input current is 7.8 – 8. A.

KEPCO

BOP

BIPOLAR OPERATIONAL

POWER SUPPLY

Model BOP 15—20 (M)

Serial No. ....

INSTRUCTION MANUAL

The KEPCO equipment described in this instruction manual is of proprietary design, and is licensed under the United States patent rights of Forbro Design Corp.

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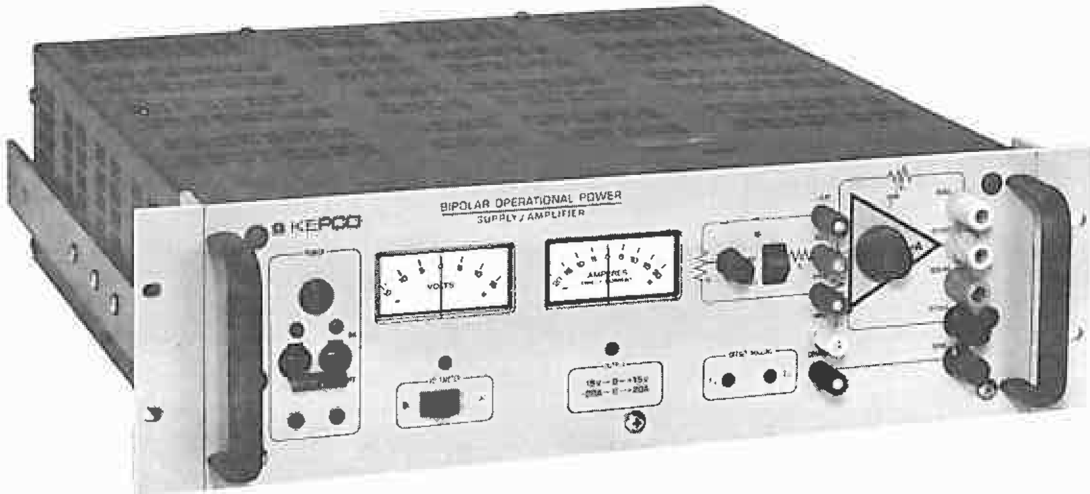


FIG. 1-1 TYPICAL FRONT VIEW, KEPCO BIPOLAR OPERATIONAL POWER SUPPLY.

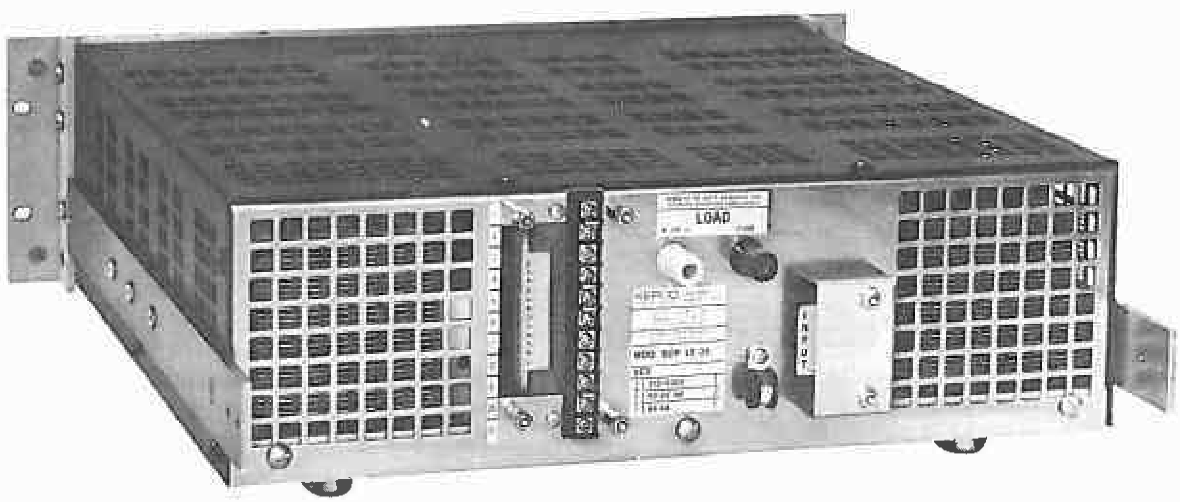


FIG. 1-2 TYPICAL REAR VIEW, KEPCO BIPOLAR OPERATIONAL POWER SUPPLY.

SECTION I — INTRODUCTION

1-1 SCOPE OF MANUAL

1-2 This manual contains instructions for the installation, operation and maintenance of the Kepco Model BOP 15—20M and Model BOP 15—20 Bipolar Operational Power Supplies.

1-3 INTRODUCTION

1-4 The Kepco Models BOP 15—20M and BOP 15—20 are similar in their electrical design, mechanical outline, and specifications except as described below. (Refer to FIG. 1-1.)

a) Model BOP 15—20M has an operational front panel with a-c circuit breaker and pilot light, recessed offset controls, carrying handles, output metering, input/output binding post terminals, and rheostats for the control of the gain and the d-c reference potentials. This model is intended to be operated as a laboratory "bench model."

b) Model BOP 15—20 front panels have only the a-c circuit breaker, a-c pilot light, and the recessed offset controls at the front panel.

1-5 Both models are equipped with identical rear barrier terminal strips which provide for all input and output connections. Both models are constructed in a "full rack" configuration for rack installation into a standard 19 inch rack.

1-6 All descriptions, instructions and drawings in this manual are applicable to both BOP models, unless they are identified by the specific model designations.

1-7 DESCRIPTION (Refer to FIGS. 1-1, 1-2.)

1-8 The Kepco Bipolar Operational Power Supply (BOP) is a dual purpose instrument capable of responding to a-c or d-c input signals of either polarity. Bipolar input and output are referred to the "common" terminal. The BOP may be represented as a d-c coupled power amplifier in the inverting configuration, delivering a NEGATIVE output for a POSITIVE input and vice versa.

1-9 The BOP is equipped with internal d-c reference sources, accessible at the rear barrier-strip (and on front panel binding posts on models with suffix "M") which deliver a nominal ±6.2 volts, 0—1 mA. This feature allows continuous d-c output control "through zero" by means of a potentiometer connection between the two reference sources and the NULL junction (built-in and labeled "REF." control in models with suffix "M"). The fixed parts of the amplifier offset voltage and offset current can be nulled by using the provided (recessed from the front panel) controls. Offset nulling is especially important if the BOP is used in precision programming by resistance, control voltages or currents.

1-10 An internal PROGRAMMING SPEED switch in the BOP allows transfer of the instrument to two operating modes. In the SLOW mode, the BOP is unconditionally stable for any feedback (including 100%) and any load reactance. The sinusoidal full power frequency response in this operating mode is 1 kHz. In the FAST mode, the BOP is stable for any feedback (including 100%). Load capacitance should be restricted to 0.001 microfarad. The sinsusoidal full power frequency response in this operating mode is approximately 25 kHz.

1-11 The BOP is rendered completely short-circuit proof by two individually adjustable current limit circuits protecting the NPN and PNP leg of the complementary output stage. The a-c input circuit is protected by a circuit breaker.

1-12 The main chassis of the Model BOP Operational Power Supply/Amplifier is constructed of plated steel. The wrap-around cover is perforated steel, plated and painted in a dark gray texture. The front panel material is aluminum, treated and painted light gray (Color 26440 per Fed. Std. 595). The major part of the circuitry is located on plug-in type circuit boards for convenient access.

1-13 SPECIFICATIONS, ELECTRICAL

a) A-C INPUT: 105 to 125V a-c or 210 to 250V a-c (selectable), 50 to 65 Hz, single phase. See Table 1-1 for a-c input current.

b) D-C OUTPUT RANGE: See Table 1-1.

MODEL	D-C OUTPUT RANGE VOLTS	D-C OUTPUT RANGE AMPS	CURRENT SINK	OUTPUT IMPEDANCE VOLTAGE MODE D-C OHMS + SERIES L	OUTPUT IMPEDANCE CURRENT MODE[1] D-C OHMS + SHUNT C	A-C INPUT CURRENT at 125V a-c
BOP 15—20	+15 to −15	+20 to −20	±4A	0.2 mΩ + 25 μH	1.75 kΩ + 10 μF	8A (rms)
BOP 15—20M	+15 to −15	+20 to −20	±4A	0.2 mΩ + 25 μH	1.75 kΩ + 10 μF	8A (rms)

(1) External current sensing using a 1-volt current sensing sample voltage.

TABLE 1-1 A-C INPUT/D-C OUTPUT.

c) RIPPLE AND NOISE: See Table 1-2.

d) OFFSET VOLTAGE AND CURRENT (E_{io}, I_{io}): Zero adjustments provided, accessible from the front panel. Variations of the offset parameters (ΔE_{io}, ΔI_{io}) are specified in Table 1-2.

INFLUENCE QUANTITY		AMPLIFIER OFFSETS VOLTAGE ΔE_{io}	AMPLIFIER OFFSETS CURRENT ΔI_{io}	REFERENCES 6.2V ±5%
SOURCE: 105—125/210-250V a-c		<0.1 mV	<10 nA	0.005%
LOAD: No load — full load		<1.0 mV	<10 nA	–
TIME: 8-hours (drift)		<0.1 mV	<50 nA	0.005%
TEMPERATURE: Per °C		<0.08 mV	<50 nA	0.005%
UNPROGRAMMED OUTPUT DEVIATION:(2) (Ripple and noise)	rms	<0.01% of E_o max or 3 mV(1)		
	p-p(3)	<0.05% of E_o max or 15 mV(1)		

(1) Whichever is greater.

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

(3) 20 Hz to 10 MHz.

TABLE 1-2 D-C SPECIFICATIONS.

NOTE: E_{io} is the offset voltage and I_{io} the offset current referred to the input of the voltage comparison amplifier. Refer to Section IV (Theory of Operation) for an extensive definition and an error analysis.

e) OPEN LOOP D-C GAIN: >35,000 V/V; Roll-off: −6 dB per octave.

f) CLOSED LOOP: Models with suffix "M" have built-in input resistor and precision gain control adjustable from zero to 10. With external components, closed-loop gain may be set as desired.

g) A-C STABILITY:

1) In "slow" mode (selectable by internal switch) device is unconditionally stable for any gain setting including 100% feedback and for any reactive load.

2) In "fast" mode (selectable by internal switch) device is stable for any gain setting including 100% feedback with capacitive loads up to 0.001 μF.

h) DYNAMICS: See Table 1-3.

SPECIFICATION	MODE	MODEL BOP 15–20(M)
SMALL SIGNAL FREQUENCY RESPONSE frequency at which the open loop gain becomes unity	FAST SLOW	300 kHz 10 kHz
LARGE SIGNAL FREQUENCY RESPONSE frequency at which the fully modulated, fully loaded output reaches 3% harmonic distortion	FAST SLOW	25 kHz 1 kHz
AMPLIFIER SLEWING RATE	FAST SLOW	2V/μsec. 0.1V/μsec.
PROGRAMMING TIME CONSTANT input/feedback set for gain=10	FAST SLOW	12 μsec. 500 μsec.
VOLTAGE RECOVERY TIME CONSTANT for step load current	FAST SLOW	50 μsec. 500 μsec.
CURRENT RECOVERY TIME CONSTANT for step load voltage	FAST SLOW	50 μsec. 1 m sec.

TABLE 1-3 DYNAMIC OUTPUT SPECIFICATIONS.

i) DISTORTION: (for 2 volt p-p output, no load) <0.5% harmonic.

j) COOLING: Forced air cooling by high efficiency, long-life fans.

k) REMOTE ERROR SENSING: Special terminals (available at front panel binding posts on models so equipped) and at the rear barrier-strip, permit the connection of the amplifier common and the feedback resistor directly to the load, thus maintaining a low d-c source resistance at the load terminals. Up to 0.5V d-c voltage drop per load lead (due to load current) can be compensated for by remote sensing.

l) OVERLOAD PROTECTION: Output is continuously protected for both polarities and in both operating modes against short circuits. Output current will limit at 21A as delivered and can be reset to lower values. (See Section V.)

m) AMBIENT OPERATING TEMPERATURE RANGE: -20°C to +65°C.

n) STORAGE TEMPERATURE: -40°C to +65°C.

o) ISOLATION VOLTAGE: ±500V (d-c or a-c peak) maximum may be connected from chassis to either output terminal.

p) INTERNAL REFERENCE SUPPLIES: Precision regulated zener sources of plus (+) and minus (−) 6.2 volts (nominal) are provided internally and terminated at the rear as well as on front panel binding posts (on models so equipped). The zener reference sources are temperature compensated and optimized for stability at a load current of 1 mA.

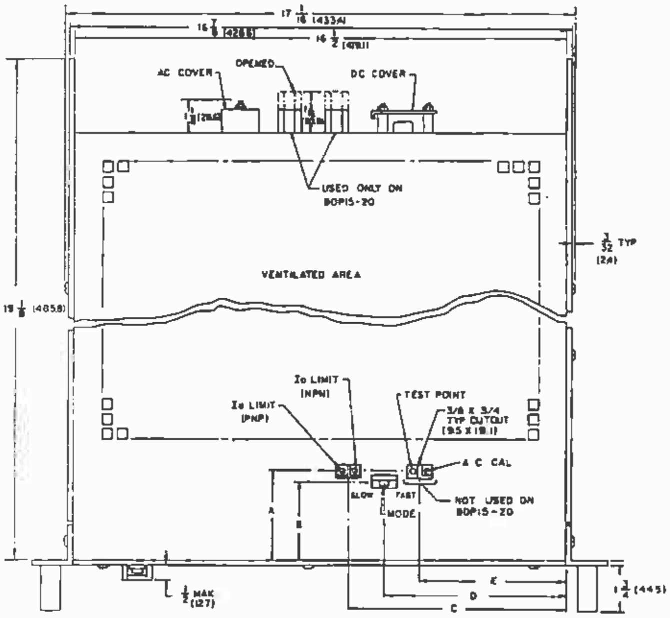
1-14 SPECIFICATIONS, PHYSICAL

a) METERS (Models with suffix "M" only.):

   1) Voltmeter, dual purpose moving coil type, ±1% FS, with selector switch to select the ranges: (−)15–0–(+)15 volts (d-c) and 0–15V (rms).

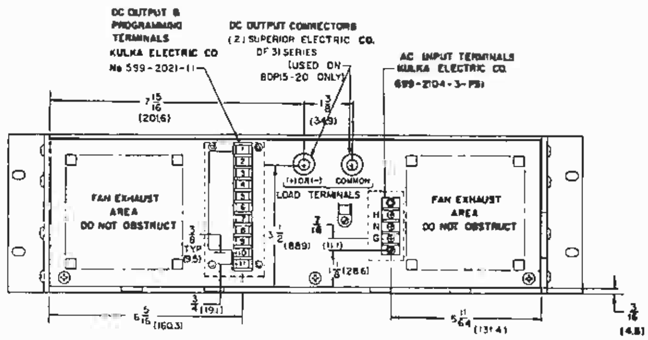
   2) Ammeter, moving coil type, ±1% FS, (−)20–0–(+)20 ampere d-c.

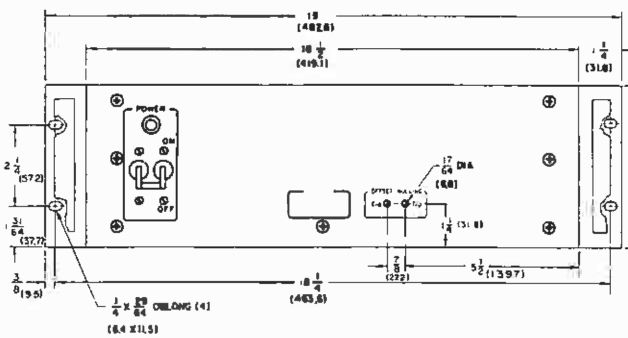
b) SIZE AND FINISH: Refer to "Mechanical Outline Drawing" (FIG. 1-3).

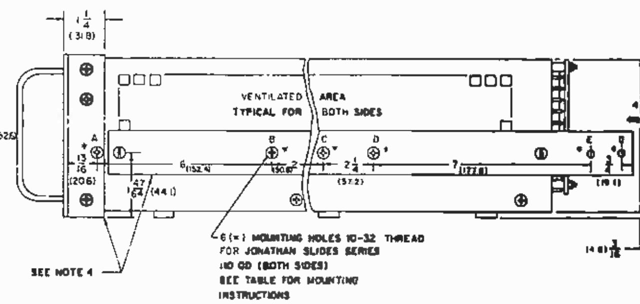


MODEL	A	B	C	D	E
BOP15-20	[illegible] (176.7)	5 11/16 (144.5)	6 23/32 (170.7)	5 11/16 (144.5)	NA
BOP72-15	[illegible] (173.0)	[illegible] (166.7)	7 (177.8)	5 15/16 (150.8)	4 3/4 (120.7)
BOP72-5	[illegible]	[illegible]	7 (177.8)	5 15/16 (150.8)	4 3/4 (120.7)

BOP72-15 AND BOP 72-5 REAR OUTPUT AND PROGRAMMING TERMINAL FUNCTIONS	BOP15-20 REAR OUTPUT AND PROGRAMMING TERMINAL FUNCTIONS
1 SENSING	1 SENSING
2 OUTPUT	2 OUTPUT MONITOR
3 GROUND	3 GROUND
4 OUTPUT COMMON	4 COMMON MONITOR
5 SENSING	5 SENSING
6 INPUT COMMON	6 NON INVERTING INPUT
7 INPUT	7 INVERTING INPUT (R_I = 4K)
8 (+) 6.2V (REFERENCE)	8 (+)6.2V (REFERENCE)
9 NULL JUNCTION	9 INVERTING INPUT (R_I = 0)
10 R_f	10 R_f
11 (-) 6.2V (REFERENCE)	11 (-) 6.2V (REFERENCE)

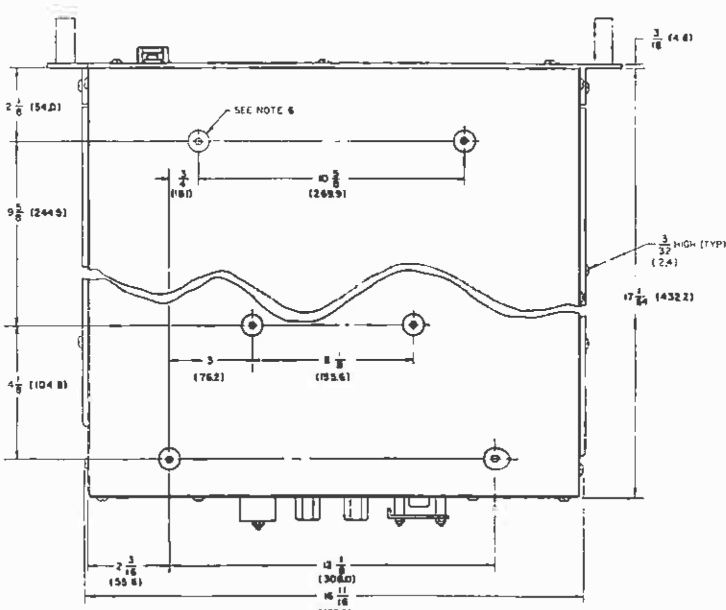






MOUNTING TABLE						
SLIDE TYPE	USE MOUNTING HOLES					
	A	B	C	D	E	G
110 QD 20-2	X	X	NOT USED	X	NOT USED	X
110 QD-22-2	X	NOT USED	X	NOT USED	NOT USED	X
110 QD-24-2	X	NOT USED	X	NOT USED	X	NOT USED

*"G" HOLE HAS TO BE ADDED TO SLIDES # 110 QD-22-2 .199 DIA 18' FROM 'A' HOLE



NOTES

1. THIS DRAWING USED FOR MODELS BOP15-20, BOP72-15 AND BOP72-5
2. MATERIAL A) CHASSIS # 11 GA C R S (BOP72-15 CHASSIS @ #14 GA C R S
   B) FRONT PANEL 3/16 THICK AL
   C) COVER #16 GA C R S
3. FINISH A) CHASSIS CADMIUM PLATE WITH A CHROMATE WASH
   B) FRONT PANEL LIGHT GRAY PER FEDERAL STD 595, COLOR # 26440
   C) COVER CHARCOAL GRAY VINYL TEXTURE
4. FIXED ANGLE BRACKETS AND CHASSIS SLIDES SUPPORT BARS (BOTH SIDES) USED FOR RACK OR CABINET INSTALLATION
5. IF INSTALLATION WITHOUT SLIDES IS DESIRED, THE UNIT MUST BE SUPPORTED BY A RIGID PLATFORM, OR BY FIXED BRACKET MOUNTED IN THE RACK SLIDES AND RIGID PLATFORM NOT SUPPLIED
6. (6) PLASTIC MOUNTING INSERTS, FOR 1/4-20 THREAD CUTTING SCREWS, 5/8 LONG (WITH 1/8 THICK MOUNTING PLATE)
7. DIMENSIONS IN PARENTHESES ARE IN MILLIMETERS.
8. TOLERANCES A) BETWEEN MOUNTING HOLES ± 1/64 INCH (±0.4 MILLIMETER)
   B) ALL FRONT PANEL DIMENSIONS SEE MIL STD 189.
   C) ALL OTHER DIMENSIONS ± 1/32 INCH (±0.8 MILLIMETER)

FIG. 1-3 MECHANICAL OUTLINE DRAWING

SECTION II — INSTALLATION

2-1 UNPACKING AND INSPECTION

2-2 This instrument has been thoroughly tested and inspected prior to packing. After careful unpacking, inspect for shipping damage before attempting operation. Perform the preliminary operational check as outlined in paragraph 2-18 below. If any indication of damage is found, file immediately a claim with the responsible transport service.

2-3 TERMINATIONS AND CONTROLS

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

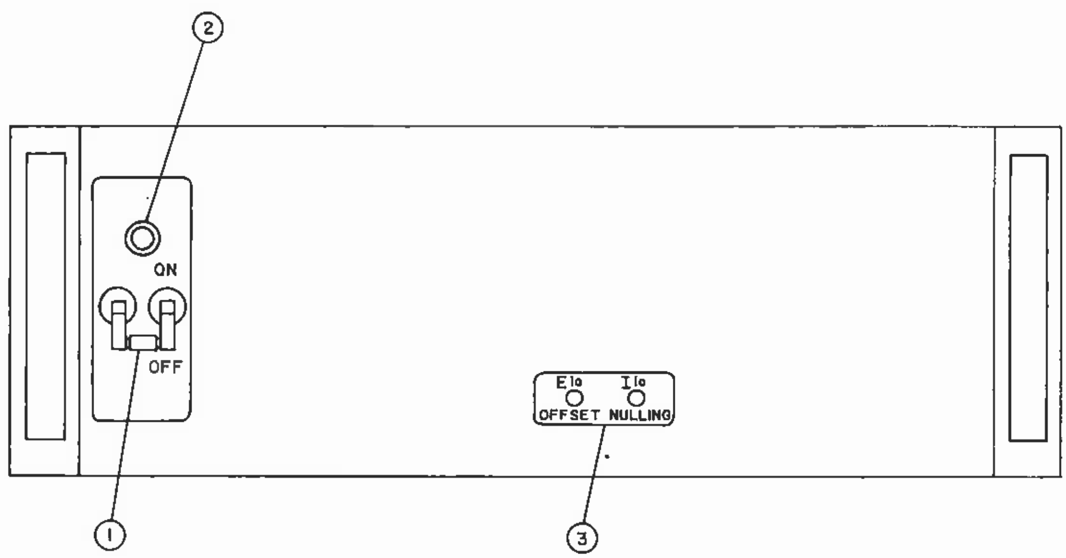


FIG. 2-1 FRONT TERMINALS AND CONTROLS.

NO.	DESCRIPTION OF TERMINATION
1	A-C INPUT POWER SWITCH AND CIRCUIT BREAKER
2	A-C INPUT POWER INDICATOR LIGHT
3	OFFSET NULLING CONTROLS (RECESSED)

TABLE 2-1 FRONT PANEL CONTROLS AND TERMINATIONS.

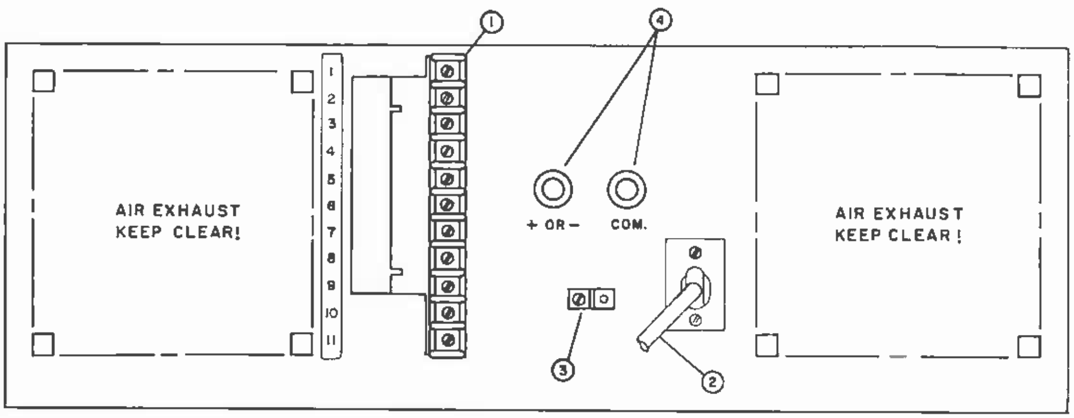


FIG. 2-2 REAR TERMINALS

NO.		DESCRIPTION OF TERMINATION
1		REAR BARRIER-STRIP (TB1301), TERMINAL FUNCTIONS ARE:
	1	PLUS (+) OR MINUS (−) MONITOR (2) AND SENSING (1) LINKED AT FRONT*
	2	OR REAR, OR CONNECTED AT THE LOAD (REMOTE SENSING)
	3	CHASSIS CONNECTION; RETURN TO A-C GROUND
	4	COMMON MONITOR (4) AND SENSING (5), LINKED AT FRONT* OR
	5	CONNECTED AT THE LOAD (REMOTE SENSING)
	6	NONINVERTING INPUT, LINK-CONNECTED TO SENSING COMMON (5)
	7	INVERTING INPUT FOR 0–10 GAIN WITH BUILT-IN GAIN CONTROL (R_i = 4 K ohm)
	8	PLUS (+) REFERENCE (+6.2V NOM., REFERRED TO COMMON)
	9	NULL JUNCTION. (INVERTING) INPUT TO AMPLIFIER
	10	R_f GAIN CONTROL LINKED TO NULL (9)
	11	MINUS (−) REFERENCE (−6.2V NOM., REFERRED TO COMMON)
2		A-C POWER INPUT CORD* OR INPUT REAR BARRIER-STRIP
3		SPARE SHORTING LINKS*
4		HEAVY DUTY LOAD TERMINALS

*Models with suffix "M" only.

TABLE 2-2 REAR TERMINALS.

c) INTERNAL ADJUSTMENTS. Refer to FIG. 2-3 and Table 2-3.

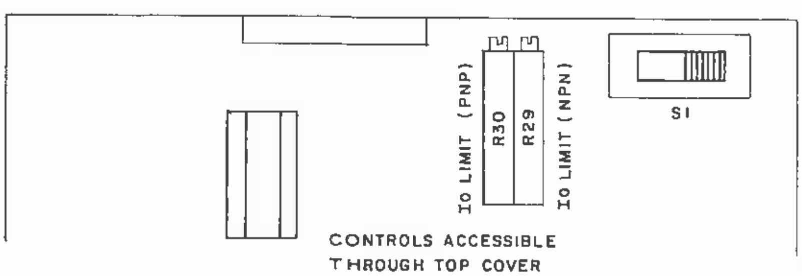


FIG. 2-3 LOCATION OF INTERNAL CONTROLS

REFERENCE DESIGNATION	ADJUSTMENT	PURPOSE	ADJUSTMENT PROCEDURE
R29	I_o Limit (NPN)	Output Current Limit Adjustment	Par. 5-7
R30	I_o Limit (PNP)	Output Current Limit Adjustment	Par. 5-7
R503	E_{io} Null*	Offset Voltage Zero Adjustment	Par. 3-15
R504	I_{io} Null*	Offset Voltage Zero Adjustment	Par. 3-15
S1	Mode Switch	Slow/Fast Operating Mode	

*The Offset Zero Adjustments (E_{io} Null, I_{io} Null) are (recessed) front panel controls.

TABLE 2-3 INTERNAL ADJUSTMENTS.

2-4 A-C INPUT SOURCE REQUIREMENTS

2-5 The BOP Power Supply/Amplifier is normally delivered for operation on a single phase, 105 to 125 volts a-c input source, 50 to 65 Hz. For operation on 210 to 250 volts a-c input, the jumper connections on the main transformer (T201) must be changed as described below.

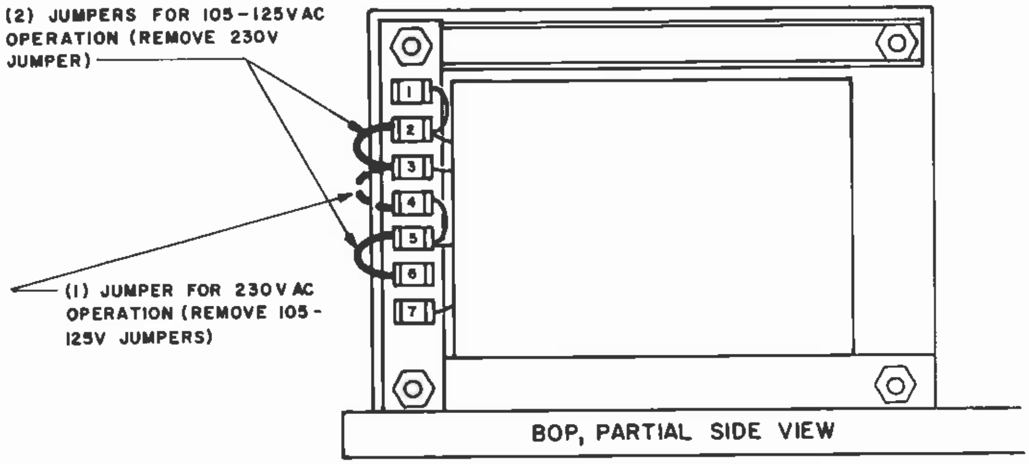


FIG. 2-4 MAIN TRANSFORMER PRIMARY CONNECTIONS

2-6 PROCEDURE (Refer to FIG. 2-4.)

a) Disconnect the BOP from the a-c input source.

b) Remove cover and rear chassis bracket.

c) Unsolder and remove the bare wire jumpers between transformer terminals (2) — (3) and (5) — (6).

d) Connect and solder new jumper between transformer terminals (3) — (4).

2-7 GROUNDING

WARNING

2-8 A-C SAFETY GROUND. This instrument is either equipped with a three-wire safety line cord and a polarized plug (metered models, suffix "M") or a three-terminal barrier-strip for a-c power input. THE POLARIZED PLUG ON THE METERED MODELS MUST BE CONNECTED TO A GROUNDED A-C POWER OUTLET, AND THE GROUND TERMINAL (G) ON THE UNMETERED MODELS MUST BE RETURNED TO A-C GROUND TO ASSURE OPERATOR SAFETY.

2-9 SIGNAL GROUND. The output of this instrument has no d-c connection to the a-c power source or the chassis. An internal signal ground is provided consisting of a resistor/capacitor combination (R501, C502) connected from the COMMON OUTPUT to ground. If an external signal ground is desired, the internal ground may be opened by removing the capacitor from the printed circuit board (A5, see FIG. 6-3 for location).

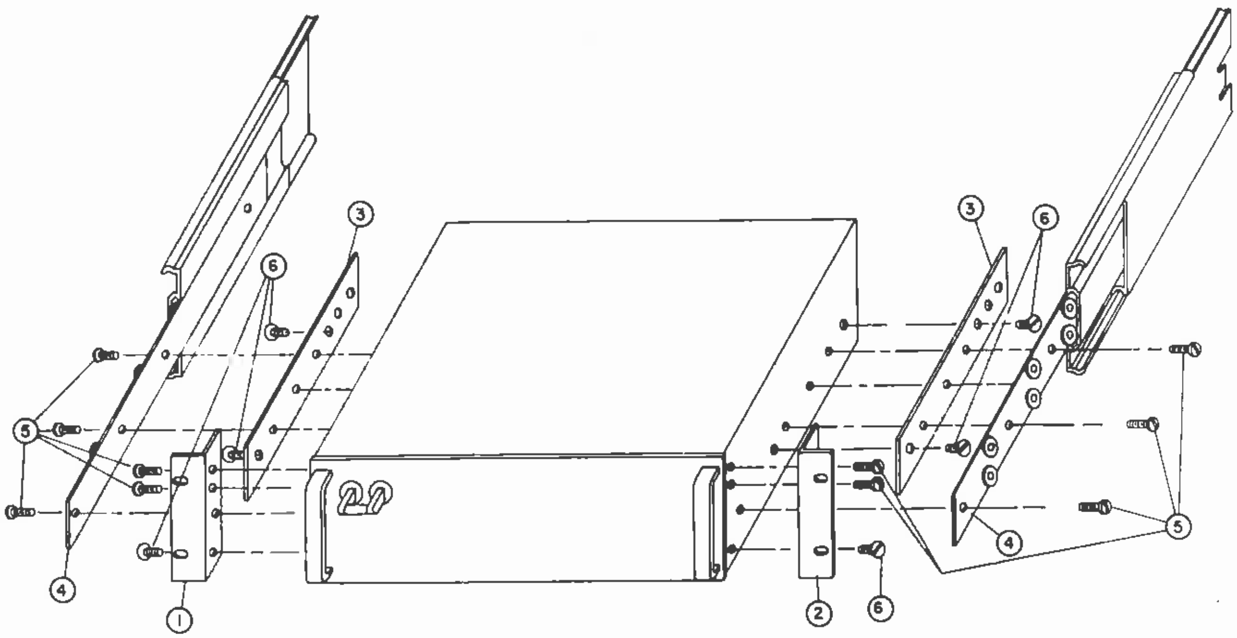
2-10 ISOLATION

2-11 All output and input terminals on the BOP are (d-c) isolated from the a-c power input source and from the chassis. Either output terminal may therefore be grounded or a maximum of 500 volts (d-c or peak) may be connected between the chassis and either output terminal. The common-mode current from either output terminal to ground is less than 5 μA (rms) or 50 μA peak-to-peak at 115V a-c, 60 Hz.

2-12 INSTALLATION

2-13 METERED MODELS (SUFFIX "M"). The BOP may be operated as a bench instrument or with the assistance of the provided mounting brackets, it may be installed into any standard 19 inch rack. Please refer to paragraph 2-15 (Cooling) if the instrument is to be mounted into a multiple-unit rack installation. Instructions for rack-mounting are provided. (See FIG. 2-5.)

2-14 UNMETERED MODELS (NO SUFFIX). The unmetered instruments are constructed in modular form for direct chassis mounting into systems installations. For mounting-hole dimensions and layout, see "Mechanical Outline Drawing" (FIG. 1-3). Please refer to paragraph 2-15 if the instrument must be installed into confined spaces.



RACK MOUNTING ACCESSORIES, PARTS LIST		
ITEM	DESCRIPTION	QTY.
1	FRONT ANGLE LEFT	1
2	FRONT ANGLE RIGHT	1
3	FILLER BRACKET	2
4	SLIDES: 110 QD JONATHAN SERIES	2
5	10–32 SCR BDG. HD.	10
6	10–32 FLATHEAD 82°	6

NOTE: ITEM (4) NOT SUPPLIED.

INSTRUCTIONS FOR SLIDE INSTALLATION

1) Items 1, 2, 3 are installed at the factory.
2) Item 3 (filler bracket) is predrilled and tapped for Jonathan Slides, Series 110 QD. Remove the three binding head screws on each side of Item 3. (These screws are part of Item 5.)
3) Line up slide with filler bracket and reinsert the binding head screws through the appropriate mounting holes in the slide.
4) If Jonathan Slide 110 QD–24–1 is used, an additional hole must be drilled into the slide. See FIG. 1-3 for further information.

FIG. 2-5 RACK INSTALLATION, "FULL RACK" MODELS.

NOTE: If slide installation (as described above) is not desired, other means of supporting the unit in the rear must be provided (additional rear brackets or a solid platform, for example) since the front angle brackets (Items 1, 2) alone are not sufficient to support the full weight of the unit.

2-15 COOLING

2-16 The power transistors in the BOP are located on highly efficient heat sinks and cooled by forced air. SIDES, REAR AND TOP OF COVER MUST BE FREE FROM OBSTRUCTIONS SO THAT FREE AIR CIRCULATION IS NOT IMPEDED. Periodic cleaning of the interior of the instrument is recommended. If the instrument is rack mounted or installed into confined spaces, care must be taken that the temperature immediately surrounding the instrument does not rise above the specified limit (+65°C).

2-17 PRELIMINARY ELECTRICAL CHECK

2-18 A simple electrical checkout after unpacking and before permanent installation is advisable to ascertain whether the instrument has suffered damage during shipment. Refer to FIGS. 2-1, 2-2 and Tables 2-1, 2-2 for the identification and location of all controls and terminations. The nomenclature used will be followed throughout this manual. Controls and terminations pertaining to the BOP will be capitalized throughout the text.

a) METERED BOP MODELS (SUFFIX "M")

1) CIRCUIT BREAKER/POWER SWITCH "off." Connect the BOP to the 115V a-c input power source or check paragraph 2-4 for conversion to 230V a-c operation if desired.

2) CIRCUIT BREAKER/POWER SWITCH "on." The red a-c pilot lamp should be energized. With the "REF." switch in the "IN" position and the "REF." control fully clockwise, unlock the GAIN control by turning the rear knob fully counterclockwise. The GAIN control is a high resolution vernier potentiometer connected as a rheostat and acting as a "coarse/fine" gain adjustment. Slowly turn the GAIN control clockwise. Observe the panel VOLTMETER. (SELECTOR SWITCH should be in the d-c position.) The output voltage should vary smoothly from zero to (positive) full scale as the GAIN control is varied through its complete range.

3) Repeat check with the "REF." control counterclockwise. Output voltage should vary from zero to the rated negative value as the GAIN control is turned through its complete range.

4) Check AMPERE METER action by loading the BOP with an appropriate resistor load ($R_L = E_{o\,max}/I_{o\,max.}$) connected across the OUTPUT terminals. As the GAIN control is varied through its complete range with the "REF." control first fully counterclockwise, then clockwise, the output current should smoothly vary from the rated maximum negative value to the rated maximum positive value. This concludes the preliminary check for metered BOP models.

b) UNMETERED BOP MODELS (NO SUFFIX)

1) CIRCUIT BREAKER/POWER SWITCH "off." Connect a 1 K ohm potentiometer ("REF." control), a temporary feedback resistor (R_f = 40 K ohms) the external metering and the load to the BOP rear terminals as shown in FIG. 2-6 below. Disconnect ballast resistor R505 (located on A5, see FIG. 6-3). This resistor is mounted on turret lugs for convenient access. It may be removed completely if an external "REF." control is used permanently.

2) CIRCUIT BREAKER/POWER SWITCH "off." Connect the BOP to the 115V a-c input power source or check paragraph 2-4 for conversion to 230V a-c if desired.

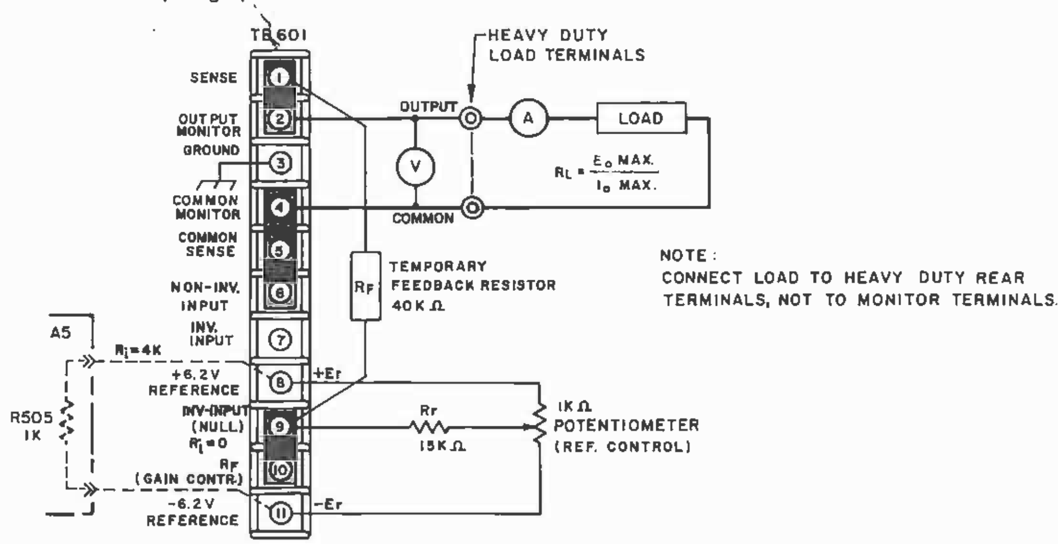


FIG. 2-6 TEST SETUP FOR PRELIMINARY CHECK ON UNMETERED BOP MODELS

3) CIRCUIT BREAKER/POWER SWITCH "on." Observe output metering while varying the external "REF." control. The output (voltage and current) should vary smoothly from the maximum rated negative values through zero, to the maximum rated positive values as the "REF." control is varied through its complete range. THE METER CONNECTIONS MUST BE REVERSED AS THE BOP OUTPUT CHANGES POLARITY. This concludes the preliminary check for unmetered BOP models.

4) IMPORTANT NOTE:

If output effects due to time (drift) or due to temperature (temperature coefficient) are to be measured, the temporary feedback resistor and the external "REF." potentiometer must be replaced by high quality components having temperature coefficients of 20 parts per million or less.

5) An alternate method of output control may be performed by replacing the fixed temporary feedback resistor by a variable GAIN control while the "REF." control potentiometer is left at a fixed position. The external GAIN control (40 K ohm potentiometer connected as a rheostat) is connected in place of the fixed feedback resistor between rear terminals (1) and (9). The external GAIN control will now control the output from zero to a value given by the position of the "REF." control. If the wiper "REF." control potentiometer is set completely towards the positive reference voltage (+6.2V, terminal 8), the maximum output will be the rated negative value, for example.

NOTE: THE CIRCUIT BREAKER ON THIS OPERATIONAL POWER SUPPLY CANNOT BE REACTIVATED IMMEDIATELY AFTER IT HAS BEEN TRIPPED. A TIME DELAY OF APPROXIMATELY TWO SECONDS IS INTRODUCED BY A PROTECTIVE CIRCUIT. THIS PROTECTIVE CIRCUIT ALLOWS DISCHARGE OF THE MAIN FILTER CAPACITORS, THUS PREVENTING LARGE SURGE VOLTAGES IN CASE OF REPEATED TURN-ON CYCLES.

SECTION III – OPERATION

3-1 D-C OUTPUT, LOCAL CONTROL

3-2 GENERAL. Kepco Bipolar Operational Power Supplies (BOP) can be locally controlled either by means of built-in front panel controls (models with suffix "M" only) or with external controls connected to the rear barrier-strip (all models). Two basic methods of locally controlling the d-c output voltage have been briefly described in the previous section. (See "Preliminary Electrical Check," par. 2-17.) These two methods may be used separately or combined. If the "REF." control is set either fully clockwise or counterclockwise (by means of the internal or external potentiometer), a negative or positive control current (I_b) of approximately 0.4 mA is produced. (Refer to Section II, FIG. 2-6)

$$E_r/R_r = I_b \text{ or } 6V/15\text{ K} \approx 0.4\text{ mA} \qquad \text{(Eq. 1)}$$

The output voltage can now be linearly controlled by means of the built-in GAIN control (models with suffix "M") or the externally connected feedback resistor (R_f) if the latter is changed to a rheostat The (simplified) transfer function governing this method of control can be expressed by:

$$E_o = (E_r/R_r)\, R_f \qquad \text{(Eq. 2)}$$

Combining equations (1) and (2), we have:

$$E_o = I_b(R_f) \qquad \text{(Eq. 3) where.}$$

E_o = Output Voltage
E_r = Reference Voltage
R_f = Gain Control (Feedback Resistor)
R_r = Reference Resistor
I_b = Control Current

3-3 Referring to Eq. 3, both control methods become obvious With I_b a fixed 0.4 mA, the output voltage becomes a linear function of the internal or external setting of the GAIN control (R_f). Alternately, if the GAIN control is left in any fixed position and the "REF." control is varied, the output voltage becomes a function of the control current I_b. The control current is determined by the setting of the "REF." control which is connected between the ± 6.2 volt reference voltages. Since the reference resistor (R_r) is connected in series with the wiper of the "REF." potentiometer, the control current (I_b) can be selected between the values of −0.4 mA and +0.4 mA Output voltage control from the maximum rated negative to the maximum rated postive value (continuous through zero) is therefore possible with this method. If, for example, a BOP 15–20 is to be controlled as described above, the output voltage at any setting can be expressed by.

$$\pm E_o = \pm E_r \left[\frac{R_f}{R_r}\right], \text{ or}$$

$$\pm 15V \approx \pm (0 \text{ to } 6V) \left[\frac{0 \text{ to } 40 \text{ K ohms}}{15 \text{ K ohms}}\right]$$

3-4 While output voltage control by means of the GAIN control is linear from zero to either a negative or positive end value (depending upon the polarity of the control current), continuous control, through zero, by means of the "REF." control is inherently somewhat nonlinear (≈20%) due to the flow of current through the potentiometer ("REF." control).

3-5 LOAD CONNECTION. BOP models with functional front panels (models with suffix "M") have the links between output and error sensing terminals connected at the front panel binding posts. (See FIG. 3-1.) A pair of "spare links" are provided for these models at the rear (See FIG. 3-2) for the case where the load is to be connected at the rear. In the latter case, the front links must be removed and the rear links connected as shown. BOP models without functional front panel (no suffix) have the links connected at the rear as shown. (See FIG. 3-2)

3-6 The load may be connected to the heavy duty output terminals at the rear or at the front panel binding posts. (See FIGS. 3-1, 3-3, 3-4.) Load wires should be of the largest practicable diameter to reduce voltage drops due to load current and to keep the output impedance as low as possible. If specified d-c performance directly at the load is required, remote error sensing must be used as described below.

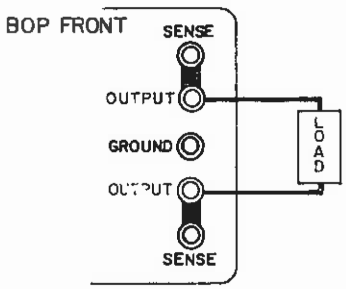


FIG. 3-1 LOAD CONNECTION, FRONT PANEL (without error sensing).

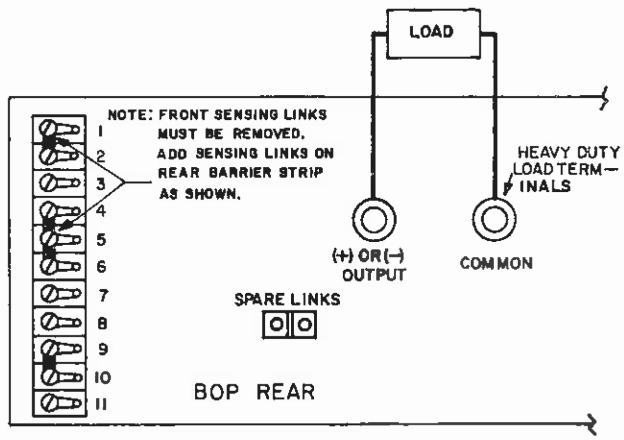


FIG. 3-2 LOAD CONNECTION, REAR (without error sensing).

3-7 REMOTE ERROR SENSING. For applications requiring specified d-c performance directly at the load, remote error sensing may be used to compensate for voltage drops along the load connecting wires. Up to 0.5V per load lead can be corrected. Error sensing may be used either from the front binding posts or at the rear barrier-strip. In the latter case, the front links between output and sensing terminals must be removed. (Refer to FIGS. 3-3, 3-4.)

NOTE: If error sensing is NOT used, links must be used either on rear barrier-strip or at the front.

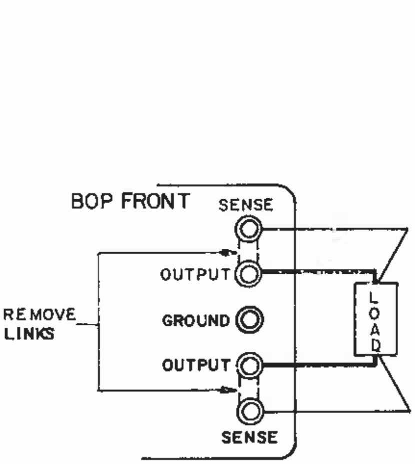


FIG. 3-3 LOAD CONNECTION, FRONT PANEL (with error sensing)

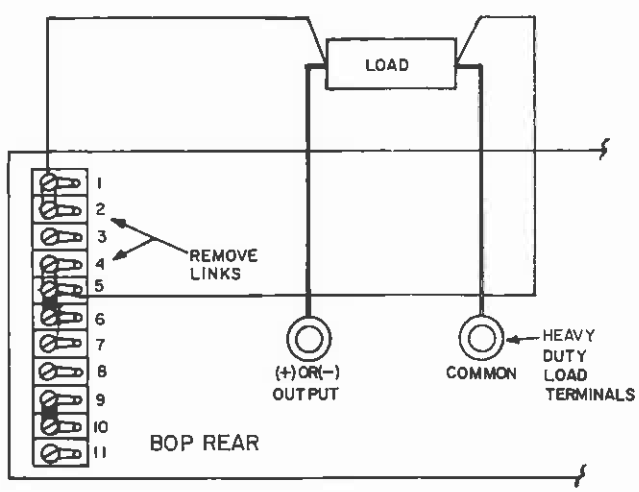


FIG. 3-4 LOAD CONNECTION, REAR (with error sensing).

3-8 INTRODUCTION TO REMOTE PROGRAMMING

3-9 GENERAL. The following paragraphs contain a sampling of possible applications of the BOP Operational Power Supply/Amplifier. The scope of this manual allows for the discussion of only a few of the almost unlimited number of operational circuits. The reader is referred to Section IV (Theory of Operation) for a short review of operational theory and to the available literature on operational amplifiers. For an extended treatment of power supply programming, please refer to the current Kepco literature, available from your Kepco Representative or directly from.

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Flushing, New York 11352

3-10 DIAGRAMS. The operating and test setup diagrams in this section represent ALL BOP models. The diagrams are simplified, symbolic illustrations of the BOP Operational Power Supply. Encircled, numbered terminals are rear barrier-strip connections (part of ALL BOP models) while the nomenclature on all terminals coincides with the front panel labeling on those models which carry the suffix "M." The GAIN control, the "REF." switch, the "REF." control and the reference resistor (R_r = 15 K ohm), although shown in all diagrams, are only part of the models with functional front panels (suffix "M"). These components can be added on models without functional front panel (without suffix "M") if the applications so require.

3-11 GROUNDING. Excessive ripple (line frequency "pickup") at the output is often due to improper or multiple grounding (ground loop). All remote programming or amplifier systems must have a single ground point only to which all shields, equipment cases and the COMMON input/output lead should be connected. (See also pars. 2-7 and 2-9.)

3-12 EXTERNAL PROGRAMMING COMPONENTS

a) RESISTORS. Resistors for external programming should be high quality, wirewound units with temperature coefficients of 20 parts per million or better. Their wattage rating should be at least 10 times the quiescent power dissipation. (Although the control current flowing through these resistors is normally quite low, large energy peaks may occur when programming voltage step functions.)

b) INPUT SOURCES. External programming sources should have stability specifications equal to or better than the BOP.

c) EXTERNAL SWITCHES. If step switch devices are used in resistance programming, they must be of the "make before break" variety to avoid opening the feedback loop.

d) EXTERNAL LEADS. Shielded leads should be used for all external connections, except for load wires, which should be of the heaviest diameter practicable and twisted, to reduce inductance. (Excessive load wire inductance adds to the power supply impedance and may cause deterioration of transient response.) Load capacity, see bandwidth specifications, paragraph 1-13.

3-13 PRELIMINARY ADJUSTMENTS

3-14 The initial offsets (E_{io}, I_{io}) of the amplifier are carefully zeroed at the factory at 25°C and after 30 minute warmup. Built-in trim rheostats accessible through front panel openings and appropriately labeled are provided for readjustment after component replacement or at other operating temperatures. For applications requiring high programming accuracy, the procedures described below should always precede actual operation.

3-15 PROCEDURE, OFFSET ZEROING

a) EQUIPMENT REQUIRED:

1) Sensitive Null Detector, MILLIVAC MODEL MV-07A or equivalent, or oscilliscope, TEKTRONIX MODEL 502 A (M1).

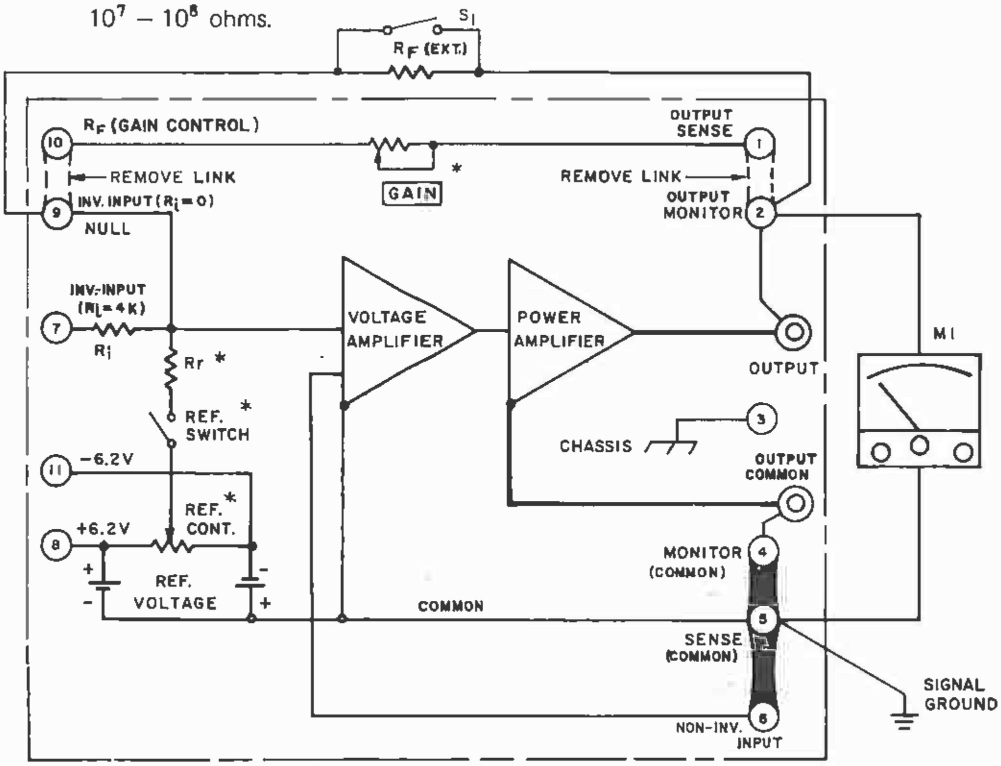
2) Switch, SPST (S1).

3) Resistance Decade Box (megohm range) or single resistor (R_f).

b) OFFSET VOLTAGE ZERO ADJUST (Refer to FIG. 3-5):
Close S1. Locate OFFSET VOLTAGE NULLING adjustment (marked E_{io}) at the front panel. Adjust control until null detector (M1) reads precisely zero. The adjustment may shift slightly as the BOP amplifier (and the null detector) reach thermal equilibrium. Repeat adjustment as necessary.

c) OFFSET CURRENT ZERO ADJUST (Refer to FIG. 3-5):
Open S1. Locate OFFSET CURRENT NULLING ADJUSTMENT (marked I_{io}) and set to exact zero as indicated on M1. Increase sensitivity of adjustment by increasing the resistance (R_f) across the feedback terminals. Repeat adjustment as necessary. With care, the offset current can be reduced to a few

nanoamperes. (One nanoampere across 5 megohms represents an output voltage of 5 mV as read out on M1.) Offset current nulling results in increasing input impedance (looking into the feedback terminals). This becomes important in applications where the BOP is used as an impedance transformer since the feedback terminals represent the input of the circuit. Impedance in this case will be directly proportional to the residual effect of the offset current. With careful adjustment, Z_{in} can be raised to $10^7 - 10^8$ ohms.



NOTES:
1) Encircled nos. are terminal designations on the rear barrier-strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.
3) Connect load to heavy duty rear binding posts, not to barrier-strip terminals.

FIG. 3-5 TEST SET-UP FOR OFFSET NULLING.

3-16 REMOTE RESISTANCE PROGRAMMING

3-17 The output voltage of the BOP may be controlled remotely by means of an external feedback resistance connected between the appropriate front or rear terminals. The external feedback resistance may be fixed, continuously adjustable or step-controlled or it may be a combination of these. Its high speed characteristics and specifications make the BOP especially suitable for high speed remote control where the external feedback resistance is changed by means of relays or solid-state switching arrangements.

3-18 The value of the feedback resistance for any given output voltage is given by the transfer function.

$$E_o = I_b R_f, \quad \text{where:}$$

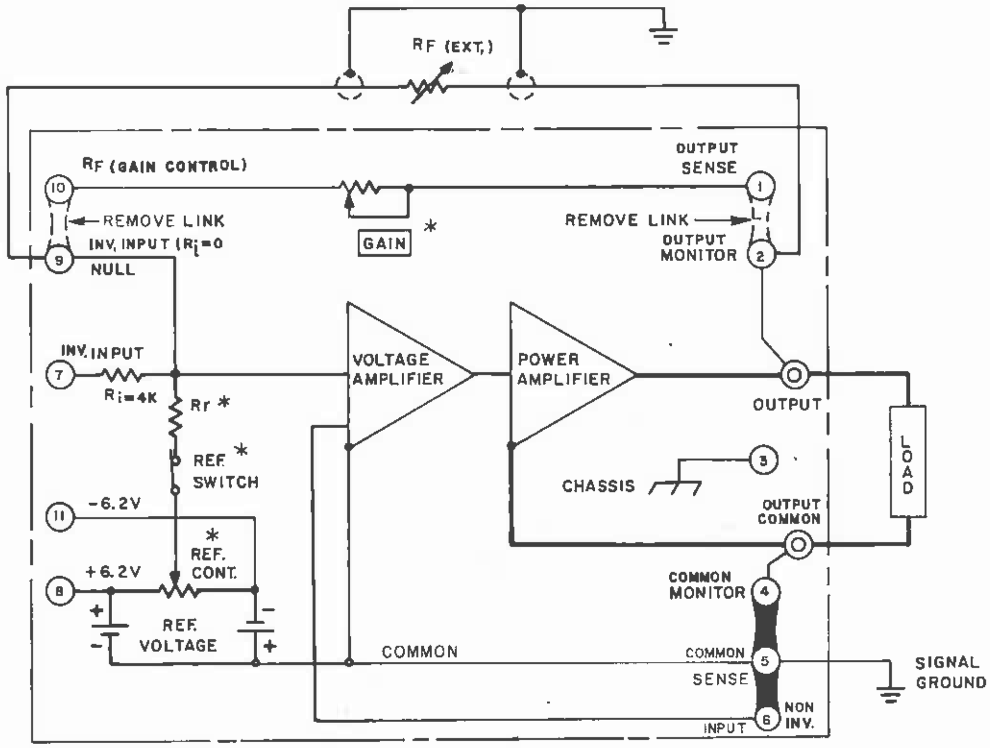
E_o = Desired Output Voltage
I_b = Control Current
R_f = Feedback Resistance

If the internal reference sources are used ("REF." switch in position "in"), I_b becomes a function of the position of the "REF." control. I_b may be made any value between −0.4 mA and +0.4 mA, depending on the position of the "REF." control. If, for example, we desire a zero to −10V output swing on a Model BOP 15–20(M), the "REF." control would be set to −0.4 mA (extreme counterclockwise position) and R_f calculated by.

$$E_o = I_b R_f, \text{ or. } -10V = (-0.4 \text{ mA})\ R_f$$

$$(R_f) = 40 \text{ K ohms.}$$

Resistor tolerances may be corrected by adjusting the "REF." control, until a precision meter at the output shows exactly 10 volts. If, on the other hand, a precision resistor with low tolerance is available for R_f, the output voltage may be adjusted with the "REF." control to exactly 0.4 mA X (R_f), thus establishing a "programming ratio" of 250 ohms per volt, i.e., for each 250 ohms of feedback resistance, one volt will appear at the output.



NOTES
1) Encircled nos are terminal designations on the rear barrier strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.
3) Connect load to heavy duty rear binding posts, not to barrier-strip terminals.

FIG. 3-6 PROGRAMMING WITH EXTERNAL RESISTANCE.

3-19 PROCEDURE (Refer to FIG. 3-6.)

a) Determine value of programming resistor (R_f) for output voltage desired.

b) Using two-wire, shielded cable, connect R_f to either front or rear terminals as shown. Connect shield to signal ground.

c) The output voltage will vary from (−0.4 mA) times (R_f minimum) to (+0.4 mA) times (R_f maximum) as the feedback resistor value is changed between its limits.

NOTE: Transfer internal bandwidth switch to the SLOW position, if overshoot, ringing or instability (oscillation) indicate excessive phase shift caused by the load.

3-20 AMPLIFIER OPERATION, VOLTAGE MODE

3-21 Standard bipolar programming with the BOP Operational Power Supply/Amplifier may be performed without elaborate preparation. Once the amplifier offsets have been adjusted (see par. 3-13), the "REF." switch is transferred to position "out" (if d-c biasing is not needed), and the BOP is ready for operation. Now the required operational gain can be determined and the necessary input and feedback components selected. For the calculations, we make use of the (idealized) operational amplifier equation:

$$E_o = E_i \left[\frac{R_f}{R_i}\right]$$ (Eq. 2), where:

E_o = Output Voltage
E_i = Input Voltage
E_i = Input Resistor
R_f = Feedback Resistor

The ratio R_i/R_f is the "closed-loop" or "operational" gain of the BOP. If the provided INPUT (R_i = 4 K ohm at rear terminal 7 or at the front panel if BOP is so equipped) in combination with a 40 K ohm GAIN control is used (built-in on models with suffix "M"), the operational gain is variable from zero to 10 (R_f/R_i = 40 K/4 K = 10). Other gain ratios may be selected by calculating the necessary input and feedback components and, using the (direct) NULL input terminal, connecting these components externally.

3-22 Before any application, the gain/frequency properties of the BOP in the amplifier mode should be considered. An idealized graph of this characteristic (Bode plot) is shown in FIG. 3-7 below.

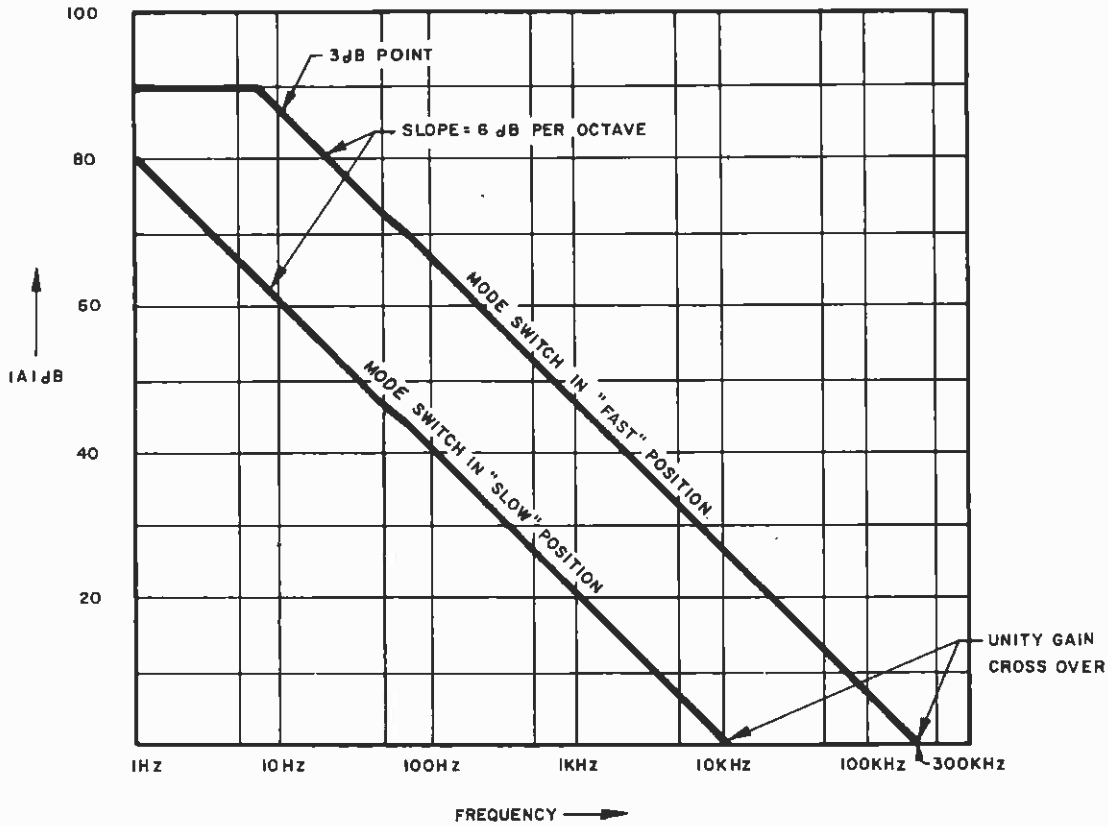
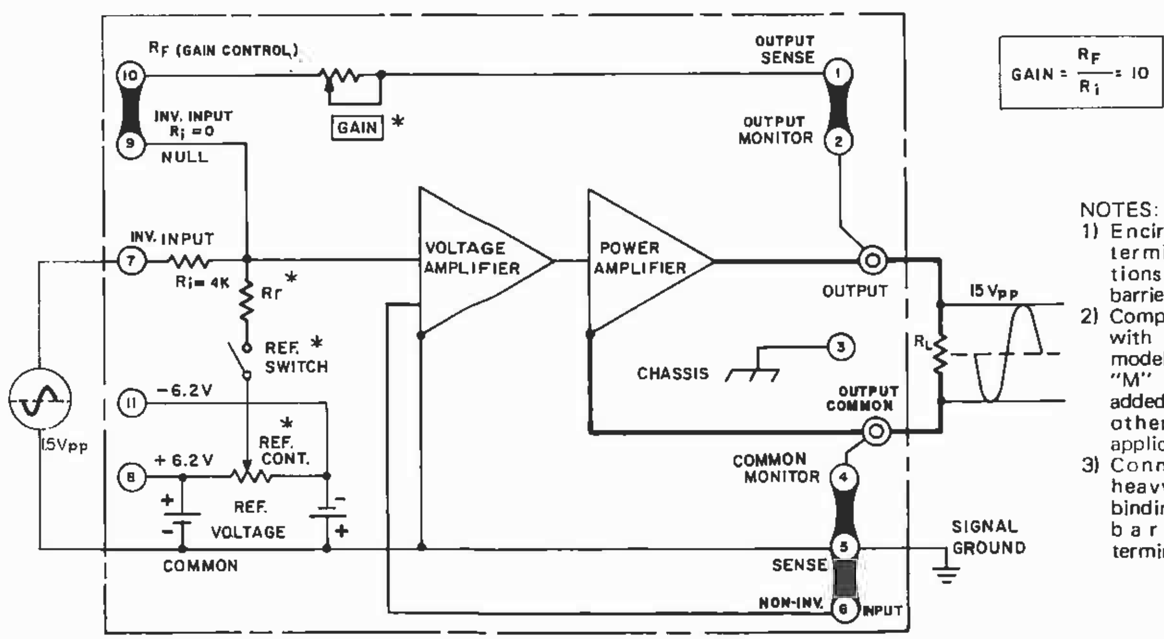


FIG. 3-7 BODE PLOT FOR BOP

3-23 BIPOLAR INPUT WITH VARIABLE GAIN (Local and Remote Control)

3-24 Example I: A Model BOP 15–20(M) is to be programmed to deliver a 15V p-p sine wave into a resistor load. The input source available is a generator with a maximum output of 1.5V p-p into 600 ohms. Since a gain of 10 (20 dB) is needed, we can expect maximum frequency response of about 25 kHz with the bandwidth switch in the FAST position. Using the internal GAIN control in combination with the INPUT terminal results in a convenient output control for the amplified sine wave. (Refer to FIG. 3-8.)



NOTES:
1) Encircled nos. are terminal designations on the rear barrier-strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.
3) Connect load to heavy duty rear binding posts, not to barrier-strip terminals.

FIG. 3-8 BIPOLAR INPUT WITH VARIABLE GAIN (LOCAL CONTROL).

3-25 If other gain ratios are desired or the instrument is to be remote controlled, the necessary input and feedback resistors may be readily calculated utilizing Equation 2.

$$E_o = E_i \left[\frac{R_f}{R_i}\right]$$

If, for example, the available input voltage is only 0.5V p-p, we would need a gain of 30 (50 dB) to produce a 15V p-p output. The value of the input resistor (R_i) will depend upon the source impedance of E_i if, for example.

$$R_{source} = 400 \text{ ohms},$$

R_i' could be chosen 600 ohms, so that

$$R_{source} + R_i' = R_i = 1 \text{ K ohm},$$

then R_f would be calculated by:

$$R_iG = R_f = (1 \text{ K}) (30) = 30 \text{ K ohms}.$$

Making R_f a variable resistor will result in convenient control over the required range. (Refer to FIG. 3-9).

3-26 Other input sources such as sawtooth or square-wave voltages may be used to program the BOP if the gain/bandwidth criterium is kept in mind. If the input source has a d-c component which must be blocked, the coupling capacitor must be selected large enough to pass the lowest frequency of interest or.

$$C \geqslant \frac{10}{2\pi f R_i} \qquad X_c \leqslant \frac{R_i}{10}$$

Where R_i is the input resistance, and (f) is the frequency of interest (3 dB point).

NOTE: If the input source has an appreciable source resistance, it must be considered in all gain calculations. Although the equation for the output voltage (2) does not change, we must remember that e_i is not the open circuit output from the generator but the input voltage to the closed-loop system (FIG. 3-9).

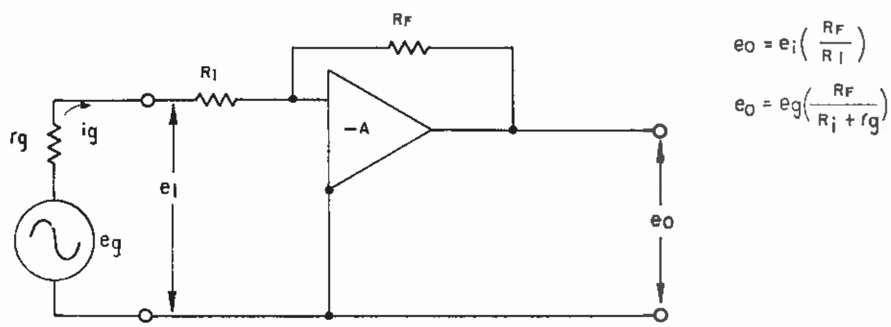


FIG. 3-9 INPUT SOURCES WITH HIGH INTERNAL IMPEDANCE

If (FIG. 3-9) e_g is the open-loop generator voltage, and r_g its internal impedance, e_i may be calculated from:

$$e_i = e_g - \left[\frac{e_g}{R_i + r_g}\right] r_g, \text{ where:}$$

$$e_g/(R_i + r_g)$$

represents the control current i_g so that e_i may also be expressed by:

$$e_i = e_g - i_g r_g$$

We can also (analytically) convert the generator into a current source capable of delivering a signal current i_g. (See FIG. 3-10.) In this case the transfer function (Eq. 2) simplifies to:

$$e_o = -i_g R_f.$$

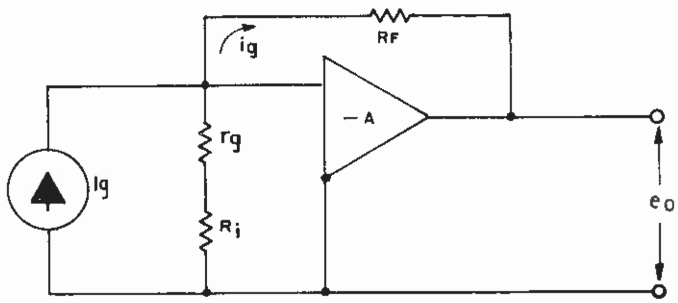


FIG. 3-10 CURRENT GENERATOR AS AN INPUT SOURCE

3-27 APPLICATIONS WITH SIMULTANEOUS A-C/D-C OUTPUT

3-28 There are many practical applications where it is required to add or subtract d-c levels to or from the a-c signal input. The BOP with its built-in bipolar d-c reference sources is ideally equipped for level shifting of a-c input signals.

Example I: A negative-going triangular wave with an amplitude of 15 volts is desired from the output of a Model BOP 15—20M The input source is a signal generator with a peak-to-peak amplitude of 1 volt, transformer coupled into a 600 ohm impedance. Fig. 3-11 shows the input signal and the output desired.

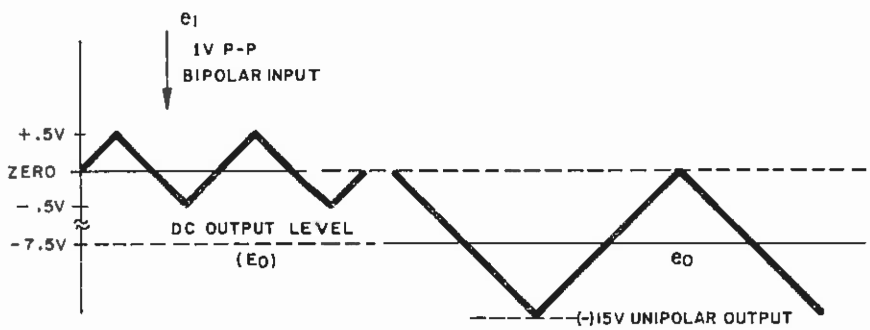


FIG. 3-11 UNIPOLAR OUTPUT FROM A BIPOLAR INPUT SOURCE

In the above example, since we require an a-c output swing from zero to −15V peak and the input source is bipolar, we must produce a d-c output of −7.5V so that the amplified a-c signal can swing around this axis without going positive and produce the desired output which now has, in addition to the a-c signal, the desired d-c level shift.

3-29 The operational equation (Eq. 2) is now applied to both a-c and d-c conditions, and both a-c and d-c inputs are applied to the amplifier in a summing configuration to obtain the desired results

a) D-C CONDITIONS

$$E_o = -E_i \left[\frac{R_f}{R_i}\right] \qquad \text{(Eq. 2)}$$

$$E_o \text{ desired} = -7.5V$$

Since the reference voltage (E_i = −6.2V) is available, the GAIN control (internal or external) is adjusted to 15 K ohms and the "REF." control (internal or external) such that the d-c output is equal to −7.5 volts. This adjustment establishes the necessary d-c bias level

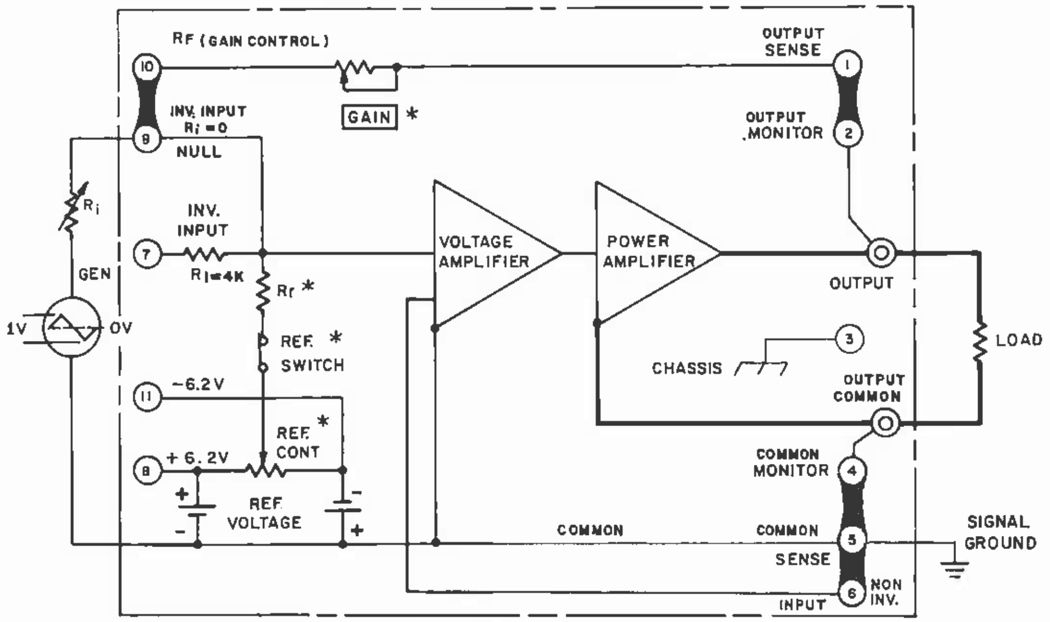
b) A-C CONDITIONS

$$e_o = e_i (R_f/R_i);$$

$$e_o \text{ desired} = 15V \text{ p-p}$$

$$e_i \text{ max.} = 1V \text{ p-p}$$

The required gain (R_f/R_i) is therefore 15. Since the built-in feedback control (R_f = 15 K ohms) is used, the input resistance must be $R_i = R_f/15$ or 1 K ohm. If an amplitude control on the input source is available, R_i may be chosen somewhat smaller, and the proper signal amplitude can be adjusted on the generator. Alternately, R_i may be made adjustable in order to obtain the correct signal input. The d-c zero level may be corrected by adjusting the "REF." control on the front panel of the BOP. The necessary external connections to the BOP are shown in FIG. 3-12 below.



NOTES
1) Encircled nos. are terminal designations on the rear barrier strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.
3) Connect load to heavy duty rear binding posts, not to barrier-strip terminals.

FIG. 3-12 CONNECTIONS FOR SIMULTANEOUS AC/DC OUTPUT (EX. 1)

3-30 Similar circuits with similar external connections as the example given (FIG. 3-12) may be constructed for a great variety of applications. If, for instance, a positive-going output is required (instead of the previous negative output) under otherwise identical conditions, the d-c output need only to be adjusted (by means of the "REF." control) to +7.5V Unipolar signal sources (positive or negative) may be used with equal ease. An example is given below.

Example II: A bipolar, 10V p-p square-wave output is desired from a Model BOP 15–20(M). The input source is a positive-going square-wave generator with a peak amplitude of 1 volt and with 2 K ohm source resistance.

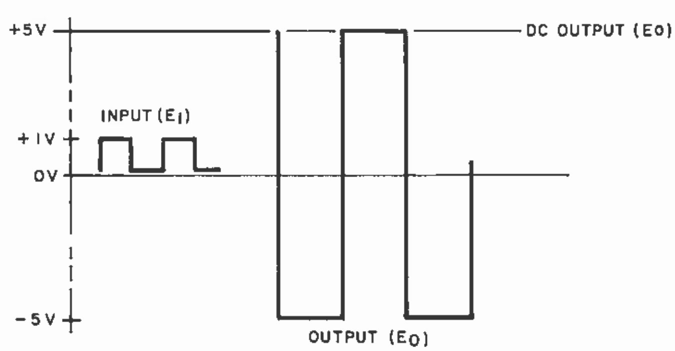


FIG. 3-13 BIPOLAR OUTPUT FROM UNIPOLAR INPUT SOURCE

As seen from FIG. 3-13, for this input a "prebiasing" of the d-c output to +5V is needed, along with an a-c gain of 10 in order to produce the desired a-c voltage swing. We proceed as before:

a) D-C CONDITIONS:
With the GAIN control fully clockwise, adjust the output to +5V by means of the "REF." control.

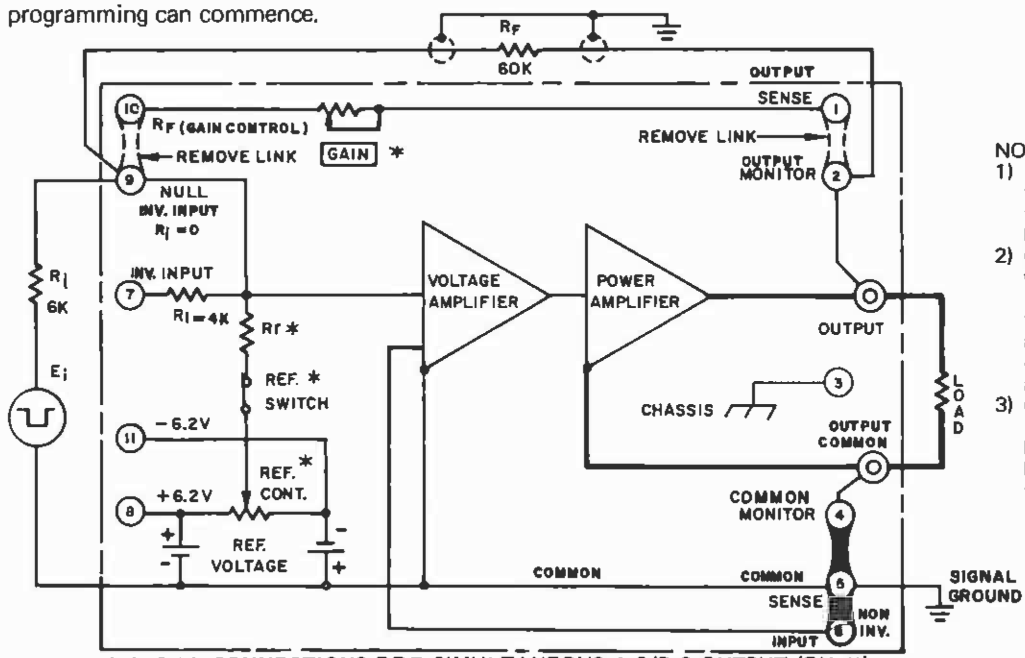
b) A-C CONDITIONS:

$e_O = 10V$ p-p

$e_i = 0.5V$ p-p

$$\therefore \text{gain needed: } \frac{R_f}{R_i} = 20$$

Since with the built-in gain control R_f is given with 40 K, R_i must be 40 K/20 ≈2 K ohms. Since the source resistance of our generator is 4 K ohm however, we find the internal gain control cannot be used in this case. Instead, since $R_f/R_i = 20$, R_f must be 80 K ohms and is connected externally. The components are now connected externally as shown in FIG. 3-14, the d-c output readjusted with the "REF." control, and programming can commence.



NOTES:
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2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.
3) Connect load to heavy duty rear binding posts, not to barrier-strip terminals.

FIG. 3-14 CONNECTIONS FOR SIMULTANEOUS A-C/D-C OUTPUT (EX. II).

3-31 BOP AS A CURRENT STABILIZER

3-32 The BOP Operational Power Supply operated as a stabilized current power supply or amplifier comes as close to an ideal current source as the state of the art permits. Due to its low output capacitance, the BOP exhibits excellent current recovery properties for rapidly changing loads. The recovery time for the output current in response to a voltage step-function (or load resistance change) is specified for the SLOW and the FAST mode of operation. (Refer to par. 1-13.)

3-33 To operate the BOP in the current stabilized mode, an external current sensing resistor is added. This resistor R_S) yields a voltage drop proportional to the output current. The voltage drop (V_S) is now held constant in reference to either the internal d-c reference or to an input signal. In effect, therefore, the main difference between voltage and current mode operation is that in the former, the voltage across the load is regulated and in the latter, the voltage across R_S.

3-34 SELECTION OF THE CURRENT SENSING RESISTOR

3-35 R_S must be chosen with care. The high gain amplifier connected across it will indiscriminately respond to all changes produced. Variations not due to load current changes, such as those produced by noise and temperature rise, must therefore be kept as low as possible. The current sensing resistor should consequently be a wirewound, high quality unit with a temperature coefficient as low as possible and a wattage rating of at least 10 times the actual power dissipated. In addition, it should have the configuration of a four-terminal network. (Tepro TM series or equivalent.)

3-36 The value of R_S is chosen on the basis of a 0.5 volt sample at the maximum output current desired: $R_S = 0.5V/I_{O\ max.}$ where I_O is the output current. The absolute value of R_S is not critical and can be the nearest standard resistance available since I_O can be readily adjusted. The sample voltage (V_S) should not be chosen too high, however, since the detrimental effects of higher power dissipation must be avoided. On the other hand, with a too low value of V_S, the signal to noise ratio becomes a problem. The suggested 0.5 volt represents therefore a practical compromise for a large number of applications. If a large range of output current must be regulated, several sensing resistors must be used selectively to achieve optimum performance.

3-37 SELECTION OF THE CURRENT CONTROL RESISTOR

3-38 If the internal references in the BOP are used, current control is available by means of the "REF." control, and a fixed "coupling" resistor (R_C) may be used to complete the closed-loop circuit. Since a nonlinear control is not always desirable, however, the coupling resistor may be made variable and the "REF." control left at a fixed value, thus providing linear current control. Actual values may be calculated by referring to the simplified circuit shown in FIG. 3-15.

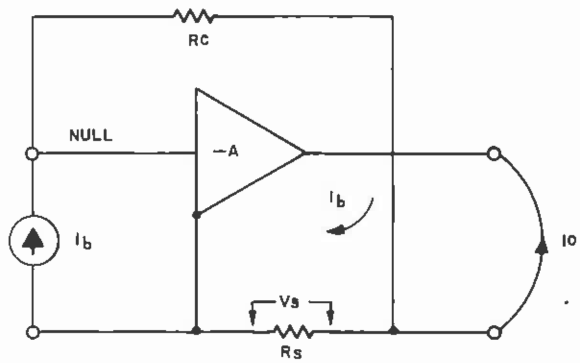
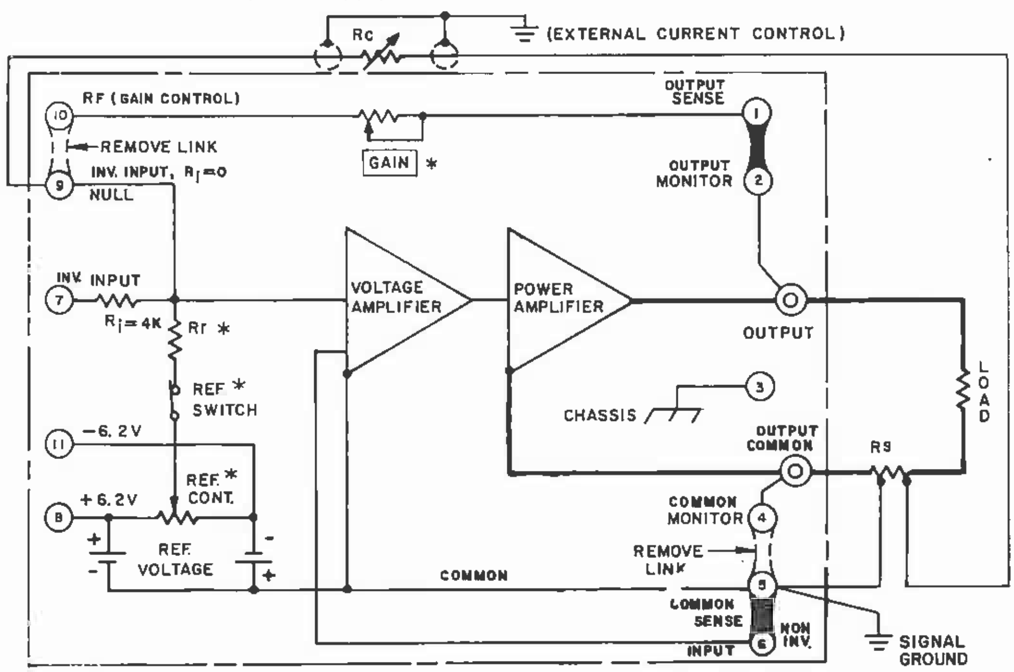


FIG. 3-15 CURRENT STABILIZER, SIMPLIFIED.

The internal reference source delivers 0.4 mA to the null junction. At balance, 0.4 mA control current must flow so that $I_b R_C = I_O R_S$. If, therefore, R_S was selected to drop 0.5 volt at a certain I_O, R_C must be 1250 ohms since we selected a control current (I_b) of 0.4 mA. Practical component selection will be demonstarted by means of examples below.

3-39 STANDARD CURRENT STABILIZER

3-40 FIG. 3-16 shows the BOP Operational Power Supply/Amplifier connected as a continuously variable, d-c current stabilized power supply with reversible polarity.



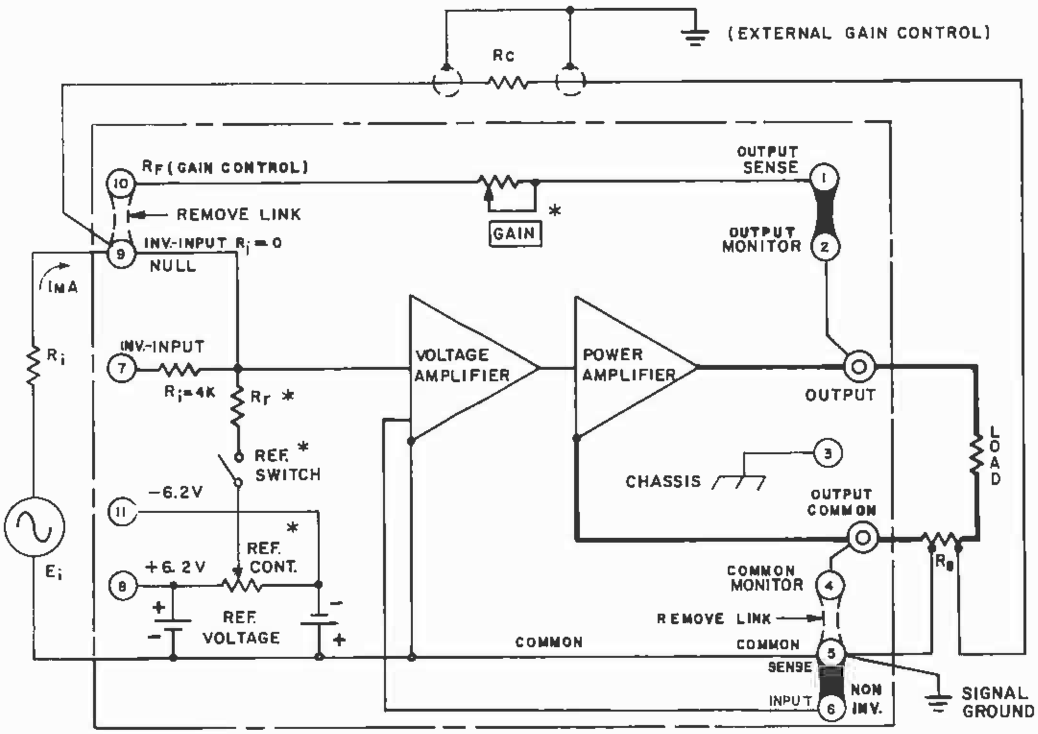
NOTES:
1) Encircled nos. are terminal designations on the rear barrier-strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.
3) Connect load to heavy duty rear binding posts, not to barrier-strip terminals.

FIG. 3-16 STANDARD CURRENT STABILIZER.

As indicated previously, control is possible two ways: with the built-in "REF." control and a fixed coupling resistor R_C (nonlinear); or setting the "REF." control to 0.4 mA (either polarity) and making R_C a variable resistor (linear control). In the latter case, control can then be effected remotely by rheostat or step switches with precision resistors (programming by resistance) as described in paragraph 3-16 for the standard voltage mode operation.

3-41 CURRENT STABILIZED AMPLIFIER MODE

3-42 If the internal d-c reference source is disconnected ("REF." switch "out") and an a-c signal source is applied to the input as shown in FIG. 3-17, the BOP functions as an amplifier as described in previous paragraphs. Similar criteria for selection of feedback components and identical limitations apply as for the circuitry in the stabilized voltage mode. If input sources have a d-c component, for example, it can be either eliminated or the output level can be shifted to accommodate the input. In these cases the "REF." switch is transferred to the "in" position and the d-c level adjusted until the desired output wave shape is achieved as observed with an oscilloscope parallel to the load. FIG. 3-17 shows the connections for standard amplifier operation in the stabilized current mode.



NOTES:
1) Encircled nos. are terminal designations on the rear barrier-strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.
3) Connect load to heavy duty rear binding posts, not to barrier-strip terminals.

FIG.3-7 CONNECTIONS FOR CONSTANT CURRENT AMPLIFIER

3-43 Variations on the standard amplifier circuit (FIG. 3-17) to accommodate specific operating requirements can be readily implemented by calculating the external component values to suit the application. The transfer function for the constant stabilized mode is used for this purpose

$$I_o = I_b (R_c/R_s),$$

where I_b is the control current from the input source, or.

$$I_b = e_i/R_i$$

As long as I_b = 1 mA is available from the input source, the circuit shown in FIG. 3-17 may be used. Linear gain control can be achieved by making R_c a variable resistor. D-C components may be added or subtracted by means of the internal "REF." sources as previously described for operation in the voltage mode. If less control current is available from the input source, or higher value sensing resistors are used for lower maximum output currents, the control resistor must be recalculated. If, for example, our input source has a maximum amplitude of 10V and a source impedance of 25 K ohms, the available control current is 10V/25 K ohms = 0.4 mA. If we desire a maximum output current of 10 amperes, the sensing resistor is selected by $V_s/R_s = I_o$. 0.5V/10A = 0.05 ohm. The actual power dissipation of R_s = 0.5V (10A) = 5 watts. A 50 watt wirewound unit is selected for R_s. Since a gain of I_o/I_b = 10A/0.4 mA = 2.5 X 10^4 is required and R_c/R_s must equal this ratio, the value of R_c equals 25 K ohms. A wirewound, precision rheostat of that value will provide linear control of the output current.

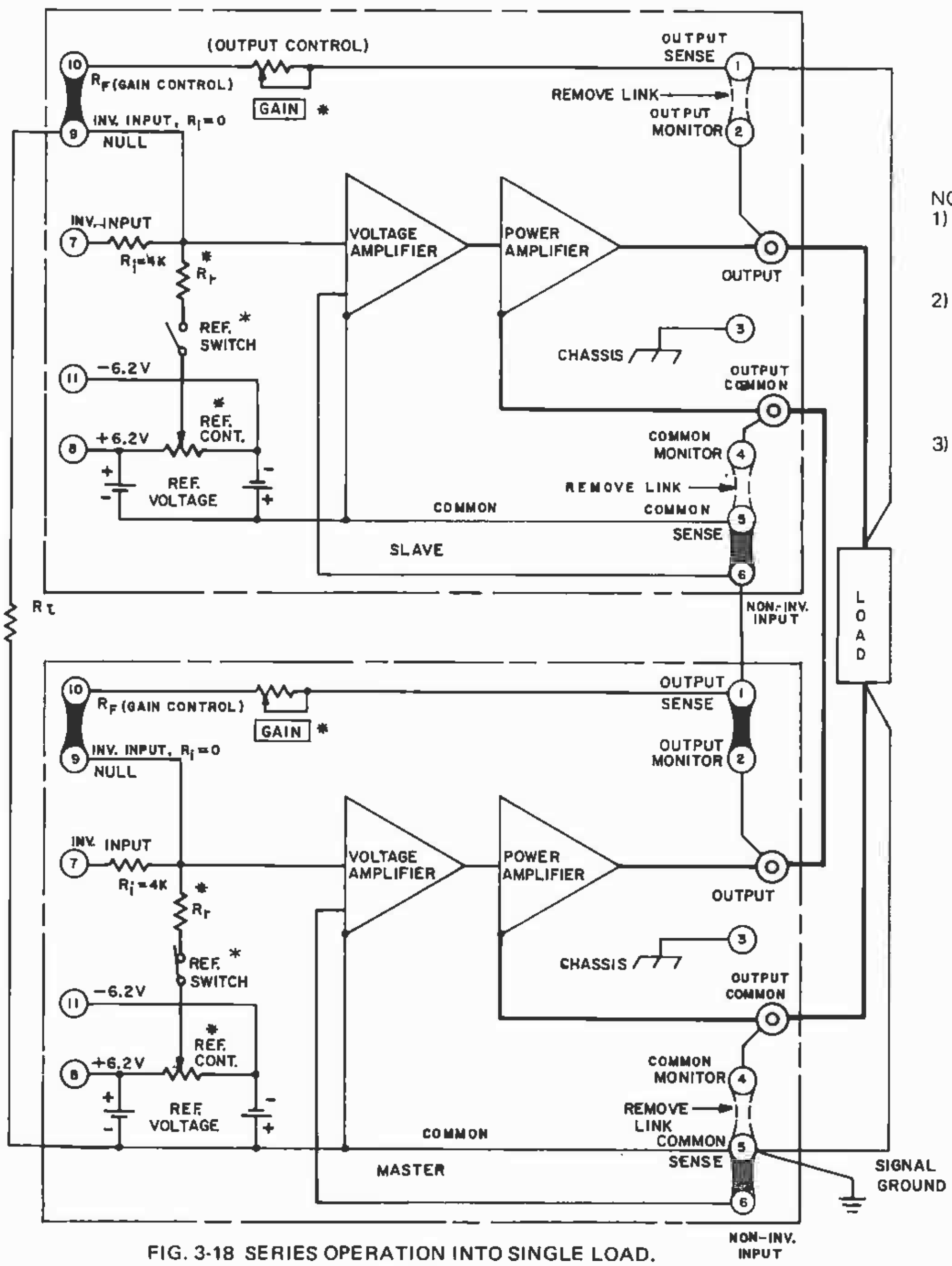
3-44 SERIES OPERATION

3-45 The BOP POWER SUPPLY/AMPLIFIER may be connected in series with an identical unit to achieve increased voltage output. Several precautions must be observed, however, to insure successful operation

a) The nature of the BOP circuitry does not permit series connection with INDIVIDUAL output control. A "master/slave" configuration is recommended instead, operating into separate—or into a common load.

b) The "current limit" controls of the SLAVE supply must be adjusted to a slightly higher value than those of the MASTER supply if maximum rated current output is expected from the series connected BOP's. This will insure the necessary lead of the MASTER supply in the process of current limiting.

c) The setup procedure described below should be followed closely. DO NOT ADJUST THE CURRENT LIMIT CONTROLS TO VALUES GREATER THAN 23 AMPERES. Although this may be possible (due to component tolerances), increased dissipation in the pass element sections with possible destruction of the transistors may result.



NOTES.
1) Encircled nos. are terminal designations on the rear barrier-strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.
3) Connect load to heavy duty rear binding posts, not to barrier-strip terminals.

FIG. 3-18 SERIES OPERATION INTO SINGLE LOAD.

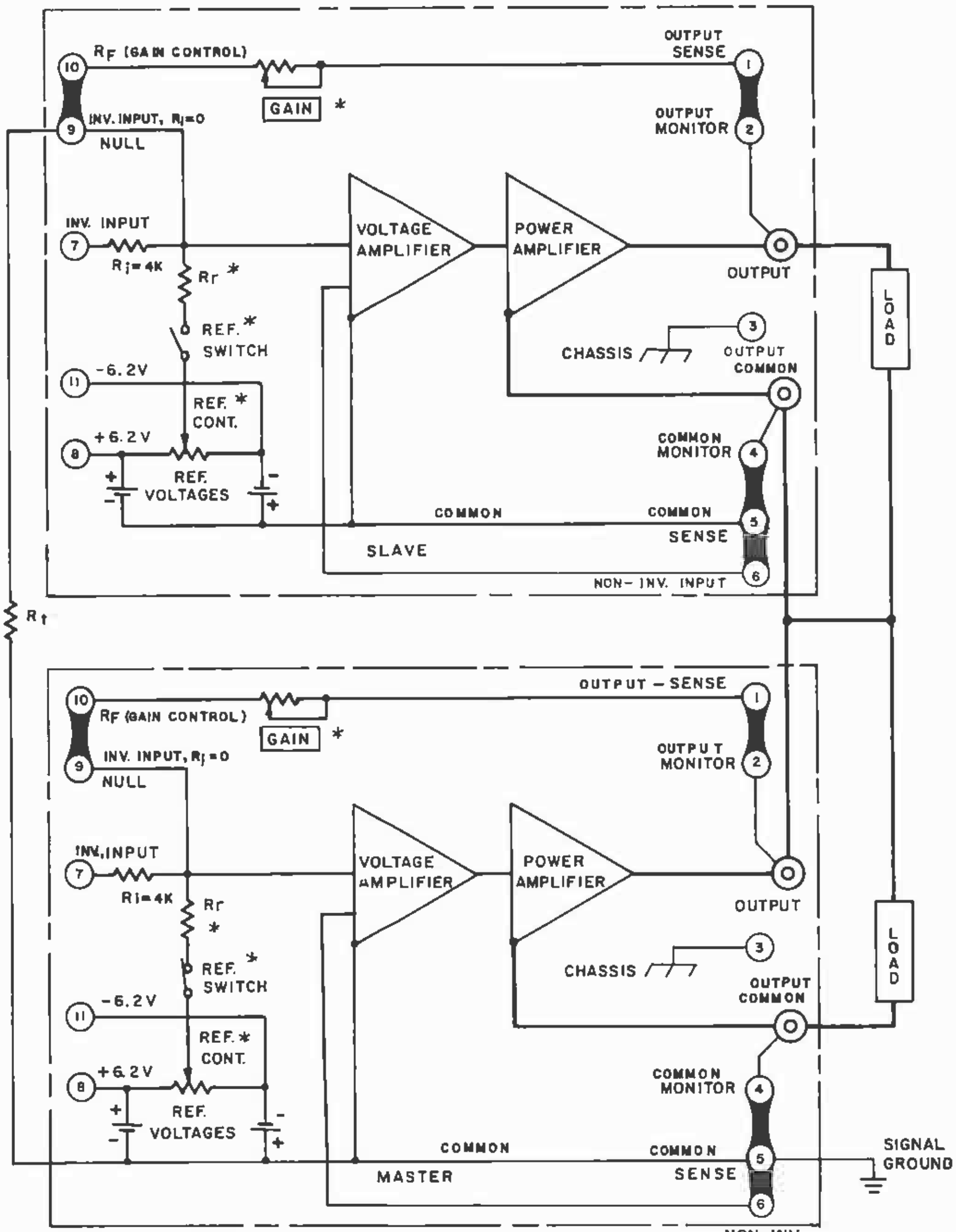


FIG. 3-19 SERIES OPERATION INTO SEPARATE LOADS

NOTES:
1) Encircled nos. are terminal designations on the rear barrier-strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.
3) Connect load to heavy duty rear binding posts, not to barrier-strip terminals.

3-46 SETUP PROCEDURE (Example for BOP 15–20)

a) PRELIMINARY ADJUSTMENTS. Since two sets of series regulator transistors are used in the BOP Power Supply/Amplifiers, there are two current limit controls which are factory-set to limit at a short circuit current of 22A d-c. For a series connection of two BOP units, the two current limit controls of the SLAVE supply must be reset to limit at a slightly higher value. This will insure full output current from the series combination and provide proper current limiting sequence (first MASTER, then SLAVE).

b) CURRENT LIMIT ADJUSTMENTS, SLAVE UNIT. Connect an accurate ammeter, such as the Weston Model 931, across the output terminals of the unit designated as the SLAVE. Turn the "REF." control fully counterclockwise and place the "REF." switch in the "IN" position. Turn POWER switch "ON." Observe the external ammeter. Adjust the GAIN control until output current does no longer increase. The short circuit current will be approximately 22A.

c) Locate the two "I_O Limit" controls (R23, R24) and the MODE switch (S1) on the printed circuit board. (Refer to the location diagram, FIG. 2-3.) Turn R24 slowly clockwise until the ammeter shows an increased short circuit current of about 23A. Turn POWER switch "OFF." Reverse polarity of the external ammeter. Turn "REF." control fully clockwise.

d) Turn POWER "ON." The ammeter should again show approximately 22A. Adjust the short circuit current by turning R23 slowly clockwise until 23A is reached. This completes the preliminary adjustment on the SLAVE unit.

e) The two BOP units can now be series connected as shown in FIGS. 3-18 or 3-19. Some load connections may require the operation of the BOP combination in the SLOW mode. Locate the MODE switch (S1) by referring to FIG. 2-3 and transfer both MASTER and SLAVE supplies to the SLOW position if a-c instability occurs.

f) As seen from FIG. 3-19, the output of the SLAVE supply is completely dependent upon that of the MASTER and in fact "tracks" the MASTER supply in an exact ratio of 1:1 if both GAIN controls are set to the same value and if R_t is selected such that:

$R_{vcs}/R_t = 1$, since: $E_{os} = E_{om}R_{vcs}/R_t$, where:

E_{om} = Output Voltage, "Master"

E_{os} = Output Voltage "Slave"

R_t = Tracking Resistor.

In this case, $E_{om} = E_{os}$, where E_{os} is the SLAVE output voltage since $R_{vcm} = R_{vcs}$, i.e., the setting of the two GAIN controls is identical. If, for example, in the connection shown in FIG. 3-19, the voltage across both loads must be 10 volts, the "REF." control of the MASTER is set to the desired polarity and the GAIN control to the required 10 volts. A 10 K ohm resistor for R_t connected as shown will result in a control current of E_{om}/R_t = 1 mA and consequently in a SLAVE output of:

$$E_{os} = 1\text{ mA } [R_{vcs} = 10\text{ volts (if } R_{vcs}) = 10\text{ K}]$$

where R_{vcs} is the GAIN control resistance of the SLAVE unit. Both SLAVE and MASTER output are thus equal and track in a 1:1 ratio. The tracking ratio may be altered by either changing the GAIN control settings by replacing the built-in GAIN controls with external resistors or by selecting the value of R_t such that the desired tracking ratio is achieved. Amplifier operation of the MASTER supply as described in previous paragraphs may be used. The amplified output will either appear on both loads simultaneously, or if a common load is used, twice the output is applied to the load.

FIG. 4-2

4-7 THE IDE

4-8 For the p
assumption

a) The i
b) The o
c) The in

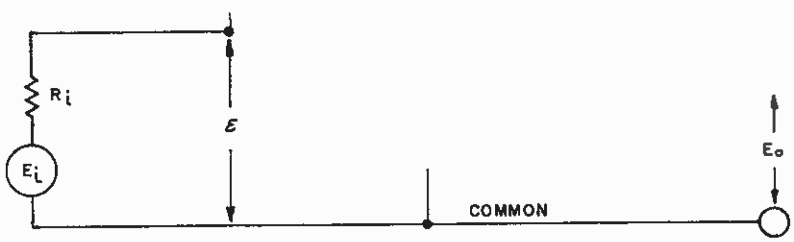


FIG. 4-3 MODEL OF IDEAL OPERATIONAL AMPLIFIER WITH FEEDBACK (INVERTING CONFIGURATION).

4-9 Refer to FIG. 4-3. Since (by the previous assumptions) the currents in R_f and R_i are equal, Kirchhoff's loop equation may be written as:

$$\frac{E_i - \epsilon}{R_i} + \frac{E_o + \epsilon}{R_f} = 0$$

By definition, $E_o = -A\epsilon$, where A represents the "open-loop" gain. Also:

$$\epsilon = \frac{E_o}{A}$$

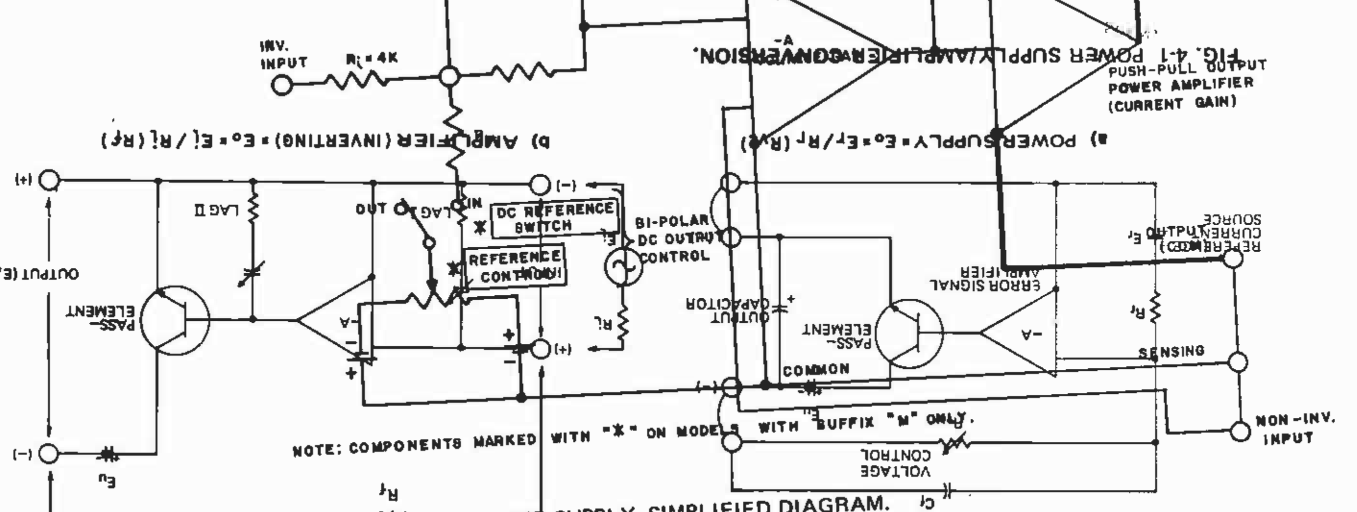


FIG. 4-2 BOP OPERATIONAL POWER SUPPLY, SIMPLIFIED DIAGRAM.

4-7 THE IDEAL AMPLIFIER

4-8 For the purpose of analysis, an ideal model of the operational amplifier is proposed, and the following assumptions are made:

a) The input terminal (null junction) will not conduct current to or from the amplifier.

b) The open-loop gain is very large ($A \rightarrow \infty$).

c) The input voltage ϵ approaches zero when the feedback loop is closed ($\epsilon \rightarrow 0$).

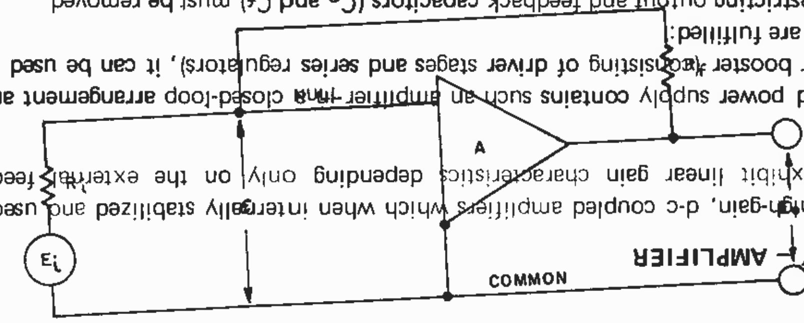


FIG 4-3 MODEL OF IDEAL OPERATIONAL AMPLIFIER WITH FEEDBACK (INVERTING CONFIGURATION)

4-9 Refer to FIG. 4-3. Since (by the previous assumptions) the currents in R_f and R_i are equal, Kirchoff's loop equation may be written as:

$$\frac{E_i-\epsilon}{R_i} = -\frac{E_O+\epsilon}{R_f}$$

By definition, $E_O = -A\epsilon$, where A represents the "open-loop" gain. Also:

E_O

If we let $A \to \infty$, $\epsilon \to 0$, then the original loop equation reduces to:

$$\frac{E_i}{R_i} + \frac{E_o}{R_f} = 0, \text{ or in the more familiar form: } E_o = E_i \frac{R_f}{R_i}$$

which is recognized as the (ideal) transfer function of an operational amplifier in the inverting configuration.

4-10 THE PRACTICAL AMPLIFIER

4-11 The closed-loop relationships derived for the ideal model of the operational amplifier may be applied to the practical case with very small predictable errors which in addition can be compensated for. The "ideal" amplifier equation for example, may be used to calculate the magnitude of the feedback and input components with negligible errors, which will be well within the component tolerances. In evaluating the d-c performance, however, these errors cannot be neglected.

4-12 AMPLIFIER OFFSETS. In developing the ideal amplifier model, we tacitly assumed the null junction voltage and current to be zero, causing the "ideal" equation to be valid. In reality, however, nonidealities do exist at the null junction or input terminal of the amplifier. These errors are of the form of an offset voltage (E_{io}) and an offset current (I_{io}). The modified version of the amplifier model can be shown with these error sources as in FIG. 4-4.

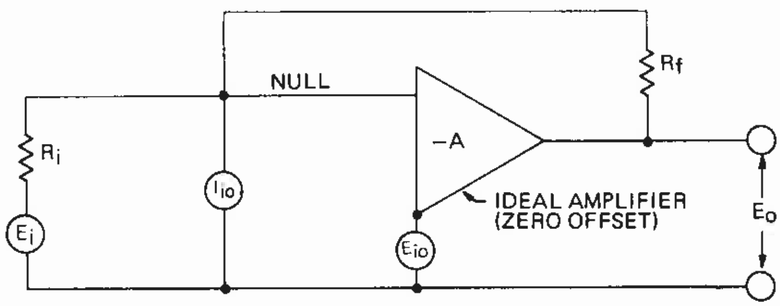


FIG. 4-4 AMPLIFIER WITH INPUT OFFSET SOURCES.

4-13 Although the initial values of both offsets may be zeroed by compensating sources of opposite polarities (as in the BOP), their VARIATIONS with a-c input line, output load, temperature and time do appear at the input and are specified as ΔE_{io} and ΔI_{io} in Section I and repeated here:

SPECIFICATION	VOLTAGE AMPLIFIER OFFSETS		6.2V REFERENCES
	ΔE_{io}	ΔI_{io}	
SOURCE: 105 – 125 or 210 – 250V a-c	<0.1 mV	<10 nA	<0.00
LOAD: No Load/Full Load	<1.0 mV	<10 nA	N.A.
TIME: 8 Hours (Drift)	<0.1 mV	<50 nA	<0.005%
TEMPERATURE: Per °C (Coefficient)	<0.08 mV	<50 nA	<0.005%

4-14 Considering both offset variations, the modified expression for the output voltage (with the initial or fixed parts of E_{io} and I_{io} nulled) becomes:*

$$E_o = \underbrace{E_i \frac{R_f}{R_i}}_{\text{Ideal part}} \underbrace{\pm \Delta E_{io} \left[\frac{R_f}{R_i}\right]}_{\text{Output error due to offset voltage.}} \underbrace{\pm \Delta I_{io} R_f}_{\text{Output error due to offset current.}} \quad \text{(Eq. A)}$$

*The error term: $\pm \Delta E_i \frac{R_f}{R_i}$ is considered a secondary effect in this analysis.

As seen from Equation A, the offset voltage variations (ΔE_{io}) are multiplied by unity plus the gain ratio R_f/R_i to obtain its contribution to the output voltage change, while the offset current variations are multiplied by the value of the feedback resistor (R_f). The separation of the specifications for ΔE_{io} and ΔI_{io} not only allows an analysis of the contributions from each offset variation but also permits component selection such as to minimize the effects of either offsets or find an acceptable compromise.

4-15 Practical examples will illustrate the usefulness of the concept:

a) For an application requiring a gain of 10, an operational programming circuit is to be set up with a KEPCO BOP. From the table of specifications the change in offset voltage due to a-c input source variations is specified as:

$$\Delta E_{io} = 0.1 \text{ mV}$$

$$\Delta I_{io} = 10 \text{ nA}$$

If we let R_i = 100 K ohms, then for R_f/R_i = 10, we need R_f = 1 megohm. The expected output effect due to a-c line changes are (from Eq. A):

$$\Delta E_o \text{ (due to a-c input source variations)} = \Delta E_{io} \left[\frac{R_f}{R_i} + 1\right] + \Delta I_{io} R_f$$

$$= 0.1 \text{ mV } (10+1) + 10 \text{ nA } (10^6 \text{ ohms})$$

$$= 1.1 \text{ mV} + 10 \text{mV}$$

ΔE_o due to offset voltage change | **ΔE_o due to offset current change**

The contributions of ΔI_{io} are seen to be almost ten times that of ΔE_{io} due, of course, to the choice of a relatively large feedback resistor. Generally, in low gain applications, it is wise to select lower values for the feedback and input resistors if the loading on the input source will permit it. If, for example:

$$R_i = 10 \text{ K and } R_f = 100 \text{ K}$$

(retaining the previous gain ratio of R_f/R_i = 10), ΔI_o would only be 1 mV, calculated similar to the previous results.

b) Using the same amplifier in an application with a required operational gain of 100, we select R_i to be 1 K ohm and R_f = 100 K, thus establishing the desired gain ratio (R_f/R_i = 100). For the choice of input and feedback elements, we find the output effect due to a-c input source variations to be:

$$\Delta E_o = 0.1 \text{ mV } (100 + 1) + 10 \text{ nA } (10^5 \text{ ohms})$$

$$= 10.1 \text{ mV} + 1 \text{ mV}$$

ΔE_o due to offset voltage change | **ΔE_o due to offset current change**

In this case the contribution from ΔE_{io} is dominant. Its effect can only be reduced by externally limiting wide variations of the a-c input source. Similar calculations to the above examples may be made to predict the output effects due to load changes, temperature variations or drift (changes in output voltage with time).

4-16 GAIN FREQUENCY CHARACTERISTICS (Please refer to Sect. III, FIG. 3-7 and FIG. 4-2, Sect. IV)

4-17 A flat frequency response to greater than 500 kHz is readily obtainable from the push-pull power amplifiers since no voltage gain is requested from this part of the BOP. Since the voltage amplifier is stabilized with internal resistor/capacitor networks, the frequency characteristics are determined by R_iC_f only. C_f can be selected by an internal slide switch for two unity gain crossover frequencies. In the SLOW position the instrument is unconditionally stable for any closed-loop gain (including 100% feedback) and for any amount of capacitive loading at the output. The maximum full power frequency response in this position is approximately 1 kHz. In the wide-band position (FAST), capacitive loading is restricted to 0.001 μF, maximum. In this position, however, with a unity gain crossover frequency of 300 kHz, the instrument is still stable for any closed-loop gain including 100% feedback. As seen from the gain vs. frequency plot (Bode plot) shown in FIG. 3-7, the theoretical frequency response of the instrument with, for example, a closed-loop gain of 10 (20 dB) is (in the FAST position) approximately flat to 30 kHz. However, due to capacitive loading at the amplifier output, actual frequency response is about 25 kHz.

4-18 SIMPLIFIED DIAGRAM DISCUSSION (Refer to FIG. 4-5.)

4-19 The a-c power input is converted by the main and auxiliary transformers to the levels needed for production of the unregulated MAIN POWER SUPPLY and the AUXILIARY D-C SUPPLY voltages. The MAIN POWER SUPPLY delivers the power output via the PUSH-PULL POWER AMPLIFIER STAGE which is series-connected with the unregulated MAIN POWER SUPPLY and the external load and driven by the VOLTAGE AMPLIFIER. The VOLTAGE AMPLIFIER inputs are made available on the REAR BARRIER-STRIP and and at the FRONT PANEL TERMINALS (models with suffix "M" only). Both inputs accept signals with reference to the COMMON SENSING terminal. The INVERTING INPUT can be biased for d-c output, biasing, or level shifting with the built-in REFERENCE VOLTAGE SOURCES. On metered models (models with suffix "M") a REF. switch and a REF. control as well as a GAIN control are provided on the front panel. On unmetered models these components may be connected to the REAR BARRIER-STRIP.

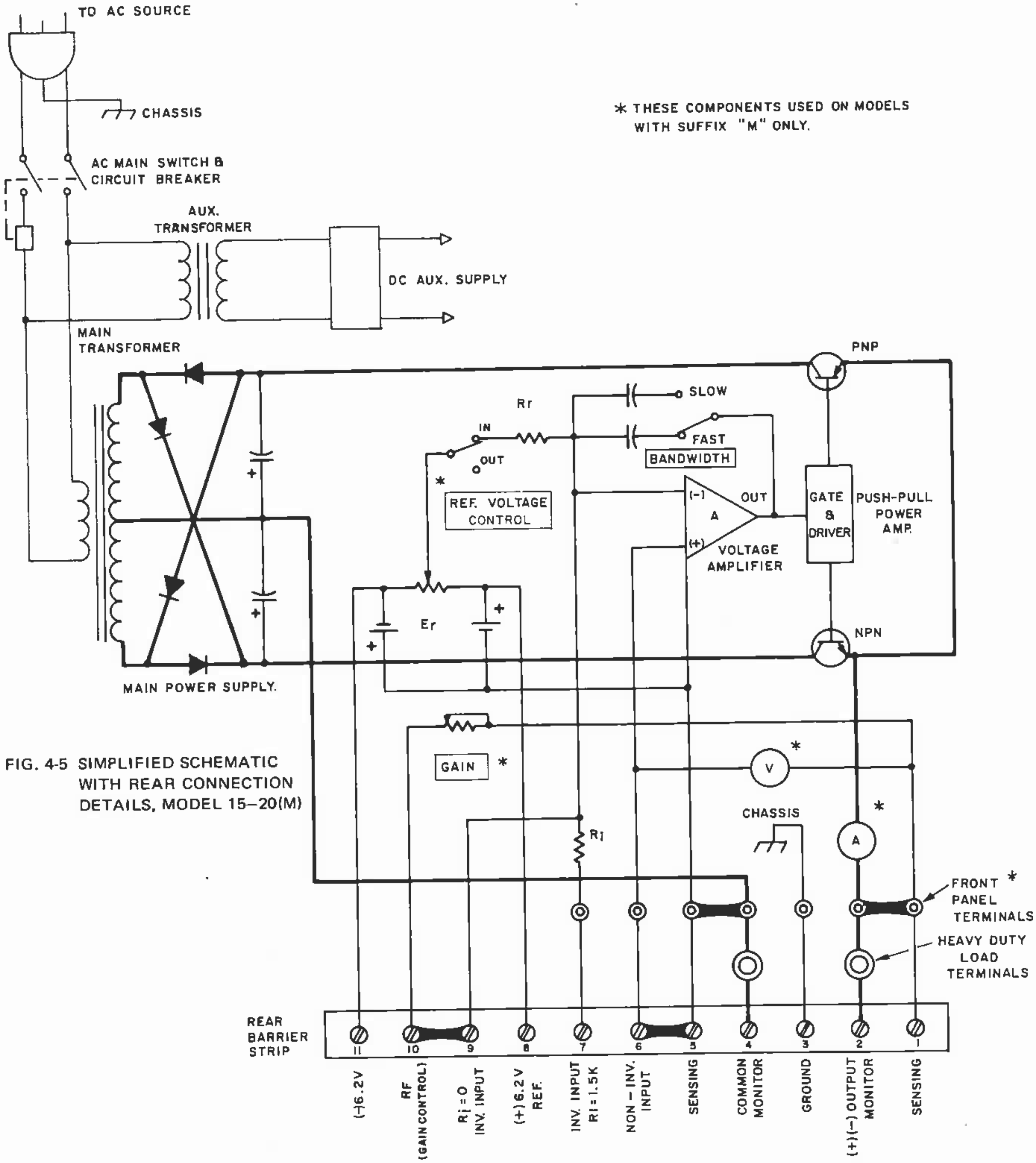


FIG. 4-5 SIMPLIFIED SCHEMATIC WITH REAR CONNECTION DETAILS, MODEL 15–20(M)

4-20 CIRCUIT DESCRIPTION (Refer to Main Schematic, FIG. 6-4.)

4-21 This section contains a description of the major circuitry of the Kepco Model BOP 15–20(M) Operational Power Supply/Amplifier. The BOP consists of a full rack main chassis assembly (A2) with attached front panel and contains a total of 5 subassemblies (A1, A3, A4, A5, A6), the main power transformer (T201), the auxiliary transformer (T202), the main rectifier and filter components (C201–204, CR201–204, L201, L202), and the distribution harnesses. The subassemblies and the main chassis are interconnected by printed circuit connectors. The interconnecting diagram (FIG. 6-1) represents a symbolic illustration of all plug-in connections to the main wiring harness. The identification of all connectors coincides with that of the main schematic diagram. Any component in the main schematic can be readily traced to its location on a subassembly by means of its reference designation and the information given in the interconnecting diagram (FIG. 6-1.)

4-22 A-C INPUT CIRCUIT (Refer to Main Schematic and FIG. 4-6.)

4-23 The a-c line power is introduced through the 3-wire line cord with safety plug.* The line cord wire connected to the grounding pin of the safety plug is connected directly to the metal chassis of the BOP. If a properly grounded a-c power outlet is therefore used, safety grounding is automatically provided.

4-24 Once the a-c circuit breaker/a-c power switch (CB101) is closed, the front panel a-c power indicator (DS101) will energize, and a-c line power is applied simultaneously to the primary windings of the main transformer (T201), the auxiliary transformer (T202), and the fan motors (B201 202). The dual primary windings on the main power transformer (T201) are either connected in parallel (for 115V a-c operation) or in series (for 230V a-c operation). The auxiliary transformer and the fan motors (T202, B201, 202) are always connected to 115V a-c even if the main transformer primary connections are altered for operation on a 230V nominal a-c line.

4-25 (Refer to FIG. 4-6.) The a-c circuit breaker/a-c power switch (CB101) is a dual coil device which not only serves as a manually operated a-c power switch but also automatically disconnects both a-c line wires to and from the a-c input circuit in case of an overload. While one coil of CB101 is connected in series with a primary winding on T201, the other is connected to the overshoot prevention and thermal protection circuit. Since the primary current of the main transformer (T201) is monitored by the main sensing coil of the circuit breaker (CB101), any overload reflecting into the primary of T201 will energize the "main" coil, trip the breaker mechanism, and disconnect the a-c input source from the BOP.

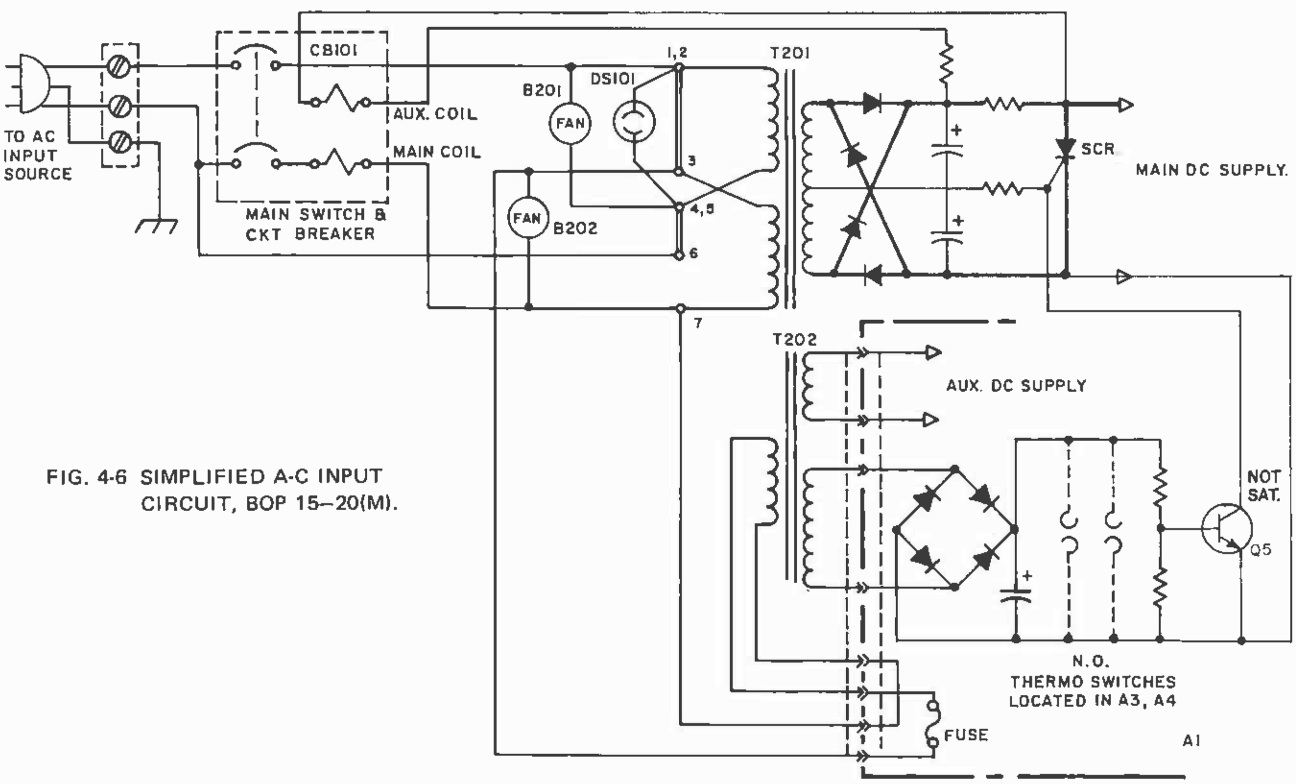


FIG. 4-6 SIMPLIFIED A-C INPUT CIRCUIT, BOP 15–20(M).

*Used on metered models (suffix "M") only. On unmetered models, which have an a-c input barrier-strip, terminal "G" must be returned to a-c ground.

4-26 The "auxiliary" coil of CB101 energizes and trips the circuit breaker on conducting of the SCR across the main d-c supply. The SCR is controlled by the switching transistor (Q1) which is biased into saturation on "turnon" of the BOP, thus holding the SCR in the nonconducting state. If the a-c input power should be interrupted for any reason (power failure, shutdown, etc.), or if the thermal switches in the power transistor heat sinks should close (overtemperature condition), Q1 goes out of saturation, thus providing a turnon signal for the SCR. The resulting current flow through the SCR will energize the "auxiliary" coil of CB101, the breaker mechanism will trip, and the BOP will be disconnected from the a-c input source. The SCR will keep conducting until the input capacitors (C201 through C206) are discharged, thus preventing immediate turnon after shutdown and associated large "overshoot" voltage.

4-27 MAIN D-C SUPPLIES

4-28 The d-c output power is derived from a center-tapped secondary winding on the main transformer (T201). A bridge type rectifier circuit (CR201–204) in combination with dual "Π" filter section (C201, 202, L201, C205 for the positive section; C203, 204, L202, C206 for the negative section) provides the negative and positive unregulated voltages for the push-pull amplifier stage. The filter sections are paralleled by "bleeder" resistors (R201, 202). The dual main d-c supplies are the source for the output current, delivered via the push-pull amplifier stage.

4-29 PUSH-PULL AMPLIFIER AND DRIVER ASSEMBLIES

4-30 The power transistors for the push-pull amplifier and driver stages are located on separate heat sinks (A3–NPN amplifier and driver stage, A4–PNP amplifier and driver stage) cooled by fans (B201, 202) and protected by thermal cutout switches (S301, S401). The power transistors are connected as a single-ended, push-pull amplifier stage and biased for class AB operation. The NPN/PNP complementary circuitry eliminates the need for an inverting stage. The NPN type power transistors (Q301–311) are in series with the positive, unregulated d-c source while the PNP type power transistors (Q403–413) are in series with the negative, unregulated d-c source.

4-31 The push-pull output stage is driven by the principal driver stage (Q314) which is connected as an emitter-follower, therefore having no voltage gain. The necessary operating bias for class AB operation is provided by the constant current stage (Q401). The series-connected silicon diodes keep the quiescent current constant with changes in junction temperature since they are thermally coupled with the output transistors while tracking their V_{BE} voltages.

4-32 CURRENT LIMITING

4-33 Bipolar output requires current limiting when the output is positive (NPN power transistors conducting) as well as when the output is negative (PNP power transistors conducting) with respect to the common output lead. For this reason a dual current limit stage is used in the BOP which senses the output current across the sensing resistor (R205). Increasing output current produces an increasing voltage drop across the sensing resistor (R205). The current limit adjustments (R29 – "I_O Limit, NPN and R30 = I_O Limit, PNP) and preadjusted such that the current limit stages are biased "on" if output current produces a voltage drop corresponding to the maximum rated output current value. The PNP limit stage (Q6) acts on positive sensing voltage drops and the NPN stage (Q5) on negative sensing voltage drops. The negative stage (Q5) acts via an "OR" gate circuit directly on the drive to the push-pull stage, reducing the drive current and thereby the positive output current. The positive stage (Q6) responds to overcurrent in the PNP (negative output) power transistors. Its turnoff signal is amplified by Q2 and acts on the constant current stage (Q401) in the push-pull amplifier, thus reducing the output current in the process.

4-34 VOLTAGE AMPLIFIER SECTION

4-35 Since the push-pull output stage has large power gain but no voltage gain, the main amplifier (A_V) must produce the full output voltage swing of the BOP (±15V). The amplifier is a plug-in type integrated circuit differential device, operating into a constant load (constant current source, Q4) via the diode gate circuit (CR8, 9). Both inputs (±IN) are terminated at the rear barrier-strip (TB601) and at the front binding posts (BOP models with suffix "M" only). One inverting input (R_i = 4 K) provides the necessary input resistor which, with the built-in gain control (BOP models with suffix "M" only), will yield a gain range from zero to ten. The main amplifier is d-c compensated for the initial offsets by the built-in offset controls (E_{io} Null – R503, I_{io} Null – R504) which are recessed and adjustable through openings in the front panel. The amplifier is frequency-compensated by a fixed capacitor (C10) and its bandwidth can be restricted by the "programming speed" switch (S1) which introduces an additional feedback capacitor (C11) and an output lag network (C4, R9) in the SLOW position.

4-36 The d-c bias and reference circuitry consists of two temperature compensated zener sources (part of all BOP models) and the control circuitry (BOP models with suffix "M" only). The bias or reference control (R101) is connected between two extremely stable (±6.2V) d-c current sources in the form of zener diodes (CR9, 10). These bias or reference voltages are available at the rear barrier-strip (TB601) and on the front panel (models with suffix "M" only) and may be used for continuous d-c output control (through zero), d-c signal biasing, or level shifting. The reference switch (S101 – models with suffix "M" only) connects the d-c bias or reference sources to and from the null junction (- INPUT) of the amplifier.

4-37 The GAIN AND REF. controls, contained in metered BOP models only, may be connected to the rear barrier-strip in the unmetered version of the BOP since all necessary circuit points have been terminated at the rear barrier-strip of the BOP.

4-38 AUXILIARY CIRCUITRY

4-39 AMPLIFIER POWER SUPPLY. This d-c source provides the operating voltage for the main amplifier, the d-c bias or the reference sources, and the current limit stages. The supply is derived from a secondary winding on the auxiliary transformer (T202). Rectified by a bridge rectifier (CR3) and capacitor-filtered (C6), the d-c voltage is preregulated by zener diodes (CR4, CR10 and CR11) and applied to the integrated circuit regulator (IC–1) with current booster transistor (Q3). The voltage adjustment (R16 – "V_{CC} Adj.") allows the setting of the regulated d-c output voltage.

4-40 PROTECTIVE CIRCUITRY. (Refer also to FIG. 4-6.) Aside from the current limiting circuits (see par. 4-32), additional circuitry has been provided in the BOP to protect the instrument from thermal overload and the external load from the output voltage overshoot at a-c input source shutdown or power failure. A silicon controlled rectifier SCR – CR205) is connected across the unregulated main d-c source and controlled by a sensing circuit consisting of the sensing transistor (Q1) and a bias supply derived from the auxiliary transformer (T202). Q1 is an NPN transistor which is biased for saturation via the bias supply consisting of the bridge rectifier (CR1), filter capacitor (C1), and the voltage divider (R1, 2). Since the collector and emitter of Q1 are connected between gate and cathode of the SCR crowbar (CR205), the latter has very little forward bias and is normally "off." As soon as a sufficient voltage drop is sensed in the voltage divider (originating from power turnoff or failure), or as soon as one or both of the thermal sensing switches close (as a result of excessive temperature), Q1 goes out of the saturated condition, thus producing a positive turnon signal for the SCR crowbar (CR205). As the SCR conducts, the auxiliary coil of the circuit breaker/mainswitch is energized due to the heavy current flow, and the breaker mechanism trips, removing a-c power from the BOP. IMMEDIATE TURNON OF THE BOP IS PREVENTED BY A TIME DELAY (approximately 2 seconds) until the main filter capacitors are discharged. The delay is due to the continuing current flow through the SCR, keeping the auxiliary circuit breaker coil energized until most of the capacitor energy has been discharged.

SECTION V – MAINTENANCE

5-1 GENERAL

5-2 This section covers maintenance procedures and calibration of the BOP Operational Power Supply/Amplifier as far as not covered previously in this manual. Conservative ratings of components and noncongested layout should keep maintenance to a minimum. If trouble does develop, however, the easily removed wrap-around cover in conjunction with the plug-in feature of all major component boards provide exceptional accessibility of the circuitry.

5-3 COVER REMOVAL

5-4 The wrap-around cover may be readily removed by loosening the four (4) holding screws on the top of the front panel, the five (5) holding screws on each side of the unit and two (2) holding screws on the rear of the cover.

5-5 PERIODIC MAINTENANCE

5-6 The fan motors in the BOP units have permanently lubricated bearings and do not require maintenance. The inside of all BOP's should be cleaned periodically to insure full cooling efficiency.

5-7 INTERNAL ADJUSTMENTS

a) CURRENT LIMIT CONTROLS. The output current limit controls (R29, R30) are factory-adjusted to limit the output current at 10% above the maximum rated value. Calibration is necessary only if components associated with the current limit circuitry have been replaced or if a lower limit is desired. The current limits are individually adjustable in the range from 65% to 110% of the maximum rated output current. The current limit potentiometers are located on the amplifier printed circuit board (PCB 1-A1, see FIG. 2-3 for location) and are readily accessible from the top of the unit. Adjustment takes place as follows:

1) Connect BOP as a power supply for negative output. Connect load so that the desired output current (plus 10%) is drawn from the unit.

2) Observe output ripple on the oscilloscope across the load. Turn "I_O Limit" control (R30) counterclockwise until the output ripple sharply increases. (This is the point at which current limiting takes place.) Turn R30 slightly clockwise until the output ripple appears just normal again.

3) Repeat above procedure by transferring to a positive output and adjusting R29 as described above. The current limit is now set to the new value.

5-8 TROUBLE SHOOTING

5-9 The repair of precision power supplies and operational amplifiers requires a thorough understanding of the operational concept, experience with solid-state circuitry and appreciation of the problems encountered in closed-loop systems. Repair beyond simple part replacement and recalibration should therefore be handled only by personnel familiar with these concepts. "Trouble Shooting Charts" giving resistance and voltage ratings at various parts in the circuitry are of little value in feedback amplifiers and for this reason are not included here. Presented instead are:

a) Extensive Operational Theory (Section IV).

b) Parts Location Diagrams (Section VI).

c) Main Schematic with Voltage Readings on All Essential Points (Section VI).

d) Parts List (Section VI).

e) Circuit Description (Section IV).

It has been our experience that this material will provide the necessary information in the majority of all cases of equipment failure. The following basic trouble-shooting steps may also be found helpful:

a) Disconnect BOP from the a-c input source, from the load and from all auxiliary sources such as input signal generators, etc.

b) Restore ***ALL*** jumper links on the rear barrier-strip and reconnect BOP to a-c power input.

c) Perform the PRELIMINARY ELECTRICAL CHECK, as described in Section II of this manual. If the BOP functions as described in this operating mode, the trouble or malfunction must be traced to external causes or interface problems. Check all interconnecting wires between the input sources and the BOP and all load and error-sensing wiring between the BOP and the load. If the BOP does ***not*** function in the standard power supply mode, determine the failure mode (no output, high output or poor performance) and check as follows:

d) NO OUTPUT. Check a-c input source for prevailing line voltage. Refer to A-C INPUT REQUIREMENTS as presented in Section II of this manual and check if the BOP main transformer connections are correct. (BOP is normally delivered for 115V a-c service.) Check fuse (or circuit breaker) and restore if open. NOTE: THERE IS A 2-SECOND TIME DELAY AFTER EACH A-C TURN-OFF. SEE NOTE AT END OF SECTION II IN THIS MANUAL.

e) HIGH OUTPUT. Often indicative of an open feedback loop. Recheck correct placement of error-sensing links, ***either*** at the front ***or*** at the rear (NOT both). High or unstabilized output is always accompanied by excessive output ripple and often the output voltage cannot be controlled by the standard panel (or external) controls. Localize the problem as follows:

   1) Remove BOP cover and locate the TEST POINT (J1) on the main amplifier board (A1—refer to "Component Location, Main Amplifier Board A1" in Section V of this manual). Disconnect ***both*** mating jacks from the main heat sink and one mating jack from the driver assembly (not used in BOP 36–1.5) (A4, A5—refer to "Component Location, Main Chassis" in Section V of this manual).

   2) Connect a short lead from the TEST POINT to the "Output Sensing" terminal (NOT to the "Common sensing" terminal). If the output of the BOP can now be controlled by the GAIN and the REF controls, as evidenced by observing the front panel meter (or connecting a suitable voltmeter to the output terminals), the voltage amplifier (including predriver stage) is operating correctly and can be eliminated from further analysis. In these cases, the main driver and output stages, located on separate heat sinks (A4, A5 in all models except BOP 36–1.5(M) where A5 is not used and the driver is located together with the output stages on the A4 assembly) must be thoroughly investigated for burned components and/or shorted power transistors.

   3) If the BOP cannot be controlled locally when by-passing the main driver and output stages, as described in par. 5-9e2 above, proceed with circuit analysis by means of the "Main Schematic" (Section VI in this manual). Measure all relevant voltages and compare with listed values. Inspect printed circuit board for visual evidence of damaged components. Test transistors and repair defective components as required.

f) POOR PERFORMANCE. If the BOP is basically functioning but poor performance is evident, reinspect all external connections and test the instrument by following the instructions in the PERFORMANCE MEASUREMENTS paragraph (Section V in this manual). Poor d-c performance (excessive output effects) is often due to incorrectly connected load, instrumentation or faulty measurement techniques. Follow the recommended procedures closely and refer to the applicable diagrams. High-frequency oscillations, as observed at the output or across the load, is often due to excessive capacitive loads, when the BOP is operated in the FAST mode. Transferring the MODE switch (S1—refer to "Component Location, Main Amplifier Board A1," Section V in this manual) to the SLOW position should eliminate this condition and make the BOP stable for any load condition.

g) KEPCO FIELD ENGINEERING OFFICES AND THE KEPCO REPAIR AND APPLICATIONS ENGINEERING DEPARTMENTS ARE ALWAYS AVAILABLE FOR PROMPT SERVICE IN DIFFICULT REPAIR OR APPLICATION CASES.

5-10 TEST MEASUREMENTS

5-11 GENERAL. Test measurements to verify the specifications of the operational power supply are often required as a part of incoming inspection, following repairs, or as a part of a regular maintenance procedure. Adequate test facilities and equipment as well as great care in the performance of these measurements are of prime importance to insure valid results. Since many measurements on operational power supplies and amplifiers require specialized test equipment and rigidly controlled environment conditions, only the more readily verifiable ones are described here.

5-12 MEASUREMENT TECHNIQUES. The importance of proper interconnection of test instruments and the device under test cannot be overemphasized. Indiscriminate connection of measuring devices to the output may cause erroneous readings of d-c output effects, offset parameters or output impedance. The following recommendations should therefore be followed when measurements are to be performed.

a) Connect equipment exactly as shown on the measurement setup diagrams (FIGS. 5-1, 5-2, 5-3). Do not attempt to measure performance characteristics at the front terminals while drawing load current from the rear terminals (or vice versa).

b) Output current measurements require the use of a high quality, wirewound measuring resistor which should be of the four-terminal type and have a low temperature coefficient as well as a wattage rating of at least ten times the actual power dissipated (TEPRO Type TMK or equivalent).

c) Ripple and noise measurements require the strict adherence to sensible equipment grounding practices. There can be only one ground point in a test setup. All equipment is therefore operated off line ground, the equipment cases or ground connections brought to the unit under test, and the latter is then grounded at a single point.

5-13 TEST EQUIPMENT REQUIRED. The following represents a listing of equipment required to perform the suggested performance tests:

a) LINE STEP DEVICE OR VARIABLE TRANSFORMER capable of adjusting the power line from 105V to 125V a-c and rated to deliver the maximum input current for the instrument under test.

b) RESISTOR LOAD, adjustable to load the power supply to 10%, 50% and 100% in both voltage and current operating modes and equipped with a shorting switch.

c) VOLTAGE MONITOR. Differential or digital voltmeter with a resolution of at least 1 mV and a range covering the maximum output voltage of the instrument under test.

d) RMS READING VOLTMETER for ripple monitoring, Ballantine Model 320A or its equivalent.

e) OSCILLOSCOPE for output ripple observance, Tektronix Model 502B or equivalent. (Optional)

f) MULTIMETER for measuring pass element voltage and general trouble shooting measurements. 20 K ohm/V, Weston Analyzer Model 980 or its equivalent.

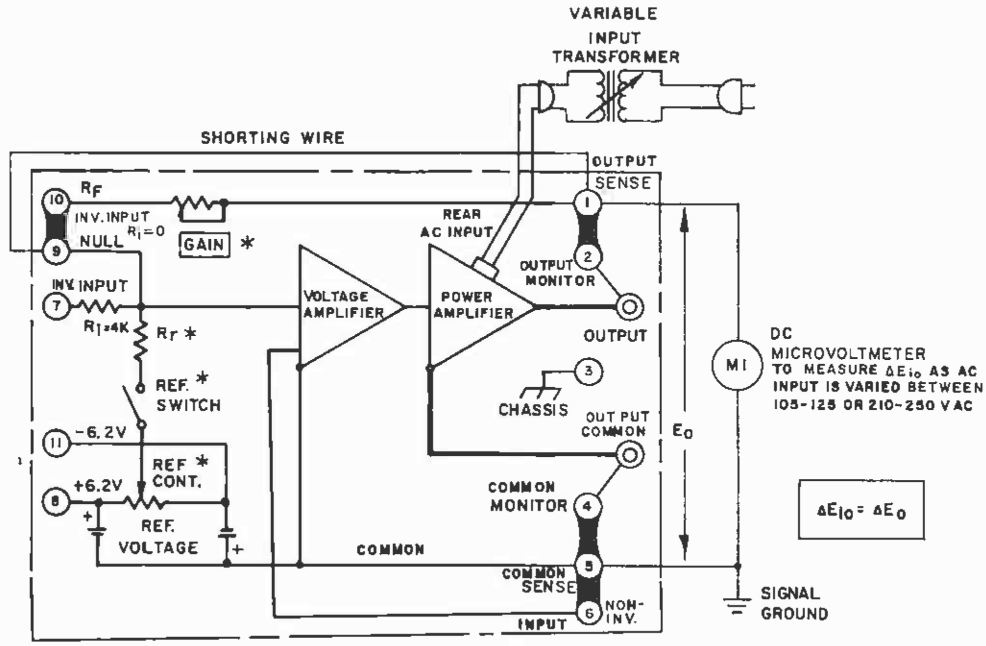
g) PRECISION D-C AMMETER with a range covering the maximum output current of the model under test. (Weston Model 931 or equivalent)

h) OSCILLOSCOPE for the measurement of the programming time constant, Tektronix Model 545A or equivalent.

i) SIGNAL GENERATOR for the measurement of the programming time constant, Hewlett Packard Model 211A or equivalent.

j) D-C MICROVOLT/AMMETER for offset measurements, Millivac Model MV-07C or equivalent.

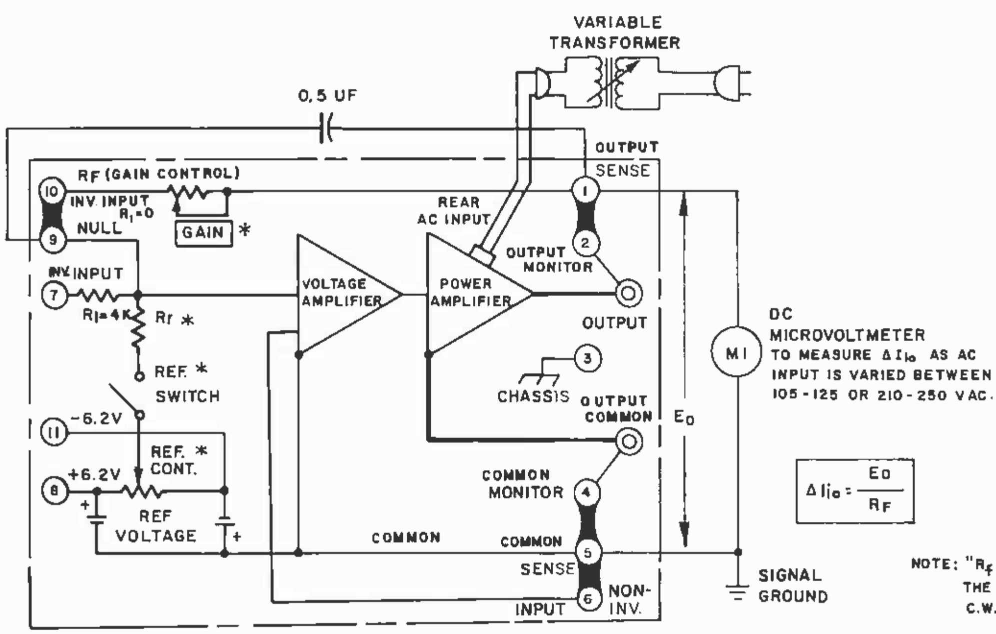
5-14 D-C MEASUREMENTS. Variations of the offset voltage (ΔE_{io}) and offset current (ΔI_{io}) with a-c input source changes over the specified range are an excellent indication of the d-c performance of the operational power supply. These measurements may be readily duplicated by following the instructions and diagrams below:



NOTES:
1) Encircled nos. are terminal designations on the rear barrier-strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.

FIG. 5-1 D-C TEST MEASUREMENTS (ΔE_{io} vs. A-C LINE).

a) Variations in Offset Voltage (ΔE_{io}). Measurements are made with the circuit shown in FIG. 5-1. Since the feedback terminals are shorted out and the input is disconnected, the operational gain is unity. Whatever offset voltage exists between null junction and common will be transferred directly to the output. Monitoring the output by means of a sensitive null detector while varying the A-C line input (or temperature or time if facilities permit) will allow measurement of ΔE_{io} at the output.



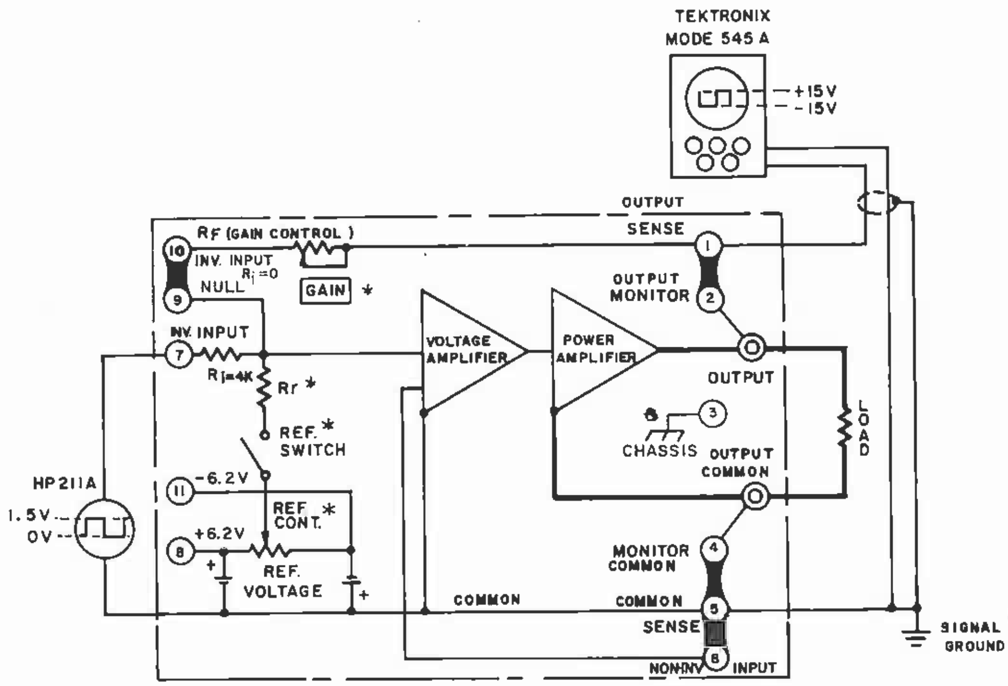
NOTES:
1) Encircled nos. are terminal designations on the rear barrier-strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.

NOTE: "R_f" IS THE RESISTANCE VALUE OF THE GAIN CONTROL = 40 K OHM FULLY C.W.

FIG. 5-2 D-C TEST MEASUREMENTS (ΔI_{io} vs. A-C LINE).

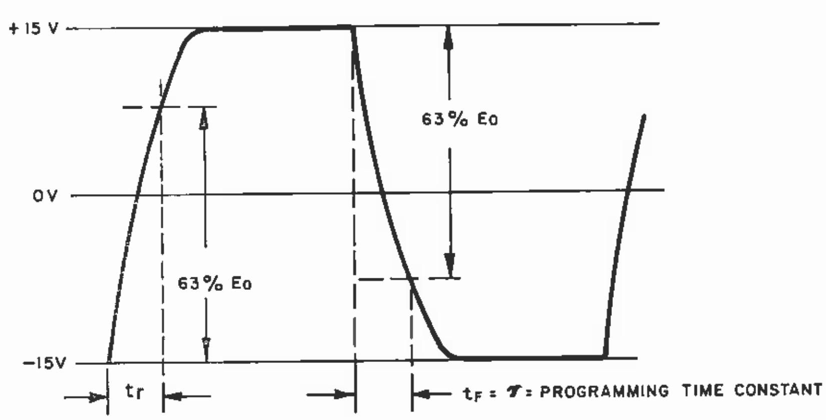
b) Variations in Offset Current (ΔI_{io}). Measurements are made with the circuit shown in FIG. 5-2. Since the offset current will have to flow through the feedback resistor, it produces an output voltage E_o which is equal to $I_{io}R_f$. If this output voltage is monitored while varying the a-c line input (or temperature or time if facilities permit) will yield an indication of ΔI_{io} when the output voltage is divided by the value of the feedback resistor.

5-15 DYNAMIC MEASUREMENTS. Measurement of the programming time constant of the BOP Operational Power Supply/Amplifier is a convenient and simple way of verifying the dynamic performance of the instrument. The programming time constant is evaluated by measuring the fall time (worst case) at the output as the BOP is programmed with a square wave for full output swing. FIG. 5-3 below illustrates the test setup and the output waveform to be expected.



NOTES:
1) Encircled nos. are terminal designations on the rear barrier-strip.
2) Components marked with "*" used on models with suffix "M" only. May be added externally on other models, if application requires.
3) Connect load to heavy duty rear binding posts, not to barrier-strip terminals.

A) TEST SET UP



B) OUTPUT WAVE FORM.

FIG. 5-3 DYNAMIC MEASUREMENTS, BOP.

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

B) Descriptive Abbreviations

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

KEPCO® REPLACEMENT PARTS LIST

AMPLIFIER ASSEMBLY (A1), MODEL BOP 15–20(M)

Code 2-2274

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
A_V	1	Amplifier,Main	Analog Devices Type 165M	250-0022	1
C1,8,9	3	Capacitor,Mylar,Metal 1 µF, 200V, 10%	Wesco Type 33MM	117-0207	1
C2,11	2	Capacitor,Mylar 0.0047 µF, 200V, 10%	Wesco Type 32M	117-0588	1
C3	1	Capacitor,Elec.,Axial Leads 150 µF, 3V, +75% - 10%	Sangamo Type 556	117-0512	1
C4	1	Capacitor,Mylar,Metal 0.5 µF, 200V, 10%	TRW Type X663F	117-0123	1
C5	1	Capacitor,Mylar,Axial Leads 0.01 µF, 200V, 20%	Sprague Type 192P	117-0353	1
C6	1	Capacitor,Elect.,Axial Leads 200 µF, 100V, +100% - 10%	Sangamo Type 052	117-0598	1
C7	1	Capacitor,Ceramic,Disc 0.005 µF, 500V, 20%	Radio Materials Type SM	117-0061	1
C10	1	Capacitor,Mica,Silver Dip 100 pF, 500V, 5%	Sangamo Type D 155	117-0673	1
C12	1	Capacitor,Mylar,Axial Leads 0.001 µF, 200V, 10%	Sprague Type 192P	117-0670	1
CR1,3	2	Rectifier,Silicon,Bridge 200V PIV, 1A	General Instruments Type W 02	124-0346	1
CR2,7	2	Stabistor Diode,Axial Leads 20V PIV, 400 mW	American Power Devices APD 203	124-0435	1
CR4,10,11	3	Zener Diode 12V, ±10%, 1 W	International Rectifier 1N1773	121-0012	1
CR5,6	2	Zener Diode 5.9V to 6.5V, 7.5 mA	International Resistance 1N821	121-0041	1
CR8,9	2	Rectifier,Silicon,Axial Leads 400V PIV, 1A	Semicon SI-4	124-0023	1
F1	1	Fuse,Slo Blo 1/16 Amp	Bussmann MDL 1/16	141-0021	5
IC-1	1	IC-Regulator, Dip	Motorola µ723C	250-0021	1
Q1	1	Transistor,Silicon,NPN Small Signal, TO-106	Fairchild 2N3569	119-0092	1
Q2	1	Transistor,Silicon,NPN Small Signal, TO-5	General Electric 2N336A	119-0056	1
Q3	1	Transistor,Silicon,PNP Small Signal, TO-5	RCA 2N4036	119-0074	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

AMPLIFIER ASSEMBLY (A1), MODEL BOP 15–20(M) Code 2-2274

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
Q4,6	2	Transistor,Silicon,PNP Small Signal,TO-105	Fairchild 2N4355	119-0076	1
Q5	1	Transistor,Silicon,NPN Small Signal,TO-5	RCA 2N3053	119-0059	1
R1	1	Resistor,Fixed,Molded 15 k ohm, 1/2 W, 10%	Allen Bradley EB1531	115-1152	1
R2,8	2	Resistor,Fixed,Molded 1 k ohm, 1/2 W, 10%	Allen Bradley EB1021	115-0547	1
R3,6	2	Resistor,Fixed,Power,Axial 1 k ohm, 5 W, 5%	Tepro Type TS-5W	115-0512	1
R4	1	Resistor,Fixed,Power,Axial 5 ohm, 5 W, 5%	Hardwick Hindle 1WA-46-5	115-0516	1
R5,9	2	Resistor,Fixed,Molded 100 ohm, 1/2 W, 10%	Allen Bradley EB1011	115-0626	1
R7	1	Resistor,Fixed,Molded 51 ohm, 1/2 W, 5%	Allen Bradley EB5105	115-0940	1
R10	1	Resistor,Fixed,Power,Axial 2.5 k ohm, 3 W, 5%	Hardwick Hindle Type 742	115-0469	1
R11	1	Resistor,Fixed,Molded 1 k ohm, 2 W, 10%	Allen Bradley HB1021	115-0179	1
R12	1	Resistor,Fixed,Molded 2.4 k ohm, 1/2 W, 5%	Allen Bradley EB2425	115-0795	1
R13,14	2	Resistor,Fixed,Precision,M.F. 1.5 k ohm, 1/4 W, 1%	Dale Type MFF 1/4	115-1838	1
R15	1	Resistor,Fixed,Precision,M.F. 48.7 k ohm, 1/4 W, 1%	Dale Type MFF 1/4	115-1812	1
R16	1	Resistor,Variable,Cermet 500 ohm, 3/4 W, 20%	Beckman 78PR500	115-2063	1
R17	1	Resistor,Fixed,Precision,M.F. 3.32 k ohm, 1/4 W, 1%	Dale Type MFF 1/4	115-1844	1
R18,19	2	Resistor,Fixed,Precision,M.F. 287 ohm, 1/4 W, 1%	Dale Type MFF 1/4	115-1891	1
R20	1	Resistor,Fixed,Molded 51 k ohm, 1/2 W, 5%	Allen Bradley EB5135	115-0939	1
R21,22	2	Resistor,Fixed,Precision,M.F. 3.01 k ohm, 1/4 W, 1%	Dale Type MFF 1/4	115-1852	1
R23	1	Resistor,Fixed,Precision,M.F. 511 ohm, 1/8 W, 1%	Dale Type MFF 1/8	115-2260	1
R24	1	Resistor,Fixed,Precision,M.F. 232 ohm, 1/4 W, 1%	Dale Type MFF 1/4	115-1953	1
R25,26	2	Resistor,Fixed,Precision,M.F. 10 k ohm, 1/4 W, 1%	Dale Type MFF 1/4	115-1821	1
R27	1	Resistor,Fixed,Molded 20 k ohm, 1/2 W, 5%	Allen Bradley EB2035	115-0555	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

AMPLIFIER ASSEMBLY (A1), MODEL BOP 15–20(M) — **Code 2-2274**

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
R28,33	2	Resistor,Fixed,Molded 220 ohm, 1/4 W, 10%	IRC Type GBT 1/4	115-2227	1
R29,30	2	Resistor,Variable,Cermet 10 ohm, 3/4 W, 30%	TRW Type 450-20	115-2062	1
R31,32	2	Resistor,Fixed,Molded 5.1 ohm, 1/2 W, 5%	Allen Bradley EB51G5	115-1359	1
R34	1	Resistor,Fixed,Precision,M.F. 499 k ohm, 1/8 W, 1%	Dale Type MFF 1/8	115-2309	1
*R35	1	Resistor,Fixed,Precision,M.F. 15 k ohm, 1/4 W, 1%	Dale Type MFF 1/4	115-1813	1
R36,37	2	Resistor,Fixed,Power,Axial 500 ohm, 3W, 5%	Tepro Type TS-3C	115-0459	1
S1	1	Switch,Slide DPDT	Stackpole Type SS-50	127-0279	0

*Models with suffix "M" only.

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

MAIN CHASSIS ASSEMBLY (A2), MODEL BOP 15–20(M)

Code 2-2274

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
FRONT PANEL ASSEMBLY:					
CB101	1	Circuit Breaker,2 Pole	Heinemann JA2A6A3	127-0286	1
*CR101	1	Copper Oxide,Rectifier,Bridge	Weston Type D89368	125-0003	1
DS101	1	Pilot Light Assembly 115V a-c	Industrial Devices Type IV	152-0089	3
*M101	1	Meter,Volt,Midscale Zero 15V–0–15V	Ammon Type FM-2	135-0467	0
*M102	1	Meter,Amp,Midscale Zero 20A–0–20A	Ammon Type FM-2	135-0466	0
*R101	1	Resistor,Variable,WW 1 k ohm, 3 W, 3%	IRC Type 8000	115-1304	1
*R102	1	Resistor,Variable,WW 40 K ohm, 3 W, 3%	Fluke Mfg. Type 24A-5044	115-2366	1
*R103	1	Resistor,Fixed,Precision,M.F. 13 k ohm, 1/4 W, 1%	Dale MFF 1/4	115-1909	1
*S101	1	Switch,Slide,SPST	Stackpole Type SS-47	127-0278	0
*S102	1	Switch,Slide,3DPDT	UID Electronics Type SW332	127-0282	0
B201,202	2	Fan,Motor	Howard Industries Type 23112	148-0027	1
NONE	2	Fan Blade	Howard Industries 149-0023	149-0023	1
C201,202,203, 204,205,206	6	Capacitor,Electrolytic,Can 35 k μF, 35V d-c,+100%-10%	Sangamo Type 500	117-0762	2
CR201,202	2	Rectifier,Silicon 140V PIV, 40A	International Rectifier Type 40 HF 20	124-0354	1
CR203,204	2	Rectifier,Silicon 200V PIV, 40A	General Electric 1N1186R	124-0210	1
CR205	1	Rectifier,Silicon,Controlled 150V PIV, 16A	General Electric Type C35A	124-0167	1
L201,202	2	Choke,Filter	Kepco Magnetics 100-1901	100-1901	1
R201,202	2	Resistor,Fixed,Power,Axial 3 k ohm, 3 W, 5%	Tepro Type TS-3C	115-1188	1
R203,204	2	Resistor,Fixed,Power,Strip 3 ohm, 55 W, 5%	Ward Leonard Type 55S3	115-0691	1
R205	1	Resistor,Fixed,Power,Strip 0.05 ohm,50 W 1%	Tepro Type TMK-50W	115-2355	1
T201	1	Transformer,Main	Kepco Magnetics 100-1900	100-1900	1
T202	1	Transformer,Auxiliary	Kepco Magnetics 100-1902	100-1902	1

*Used on models with suffix "M" only.

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

PASS ASSEMBLY (A3), MODEL BOP 15–20(M)

Code 2-2274

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
CR301,302	2	Rectifier,Silicon,Pigtail 400V PIV, 0.5A	Semicon Type SI-4	124-0028	1
Q301,302,303 304,305,306, 307,308.309, 310,311,312	12	Transistor,Silicon,NPN Power, T0-3	Solid Power 119-0061	119-0061	3
Q313	1	Transistor,Silicon,NPN Power, T0-66	RCA 2N5202	119-0100	1
R301,302, 303,304,305 306,307,308, 309,310,311	11	Resistor,Fixed,Power,Axial 0.4 ohm,3 W, 5%	Tepro Type TS-3W	115-1751	2
R313	1	Resistor,Fixed,Molded 51 ohm, 1/2 W, 5%	Allen Bradley EB5105	115-0940	1
S301	1	Switch,Thermostat,N.O. 260°F	Stemco 110486	127-0248	0

PASS ASSEMBLY (A4):

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO.	KEPCO PART NO.	REC. SPARE PART QTY.
C401	1	Capacitor,Mica,Silver Dip 2200 pF, 500V, 5%	Sangamo Type D 195	117-0784	1
CR401,402	2	Rectifier,Silicon,Pigtail 400V PIV, 0.5A	Semicon Type SI-4	124-0028	1
Q401	1	Transistor,Silicon,NPN Power, T0-66	RCA 2N3054	119-0060	1
Q402,403,404 405,406.407, 408.409,410 411,412,413	12	Transistor,Silicon,PNP Power, T0-3	Motorola 119-0113	119-0113	3
R401	1	Resistor,Fixed,Power,Axial 30 ohm, 3 W, 5%	Tepro Type TS-3C	115-0773	1
R402,403 404,405,406, 407,408,409, 410,411,412	11	Resistor,Fixed,Power,Axial 0.4 ohm, 3 W, 5%	Tepro Type TS-3W	115-1751	2
S401	1	Switch,Thermostat,N.O. 260°F	Stemco 110486	127-0248	0

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

OFFSET ADJUSTMENT ASSEMBLY (A5), MODEL BOP 15–20(M)

Code 2-2274

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C503	1	Capacitor,Elect.,Axial Leads 150 μF, 3V, +75% – 10%	Sangamo Type 052	117-0757	1
CR503,504	2	Rectifier,Silicon,Axial Leads 100V PIV, I_f = 5 μA at 0.5V	Solitron 124-0178	124-0178	1
C502	1	Capacitor,Mylar,Axial Leads 0.1 μF, 600V, 10%	TRW Type X663F	117-0316	1
R501	1	Resistor,Fixed,Molded 10 ohm, 1/2 W, 10%	Allen Bradley EB1001	115-0502	1
R502	1	Resistor,Fixed,Power,Axial 4 k ohm, 1 W, 1%	Tepro Type TS-1W	115-1637	1
R503	1	Resistor,Variable,WW 50 k ohm, 1 W, 5%	IRC Type 400-20	115-2362	1
R504	1	Resistor,Variable,WW 20 k ohm, 1 W, 5%	IRC Type 400-20	115-2363	1
*R505	1	Resistor,Fixed,Power,Axial 1 k ohm, 3 W, 5%	Tepro Type TS-3C	115-1302	1

*Note used in BOP models with suffix "M"

MISCELLANEOUS PARTS:

TB601	1	Barrier-Strip, 11 Terminal		167-0627	0
	2	Binding Post, Black*		151-0026	0
	2	Binding Post, Black*		151-0057	0
	1	Binding Post, Blue*		151-0027	0
	1	Binding Post, Green*		151-0058	0
	1	Binding Post, Red*		151-0025	0
	1	Binding Post, White*		151-0029	0
	2	Binding Post, Yellow*		151-0059	0
	1	Control Knob, Large*		155-0046	0
	1	Control Knob, Locking Type*		155-0047	0
	1	Control Knob, Small*		155-0048	0
	1	Handle Assembly*		139-0197	0
	1	Line Cord*		118-0506	0

*Not used in BOP models with suffix "M" only.

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

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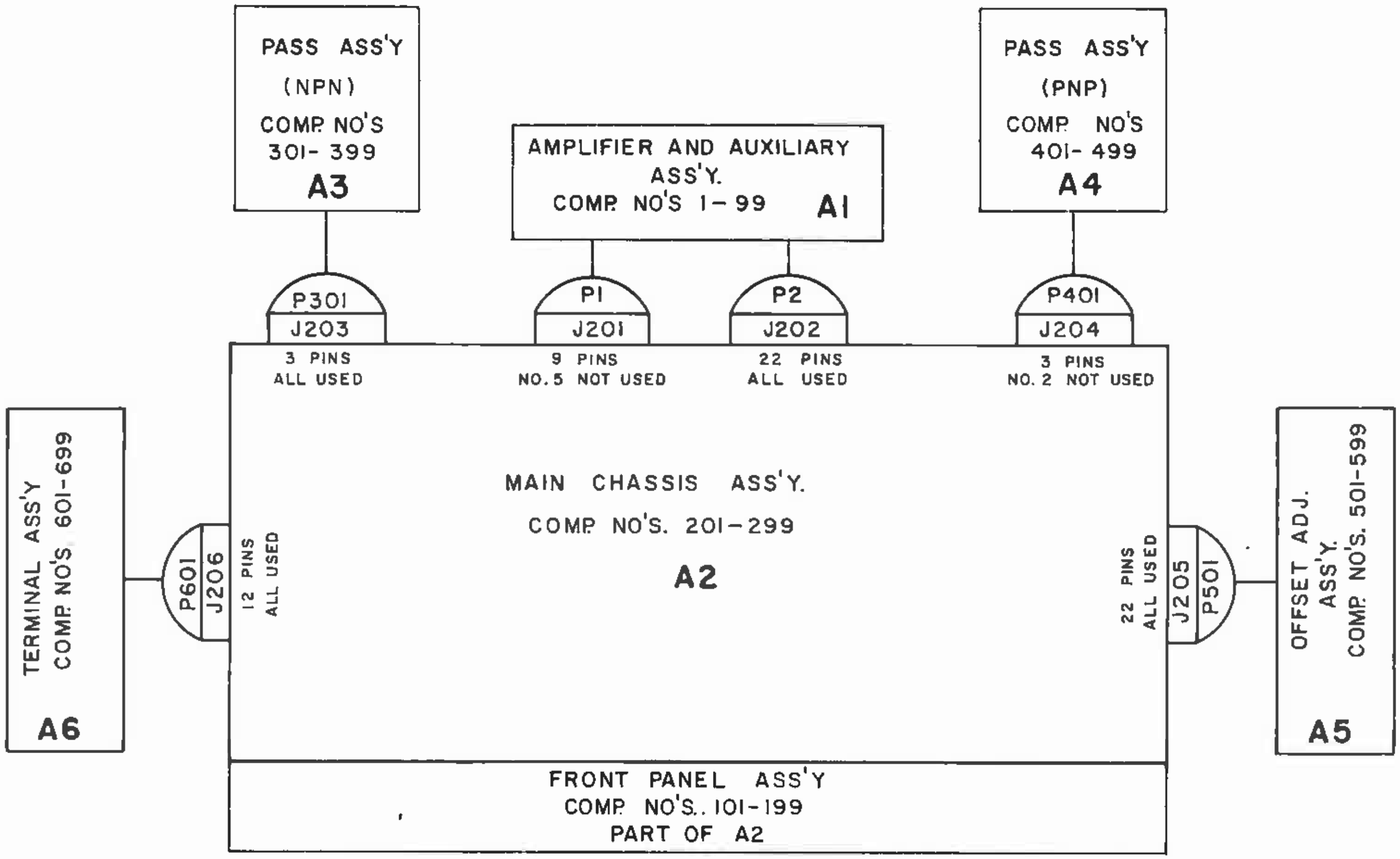
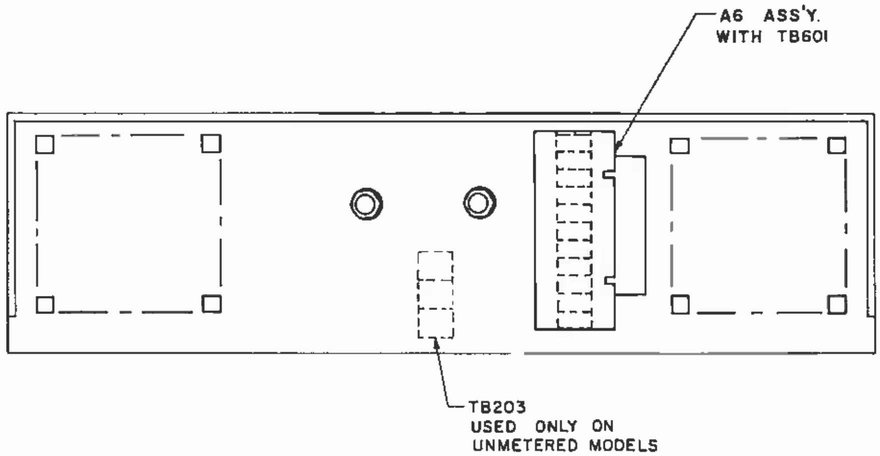
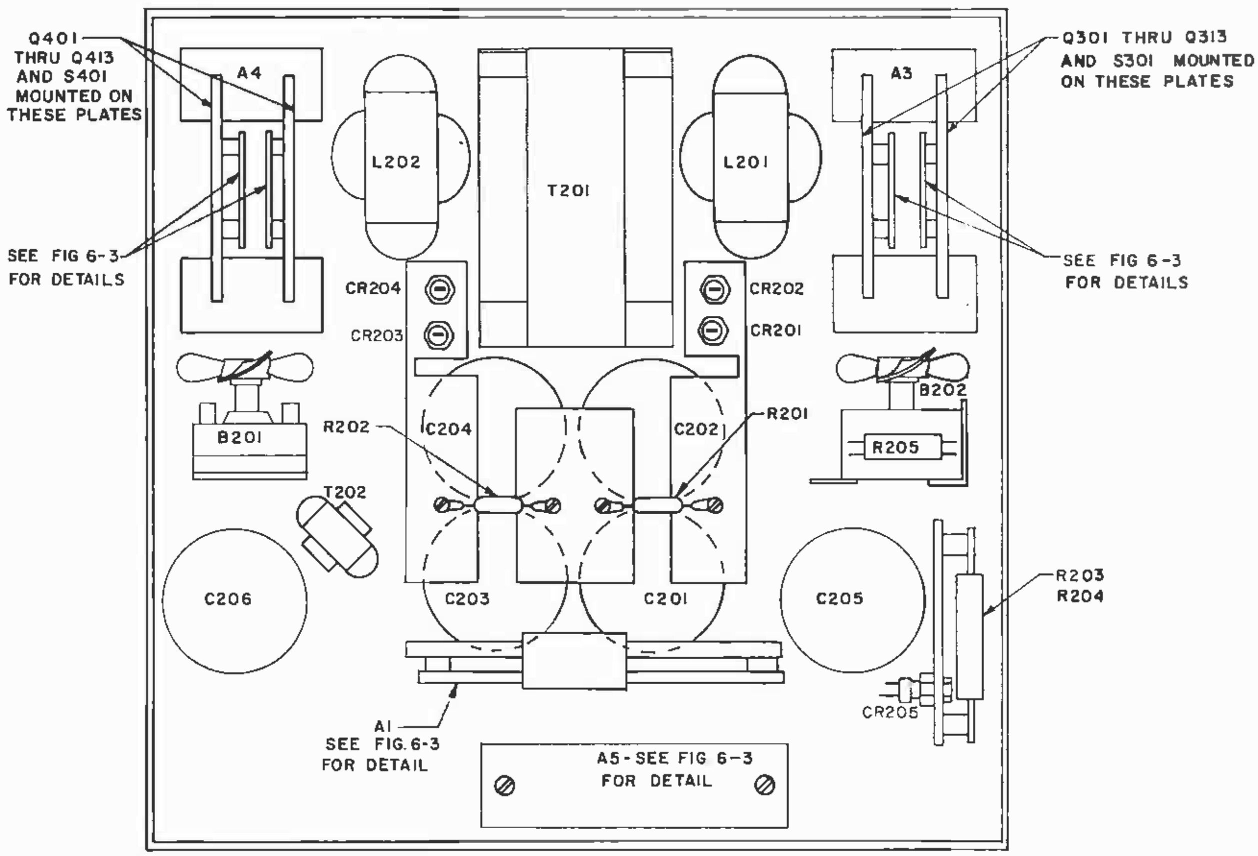


FIG. 6-1 PLUG-IN DIAGRAM, MODEL BOP15-20(M)





NOTE. FRONT PANEL (REAR VIEW)
BINDING POSTS, M101, M102, R101, R102, R103, CR101, S101 AND S102
ARE NOT USED ON UNMETERED MODELS

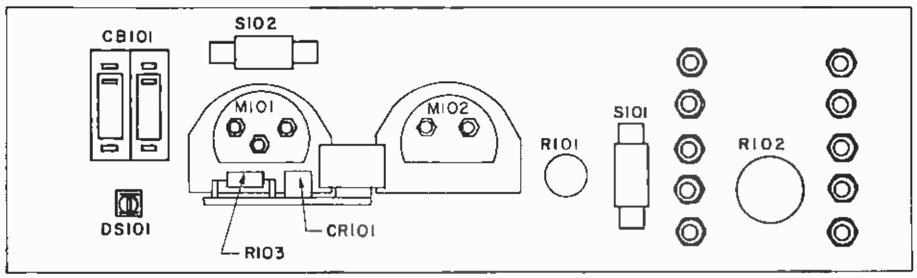


FIG. 6-2 COMPONENT LOCATION, MAIN CHASSIS

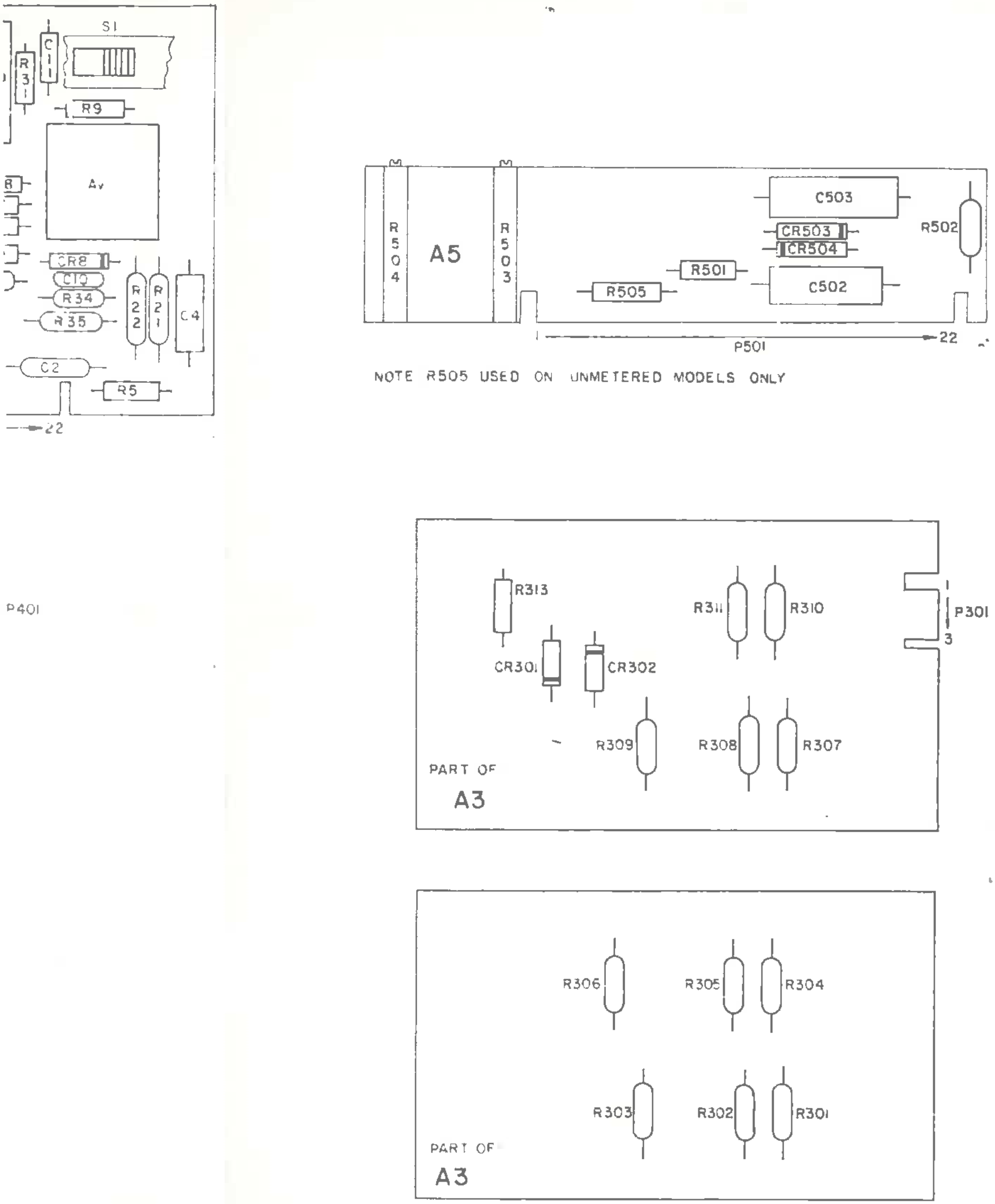


FIG 6-3 COMPONENT LOCATION, ASSEMBLIES A1, A3, A4, A5.

ENGINEERING ...GE NOTICE

MODEL NO. BOP15-20 REVISION NO. 7 CHANGE NOTICE NO. 4826 DATE: 7-10-81

CODE NO. 02320 REVISION ORDER NO. C52623 REQUESTED BY: S.N. AUTHORIZED BY: K.K.

MAKE CHANGE EFFECTIVE: ______ UNITS IN STOCK [ ] UNITS IN PRODUCTION [X] FUTURE PRODUCTION [X]

PRODUCTION ORDERS AFFECTED: (10)A47196, (20)A49444

RECOMMENDED FIRST RUN QUANTITY:

REASON FOR CHANGE: TO INCREASE RELIABILITY OF THE UNIT.

REMARKS:

ADD

QUAN.	KEPCO #	SCHEM #	LEVEL	DESCRIPTION	IN STOCK QUANTITY
1	115-1411	R206	124-0423	Resistor, Fixed, Power, Strip 2 ohm, 10W, 5% — Hardwick Hindle 3/4 BRS-56-2 1) A wire to DC Harness 241-0547 BK-#18GA-29" long from CB101-C2 to R206-1 which are from harness stations (28) to (31) respectively. 2) A jumper R-#18 GA-2¼" long from R206 - 2 to R204-2 on the 124-0422 assembly	

DELETE

QUAN.	KEPCO #	SCHEM #	LEVEL	DESCRIPTION
1	115-0633	R4	235-0533	Resistor, Fixed, Power, Axial 2 ohm, 5W, 5% A wire FROM D.C.Harness (241-0547) BK-#18-GA from CB101-2 (Station 28) to J202-12 Corr.Page Searm Makeup

RECOMMENDED PART SUBSTITUTES:

228-0085

CR.

KEPCO®

INSTRUCTION MANUAL CORRECTION

Please note the following corrections to the Manual Material as indicated:

PARTS LIST AND SCHEMATIC DIAGRAM:

1) CHANGE:	R4	Res.,Fxd.,Power,Ax,W.W.	5 ohm,5W,5%	Kepco P/N 115-0516
TO:	R4	Res.,Fxd.,Power,Ax,W.W.	2 ohm,5W,5%	Kepco P/N 115-0633

2) ADD:	C207	Capacitor,Mylar,Met.,Axial	0.1uf,200V,10%	Kepco P/N 117-0363

Note: C207 is connected between the anodes of CR201 and CR202.

3) CHANGE:	R4	Res.,Fxd.,Power,Ax,W.W.	2 ohm,5%,5W	Kepco P/N 115-0653
TO:	R206	Res.,Fxd.,Power,Ax,W.W.	2 ohm,5%,10W	Kepco P/N 115-1411

Note: R4 has been removed from Assembly A1 and relocated on the Chassis Assembly (A2). It is now designated R206. Its function and circuit connection remain identical to R4.

4) CHANGE:	Q402 to Q412 (11)	Transistor,Silicon,PNP	Kepco P/N 119-0113
TO:	Q402 to Q412 (11)	Transistor,Silicon,PNP	Kepco P/N 119-0128

BOP 15-20/10-3074/r5 C3246
BOP 15-20/17-1976/r6 C3570
BOP 15-20/07-1081/r7 C4826
BOP 15-20/06-2481/r8 C4818

KEPCO®

INSTRUCTION MANUAL CORRECTION

Please note the following corrections to the Manual Material as indicated:

Parts List and Schematic Diagram:

1. ADD: C207 Capacitor,Mylar,Met.,Axial 0.1uF,200V,10% Kepco #117-0363.

   Note: C207 is connected between the anodes of CR201 and CR202.

2. CHANGE: R4 Res.,Fixed,Power Axial,W.W. 2 ohm,5%,5W. Kepco #115-0653
   to: R206 Res.,Fixed,Power Axial,W.W. 2 ohm,5%,10W. Kepco #115-1411.

   Note: R4 has been removed from Assembly A1 and relocated on the chassis Assembly A2.It is now designated R206.Its function and circuit connection remain identical to R4.

BOP15-20/17-1976/r6 C3570
BOP15-20/07-1081/r7 C4826

KEPCO®

INSTRUCTION MANUAL CORRECTION

Please note the following corrections to the Manual Material as indicated:

PARTS LIST AND SCHEMATIC DIAGRAM:

1) CHANGE:	R4	Res.,Fxd.,Power,Ax,W.W.	5 ohm,5W,5%	Kepco P/N 115-0516
TO:	R4	Res.,Fxd.,Power,Ax,W.W.	2 ohm,5W,5%	Kepco P/N 115-0633
2) ADD:	C207	Capacitor,Mylar,Met.,Axial	0.1uf,200V,10%	Kepco P/N 117-0363

Note: C207 is connected between the anodes of CR201 and CR202.

3) CHANGE:	R4	Res.,Fxd.,Power,Ax,W.W.	2 ohm,5%,5W	Kepco P/N 115-0653
TO:	R206	Res.,Fxd.,Power,Ax,W.W.	2 ohm,5%,10W	Kepco P/N 115-1411

Note: R4 has been removed from Assembly A1 and relocated on the Chassis Assembly (A2). It is now designated R206. Its function and circuit connection remain identical to R4.

BOP 15-20/10-3074/r5 C3246
BOP 15-20/17-1976/r6 C3570
BOP 15-20/07-1081/r7 C4826

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