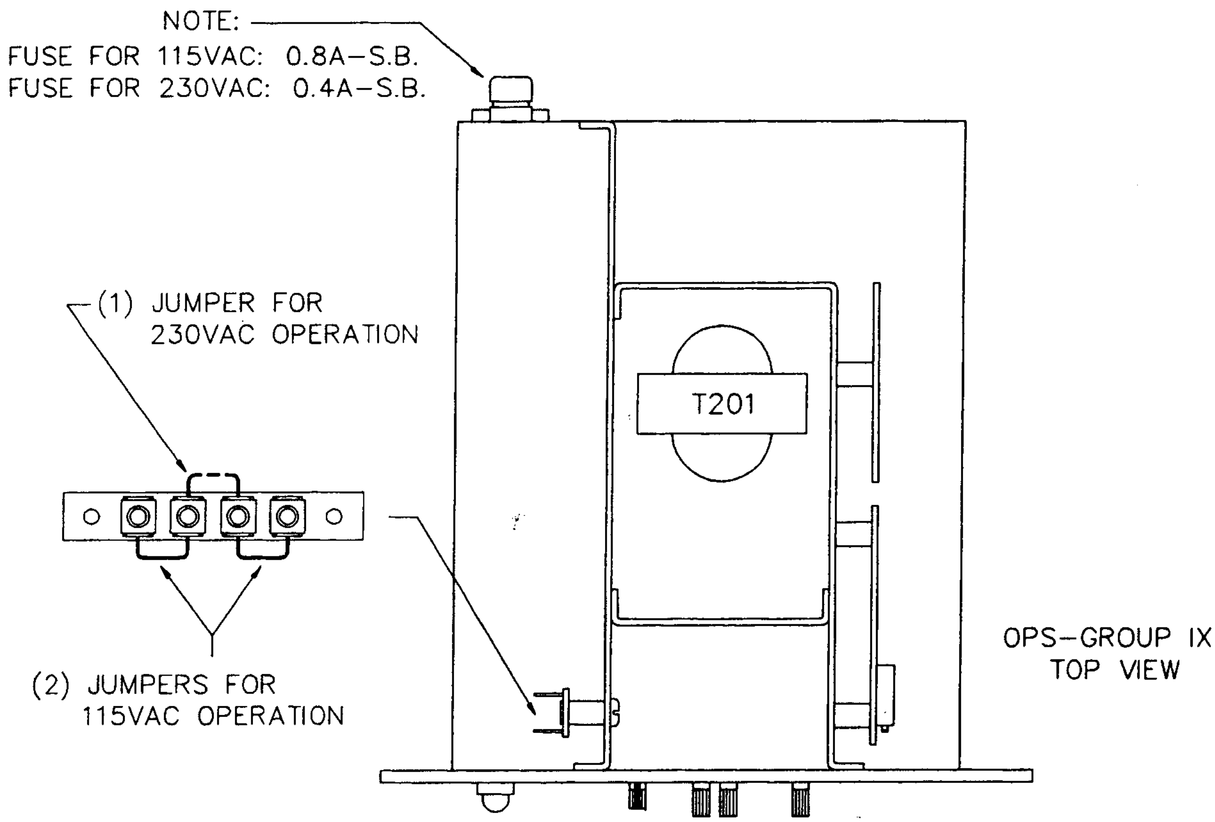


FIG. 2-3 TRANSFORMER CONNECTIONS FOR 115V A-C AND 230V A-C OPERATION.

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 OPS. (See FIG. 2-4.)

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 operational 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.

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 OPS 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 OPS BEFORE REMOVING THE PROTECTIVE FRONT OR REAR COVER. EXERCISE EXTREME CARE IN MAKING ALL CONNECTIONS TO AND FROM THE FRONT AND REAR TERMINALS.
2) WIRES AND/OR CABLES, CONNECTED FROM THE OPS TERMINALS TO EXTERNAL COMPONENTS OR PROGRAMMING DEVICES MUST BE PROPERLY INSULATED AND SECURELY TERMINATED ON BOTH ENDS, TO MAKE ACCIDENTAL TOUCH IMPOSSIBLE. REINSTALL FRONT OR REAR POTECTIVE TERMINAL COVER AFTER ALL CONNECTIONS TO THE OPS HAVE BEEN COMPLETED.
3) ***THE OPS 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) ***EITHER THE POSITIVE, OR THE NEGATIVE OUTPUT TERMINAL OF THE OPS 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 INPUT 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 CONTROL ADJUSTMENTS ON THE OPS USE ONLY THE INSULATED TOOL WHICH IS ATTACHED AT THE REAR.***

2-13 PROCEDURE, FUNCTIONAL CHECK (Refer to FIG. 2-4)

1) Without connecting the OPS to the power line, open the protective rear terminal cover.
2) Remove jumpers (1)—(2) on the REAR PROGRAMMING TERMINALS and connect wires to terminals (1), (2), and (7). Connect two (2) wires to the REAR OUTPUT TERMINALS (– out) and (+ out). NOTE: THESE TWO WIRES MUST BE HIGH VOLTAGE WIRES WITH AN INSULATION RATING OF AT LEAST 2 k VOLTS.
3) Reinstall the protective rear terminal cover.
4) Connect a 5 k ohm potentiometer in series with a 1.5 k ohm fixed resistor to the REAR PROGRAMMING TERMNALS (1), (2), (7) as shown in FIG. 2-4. Connect a fixed resistor (5 k ohm) between terminals (4) and (5). Connect a suitable voltmeter to the REAR OUTPUT TERMINALS as shown in FIG. 2-4. MAKE THE GROUND CONNECTIONS AS SHOWN IN FIG. 2-4.
5) Connect the OPS to a grounded a-c power outlet. Turn the connected VOLTAGE CONTROL potentiometer to the position of zero resistance between terminals (1) and (2) as shown in FIG. 2-4.
6) Turn OPS A-C POWER SWITCH "on." The OPS 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. Observe the voltmeter at the output and turn the VOLTAGE CONTROL potentiometer clockwise. The output voltage of the OPS 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 OPS A-C POWER SWITCH "off."

NOTE: THE FUNCTIONAL CHECK MAY BE PERFORMED BY CONNECTING TO THE FRONT PANEL BINDING POSTS INSTEAD OF THE REAR TERMINALS. SEE SECTION III, FIG. 3-1.

7) Replace the voltmeter at the output with a suitable milliammeter. LEAVE ALL OTHER COMPONENTS CONNECTED AS BEFORE.

8) Turn OPS a-c power switch "on." Allow for approximately 25 seconds warm-up. Turn VOLTAGE CONTROL clockwise, sufficiently to produce maximum output current, as evident on the ammeter across the output.

9) LOCATE THE "I_O CONTROL" (accessible ***through*** the protective front terminal cover) and turn slowly counterclockwise. Observe the milliammeter across the output. The OPS output current should smoothly change from the maximum rated value to approximately zero as the I_O CONTROL is turned through its range. Return the setting of the I_O CONTROL to its previously set value (I_O max rated) or to any intermediate value desired.

10) This concludes the functional check of the OPS. Turn A-C POWER SWITCH "off," and remove external components and metering.

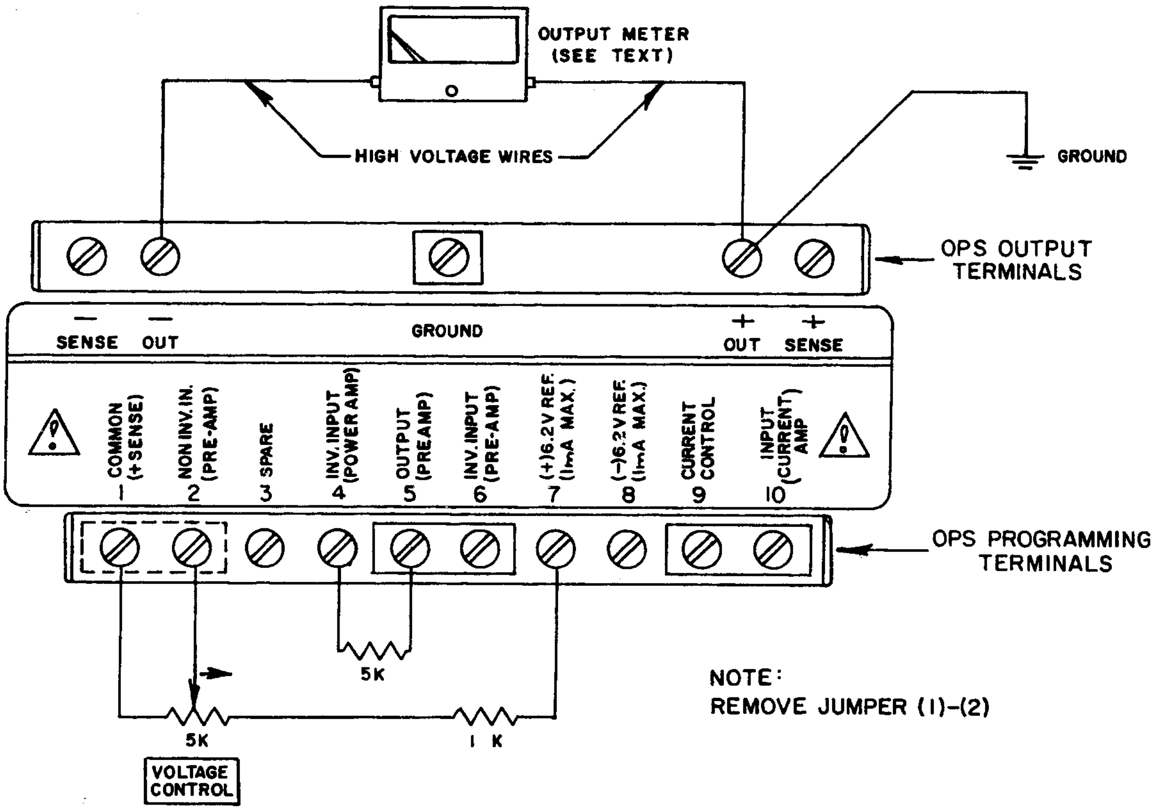


FIG. 2-4 TEST SET-UP FOR FUNCTIONAL CHECK OF THE OPS.

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

2-15 OPS GROUP IX models can be operated directly on the bench, or they can be rack-mounted, using either the Kepco RA—24 (mounts two OPS GROUP IX models), or the Kepco RA—32 (mounts one OPS GROUP IX model and three 1/6 rack width Kepco Modular Supplies) hardware systems. For rack-mounting the four bottom feet of the OPS 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. 2-5. 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 FRONT IF THE LOAD IS AT THE FRONT AND THE LINKS MUST BE CONNECTED AT THE REAR, IF THE LOAD IS AT THE REAR.

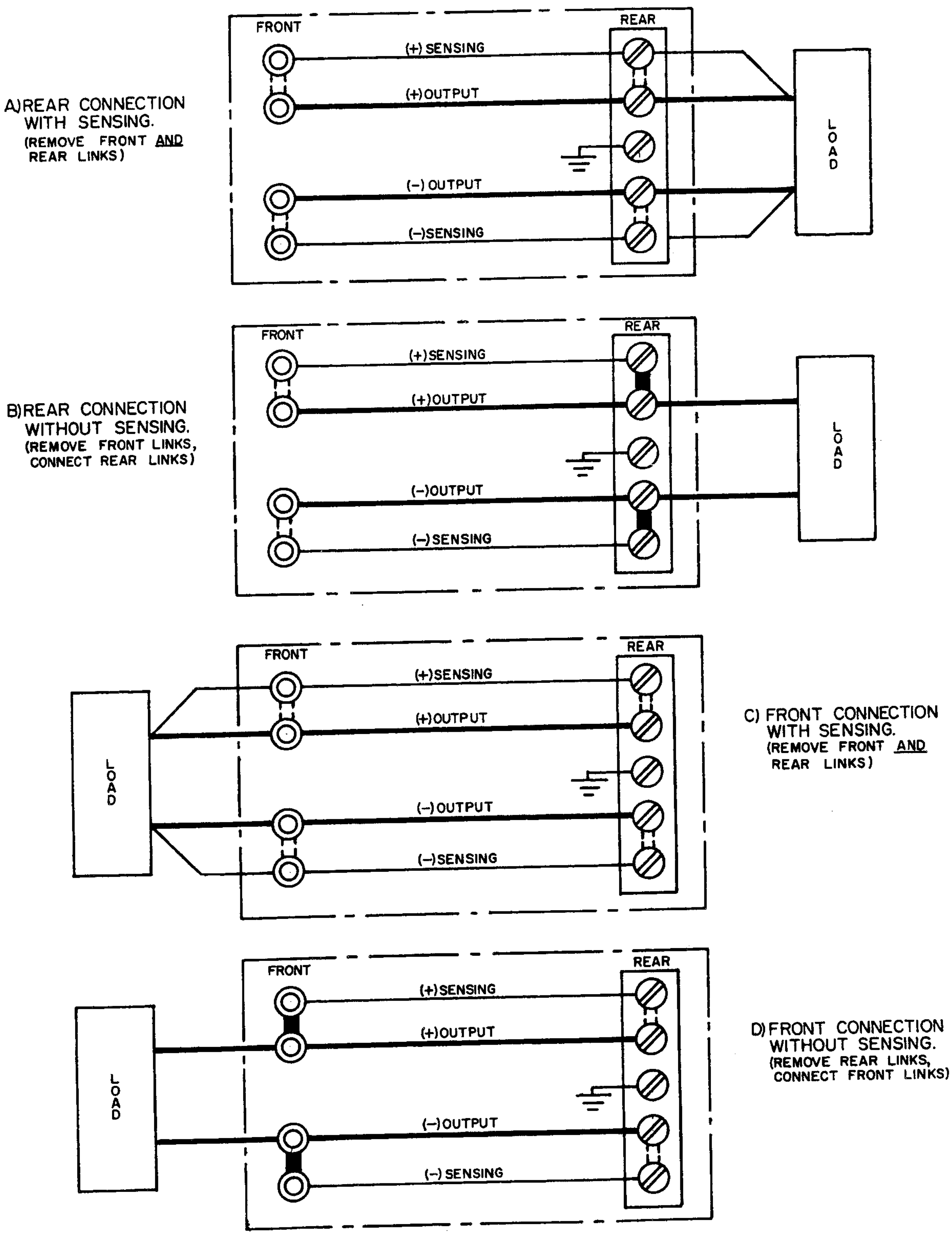


FIG. 2-5 LOAD CONNECTIONS, OPS GROUP IX.

SECTION III – OPERATION

3-1 INTRODUCTION

3-2 Kepco OPS GROUP IX and X Operational Power Supplies are two-channel, multifunction instruments which can be used in a variety of operating modes:

a) As a PRECISION, HIGH SPEED VOLTAGE SOURCE, the voltage control channel of the OPS is used to control the output either manually by means of an external potentiometer or a control voltage, or automatically, by means of digital input signals, using a Kepco SN Digital Programmer. Examples for some of these applications are given in FIGS. 3-4 and 3-7. The current control channel of the OPS serves as a "current limiter" in these examples.

b) As a UNIPOLAR WIDE-BAND VOLTAGE AMPLIFIER, the voltage channel of the OPS is used to amplify input signals to the maximum rated OPS output voltage. The current control channel of the OPS serves as a "current limiter" (see FIG. 3-12 for example).

c) The current control channel of the OPS may (independently of the voltage control channel) be programmed to provide a remote controlled current limit function. The current control channel may also be used to operate the OPS as a CONTINUOUSLY ADJUSTABLE CONSTANT CURRENT SOURCE, while the voltage channel is committed as a voltage limiter. Examples for these applications are illustrated in FIGS. 3-13 and 3-14.

d) The OPS voltage channel may be used for the precision control and stabilization of the output current in the microampere range. The control voltage may be derived from the OPS reference source, or from an external source. See FIGS. 3-16, 3-18.

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 programming should be considered:

a) LOAD CONNECTION (I). The basic interconnection between the OPS and the load are shown in FIG. 3-1. 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 (II). The recommended load connection for all applications requiring minimum load effect across a ***remote*** load is shown in FIG. 3-4. A twisted, shielded pair of wires (No. 20 AWG minimum) are connected from the OPS "± sensing" terminals to the load. This "remote error sensing" technique will compensate for load wire voltage drops up to 0.5 volts per wire.

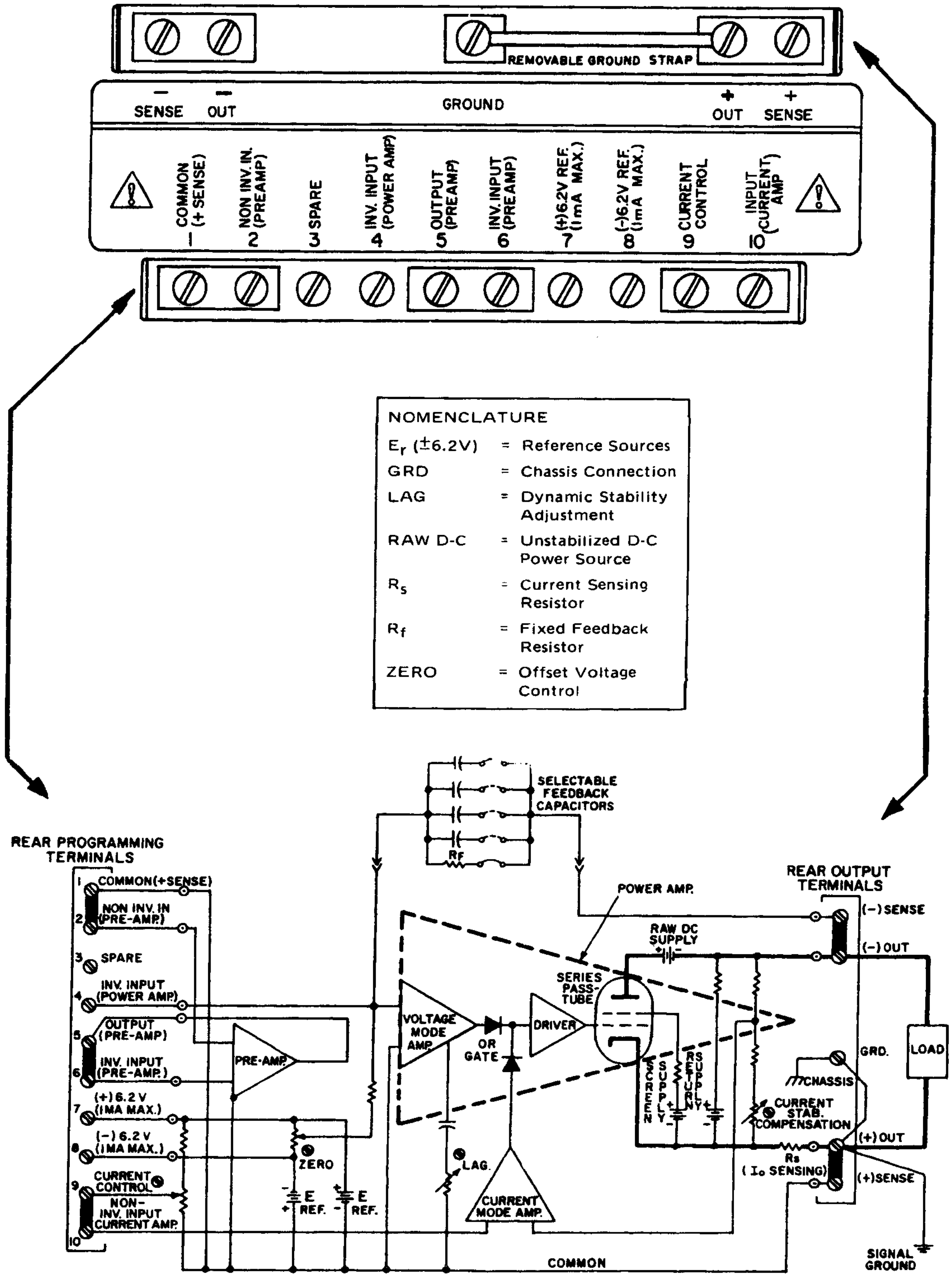
NOTE: OBSERVE POLARITIES:
THE ***NEGATIVE*** SENSING WIRE MUST GO TO THE ***NEGATIVE*** LOAD WIRE.
THE ***POSITIVE*** SENSING WIRE MUST GO TO THE ***POSITIVE*** LOAD WIRE.

c) GROUNDING

1) A-C (SAFETY) GROUND (See Section II, par. 2-6).

2) D-C (SIGNAL) GROUND. Specified ripple and noise figures for operational power supplies are valid ***only*** with one side of the output/load circuit returned to a common ground point (refer to Section I, Table 1-2). The ***positive*** side of the OPS 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 OPS output may be signal-grounded or the OPS 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. 1-7g) flows now through the load (Voltage Mode) or through the external sensing resistor (Current Mode). The signal ground point in the OPS/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 OPS 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.

a) DIAGRAMS. Application and test setup diagrams on the following pages show the symbolic and simplified representation of the OPS GROUPS IX and X Power Supply Circuit. The terminal numbers shown in these diagrams correspond with the actual terminal numbers on the two barrier-strips located at the rear of the OPS (refer to FIG. 3-1). NOTE: GROUP IX OPS MODELS HAVE FRONT PANEL TERMINALS, DUPLICATING MOST OF THE REAR TERMINAL FUNCTIONS (SEE FIG. 3-1). THE FRONT PANEL TERMINALS ARE NOT SHOWN IN SUBSEQUENT DIAGRAMS IN THIS SECTION.



NOMENCLATURE		
E_r (±6.2V)	=	Reference Sources
GRD	=	Chassis Connection
LAG	=	Dynamic Stability Adjustment
RAW D-C	=	Unstabilized D-C Power Source
R_s	=	Current Sensing Resistor
R_f	=	Fixed Feedback Resistor
ZERO	=	Offset Voltage Control

NOTE: ⊙ ARE FRONT PANEL BINDING POSTS, *NOT* PROVIDED ON OPS GROUP X MODELS.

FIG. 3-1 ACTUAL OPS REAR TERMINATIONS (TOP) AND SIMPLIFIED SCHEMATIC DIAGRAM (BELOW)

e) EXTERNAL PROGRAMMING RESISTORS. External programming resistors should be high-quality units, with low-temperature coefficients. Resistors should be selected carefully, since in most applications, the limitations for stability and drift are due, not to the OPS, but to the programming resistors. Selection criteria for resistors are (in order of importance):

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

f) 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 OPS 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 ***negative*** output is tied to the case and can be connected to the OPS "common."

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

h) EXTERNAL LEADS. Shielded (preferably twisted) lead pairs are recommended for all input connections to the OPS 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 OPS output voltage.

WARNING

THIS INSTRUMENT IS CAPABLE OF PRODUCING LETHAL VOLTAGES:

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

2) AN INTERLOCK DEVICE REMOVES THE A-C SOURCE POWER FROM THE OPS IF THE TERMINAL COVER PLATE IS LIFTED, OR IF THE MAIN COVER IS REMOVED. ***DO NOT BYPASS THE INTERLOCK!*** (OPS GROUP X ONLY.)

3) WIRES AND/OR CABLES, CONNECTED FROM THE OPS TERMINALS TO EXTERNAL COMPONENTS OR PROGRAMMING DEVICES MUST BE PROPERLY INSULATED AND SECURELY TERMINATED ON BOTH SIDES, TO MAKE ACCIDENTAL TOUCH IMPOSSIBLE. FEED-THROUGH HOLES ARE PROVIDED ON THE OPS PROTECTIVE COVER, TO BRING THE WIRES FROM THE OPS REAR TERMINALS TO THE OUTSIDE.

4) ***THE OPS 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) ***EITHER THE POSITIVE, OR THE NEGATIVE OUTPUT TERMINAL OF THE OPS 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 5000 VOLTS***, IF THE NEGATIVE OUTPUT IS GROUNDED.

6) ***FOR ALL CONTROL ADJUSTMENTS ON THE OPS USE ONLY THE INSULATED TOOL WHICH IS ATTACHED AT THE REAR.***

THE OPS AS A HIGH SPEED, PRECISION VOLTAGE SOURCE

3-4 OUTPUT VOLTAGE CONTROL, USING AN EXTERNAL CONTROL VOLTAGE

3-5 GENERAL. The output voltage of the OPS can be controlled by means of an external d-c control voltage. This can be accomplished in two ways, either by addressing the POWER AMPLIFIER input directly, or by applying the control voltage via the PREAMPLIFIER. The method best suited to ***your*** application will mainly depend on the available control voltage source.

3-6 DIRECT VOLTAGE PROGRAMMING. This control method is suitable for control voltage sources which, for the full OPS output voltage and with the built-in fixed feedback resistor, are able to supply at least 1 milliampere of control current via the series input resistor to the INVERTING INPUT of the POWER AMPLIFIER. (See FIG. 3-2.)

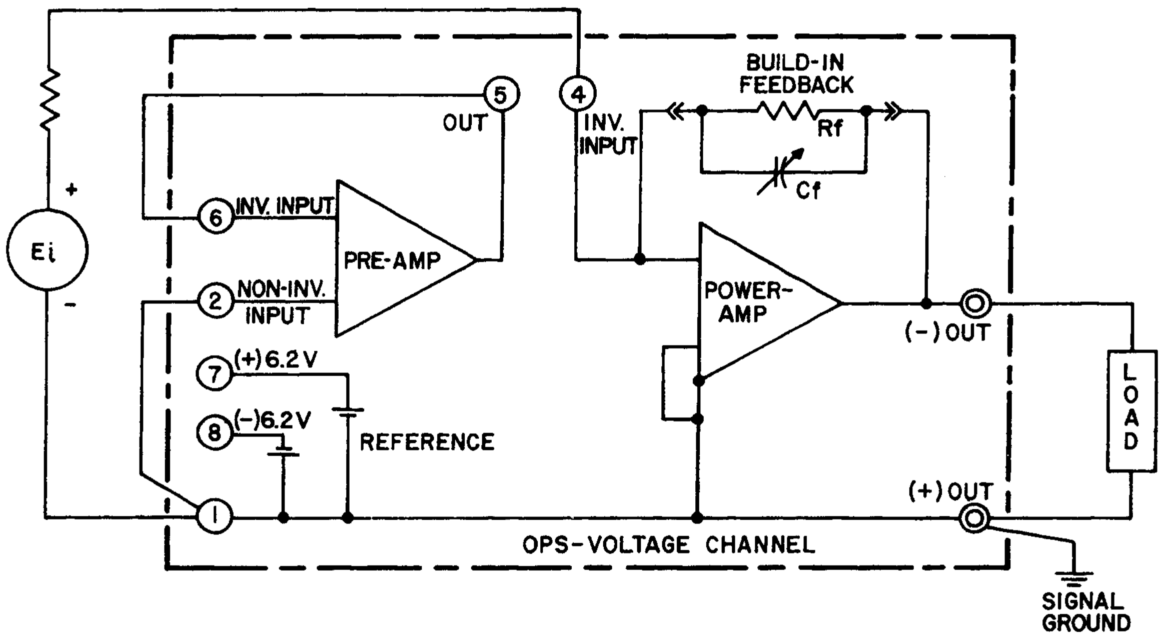


FIG. 3-2 EQUIVALENT DIAGRAM, OPS VOLTAGE CONTROL CHANNEL CONNECTED FOR DIRECT VOLTAGE PROGRAMMING.

3-7 The OPS voltage control channel is used here as an inverting power amplifier. The output equation for this programming method can be expressed by:

$$E_O = E_i\left(\frac{R_f}{R_i}\right), \text{ (Eq. 1)}, \quad \text{where:}$$

E_O = OPS Output Voltage
E_i = External Control Voltage
R_f = OPS (Fixed) Feedback Resistor
R_i = External Input Resistor

3-8 The ratio of the internal (fixed) feedback and external input resistor (R_f/R_i) represents the (fixed) closed-loop gain of the OPS. If, for example, R_i is chosen to be 5 k ohms, the closed-loop gain is dimensioned for each OPS model such that a 0–5 volt control voltage (E_i) presented to the inverting input of the POWER AMPLIFIER will produce the full output voltage range.

3-9 The input source (0–5 volts at 1 mA) must be UNIPOLAR (vary in one direction only) and POSITIVE with respect to the COMMON terminal (see par. 3-36 and par. 3-42 for control methods with NEGATIVE and BIPOLAR input sources).

3-10 VOLTAGE PROGRAMMING VIA THE PREAMPLIFIER. Since, in this control method, the external control voltage is connected to the noninverting input of the PREAMPLIFIER, the input impedance is very high. The external control voltage source, therefore, has to supply only the small preamplifier bias current (in the nanoampere range). The PREAMPLIFIER is connected (by means of strapping of the PROGRAMMING TERMINALS) as a "voltage repeater" and its output is connected to the inverting input of the POWER AMPLIFIER. (See FIG. 3-3.)

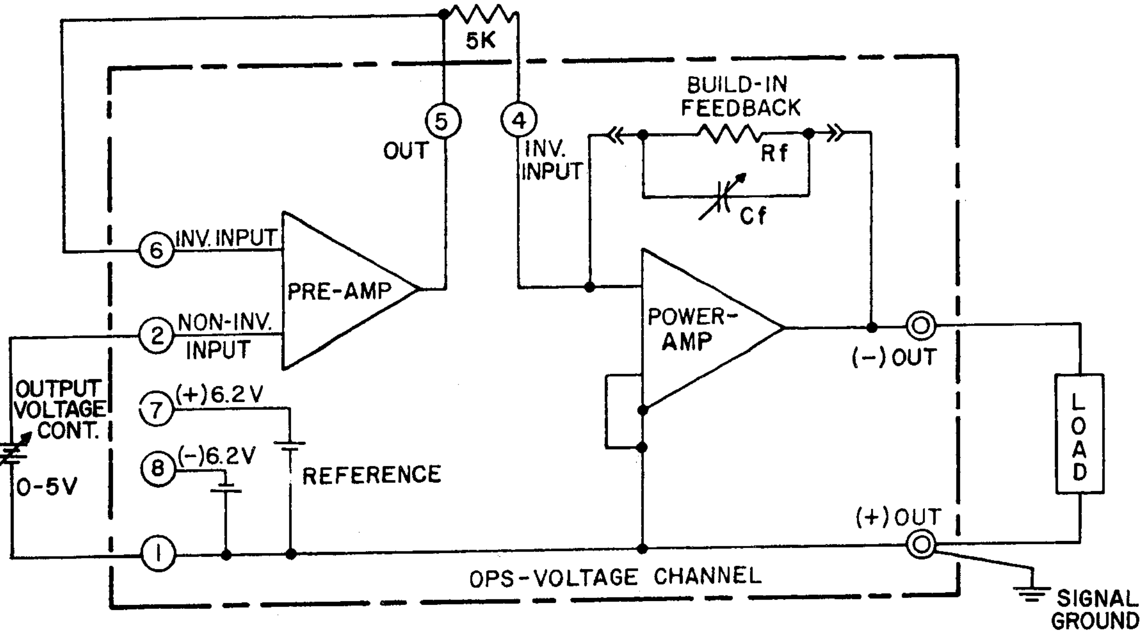


FIG. 3-3 EQUIVALENT DIAGRAM, OPS VOLTAGE CONTROL CHANNEL CONNECTED FOR VOLTAGE PROGRAMMING VIA THE PREAMPLIFIER.

3-11 As shown in FIG. 3-3, the PREAMPLIFIER output supplies the required 1 milliampere control current via the series input resistor (R_i) to the inverting input of the POWER AMPLIFIER, which responds as expressed by equation (1). A 0–5 volt control voltage and a 5 k ohm input resistor (R_i) will, therefore, control the OPS output voltage over its full range.

3-12 The uncommitted PREAMPLIFIER of the OPS has both inputs and its output terminated on the PROGRAMMING terminals. It can, therefore, be used for a variety of other tasks. If, for example, the input voltage source is ***negative,*** the PREAMPLIFIER can be connected in an inverting configuration and thus supply the control signal to the POWER AMPLIFIER input. (See par. 3-30 and 3-36 for other PREAMPLIFIER applications.)

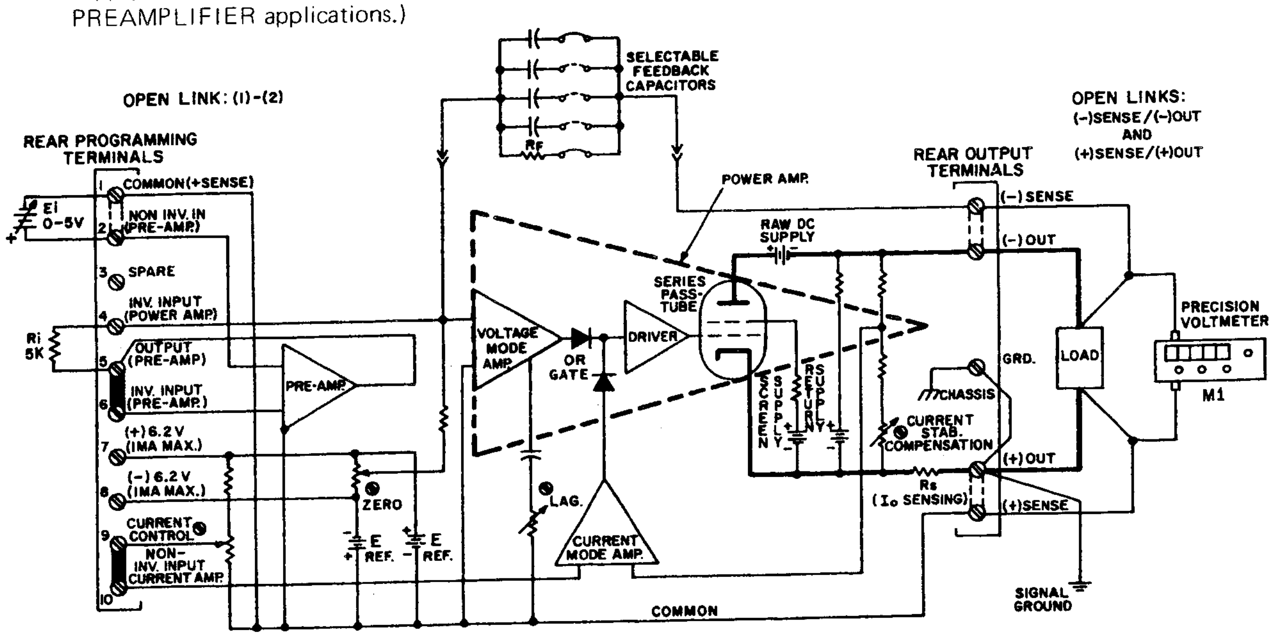


FIG. 3-4 CONNECTIONS FOR OUTPUT VOLTAGE CONTROL, USING AN EXTERNAL CONTROL VOLTAGE (REMOTE ERROR SENSING CONNECTIONS SHOWN).

3-13 VOLTAGE PROGRAMMING, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

1) Connect the input source (E_i), load and output voltmeter (M1) to the OPS as shown in FIG. 3-4. FOR INTERCONNECTION DETAILS AND SAFETY PRECAUTIONS, TURN TO THE "WARNING" PARAGRAPH ON PAGE 3-3.
2) Turn OPS "on." Set input source (E_i) to "zero" and turn "on."
3) Adjust input source from "zero" to 5 volts. The OPS output should vary smoothly from zero to its maximum rated output voltage. Return input source to "zero."

3-14 CALIBRATION (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

1) Check output voltmeter (M1) for zero reading and correct by adjusting the OPS ZERO control.
2) Set input source (E_i) to exactly 5 volts. Observe output voltmeter (M1). Calibrate the input source so that the exact value of the maximum rated OPS output voltage is read out on M1.
3) Set input source (E_i) to "zero" again, recheck the calibrated zero point and correct with the OPS ZERO control if necessary.

3-15 DYNAMIC ADJUSTMENTS

3-16 The wide-band characteristic of the OPS may give rise to dynamic instability ("ringing," "overshoot," "oscillations," etc.) at the output, especially with input sources producing a step-function and/or where the output is loaded with excessive capacitance. In the OPS, provisions have been made to stabilize the voltage channel amplifier for a fairly wide range of load conditions. A feedback capacitor "strapping arrangement" is provided on a printed circuit board (accessible after cover removal) and an adjustable lag network can be controlled through the OPS protective rear cover (OPS GROUP X) or through the front panel (OPS GROUP IX). The response characteristics of the OPS output are adjusted at the factory by optimizing the OPS square wave response at full power output (see FIG. 3-5). In cases of dynamic instability in ***your*** application, select the feedback capacitor and adjust the lag network as described in the following paragraph.

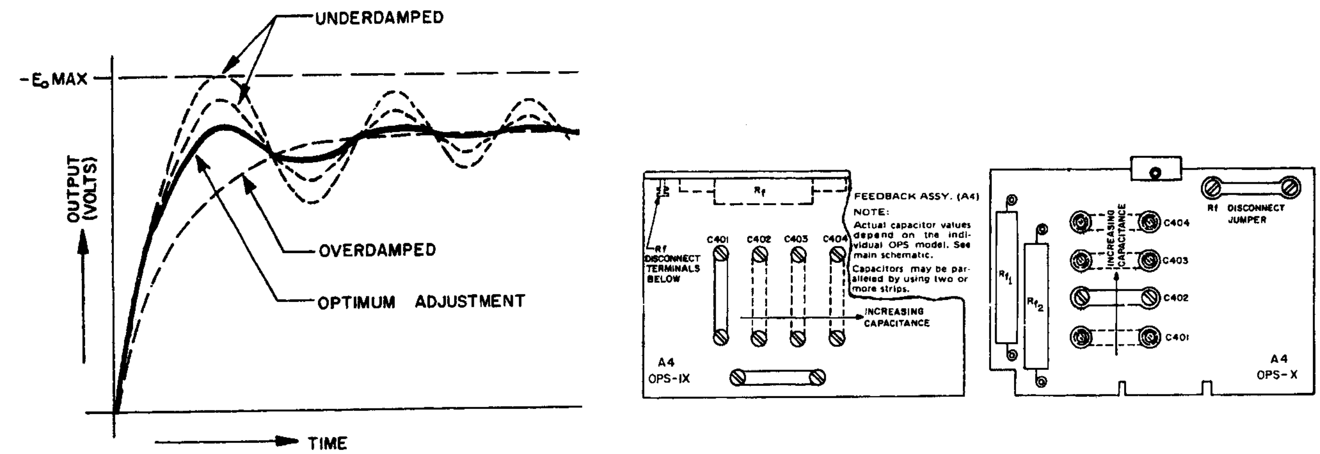


FIG. 3-5 OUTPUT RESPONSE TO A SQUARE WAVE AND FEEDBACK CAPACITOR LOCATION.

3-17 DYNAMIC ADJUSTMENTS, PROCEDURE

1) With the OPS set up with the chosen operating conditions and working into the designated load, observe the output with a suitable oscilloscope for evidence of dynamic instability.
2) If instability is present, remove a-c power from the OPS. Remove the OPS cover and increase the feedback capacitance by changing the jumper link on the auxiliary board (A4- see FIG. 3-5) to the desired position. Re-install cover and turn OPS "on" again.
3) Re-check operation and correct persistent instability by adjusting the OPS LAG control until stable operation is achieved.
4) NOTE: Persistent instability may be caused by excessive capacitive loading. (Maximum capacitive load for the OPS is specified as 0.001 μF.)

3-18 OUTPUT CURRENT ADJUSTMENT

3-19 The OPS Power Supply is equipped with a continuously adjustable output current control, which is factory adjusted for the maximum rated output current. The control is mounted recessed from the rear protective cover (OPS GROUP X) or from the front panel (OPS GROUP IX) and marked I_O CONTROL. The setting of the I_O CONTROL determines the output current limit point of the OPS, when the voltage channel is in control of the output. If the ratio of the output voltage setting to load resistance (E_O/R_L) is ***greater*** than the output current value of the I_O CONTROL setting, the current channel takes control and the OPS transfers from the "voltage" to the "current" control mode. In this mode, the OPS stabilizes the output current, reducing the load voltage proportional to the load resistance thus providing complete short circuit protection. The output current control may be set between 2% and 110% of the rated OPS output current range by following the procedure described below.

3-20 OUTPUT CURRENT ADJUSTMENT, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

1) Retain the basic programming circuit shown in FIG. 3-4, but replace the LOAD and the PRECISION VOLTMETER (M1) by a suitable ammeter. Turn OPS "on".
2) Observe the ammeter across the OPS output and adjust I_O CONTROL until the desired output current is read out on the ammeter.
3) Turn OPS "off," disconnect ammeter and reconnect the LOAD. This concludes the output current adjustment.

3-21 OUTPUT CURRENT COMPENSATION ADJUSTMENT

3-22 The fixed feedback resistance of the OPS 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 OPS, is factory adjusted for best current stabilization with the built-in feedback resistor (R_f). If other feedback resistors are used, the compensating circuit may be readjusted for optimum output current stabilization using the test set-up shown in FIG. 3-6 and following the procedure described below.

NOTE: ***Before*** **all measurements review Section III, pars. 3-18 to 3-23.**

CAUTION: **Large transient voltages may appear across R_M as S1 is opened or closed. M1 must, therefore, be protected by a surge-suppressor.**

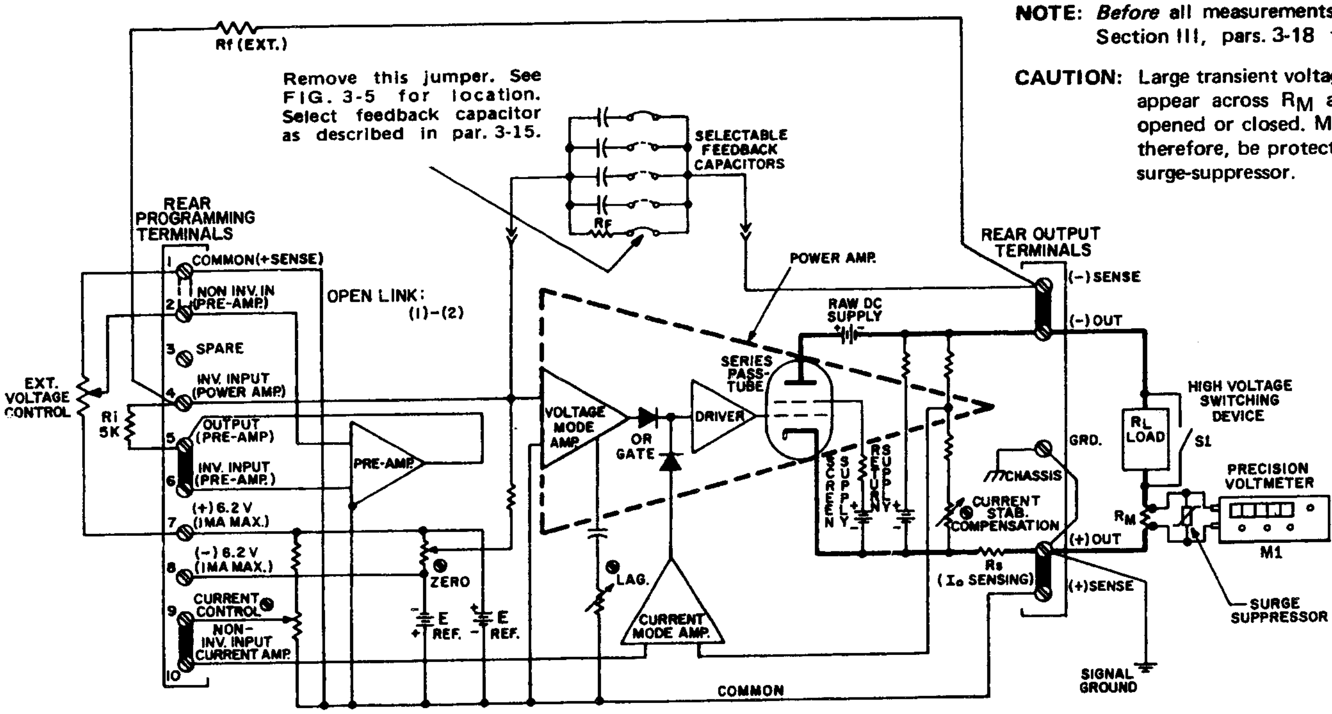


FIG. 3-6 TEST SET-UP FOR COMPENSATION ADJUSTMENT AND OUTPUT CURRENT STABILITY MEASUREMENTS.

3-23 OUTPUT CURRENT COMPENSATION ADJUSTMENT, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

1) Set up the test circuit shown in FIG. 3-6. Select R_L as required and let $R_M \approx 1$ k ohm. Follow the turn-on procedure as described in par. 3-13. Set required compliance (load voltage) with the EXT. VOLTAGE CONTROL.
2) Read and record the voltage drop (V_{RM}) across the measuring resistor (R_M). Close S1 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 (S1). Adjust for minimum ***change*** (ΔV_{RM} MINIMUM) across the measuring resistor (R_M).
4) Turn OPS "off," remove the measuring circuit components and reconnect the LOAD. This concludes the compensation adjustment.

NOTE: TO INSURE MAXIMUM ACCURACY, AND DEPENDABLE OPERATION, THE PROCEDURES DESCRIBED IN THE PREVIOUS PARAGRAPHS (3-15 THROUGH 3-23) SHOULD BE APPLIED BEFORE EACH PROGRAMMING APPLICATION.

3-24 OUTPUT VOLTAGE CONTROL, USING AN EXTERNAL POTENTIOMETER

3-25 GENERAL. By using one of the internal reference sources of the OPS ($+E_r$) to provide the input voltage (E_i), the OPS output voltage can be controlled by means of an external potentiometer. As in the previously described application (refer to par. 3-4 to 3-7), the transfer function for this control method can be expressed by :

$E_o = E_i (R_f/R_i)$ (Eq. 1), where: E_o = OPS Output Voltage
E_i = External Control Voltage
R_f = OPS (Fixed) Feedback Resistor
R_i = External Input Resistor

3-26 The ratio of the internal (fixed) feedback and external input resistor (R_f/R_i) represents the (fixed) closed-loop gain of the OPS. If the external input resistor (R_i) is chosen to be 5 k ohm this ratio is dimensioned for each OPS model such that a 0–5 volt input voltage will produce the full output range.

3-27 The input voltage (E_i) is derived from the OPS reference source ($+E_r$) via a resistive divider, consisting of the EXTERNAL VOLTAGE CONTROL potentiometer and the E_o CAL. rheostat. Since the noninverting input of the PREAMPLIFIER is used in this control method, only the small amplifier bias current (Nanoampere Range) will flow through the potentiometer arm. Control linearity and absolute accuracy are, therefore, limited only by the linearity of the potentiometer and calibration of the final circuit.

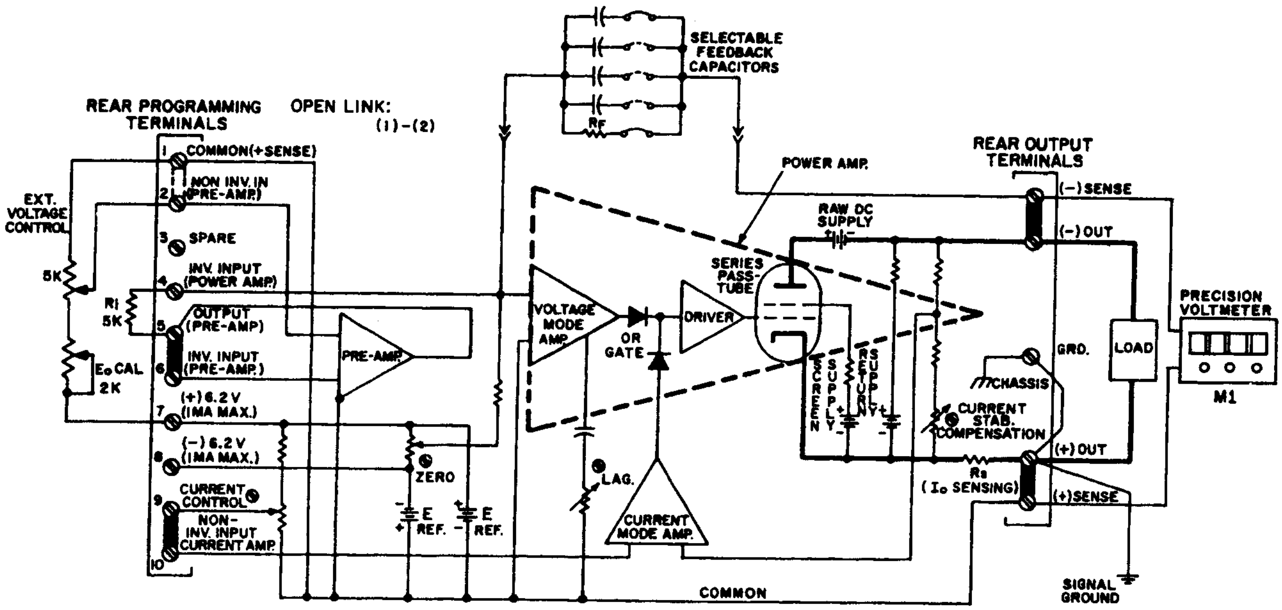


FIG. 3-7 CONNECTIONS FOR OPS OUTPUT VOLTAGE CONTROL WITH A POTENTIOMETER.

3-28 POTENTIOMETER CONTROL, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

1) Connect the potentiometer (EXTERNAL VOLTAGE CONTROL), the calibrating rheostat (E_o CAL.), the LOAD and the OUTPUT VOLTMETER (M1) to the OPS as shown in FIG. 3-7. FOR INTERCONNECTION DETAILS AND PRECAUTIONS, TURN TO THE "WARNING" PARAGRAPH ON PAGE 3-3.

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

3) Vary the EXTERNAL VOLTAGE CONTROL through its complete range. The OPS 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.

3-29 CALIBRATION (Refer to Section II, FIG. 2-1 or 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 OPS 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 OPS 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 OPS ZERO control if necessary.

NOTE: FOR DYNAMIC and OUTPUT CURRENT ADJUSTMENTS, refer to paragraphs 3-15 through 3-23.

3-30 OUTPUT VOLTAGE CONTROL BY A LINEAR RESISTANCE CHANGE

3-31 GENERAL. The OPS output voltage can be controlled by a resistance decade or other linearily varying resistors. Using again a 5 k ohm input resistor for the POWER AMPLIFIER, a 0–5 volt input control voltage (produced by the PREAMPLIFIER) will, with the built-in fixed feedback resistor, produce the full output voltage range.

3-32 The 0–5 volt control voltage input to the POWER AMPLIFIER will now be produced by the UNCOMMITTED PREAMPLIFIER. Connecting the internal built-in d-c reference source with an external variable feedback resistor to the inverting input of the PREAMPLLIFIER, the output of the PREAMPLIFIER now constitutes the required control voltage for the POWER AMPLIFIER (refer to FIG. 3-8).

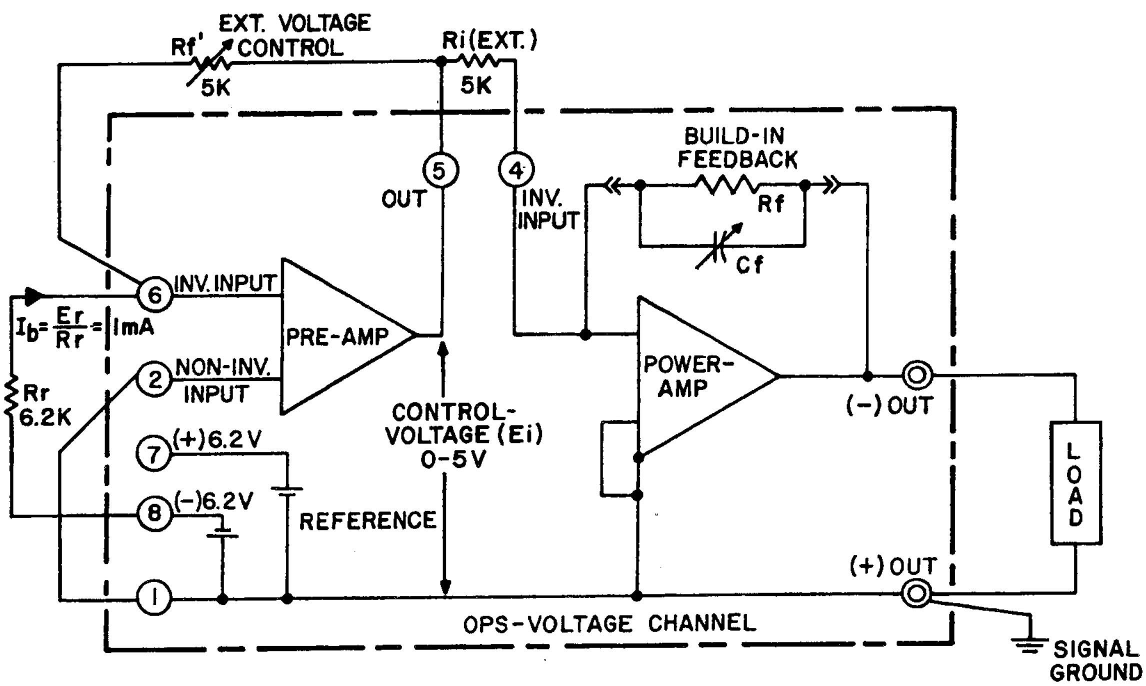


FIG. 3-8 LINEAR OUTPUT CONTROL BY RESISTANCE, OPS VOLTAGE CONTROL CHANNEL.

3-33 As seen from FIG. 3-8, the equation for the output of the PREAMPLIFIER can be expressed by:

$$E_i = \frac{E_r}{R_r}(R_{f'}), \quad \text{or}$$

$$0\text{–}5 \text{ Volts} = \frac{6.2\text{V}}{6.2\text{ k}\Omega}(0\text{–}5 \text{ k ohms}).$$

By means of the given equation, other values for the external components (R_r, $R_{f'}$, R_i) may be chosen if the suggested values are not available.

3-34 LINEAR RESISTANCE CONTROL, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

1) Connect the selected feedback resistor ($R_{f'}$ = EXTERNAL VOLTAGE CONTROL), the reference resistor (R_r = 6.2 k ohm, Note: Make part of R_r adjustable for E_O CAL. control), the LOAD and the OUTPUT VOLTMETER (M1) to the OPS as shown in FIG. 3-9. NOTE: FOR INTERCONNECTION DETAILS AND PRECAUTIONS, TURN TO THE "WARNING" PARAGRAPH ON PAGE 3-3.

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

3) Vary the EXTERNAL VOLTAGE CONTROL from its minimum to its maximum resistance position. The OPS 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.

3-35 CALIBRATION

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

NOTE: For DYNAMIC and OUTPUT CURRENT ADJUSTMENTS, refer to paragraphs 3-15 through 3-23.

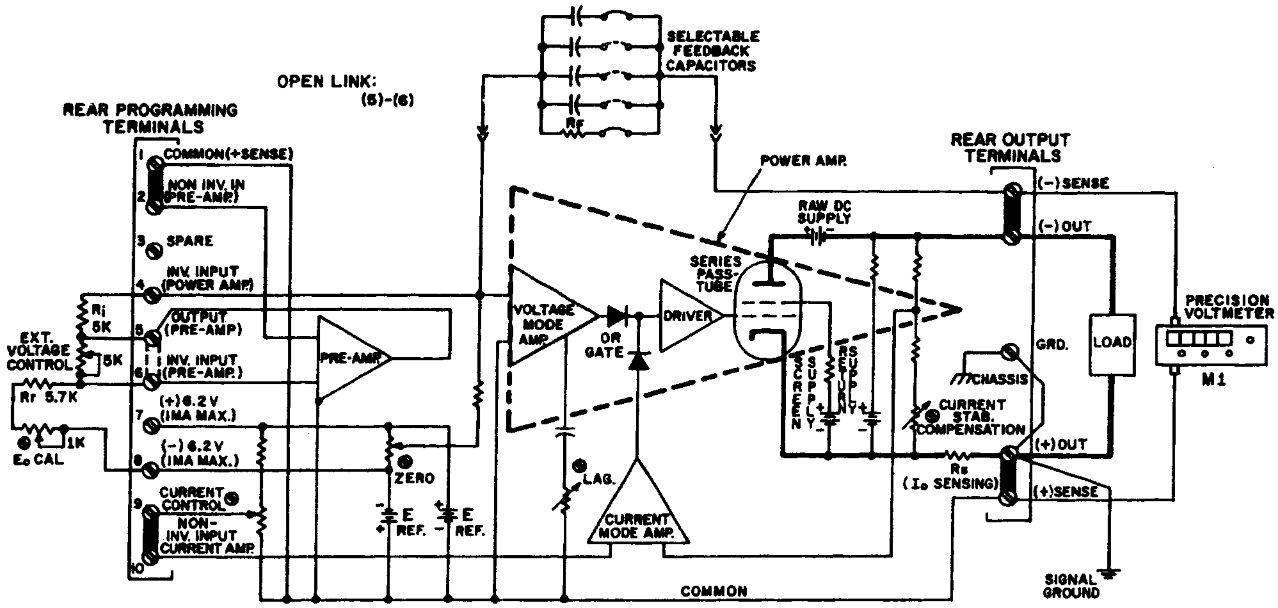


FIG. 3-9 CONNECTIONS FOR OPS OUTPUT VOLTAGE CONTROL BY A LINEAR RESISTANCE.

THE OPS AS A UNIPOLAR AMPLIFIER

3-36 GENERAL. If, instead of the previously used d-c control signal, an a-c signal is applied to the input, the OPS functions as a unipolar amplifier.

The maximum peak-to-peak amplitude of the individual OPS model is equal to its rated d-c output voltage. The average sine wave power into a resistive load is one-quarter its d-c output power. The maximum, full power sine wave frequency is given by:

$$f_{max} \approx \frac{S.\,R.}{\pi\, E_O\ max}$$, where "S. R."

is the specified OPS slewing rate, and "E_O max" is the rated maximum output voltage. The "−3 dB frequency" for the OPS, as a unipolar amplifier, is equal to:

$$f_{(-3\,dB)} \approx \frac{0.16}{\tau}$$, where τ is the OPS time constant: $R_f C_f$ (R_f = Feedback Resistor, C_f = Feedback Capacitor).

3-37 Since the output of the OPS can vary only in one direction (negative with reference to the COMMON terminal), for ***bipolar*** input waveforms, the OPS output must first be d-c biased to accommodate the resulting output waveform (refer to FIG. 3-10.)

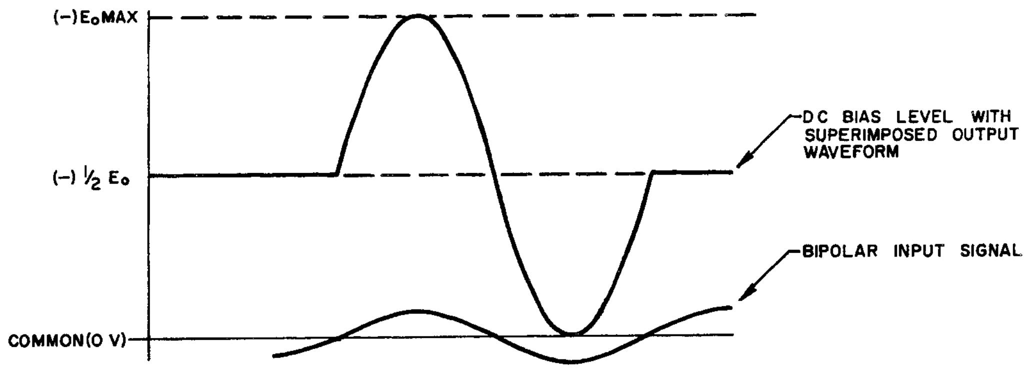


FIG. 3-10 OPS INPUT/OUTPUT WAVEFORMS WITH D-C BIAS.

3-38 The d-c output bias level can be produced by summing a d-c control current (I_b), derived from the internal reference source (E_r), with the a-c input signal (E_i'), at the inverting input of the uncommitted PREAMPLIFIER (see FIG. 3-11).

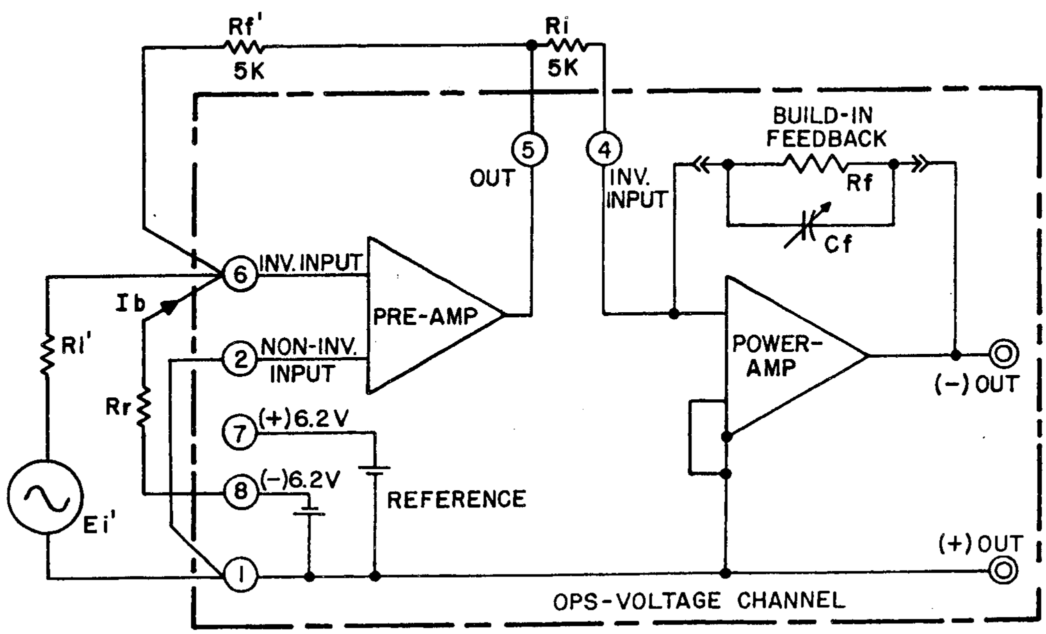


FIG. 3-11 PROGRAMMING WITH A BIPOLAR INPUT SOURCE, OPS VOLTAGE CONTROL CHANNEL.

3-39 Component selection can be best shown by considering a practical application example:

1) An OPS 3500 is to be programmed with a sinusoid through its full output range, using a bipolar signal generator.

2) As seen in previous paragraphs, to control the OPS output voltage over its rated range, we require a control voltage (E_i) of zero to 5 volts at the input of the POWER AMPLIFIER, and an external input resistor (R_i) of 5 k ohms (refer to pars. 3-4 to 3-7).

3) Since the input signal is bipolar, an output bias level of (−) 1750 volts d-c must be set at the OPS output. This requires a bias input of E_i = (+) 2.5 volts d-c. To modulate the output from the (−) 1750 volts d-c center, between zero and (−) 3500 volts d-c, requires a modulation of the input voltage (E_i) from the (+) 2.5 volts d-c center, between zero and (+) 5 volts.

4) The two equations, expressing the required input conditions are:

$$+E_i\ (2.5V\ d\text{-}c) = -E_r \frac{R_f'}{R_i'} \text{ and}$$

$$\pm E_i\ (\pm 2.5V\ a\text{-}c) = \pm E_i' \frac{R_f'}{R_i'}$$

, where:

$E_{i\ d\text{-}c}$ = Required Bias Input Voltage
$E_{i\ a\text{-}c}$ = Required Signal Input Voltage
E_i' = Generator Input Voltage
E_r = Internal Reference Voltage
R_f' = External Feedback Resistor
R_i' = External Input Resistor
R_r = External Reference Resistor
R_f'/R_i' = Closed-Loop Gain, a-c PRE-
R_f'/R_r = Closed-Loop Gain, d-c AMP

5) The values of the external feedback and input resistors (R_f', R_i') and thereby the (a-c) closed-loop gain, are determined by the output capabilities of the signal generator. If a generator voltage (E_i') of 0 to ±2.5 volts is available, the ratio R_f'/R_i' can be made unity. The value of R_f' and R_i' is chosen according to the generator impedance, if for example, the generator output is specified as "5V p-p at 1 mA," $R_i' = R_f'$ could be two 5 k ohm resistors.

6) Since R_f' has been selected according to the capabilities of the input source, the reference resistor (R_r) is calculated by using the equation for the d-c bias conditions. All quantities, except R_r are known, so that:

$$R_r = \frac{6.2V\ (5\ k\ ohm)}{2.5V} = 12.4\ k\ ohm.$$

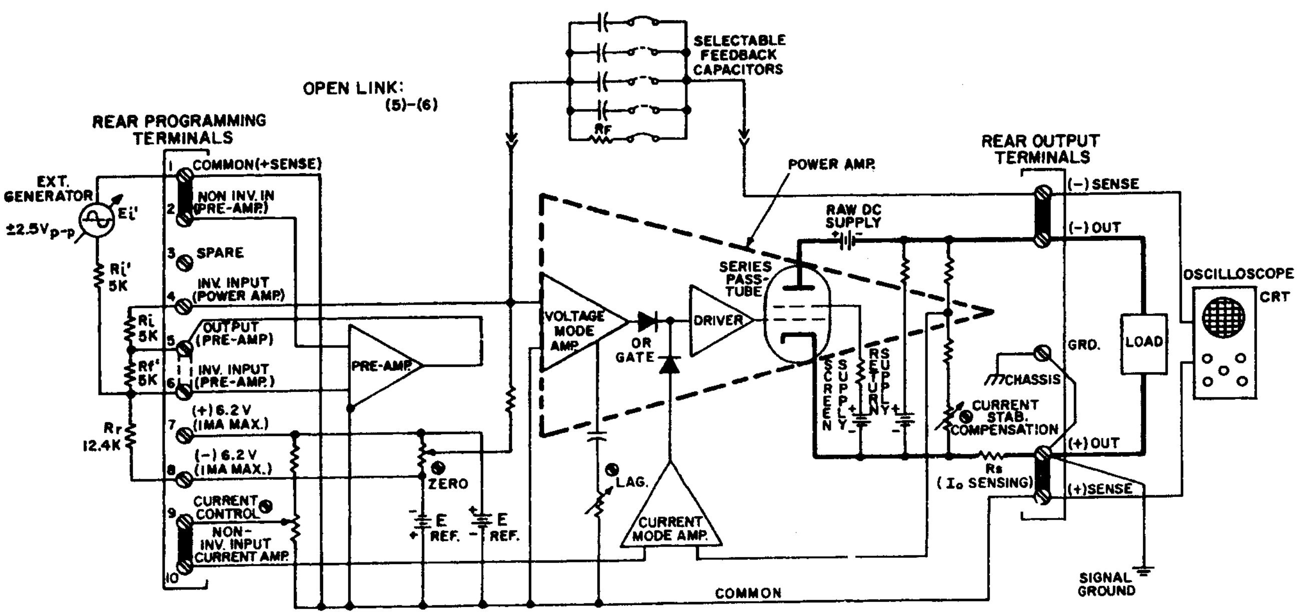


FIG. 3-12 CONNECTIONS FOR AMPLIFYING A BIPOLAR INPUT SIGNAL.

3-40 UNIPOLAR OPERATION, PROCEDURE (refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

1) Connect the generator (E_i'), the LOAD and an oscilloscope (CRT) to the OPS as shown in FIG. 3-12. FOR INTERCONNECTION DETAILS AND SAFETY PRECAUTIONS TURN TO THE "WARNING" PARAGRAPH ON PAGE 3-3.
2) Set generator (E_i') amplitude to "zero." Turn the OPS and the generator "on."
3) Adjust generator amplitude from zero to 5 volts peak-to-peak. The oscilloscope at the OPS output should display a sine wave, varying from zero to the maximum rated OPS output voltage. Return generator amplitude to "zero." TURN OPS POWER SWITCH OFF.

3-41 CALIBRATION

1) Establish the "zero" level on the oscilloscope by briefly connecting the scope lead to the "common" lead. Reconnect oscilloscope to the OPS output.
2) TURN OPS "on." Adjust the generator amplitude to 5 volts p-p and observe the output sine wave:
   a) Correct "zero" level with the OPS ZERO control.
   b) Correct maximum output amplitude with the generator amplitude control.

NOTE: 1) If "clipping" of the output waveform is evident, the d-c bias is probably not exactly at one-half E_O max. Correct by making R_r partially adjustable.
2) Refer to pars., 3-15 through 3-23 for the procedures for DYNAMIC and OUTPUT CURRENT adjustments.

3-42 For input sources other than the bipolar sine wave generator used in the previous application, the process of component selection and the equations for the control voltage (E_i) are similar. The following criteria should be kept in mind for ***all*** applications where the OPS is used as a unipolar amplifier:
The programming connections from external input sources to the OPS should be "tailored" according to the input source polarity and capability:

a) ***BIPOLAR*** input sources require a d-c bias producing ***one-half*** the required OPS output level. For input sources able to supply at least 1 milliampere of programming current, the POWER AMPLIFIER input can be driven directly. For high impedance input sources, the inverting input of the PREAMPLIFIER can be used. The d-c bias is produced by summing a d-c control current, derived from the internal reference source, with the a-c signal at the inverting input of the PREAMPLIFIER (see PAR. 3-38).
b) ***POSITIVE***-going input sources can drive the inverting input of the POWER AMPLIFIER directly. A drive current of 1 milliampere, via a 5 k ohm input resistor must be supplied by a 0–5 volt input source to program the OPS from zero to its maximum rated output voltage with the built-in feedback resistor. Alternately, the noninverting input of the PREAMPLIFIER can be driven by high impedance input sources. The PREAMPLIFIER is configured as a "voltage follower" and its output is connected (via a 5 k ohm input resistor) to the inverting input of the POWER AMPLIFIER. A 0–5 volt input source will thus program the OPS from zero to its maximum rated output voltage.
c) ***NEGATIVE***-going input sources should be connected to the inverting input of the PREAMPLIFIER. The gain of the PREAMPLIFIER is adjusted by selecting appropriate external resistors and calculated such that the output of the PREAMPLIFIER produces a 0–5 volt control signal at the inverting input of the POWER AMPLIFIER, to program the OPS from zero to its maximum rated output voltage.

NOTE: For DYNAMIC and OUTPUT CURRENT ADJUSTMENTS refer to paragraphs 3-15 through 3-23.

THE OPS AS A CURRENT CONTROLLER

3-43 OUTPUT CURRENT CONTROL BY MEANS OF AN EXTERNAL CONTROL VOLTAGE *OR* BY A POTENTIOMETER

3-44 GENERAL. By disconnecting the current control amplifier from its internal control (open link 9–10 at the REAR PROGRAMMING TERMINALS) and substituting an external d-c control voltage (≈ 0–1 volt), the output current of the OPS can be remotely controlled over its specified range.

3-45 The external d-c control voltage may be produced, for example, by a digital programmer, such as the Kepco SN–2, thus permitting digital control of the OPS output current from a computer. Another method of remote control of the OPS output current consists of duplicating the internal control method by means of an external potentiometer.

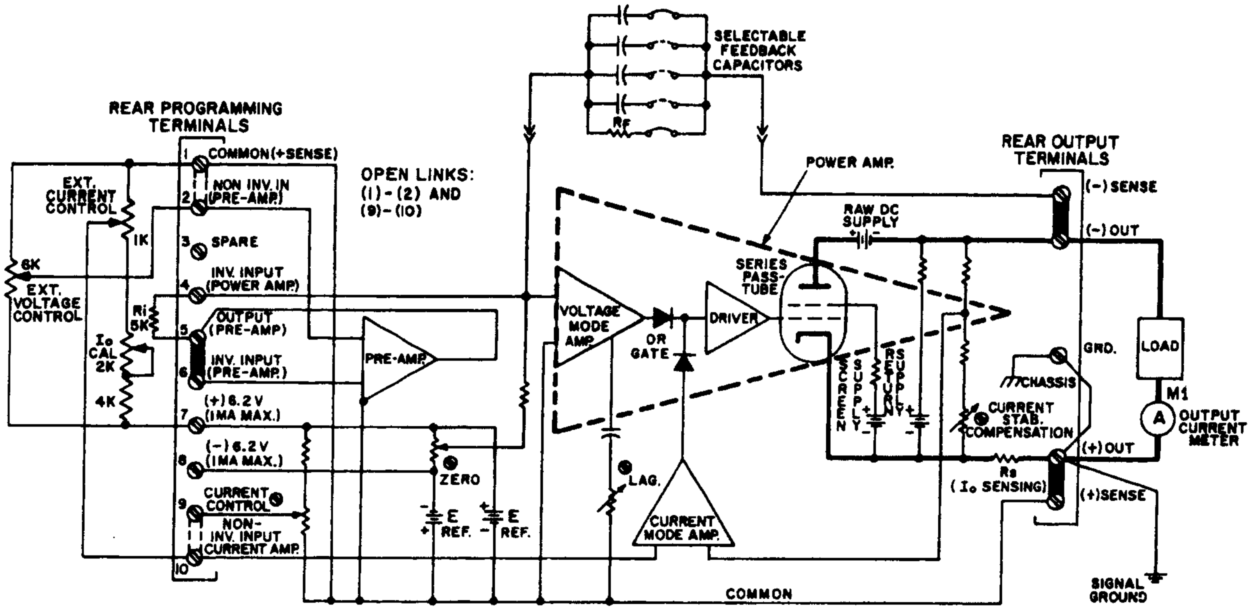


FIG. 3-13 CONNECTIONS FOR OUTPUT CURRENT CONTROL, USING AN EXTERNAL POTENTIOMETER.

3-46 CURRENT CONTROL BY EXTERNAL POTENTIOMETER, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

1) This control method duplicates the internal OPS current control circuit. The internal reference source (+6.2V) is used with a series resistor and a calibrating rheostat (I_O CAL.) to produce the control voltage (1 volt) across the potentiometer (EXTERNAL CURRENT CONTROL). The required compliance (output) voltage can be adjusted by the EXTERNAL VOLTAGE CONTROL potentiometer.

2) Refer to FIG. 3-13. Connect all external components as shown. Turn OPS "on." Adjust the EXTERNAL 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 OPS 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 also be measured 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.

3-47 CALIBRATION

1) The output current control range for the OPS is approximately 2%—100% of the specified output current capacity. The lower end of the range will depend on the offsets of the OPS CURRENT AMPLIFIER. No provisions for calibrating this offset (practical values for this offset from zero ≈ 100 μA) have been made. If a precise "zero" point is required, an alternate mode for precision current programming with the voltage mode amplifier should be chosen (refer to par. 3-50).

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

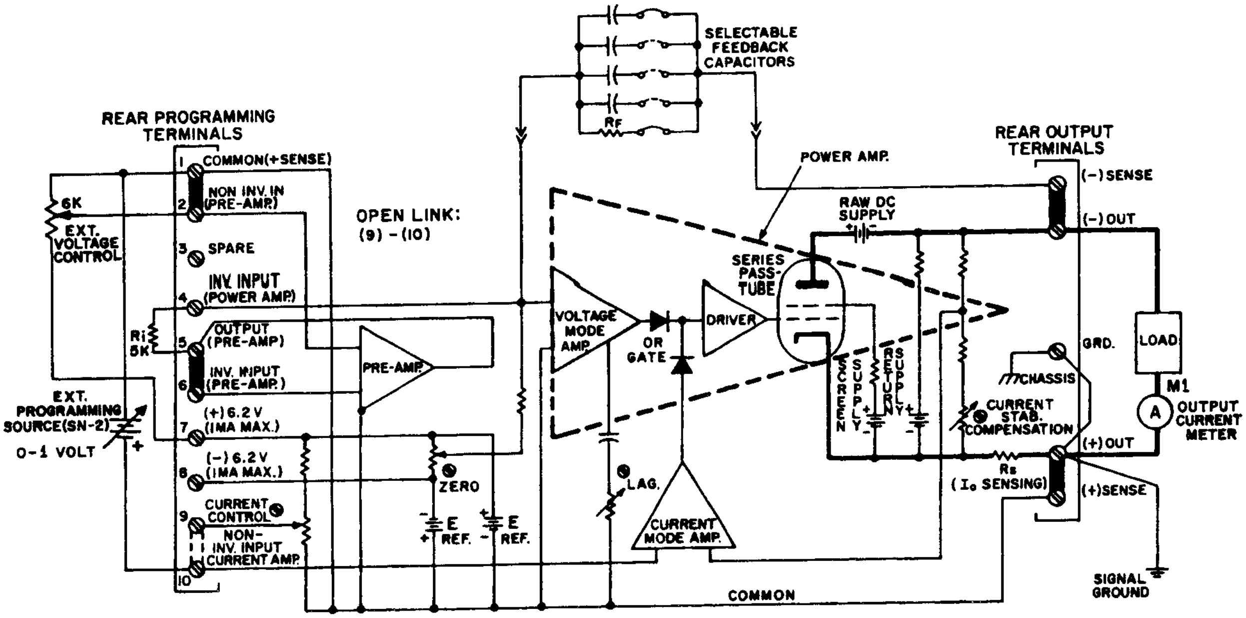


FIG. 3-14 CONNECTIONS FOR OUTPUT CURRENT CONTROL, USING AN EXTERNAL CONTROL VOLTAGE.

3-48 CURRENT CONTROL BY AN EXTERNAL CONTROL VOLTAGE, PROCEDURE (Refer to Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

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. 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. 3-14. The Kepco SN–2 is used as the EXTERNAL PROGRAMMING SOURCE, producing the control voltage between the "common" and the current amp input. The required compliance (output) voltage can be adjusted by the EXTERNAL VOLTAGE CONTROL potentiometer.

3) Refer to FIG. 3-14. Connect all external components as shown. Turn the Kepco SN–2 "on" and set to zero. Turn OPS "on." Set EXTERNAL VOLTAGE CONTROL to the required load compliance voltage.

4) Increase the programming voltage from the SN from "zero" to 1 volt. The OPS 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."

3-49 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 OPS 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.

3-50 OUTPUT CURRENT CONTROL (MICROAMPERE RANGE) USING THE VOLTAGE MODE AMPLIFIER

3-51 GENERAL. The internal shunt loads and the restrictions imposed by a single internal sensing resistor in the OPS current control circuit preclude the use of the CURRENT MODE AMPLIFIER for the control of output currents in the microampere range. For applications requiring stabilized output currents in this range, an operating mode using the VOLTAGE MODE AMPLIFIER can be chosen. Two basic control methods, suitable for output currents in the microampere range are described in the following paragraphs.

3-52 THE CONTROL OF SMALL OUTPUT CURRENTS, WITH THE LOAD IN THE FEEDBACK LOOP. In the first control method (see FIG. 3-15) the load is placed across the feedback terminals of the power amplifier section and must be completely "floating" (off ground).

This current control method is useful for applications where the load (compliance) voltage must be closely monitored. A precision voltmeter may be placed across the unused output terminals since these terminals repeat the voltage across the load at a low impedance. The built-in preamplifier of the OPS is used to repeat the control voltage, derived from the internal reference potential (see FIG. 3-15).

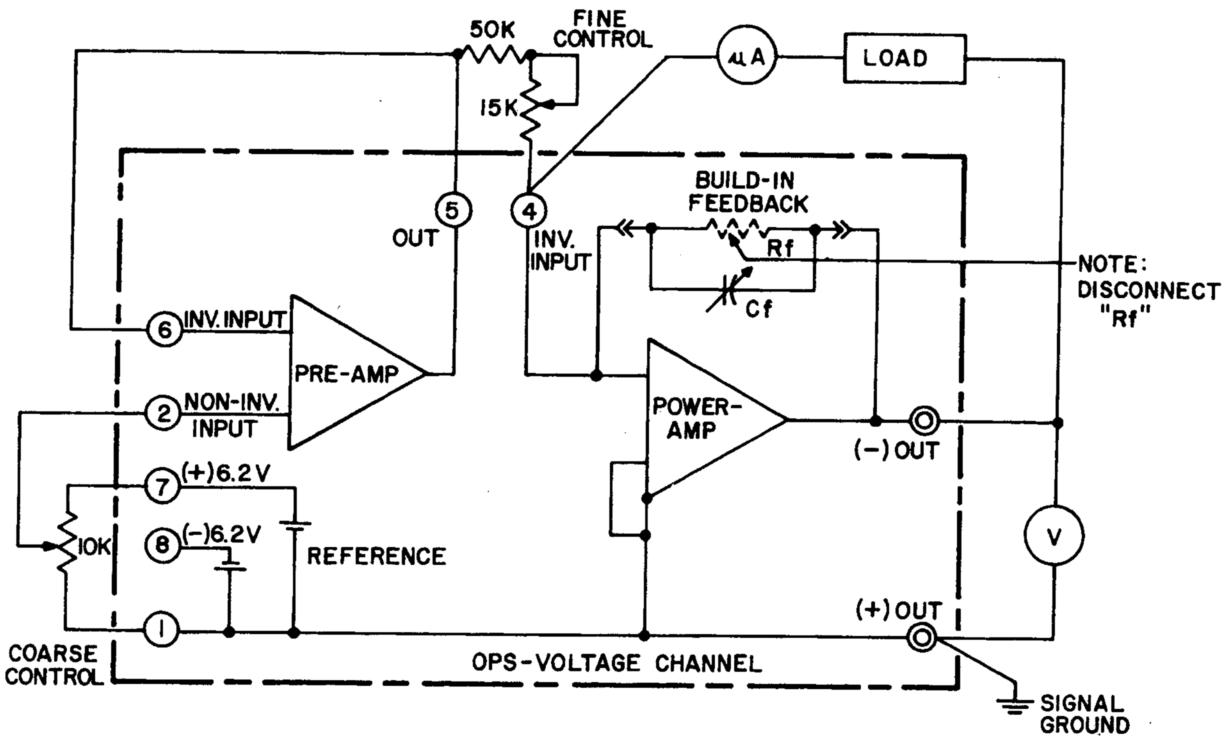


FIG. 3-15 EQUIVALENT DIAGRAM, OPS VOLTAGE CONTROL CHANNEL CONNECTED FOR THE CONTROL OF OUTPUT CURRENTS IN THE RANGE OF 0—100 μA.

3-53 OUTPUT EQUATION. The output equation for this control method is derived from the equivalent diagram (FIG. 3-15) and is given by:

At $\epsilon = 0$ and $I_{io} = 0$ (Amplifier input = 0):

$$I_o = \frac{E_{cc}}{R_c},$$

NOTE: The maximum output current (I_o) in this circuit is limited by the capability of the PRE-AMP (5 mA max.).

where: E_{cc} is the control voltage either applied externally, or derived from the internal reference voltage (E_r) and applied via the preamplifier. (See FIG. 3-15.)

R_c = Current Calibrating Resistor, consisting of a fixed and an adjustable component.

I_o = Output Current.

3-54 As seen from the output equation, the output current (I_o) varies linearly with the control voltage (E_{cc}) and inversely with variations in the value of the calibrating resistor (R_c). Either the control voltage, or the calibrating resistor can, therefore, be used to control the magnitude of the output current.

3-55 COMPONENT SELECTION. To summarize the material presented in the previous paragraphs (3-50 to 3-54) and to illustrate component selection, a sample application is described below and shown in FIG. 3-16.

3-56 An OPS is used to deliver stabilized output current from zero to 100 microamperes into a fixed load. The control voltage (E_{CC}) will be derived from a potentiometer across the internal reference source and applied via the preamplifier, operated as a voltage repeater. From the output equation, we have: $E_{CC}/I_O = R_C$, or $6.2V/100\,\mu A = 62$ k ohm for the maximum value of the calibrating resistor. With the potentiometer controlling E_{CC} serving as a "coarse control," a part of R_C may be made adjustable to serve as a calibrating control for the output current.

3-57 Connect all components as shown in FIG. 3-16. The leads going to the preamplifier and power amplifier inputs should be shielded for minimum noise pick-up. The shield must be connected (single-ended) to the signal ground point.

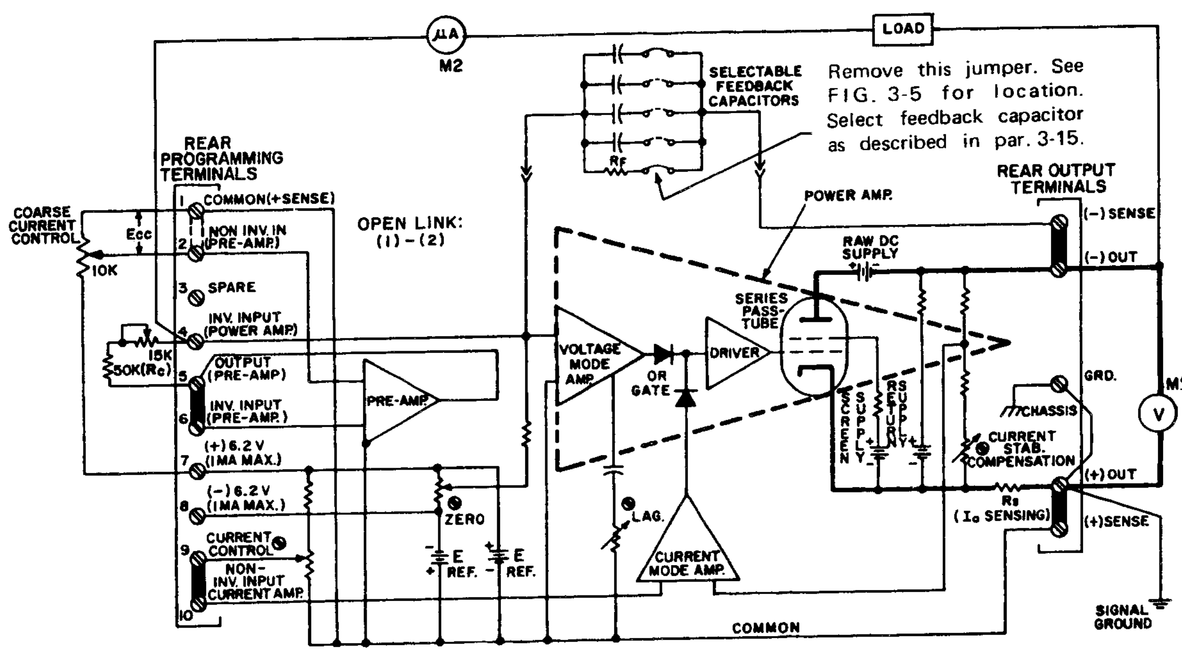


FIG. 3-16 EXTERNAL CONTROL OF THE OUTPUT CURRENT, USING THE VOLTAGE MODE AMPLIFIER. (LOAD COMMON TO THE (−) OUTPUT TERMINAL).

3-58 CALIBRATION (See Section II, FIG. 2-1 or FIG. 2-2 for the location of all calibrating controls)

a) Turn OPS "on" and allow circuit to reach thermal equilibrium.

b) Set the COARSE CURRENT CONTROL to the position of maximum output current.

c) Calibrate for exactly 100 μA by means of the CALIBRATING CONTROL (R_C).

d) Set the COARSE CURRENT CONTROL to the position of minimum output current. Calibrate for zero by means of the (internal) ZERO CONTROL.

e) Recheck maximum output current calibration by repeating (b) and (c).

3-59 OUTPUT MEASUREMENTS. Output effects may be measured with the microammeter in series with the load. (See FIG. 3-16.) With the current monitor (M2) in the position shown, a high voltage isolated measuring device is not needed and the output current measurements can be performed directly.

3-60 UNPROGRAMMED OUTPUT DEVIATIONS (RIPPLE AND NOISE). The output ripple may be observed across the voltage monitor (M1). The observed ripple voltage must be converted into current units by dividing the observed rms or p-p ripple voltage by the value of the load resistance.

3-61 EXTERNAL CURRENT SENSING AND VOLTAGE CONTROL

3-62 In this control method the load is operated close to the (+) output terminal (common), while the control source is located in the feedback loop. The control voltage must be a stabilized, positive-going d-c source, variable from zero to 10 volts (at about 100 μA) and it should have its own calibrating controls. The Kepco Model SN–2 Programmer, for example, has been used very successfully in this application. The SN can deliver a 0–10 volt input signal (manually selectable two decades) and can be addressed manually (with a Kepco MPG–2 keyboard) or by machine (parallel input, 10 lines).

3-63 The transfer function for output control by voltage is derived from FIG. 3-17 below and can be expressed by:

$I_O = E_{CC}/R_S$ (Eq. 3), where: I_O = Desired Maximum Output Current
E_{CC} = External Control Voltage
R_S = Current Sensing Resistor (See Note)

NOTE: This equation (Eq. 3) is derived from the equivalent diagram (FIG. 3-17), and is valid for the "zeroed" OPS. ***The range of the internal OPS ZERO control permits sensing resistor values up to approximately 50 k ohm.***

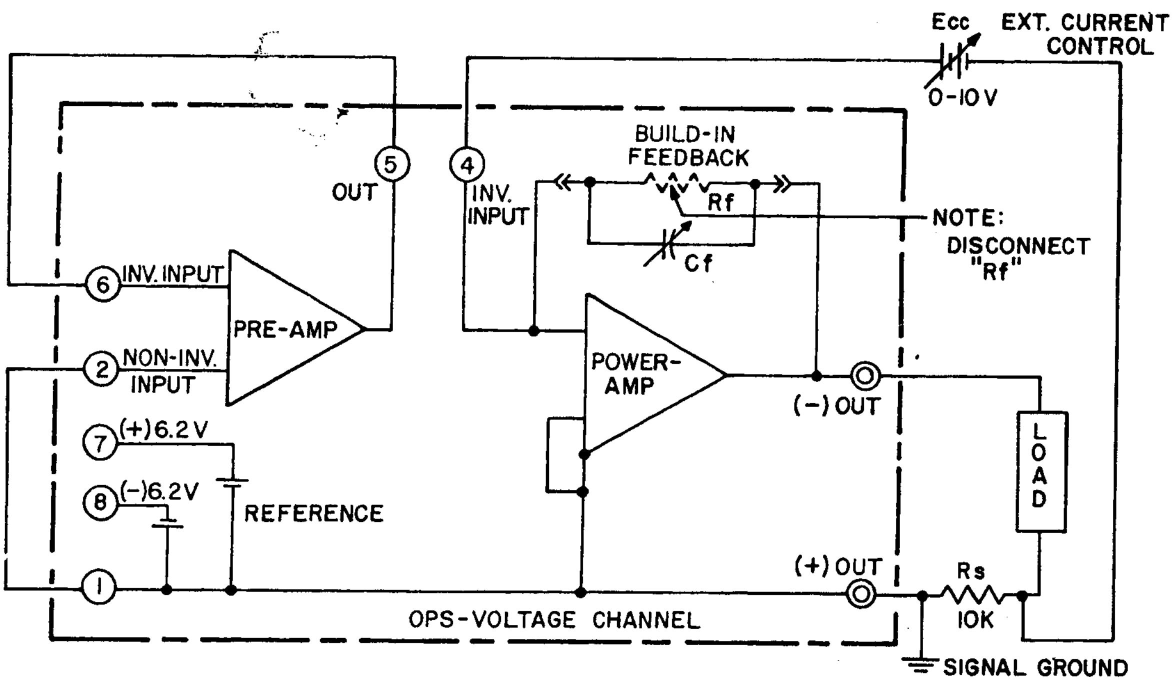


FIG. 3-17 EQUIVALENT DIAGRAM, OPS WITH EXTERNAL SENSING AND OUTPUT CURRENT CONTROL BY A CONTROL VOLTAGE.

3-64 The circuit shown in FIG. 3-17 is suitable for output current from the rated maximum output current down to 1 microampere. The necessary value for the sensing resistor (R_S) is given in FIG. 3-17 for a control voltage (E_{CC}) of 0–10 volts and an output current range of 0–1 milliampere. For other control voltages and/or output current ranges, R_S can be calculated using the output equation (Eq. 3).

3-65 The external control voltage (E_{CC}) may simply consist of a potentiometer across a mercury cell or it may be a controlled voltage source, such as the Kepco Model SN–2 (refer to par. 3-62). The voltage source (E_{CC}) must be stable, but its current capacity can be quite small (mircoampere range).

3-66 EXAMPLE I. An OPS model is used to deliver stabilized output current from 0 to 1 milliampere. The actual connecting pattern for the circuit with external sensing and voltage control is illustrated in FIG. 3-18. Connect all components as shown in FIG. 3-18, locating the sensing resistor as close as possible to the power supply. The leads connecting the control voltage (E_{CC}) must be shielded, with the shield (single-ended) connected to the common signal ground point. This ground point must be selected carefully to avoid possible ground-loop effects.

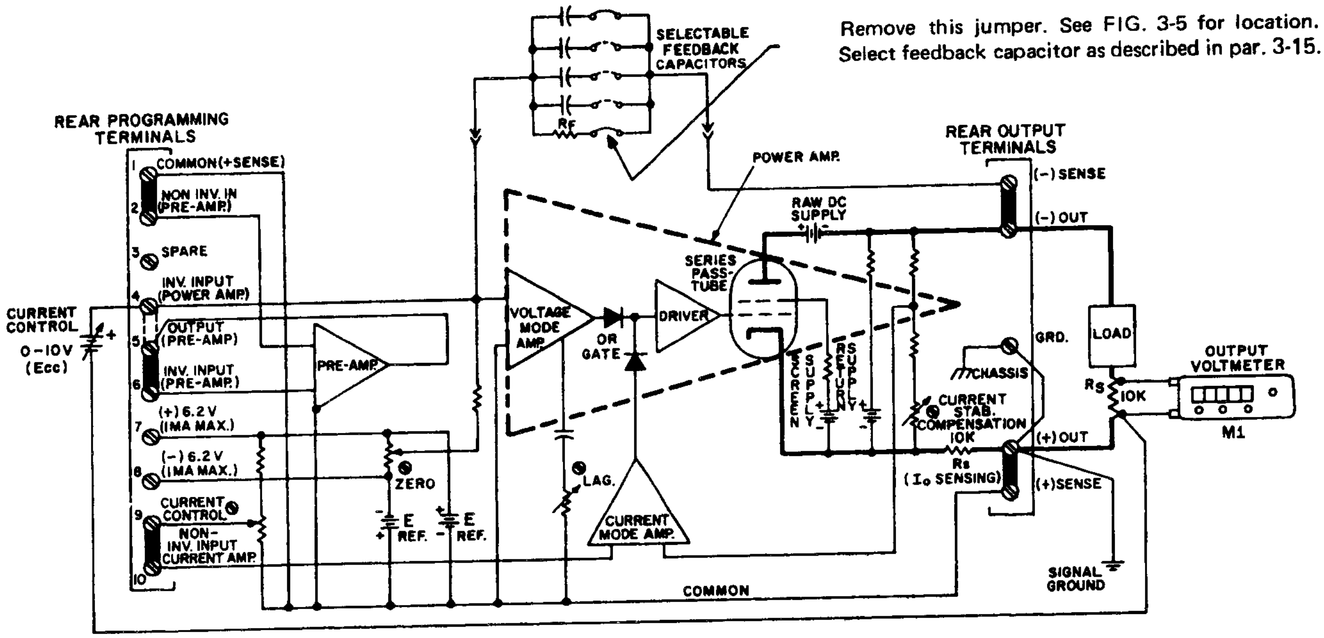


FIG. 3-18 EXTERNAL SENSING AND VOLTAGE CONTROL OF THE OUTPUT CURRENT (I_O SETTING RANGE = 0–1 mA).

3-67 CALIBRATING THE OUTPUT (See Section II, FIG. 2-1 or FIG. 2-2 for the location of all internal controls)

a) Turn OPS "on" and allow circuit to reach thermal equilibrium.

b) The maximum output current (I_O max) must be calibrated as the control voltage (E_{CC}).

c) Set E_{CC} to zero and calibrate for zero output current by means of the OPS ZERO control.

d) Recheck maximum output current calibration and correct by resetting E_{CC} if necessary.

3-68 OUTPUT MEASUREMENTS. Stabilization and ripple measurements may be performed by using the methods described in previous paragraphs (refer to pars. 3-59 to 3-60).