

KEPCO



POWER SUPPLIES

Please record the equipment nameplate
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Model BOP 500M

Serial No.

instruction manual

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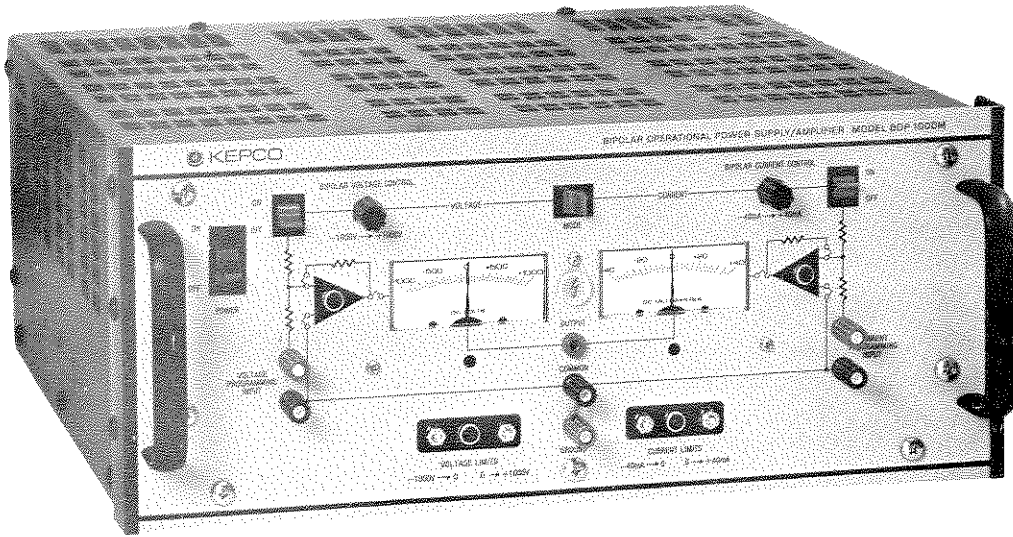


FIG. 1-1 BOP (H.V.) OPERATIONAL POWER SUPPLY, FRONT VIEW.

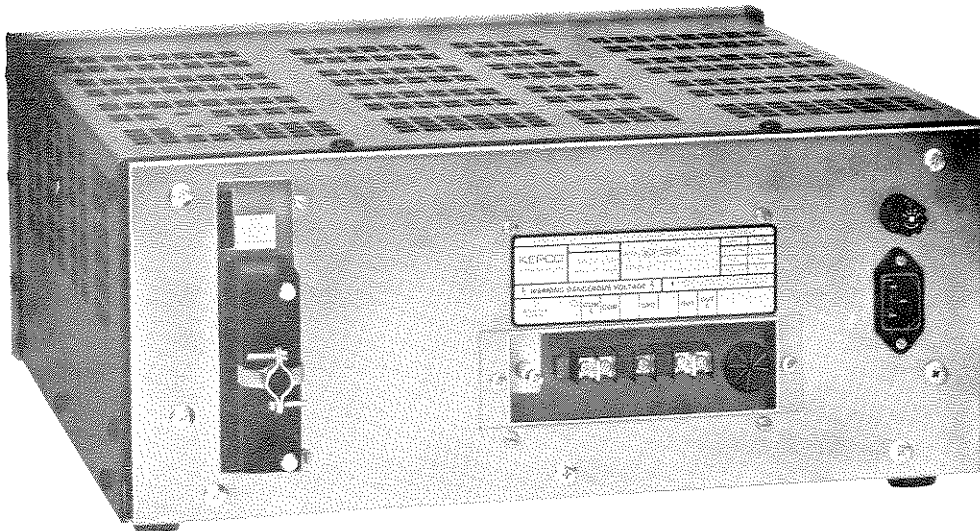


FIG. 1-2 BOP (H.V.) OPERATIONAL POWER SUPPLY, REAR VIEW

SECTION I – INTRODUCTION

1-1 SCOPE OF MANUAL

- 1-2 This manual contains instructions for the installation, operation and maintenance for the Models BOP 500M and BOP 1000M Bipolar Operational Power Supplies, manufactured by Kepco Inc., Flushing, New York, U.S.A.

1-3 GENERAL DESCRIPTION

- 1-4 The Kepco Model BOP 500M and BOP 1000M are high voltage power sources, which combine the capabilities of fast programmable power supplies with a Class A output stage, which can respond bidirectionally from zero. The "BOP" can be operated in a "Voltage Stabilizing" or "Current Stabilizing" operating mode (selectable by a front panel switch). The BOP incorporates two separate control channels, for local (front panel) or remote control of the output current and the output voltage. In addition, bounding currents for bipolar voltage and current limiting are provided which may be adjusted manually (by front panel controls) or can be remotely programmed. All control and bounding channels are connected to the bipolar (Class A) output stage via an "EXCLUSIVE-OR" gate, so that only one circuit is in control of the BOP output at any one time. Some applications are listed below:

- A) VOLTAGE MODE OPERATION. (Current limiting either front panel adjusted or remotely programmed using the current limiting channel).
 - 1) High speed, bipolar d-c voltage source (remote or locally controlled output).
 - 2) Scaling or summing amplifier with or without d-c bias.
- B) CURRENT MODE OPERATION (Voltage limiting either front panel adjusted or remotely programmed using the voltage limiting channel).
 - 1) High speed, bipolar d-c current source (remotely or locally controlled output).
 - 2) Amplification of a-c currents, with or without d-c biasing.

- 1-5 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.

1-6 ELECTRICAL SPECIFICATIONS, GENERAL

- A) INPUT SOURCE REQUIREMENTS: 105 to 125 V a-c *or* 210 to 250 V a-c, 50 to 65 Hz, selectable by the SOURCE VOLTAGE SELECTOR SWITCH (refer to Section II, FIG. 2-3). A built-in time delay circuit holds the BOP output at zero for approximately 30 seconds after a-c power is turned on. Power consumption approximately 250 Watts. Power factor: 0.8. The primary circuit is protected by a fuse.
- B) OPERATING TEMPERATURE RANGE: -20°C to $+65^{\circ}\text{C}$.
- C) STORAGE TEMPERATURE RANGE: -40°C to $+85^{\circ}\text{C}$.
- D) COOLING: By natural convection.
- E) ISOLATION FROM GROUND: The BOP circuitry, its output and programming terminals have no d-c connection to the chassis. The COMMON terminal of the BOP can be operated up to 500 volts (d-c or peak) off a-c ground. The common mode current (leakage from output to ground) is less than $50\ \mu\text{A}$ (rms) or 5 mA (p-p) at 115V a-c power input, 60 Hz.

1-7 ELECTRICAL SPECIFICATIONS, PERFORMANCE

- A) OUTPUT RANGES: See Table 1-1.
- B) OUTPUT IMPEDANCE: See Table 1-1.

MODEL	d-c OUTPUT RANGE		OUTPUT IMPEDANCE	
	VOLTS	mA	VOLTAGE MODE	CURRENT MODE
BOP 500M	-500 to +500	-80 to +80	d-c OHMS + SERIES L 0.05Ω + 10 mH	d-c OHMS + SHUNT C 100 MΩ + 0.02 μF
BOP 1000M	-1000 to +1000	-40 to +40	0.2Ω + 10 mH	400 MΩ + 0.01 μF

TABLE 1-1 OUTPUT RANGES AND IMPEDANCES

C) OUTPUT EFFECTS: See Table 1-2.

INFLUENCE QUANTITY	OUTPUT EFFECTS ⁽¹⁾		PRE-AMPLIFIER OFFSETS		REFERENCES
	VOLTAGE MODE	CURRENT MODE	ΔE _{io}	ΔI _{io}	
SOURCE: 105-125/210-250V a-c	<0.0005%	<0.0005% ⁽⁵⁾	<5 μV	<1 nA	<0.0005%
LOAD: No load - full load	<0.0005%	<0.005%	-	-	<0.0005%
TIME: 8-hour [drift]	<0.01%	<0.01%	<20 μV	<1 nA	<0.005%
TEMPERATURE: Per °C	<0.01%	<0.01%	<20 μV	<1 nA	<0.005%
UNPROGRAMMED					
OUTPUT DEVIATION: ⁽²⁾ (Ripple and Noise)	rms	<10 mV	<25 μA ⁽⁴⁾	-	<10 μV
	p-p	<200 mV ⁽³⁾	<500 μA ⁽⁴⁾	-	<100 μV

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

(2) Common terminal grounded so that the common-mode current does not flow through the load.

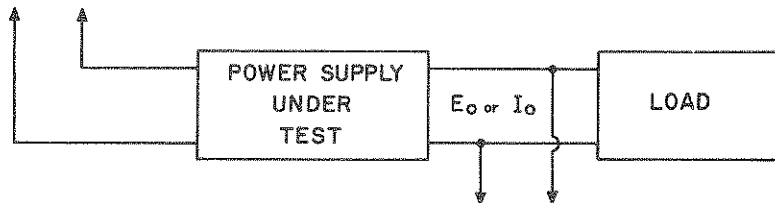
(3) 20 Hz to 10 MHz.

(4) For frequency components in the bandwidth of the current stabilizer. Beyond cutoff, noise will appear as a voltage component equal to the rated voltage mode noise.

(5) Or 0.2 μA, whichever is greater.

TABLE 1-2 OUTPUT EFFECTS, OFFSETS AND REFERENCE SPECIFICATIONS

NOTE: In this instruction manual, Kepco will follow the NEMA standards for d-c Power Supplies and speak of the "Output Effects," caused by changes in the "Influence Quantities." The "Output Effects" are specified either as a percentage change, referred to the maximum specified output voltage (E_O) or current (I_O), or as an absolute change (ΔE_O, ΔI_O), directly in millivolts or milliamperes or both. The illustration below will clarify the NEMA terms.



INFLUENCE QUANTITIES

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

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

D) The BOP *output effects*, in response to the tabulated variations in the INFLUENCE QUANTITIES, are given in Table 1-2 for the built-in input and feedback resistor values of the voltage and current channel preamplifiers. The tabulated OFFSET values (see Table 1-2) may be used to calculate the BOP *output effects* if the BOP voltage or current channel is remotely programmed and different values for the feedback resistors (R_f) and the input resistors (R_i) are used. In this case, the tabulated preamplifiers offsets and the values of the feedback and input resistors are combined in an "Error Equation", which represents the "Worst Case" output effect for the application at hand:

VOLTAGE MODE: $\Delta E_o = G [\pm \Delta E_{i_o} (1 + R_f/R_i) \pm \Delta I_{i_o} R_f \pm \Delta E_{ref}]$

CURRENT MODE: $\Delta I_o = \frac{1}{R_s} [\pm \Delta E_{i_o} (1 + R_f/R_i) \pm \Delta I_{i_o} R_f \pm \Delta E_{ref}]$

R_s = Current Sensing Resistor (BOP 500M = 125 Ω , BOP 1000M = 250 Ω)

ΔI_o = Total Output Current Change

G = Closed Loop Gain (BOP 500M = 50, BOP 1000M = 100)

where: ΔE_o = Total Output Voltage Change
 ΔE_{ref} = Change in the Voltage Reference
 ΔE_{i_o} = Change in Offset Voltage
 ΔI_{i_o} = Change in Offset Current
 R_f = External Feedback Resistor
 R_i = External Input Resistor

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

See Section IV of this manual for the derivation of the Error Equation.

- E) DYNAMICS: The dynamic response of the BOP output are tabulated in Table 1-3 in both the time domain (Output response to a step program) and in the frequency domain (bandwidth) for large and small signals.

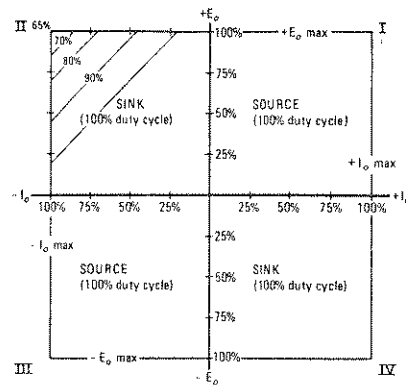
DYNAMIC SPECIFICATION	VOLTAGE CHANNEL		CURRENT CHANNEL	
	BOP 500M	BOP 1000M	BOP 500M	BOP 1000M
Closed Loop Gain:	50 V/V	100 V/V	8 mA/V	4 mA/V
Unity Gain Crossover Frequency:	150 KHz	100 KHz	300 KHz	200 KHz
Bandwidth [d-c to f-3 dB]:	2 KHz	1 KHz	1.3 KHz ⁽¹⁾	0.64 KHz ⁽¹⁾
Programming Time Constant:	75 μ sec.	150 μ sec.	125 μ sec. ⁽¹⁾	250 μ sec. ⁽¹⁾
Large Signal Frequency Response:	2 KHz	0.5 KHz	2 KHz	0.5 KHz
Slewing Rate:	6V/ μ sec.	6V/ μ sec.	6V/ μ sec.	6V/ μ sec.
Load Recovery Time Constant:	100 μ sec.	100 μ sec.	125 μ sec. ⁽¹⁾	250 μ sec. ⁽¹⁾

⁽¹⁾Calculated for a load resistance equal to E_o max/ I_o max. Current channel dynamics are a function of the load resistance and the tabulated value for the equivalent output capacitance. $T = R_L C_o$ and f-3 dB = $1/2\pi R_L C_o$. The rate limit is the ratio of current setting to the tabulated output capacitance.

TABLE 1-3 DYNAMIC SPECIFICATIONS

1-8 MISCELLANEOUS FEATURES

- A) **OUTPUT RANGE:** The BOP can be locally (front panel) adjusted, or remotely programmed, from (-) 100% to (+) 100% of its specified d-c voltage and current range. The Class A bipolar output stage permits operation as either a SOURCE OR A SINK. (See FIG. 1-3).



NOTE: Operation in the second quadrant of the graph must be derated as indicated.

FIG. 1-3 BOP OUTPUT CHARACTERISTIC

Note: The BOP is operating as a SOURCE if the direction of its output voltage is *the same* as the direction of its output current. The BOP is operating as a SINK if the direction of its output voltage is *opposite* that of its output current. An illustrative case is shown in FIG. 1-4, where the BOP is programmed to deliver a sine wave output and where the load produces a phase shift between the output voltage and current.

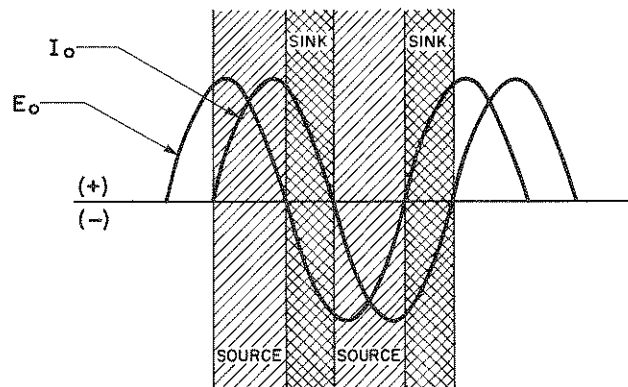


FIG. 1-4 BOP OUTPUT WAVE FORM WITH PHASE SHIFT

- B) REFERENCES: Two reference/bias sources ($\pm 10V - 1 \text{ mA MAX.}$) are provided for control and biasing purposes. These reference sources are available at the rear programming connector (with reference to the "COMMON" terminal). Their specifications are tabulated in Table 1-2.
- C) OFFSET NULLING: Controls are provided to zero the initial offsets (E_{iO}, I_{iO}) of both the voltage and current control preamplifiers.
- D) LOAD REACTANCE: To realize the full high speed potential of the BOP, the load characteristics should be mainly resistive. Load capacitance and inductance up to $0.01 \mu F$ and 0.5 mHy respectively can be tolerated without performance deterioration. **CAUTION: Stable operation into a purely inductive load in the Current Mode of operation requires a minimum series resistance of 25 ohms.**
- E) SERIES OR PARALLEL OPERATION: Not recommended.
- F) VOLTAGE CONTROL CHANNEL (Refer to Section III - FIG. 3-1A). The BIPOLAR VOLTAGE AMPLIFIER, with a fixed gain of 50 (BOP-500M) or 100 (BOP-1000M) is connected, via the MODE switch, to the (unity gain) VOLTAGE PREAMPLIFIER. If the BIPOLAR voltage switch is "on", the BOP output voltage can be locally controlled by means of the (front panel) (\pm) 10 volt bias source from (-) 100% (through zero) to (+) 100% of the rated value. The VOLTAGE PREAMPLIFIER is provided with a ZERO control and all its terminals are available at the rear programming connector for remote control of the output voltage. Control methods are described in Section III of this manual.
- G) MODE SWITCH: The BOP is equipped with a front panel mounted MODE SWITCH, which selects bipolar voltage or bipolar current control.
- H) CURRENT CONTROL CHANNEL (Refer to Section III - FIG. 3-1B). The BIPOLAR CURRENT AMPLIFIER, with a fixed gain of 8 mA/V (BOP-500M) or 4 mA/V (BOP-1000M), is connected via the MODE switch to the (unity gain) CURRENT PREAMPLIFIER. If the BIPOLAR voltage switch is "on", the BOP output current can be locally (front panel) controlled (by means of the ± 10 volt bias source) from (-) 100% (through zero) to (+) 100% of the rated value. The CURRENT PREAMPLIFIER is provided with a ZERO control and all its terminals are available at the rear programming connector for remote control of the output current. Control methods are described in Section III of this manual.
- J) BOUNDING: (Refer to Section III - FIG. 3-1C & D). The BOP has four adjustable output voltage/current limiting circuits: (-) E_O LIMIT, (+) E_O LIMIT, (-) I_O LIMIT, (+) I_O LIMIT for overvoltage/overcurrent protection in either operating mode. All limiting circuits can be screwdriver adjusted by means of four front panel controls. In addition, all four limits can be remotely controlled by means of 0 to 10 volt d-c control voltages. The four limits may be programmed independently or the (\pm) voltage and (\pm) current limits can be controlled in pairs. The adjustable/programmable limit controls are backed-up by non-adjustable limit circuits which define the four boundaries [(\pm) E_O MAX. and (\pm) I_O MAX.] of the BOP, and provide protection against accidental overprogramming of the adjustable limits.
- K) MODE LIGHTS AND FLAG SIGNAL OUTPUT: Four (4) front panel (LED type) indicator lamps monitor the prevailing operating mode of the BOP. In addition, four (4) corresponding flag signal outputs are provided at the rear programming connector. For each operating condition (VOLTAGE MODE, CURRENT MODE, $\pm E_O$ LIMIT, $\pm I_O$ LIMIT) the corresponding indicator lamp lights up and the associated flag signal changes its state from (TTL) logic "1" to "0". NOTE: If operating against back-up limit (PAR. J) all 4 lights go *out*.
- L) STANDARDS: BOP models are designed and tested in accordance with NEMA Standard for Stabilized Power Supplies, d-c output, Publication No. PY-1-1972.

1-9 MECHANICAL SPECIFICATIONS

- A) DIMENSIONS: See "Mechanical Outline Drawing", FIG. 1-5.
- B) FINISH: See "Mechanical Outline Drawing", FIG. 1-5.
- C) FRONT PANEL METERS: $2\frac{1}{2}$ inches wide, recessed. Accuracy $\pm 2\%$ full scale. Two (2) "zero center" meters monitoring the \pm d-c voltage and the \pm d-c current are provided.

1-10 ACCESSORIES

- A) MOUNTING FLANGES, for installation of the BOP into a standard (19-inch) equipment rack. (A PAIR INCLUDED WITH EACH BOP). Kepco Part No. 128-1282 (right), 128-1281 (left).
- B) SIDE COVER PLATES, for bench top use, designed to finish the two sides of the instrument when the rack mounting ears are not mounted. A pair included with each BOP. Kepco P/N 128-1285 (right), 128-1284 (left).
- C) REAR PROGRAMMING CONNECTOR, Kepco Model PC-9, 30-terminal printed circuit connector for all rear programming connections and flag signal outputs (ONE INCLUDED WITH EACH BOP).

SECTION II – INSTALLATION

2-1 UNPACKING AND INSPECTION

2-2 This instrument has been thoroughly inspected and tested prior to packing and is ready for operation. After careful unpacking, inspect for shipping damage before attempting to operate. Perform the preliminary operational check as outlined in PAR. 2-8. If any indication of damage is found, file an immediate claim with the responsible transport service.

2-3 TERMINATIONS

- a) FRONT PANEL: Refer to FIG. 2-2A and Table 2-2.
- b) REAR: Refer to FIG. 2-2B and Table 2-2.
- c) INTERNAL CALIBRATION CONTROLS: Refer to FIG. 2-1 and Table 2-1.

REFERENCE DESIGNATION	CONTROL	PURPOSE	ADJUSTMENT PROCEDURE
R18	(±) 10V CAL.	Reference Voltage Calibration	Sect. V, par. 5-8A
R31	E _O ZERO	E _O Pre-amp Zero Adjustment	Sect. III, par. 3-16
R36	I _O ZERO	I _O Pre-amp Zero Adjustment	Sect. III, par. 3-30
R303	I _{ox}	I _O Stabilization Compensation	Sect. V, par. 5-8B

TABLE 2-1 INTERNAL CALIBRATION CONTROLS

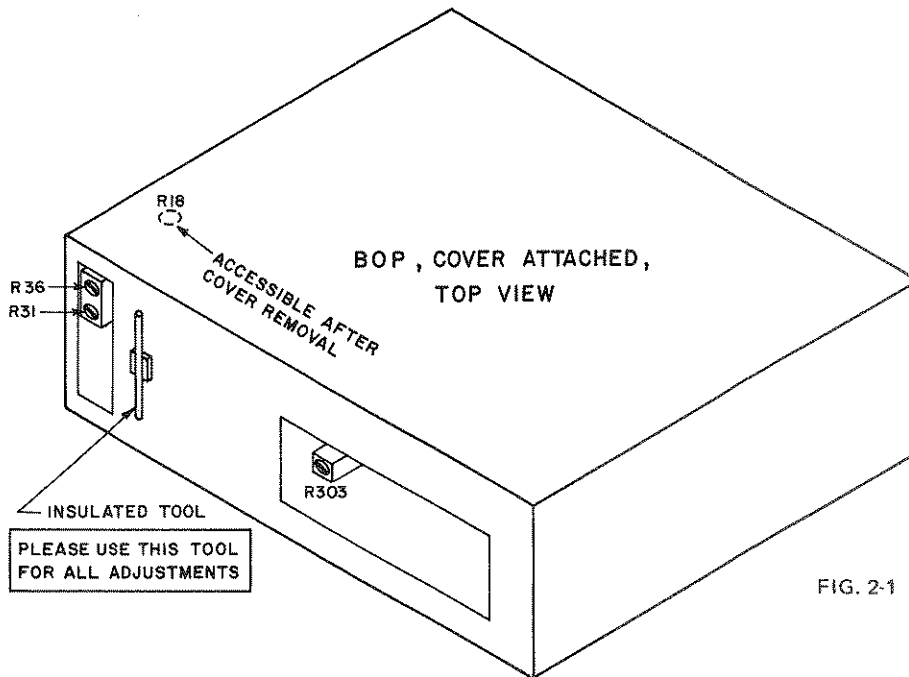
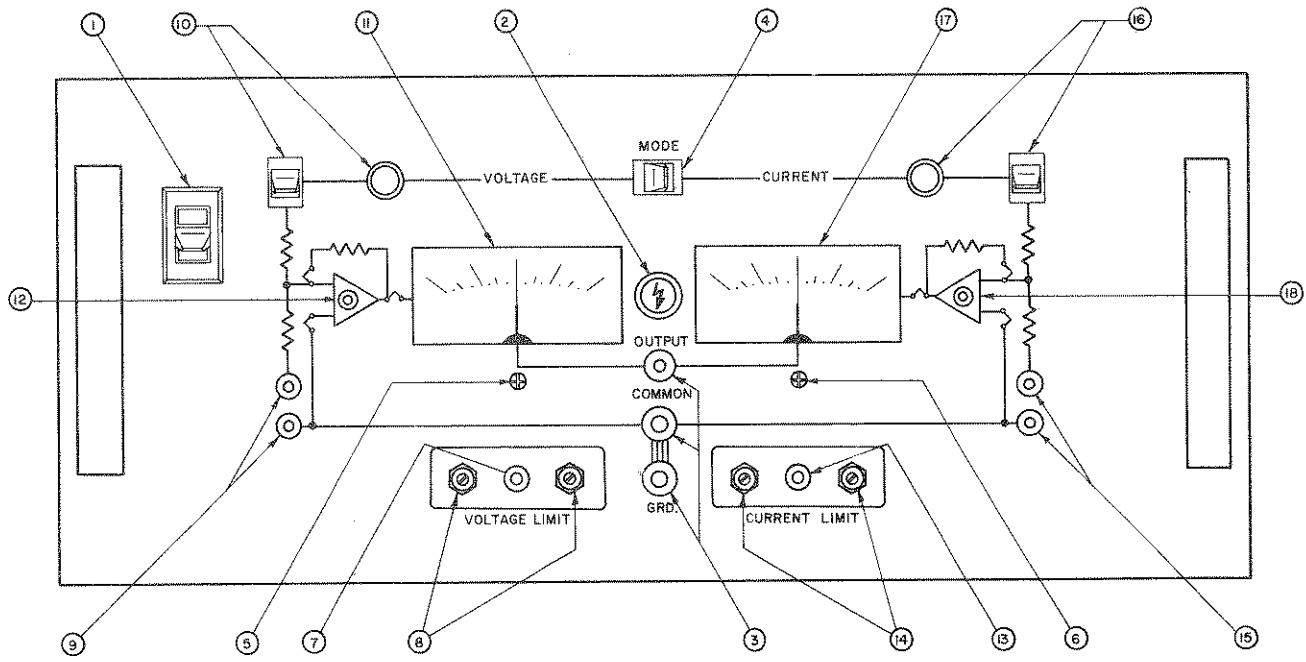
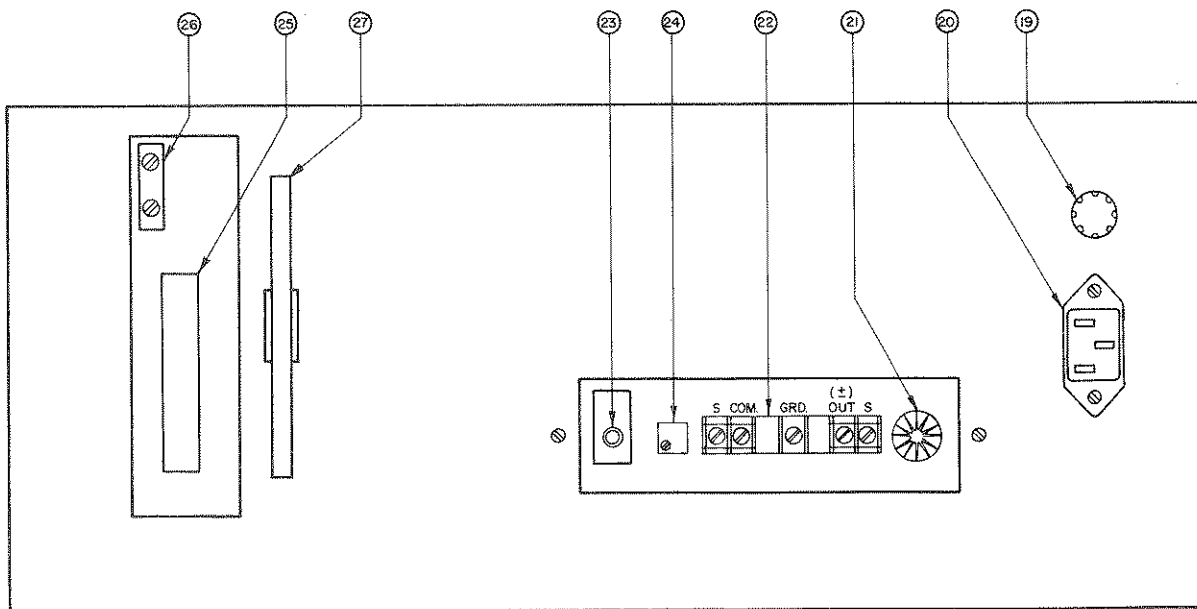


FIG. 2-1 LOCATION OF INTERNAL CALIBRATION CONTROLS.



A) BOP FRONT TERMINATIONS AND CONTROLS



B) BOP REAR TERMINATIONS AND CONTROLS

FIG. 2-2 BOP TERMINATIONS AND CONTROLS

NO.	NAME OF CONTROL OR FUNCTION	FUNCTION
1	A-C POWER	A-C INPUT POWER SWITCH AND INDICATOR LAMP.
2	—	OUTPUT "READY" LAMP. ENERGIZES 30 SEC. AFTER A-C POWER IS TURNED ON.
3	\pm OUTPUT, COMMON, GRD.	OUTPUT AND GROUNDING TERMINALS (PARALLEL WITH REAR BARRIER STRIP TERMINALS).
4	MODE	OPERATING MODE SELECTOR SWITCH FOR "VOLTAGE" OR "CURRENT" MODE.
5	—	MECHANICAL VOLTMETER ZERO ADJUSTMENT.
6	—	MECHANICAL CURRENT METER ZERO ADJUSTMENT.
7	VOLTAGE LIMIT	LED LAMP, INDICATING VOLTAGE LIMITING OPERATION.
8	\pm VOLTAGE LIMIT	CONTROLS FOR MANUAL ADJUSTMENT OF THE (\pm) VOLTAGE LIMITS.
9	INPUT	PROGRAMMING INPUT TERMINALS FOR VOLTAGE PRE-AMP.
10	BIPOLAR VOLTAGE CONTROL	"ON-OFF" SWITCH AND VOLTAGE CONTROL. FOR MANUAL ADJUSTMENT OF THE BOP D-C OUTPUT VOLTAGE (WITH SWITCH "ON")
11	E_o METER	D-C OUTPUT VOLTMETER (READS ALSO AVERAGE A-C SIGNALS)
12	E_o MODE	LED LAMP, INDICATING VOLTAGE MODE OPERATION.
13	CURRENT LIMIT	LED LAMP, INDICATING CURRENT LIMITING OPERATION.
14	\pm CURRENT LIMIT	CONTROLS FOR MANUAL ADJUSTMENT OF THE (\pm) CURRENT LIMITS.
15	INPUT	PROGRAMMING INPUT TERMINALS FOR CURRENT PRE-AMP.
16	BIPOLAR CURRENT CONTROL	"ON-OFF" SWITCH AND CURRENT CONTROL. FOR MANUAL ADJUSTMENT OF THE BOP D-C OUTPUT CURRENT (WITH SWITCH "ON")
17	I_o METER	D-C OUTPUT CURRENT METER (READS ALSO AVERAGE A-C SIGNALS)
18	I_o MODE	LED LAMP, INDICATING CURRENT MODE OPERATION.
19	FUSE	A-C POWER FUSE. PROTECTS PRIMARY A-C INPUT CIRCUIT.
20	—	A-C POWER INPUT JACK. ACCEPTS 3-WIRE LINE CORD (SUPPLIED).
21	—	CABLE HOLDER. ACCEPTS OUTPUT, SENSING AND GROUND WIRES FOR FEED-THROUGH FROM TERMINALS THROUGH SAFETY COVER.
22	REAR TERMINALS	REAR BARRIER STRIP WITH OUTPUT, SENSING AND GROUND TERMINALS.
23	INTERLOCK	SHUTS OFF BOP IF SAFETY COVER IS REMOVED. CAN BE DEFEATED BY FORWARD PULL.
24	INT. I_{ox} CONTROL	R303, COMPENSATION ADJUSTMENT. SEE SECTION V.
25	REAR CONNECTOR	ACCESS TO INTERNAL CIRCUITRY FOR PROGRAMMING CONNECTIONS.
26	INT. CONTROLS	R31, R36, CURRENT AND VOLTAGE PRE-AMP ZERO CONTROLS.
27	INSULATED TOOL	USE THIS TOOL FOR ALL INTERNAL ADJUSTMENTS.

TABLE 2-2 BOP TERMINATIONS AND CONTROLS

Note: Numbers correspond to those shown in FIG. 2-2.

2-4 A-C POWER INPUT REQUIREMENTS

2-5 The BOP is equipped with a SOURCE VOLTAGE SELECTOR permitting the user to choose between 115 and 230V a-c operation by means of a screwdriver actuated switch. The switch location is illustrated in FIG. 2-3. When changing the a-c input voltage, the A-C POWER FUSE must be altered as well, according to the information given in FIG. 2-3.

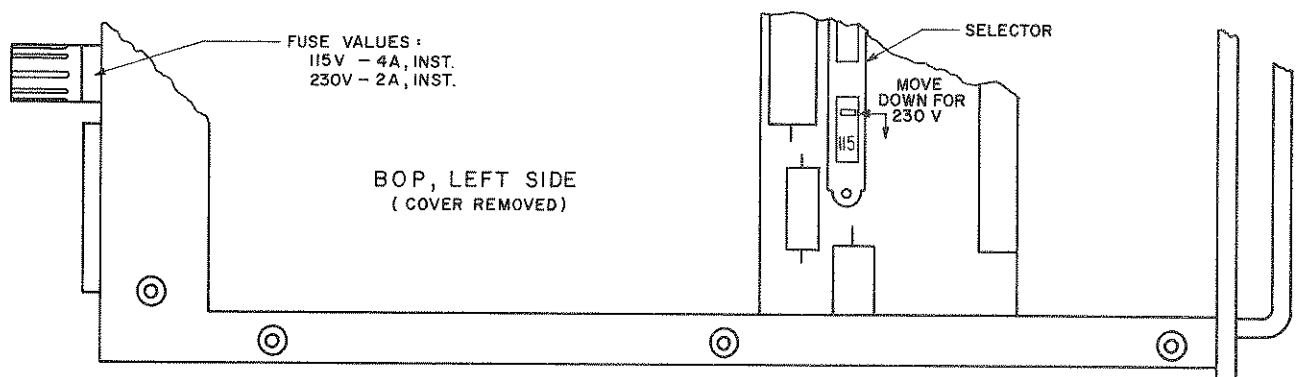


FIG. 2-3 A-C SOURCE VOLTAGE SELECTOR, LOCATION

2-6 COOLING

- 2-7 The components in the BOP power supply rely on convection cooling for the maintenance of their operating temperature. SIDE PANEL OPENINGS AND THE TOP OF THE CASE MUST BE KEPT CLEAR FROM ALL OBSTRUCTIONS TO ENSURE PROPER AIR CIRCULATION. Periodic cleaning of the interior of the power supply is recommended. If the BOP is rack-mounted or installed into confined spaces, care must be taken that the ambient temperature (the temperature immediately surrounding the power supply) does not rise above 65°C (≈ 180°F).

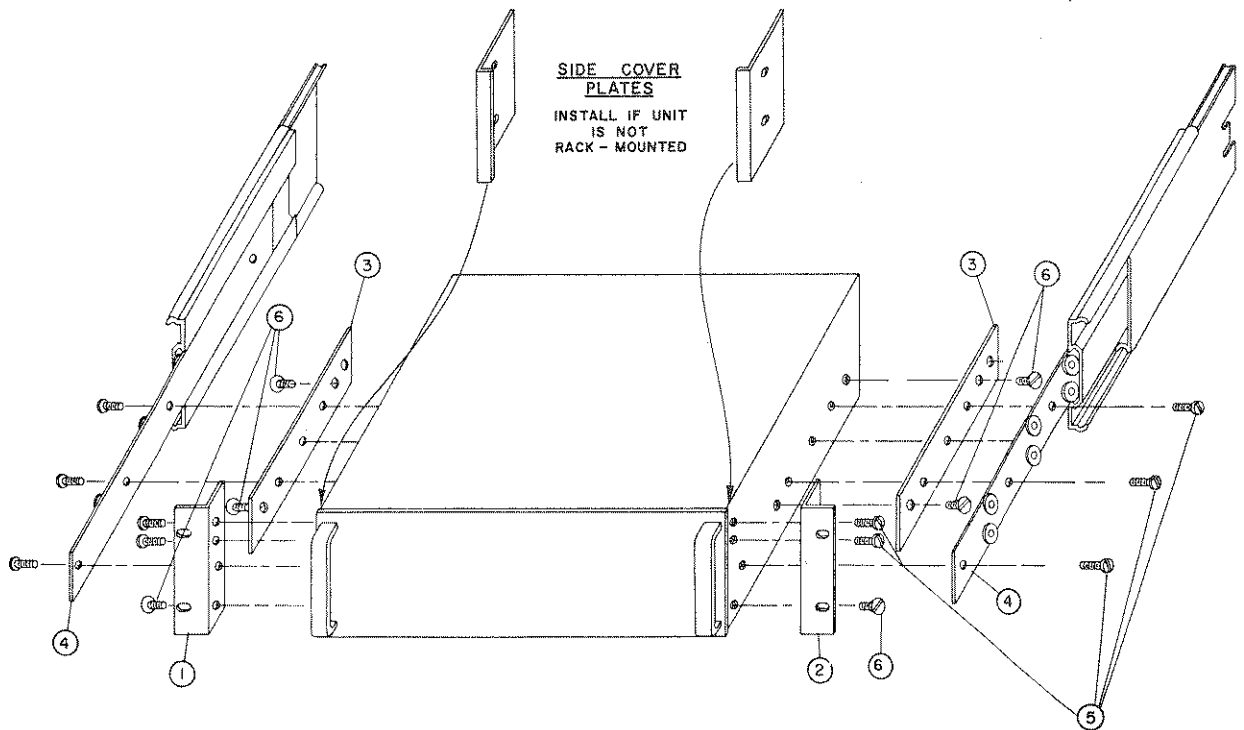
2-8 PRELIMINARY CHECKOUT

NOTE: THE REAR PROGRAMMING CONNECTOR MUST BE ATTACHED TO THE BOP AND MUST BE WIRED AS SHOWN ON THE MAIN SCHEMATIC DIAGRAM, SECTION VI, FIG. 6-5.

- 2-9 A simple operating check after unpacking and before permanent installation, is advisable to ascertain whether the BOP has suffered damage in shipment. *Refer to FIG. 2-2 and Table 2-2 FOR THE LOCATION AND DESIGNATION OF THE OPERATION CONTROLS AND TERMINALS. Proceed as follows:*
- A) Connect the BOP to a 115V a-c source, or refer to PAR. 2-4 for conversion to 230V a-c operation if required.
 - B) Note: The rear sensing links must be attached to the rear terminals of the BOP as shown in FIG. 2-2 and the rear connector must be attached and secured.
 - C) Set the BOP front panel controls as follows (refer to FIG. 2-2. The controls will be identified here and in the following manual text with the nomenclature used in Table 2-2 and identifying numbers used in FIG. 2-2):
 - 1) MODE switch (4), set to "voltage."
 - 2) BIPOLAR VOLTAGE CONTROL (10), set switch to "ON", control to its extreme counterclockwise position.
 - 3) A-C POWER switch to "ON."
 - D) The indicator lamp, part of the A-C POWER switch (1) will be "on." After approximately 30 seconds, the output "READY" lamp (2) and the "E_O MODE" Lamp (12) will be "on."
 - E) Turn the BIPOLAR VOLTAGE CONTROL (10) clockwise through its range, while observing the front panel "E_O METER" (11). The BOP output voltage should smoothly follow from the maximum negative output voltage, over zero, to the maximum positive output voltage of the BOP. Turn A-C POWER SWITCH (1) "off".
 - F) Connect a short circuit between the (±) OUTPUT to the COMMON front panel output terminals (3). Set the BOP front panel controls as follows:
 - 1) MODE SWITCH (4), set to "CURRENT".
 - 2) BIPOLAR CURRENT CONTROL (15), set switch to "ON", control to its maximum counterclockwise position.
 - 3) A-C POWER switch "ON".
 - G) The indicator lamp, part of the A-C POWER switch (1) will be "on". After approximately 30 seconds, the output "READY" lamp (2) and the "I_O MODE" Lamp (18) will be "on".
 - H) Turn the BIPOLAR CURRENT CONTROL (15) clockwise through its range, while observing the front panel "I_O METER" (16). The BOP output current should smoothly follow from the maximum negative output current, over zero, to the maximum positive output current of the BOP. Turn A-C POWER switch (1) "off". Remove the short circuit from the output terminals. THIS CONCLUDES THE PRELIMINARY CHECK-OUT OF THE BOP.

2-10 INSTALLATION (Refer to FIG. 2-4)

- 2-11 The BOP is delivered with mounted FILLER and ANGLE BRACKETS and ready for installation into any standard (19-inch) instrument rack. Please refer to PAR. 2-6 (COOLING) if the BOP is to be mounted into a multiple rack installation.
- 2-12 For bench-operation, the FILLER BRACKETS can be removed and the ANGLE BRACKETS can be replaced with the supplied SIDE COVER PLATES. Instructions for slide installation are provided in FIG. 2-4.



RACK MOUNTING ACCESSORIES, PART 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

NOTES: ITEM (4) NOT SUPPLIED

INSTRUCTIONS FOR SLIDE INSTALLATION

- 1) Items 1, 2, 3 are installed at the factory.
- 2) Item 3 (filler bracket) is pre-drilled 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 re-insert 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. 2-4 RACK INSTALLATION OF THE BOP.

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.

SECTION III – OPERATION

3-1 INTRODUCTION

- 3-2 BOP BIPOLAR OPERATIONAL POWER SUPPLIES can be used in a great variety of applications. As a PRECISION VOLTAGE or CURRENT SOURCE, the BOP output can be controlled locally (by means of the front panel BIPOLAR voltage and current controls) or remotely (by means of resistances or by voltage signals). Independently adjustable (or remotely programmable) limit circuits for both output voltage and output current protect a sensitive load from any overvoltage or overcurrent. As a BIPOLAR AMPLIFIER, the BOP output responds to such input signals as sine, square or triangular waves. A (\pm) 10 volt input signal will program the BOP output (voltage or current) through its rated output ranges. Built-in preamplifiers, for the voltage, as well as the current channel of the BOP, permit amplification of the control signals to the required amplitude and the interface with high as well as low impedance signal sources.
- 3-3 Detailed examples of the more popular applications are described in the following paragraphs. Before actual operation, however, the following general comments on the operation of the BOP should be carefully considered:

WARNING

THIS INSTRUMENT IS CAPABLE OF PRODUCING LETHAL VOLTAGES:

- 1) Exercise extreme care in making all connections to and from the BOP terminals. REMOVE A-C POWER FROM THE BOP BEFORE MAKING ANY CONNECTIONS!
- 2) An interlock device removes the A-C source power from the BOP if the rear terminal cover plate is lifted. DO NOT BYPASS THE INTERLOCK!
- 3) Wires and/or cables, connected from the BOP terminals to external components or programming devices must be properly insulated and securely terminated on both sides to make accidental touch impossible. A feed-through hole is provided on the BOP rear terminal cover, to bring the wires from the BOP rear terminals to the outside. DO NOT USE BANANA PLUGS WITH EXPOSED SCREWS OR OTHER EXPOSED METAL PARTS AT THE FRONT PANEL OUTPUT TERMINALS!
- 4) The BOP chassis and cover must be safety-grounded to a reliable a-c source ground. A safety-ground may be established by using a grounded a-c power outlet or, if the latter is not available, by means of a separate wire, from the provided "ground" terminal to a reliable a-c source ground point.
- 5) THE COMMON OUTPUT TERMINAL OF THE BOP SHOULD BE SIGNAL GROUNDED. If for any reason, grounding of the output is not possible, additional precautions must be taken to make any access to the isolated output impossible.
- 6) FOR ALL CONTROL ADJUSTMENTS ON THE BOP, USE ONLY THE INSULATED TOOL WHICH IS ATTACHED AT THE REAR. (See Section II, FIG. 2-2).

- A) DIAGRAMS. Application and test set up diagrams on the following pages show the symbolic and simplified representation of the BOP circuitry in four (4) separate diagrams, as indicated on FIG. 3-1. The diagrams represent the four programmable circuits of the BOP:

- A) Voltage Control Channel
- B) Current Control Channel
- C) (\pm) E_O Limit Circuits
- D) (\pm) I_O Limit Circuits

The *complete* simplified diagram is represented in the fold-out diagram at the end of Section IV. THE FOUR CIRCUITS CAN BE PROGRAMMED SEPARATELY AS DESCRIBED IN THE EXAMPLES IN THIS SECTION, OR THEY CAN BE USED SIMULTANEOUSLY AS THE APPLICATION REQUIRES, WITH THE EXCEPTION OF THE TWO (2) MAIN BIPOLAR VOLTAGE AND CURRENT CHANNELS WHICH ARE SELECTED BY THE FRONT PANEL MODE SWITCH AND CANNOT BE OPERATED SIMULTANEOUSLY.

The numbered terminals in the diagrams correspond to the connector terminals on the REAR PROGRAMMING CONNECTOR.

NOTE: BOP's have front and rear output terminals. Only the front terminals are shown on all subsequent simplified diagrams.

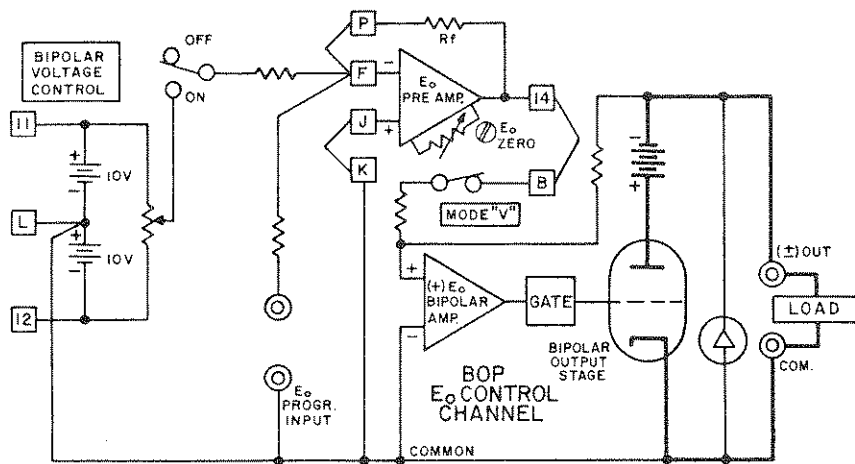


FIG. 3-1A BOP VOLTAGE CONTROL CHANNEL

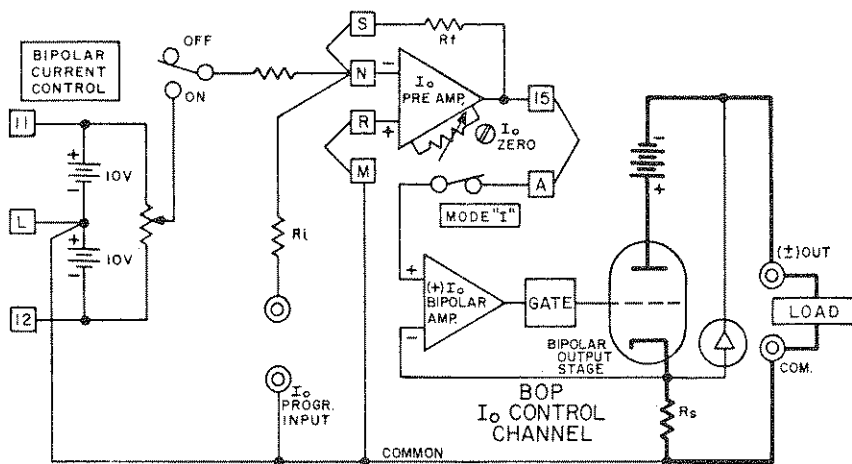


FIG. 3-1B BOP CURRENT CONTROL CHANNEL

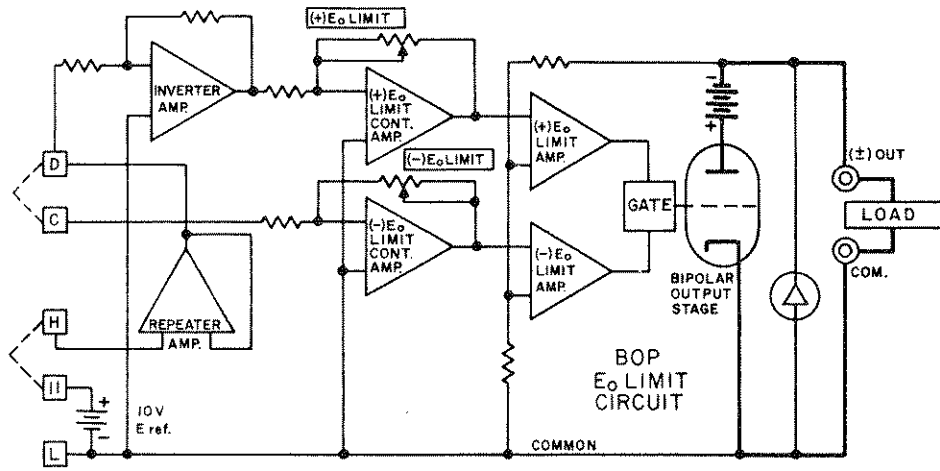


FIG. 3-1C BOP (±) VOLTAGE LIMITING CIRCUIT

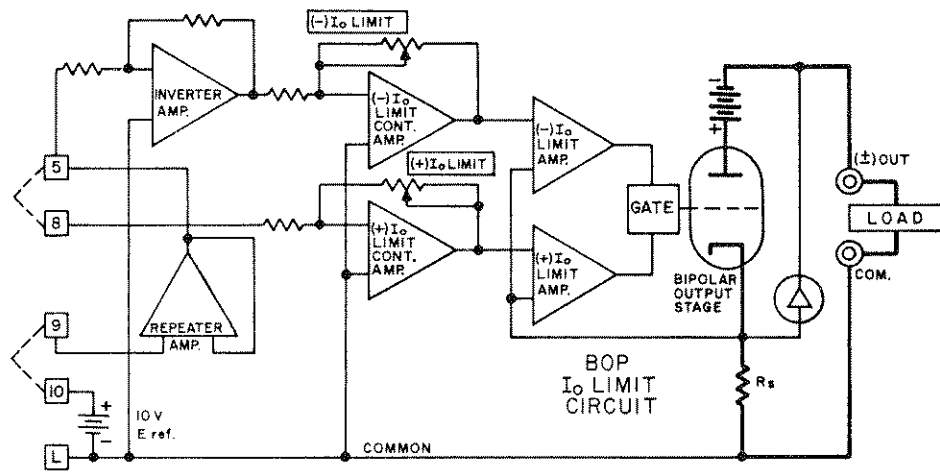


FIG. 3-1D BOP (±) CURRENT LIMITING CIRCUIT

- B) **LOAD CONNECTION (1).** The basic interconnection between the BOP and the load are shown in FIG. 3-2. The load wire size for the 2-wire connection shown should be as large as practicable to keep the series resistance and inductance low. In addition, the load wire pair should be tightly twisted, to reduce possible "pick-up" from stray magnetic fields. The basic 2-wire connection is useful where the voltage drop in the load wires is of minor consequence, as for example, operation into a constant load or in a constant current operating mode.

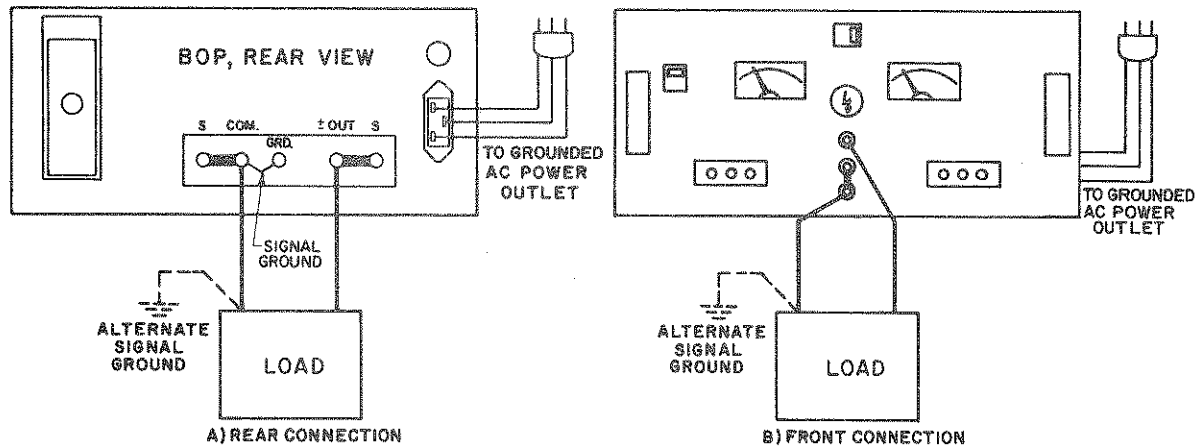


FIG. 3-2 BASIC 2-WIRE LOAD CONNECTION AND GROUNDING CONNECTIONS BETWEEN THE BOP AND THE LOAD.

- C) **LOAD CONNECTION (11).** The recommended load connection for all applications requiring minimum load effect across a remote load is shown in FIG. 3-3. A twisted, shielded pair of wires (No. 20 AWG minimum) are connected from the BOP sensing terminals to the load. This "remote error sensing" technique will compensate for load wire voltage drops up to 0.5 volts per wire.

NOTE: OBSERVE POLARITIES:
THE COMMON SENSING WIRES MUST GO TO THE COMMON LOAD WIRE. THE (±) OUT SENSING WIRE MUST GO TO THE (±) OUT LOAD WIRE.

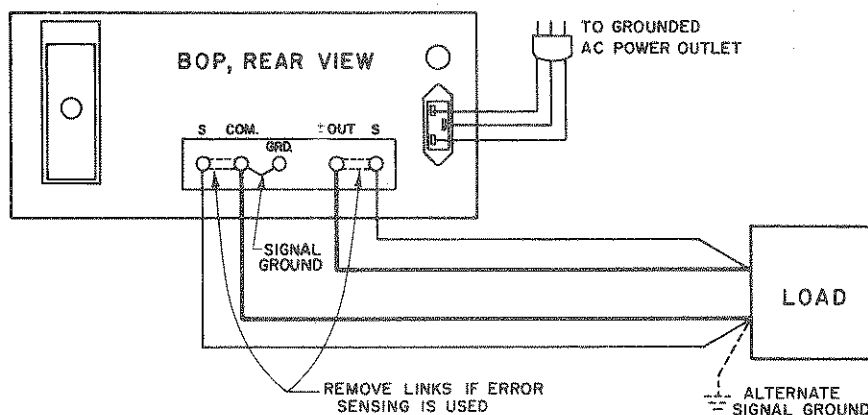


FIG. 3-3 LOAD CONNECTION WITH ERROR SENSING AND GROUNDING CONNECTIONS BETWEEN THE BOP AND THE LOAD.

WARNING

- D) A-C SAFETY GROUND. (Refer to FIG.'s 3-2, 3-3). The dangerous voltages present in this equipment make it imperative that the case be kept at ground potential at all times. If the 3-wire line cord with 3-prong safety plug (supplied with this equipment) is used in combination with a properly grounded outlet, this is taken care of automatically. If an adapter for a non-grounded outlet is used, however, the case must be grounded separately. A separate "GROUND" terminal is provided for this purpose on the rear of the BOP. (See Section II, FIG. 2-2).
- E) D-C (SIGNAL) GROUND. (Refer to FIG.'s 3-2, 3-3). Specified ripple and noise figures for operational power supplies are valid only with the common side of the output/load circuit returned to a common ground point (refer to Section I, Table 1-2). The common side of the BOP output is shown grounded in FIG.'s 3-2 and 3-3, since it is "common" to both internal reference source and any external signal source. If the application requires, the "common" side of the BOP may be floated up to 500V d-c off ground. In this case, however, the common mode current (specified in Section I, PAR. 1-6E, will flow through the impedance of whatever circuit is placed between common and ground and will give rise to a common mode voltage. The signal ground point in the BOP/load circuit must consist of a single point only, to which all input source grounds, shields and load grounds are connected. Multiple signal grounds in the BOP output/load circuit may cause "ground-loop" problems, since noise signals develop across the impedances between the multiple ground points. The exact physical location of the "best" single ground point must be carefully selected for minimum ripple/noise output.
- F) EXTERNAL PROGRAMMING RESISTORS. External programming resistors should be high-quality units, with low-temperature coefficients. Resistors should be selected carefully, since in most applications, the limitations for stability and drift are due, not to the BOP, but to the programming resistors. Selection criteria for resistors are:
 - 1) TEMPERATURE COEFFICIENT
 - 2) LEAKAGE (IN VALUES ABOVE 100 k OHM)
 - 3) HUMIDITY EFFECTS
 - 4) DRIFT WITH TIME
 - 5) SELF-HEATING (POWER DISSIPATION)
 - 6) TOLERANCE
- G) For variable resistors (potentiometers or rheostats) similar selection criteria apply. In addition, such specifications as listed below should be carefully considered if the application requires:
 - 1) END RESISTANCE
 - 2) LINEARITY
 - 3) CAPACITIVE AND INDUCTIVE EFFECTS
- H) ACTIVE PROGRAMMING SOURCES. External programming sources (Signal Generators, etc.) or reference sources should have temperature coefficients and drift specifications comparable to (or better than) the BOP Power Supply. CAUTION: A-C source-operated programming sources must have their output isolated from the case.
- J) EXTERNAL LEADS. Shielded (preferably twisted) lead pairs are recommended for all input connections to the BOP control channels. The shield should be connected (single-ended) to the chosen signal ground point. Shielded leads should be held as short as practicable. Output leads must be "high-voltage" wire, rated at least for the maximum BOP output voltage.

3-4 BEFORE USING THE BOP IN ANY APPLICATION . . . PLEASE REFER TO SECTION II TO GET ACQUAINTED WITH THE OPERATING CONTROLS, THE TURN-ON SEQUENCE AND THE A-C POWER REQUIREMENTS. REFER TO THIS SECTION (SECTION III) FOR INFORMATION ON LOAD CONNECTIONS AND GROUNDING. READ THE "WARNING" NOTE, FOLLOWING PAR. 3-3.

3-5 BOP OPERATION WITH LOCAL (FRONT PANEL) OUTPUT CONTROL

3-6 VOLTAGE MODE OPERATION WITH CURRENT LIMITING. The BOP may be used as a stabilized (d-c) source of positive or negative voltage with output current limiting for either polarity pre-selected for the application at hand.

3-7 PROCEDURE

- 1) Determine the output voltage and current requirements of your load. Set the BOP MODE switch to the VOLTAGE position and the BIPOLAR VOLTAGE CONTROL SWITCH to ON.
- 2) With the BOP A-C POWER switch "off", connect a short circuit across the output terminals. Turn the BOP "on" again; wait 30 seconds.
- 3) Adjust the I_O LIMIT CONTROLS for both polarities as required, monitoring the OUTPUT CURRENT METER for the correct limiting value. Proceed as follows: Turn BIPOLAR VOLTAGE CONTROL fully counterclockwise. Adjust the "(-) I_O LIMIT CONTROL". Turn the BIPOLAR VOLTAGE CONTROL fully clockwise. Adjust the "(+) I_O LIMIT CONTROL. Turn the BIPOLAR VOLTAGE CONTROL to the center of its range. Turn the A-C POWER switch "off" and remove the short circuit from the output and reconnect the load.
- 4) Turn the A-C POWER SWITCH "on" again; wait 30 seconds, and adjust the operating voltage by means of the BIPOLAR VOLTAGE CONTROL to the value required.

NOTE: If the output current exceeds the pre-adjusted value at any time, the VOLTAGE MODE LIGHT will go out and the $(\pm)I_O$ LIMIT LIGHT will go on. After the cause of the overcurrent is eliminated, the indicator lights will return to their initial status.

3-8 CURRENT MODE OPERATION WITH VOLTAGE LIMITING. The BOP may be used as a stabilized d-c source of positive or negative current, with output voltage limiting for either polarity, pre-selected for the application at hand.

3-9 PROCEDURE (please refer to PAR. 3-4)

- 1) Determine the output current and voltage requirement of your load. Perform I_O LIMIT adjustment as described in PAR. 3-7, steps 2 and 3. Set the BOP MODE SWITCH to the CURRENT position and the BIPOLAR CURRENT CONTROL switch to ON.
- 2) Turn the A-C POWER SWITCH "on", wait 30 seconds and adjust the $(\pm)E_O$ LIMIT CONTROLS to the required output (compliance) voltage. Turn the A-C POWER SWITCH "off."
- 3) Connect the load and turn A-C POWER SWITCH "on" again and wait 30 seconds. Adjust the required operating current by means of the BIPOLAR CURRENT CONTROL as required.

3-10 BOP OPERATION WITH REMOTE CONTROL OF THE VOLTAGE CONTROL CHANNEL

3-11 REMOTE D-C OUTPUT VOLTAGE CONTROL BY RESISTANCE. As seen in FIG. 3-4, and as described in a previous paragraph (PAR. 3-6) the BOP d-c output potential can be controlled within its specified range by means of the BIPOLAR VOLTAGE CONTROL, with the BIPOLAR VOLTAGE CONTROL SWITCH in the ON position. Since the E_O PRE-AMP, with the built-in feedback and input resistors, has a gain of one, and the E_O BIPOLAR AMP have respective gains of 50 (BOP-500M) and 100 (BOP-1000M), a d-c input signal of zero to $(\pm)10V$ will control the BOP output through its specified range. In the local (front panel) control mode, the d-c control potential is applied via the BIPOLAR VOLTAGE CONTROL.

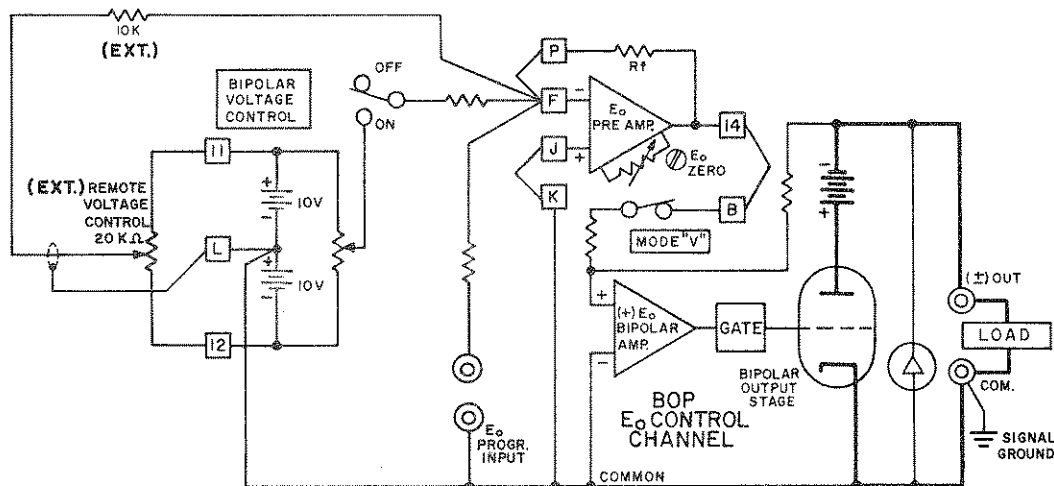


FIG. 3-4 REMOTE POTENTIOMETER CONTROL OF THE BOP D-C OUTPUT VOLTAGE

- 3-12 As shown in FIG. 3-4, this control method can readily be performed remotely, by setting the BIPOLAR VOLTAGE CONTROL SWITCH to the OFF position and connecting an external REMOTE VOLTAGE CONTROL as indicated in FIG. 3-4.
- 3-13 Two-terminal resistance control of the d-c output voltage (for example, by means of a Decade Box) can be exercised as shown in FIG. 3-5.

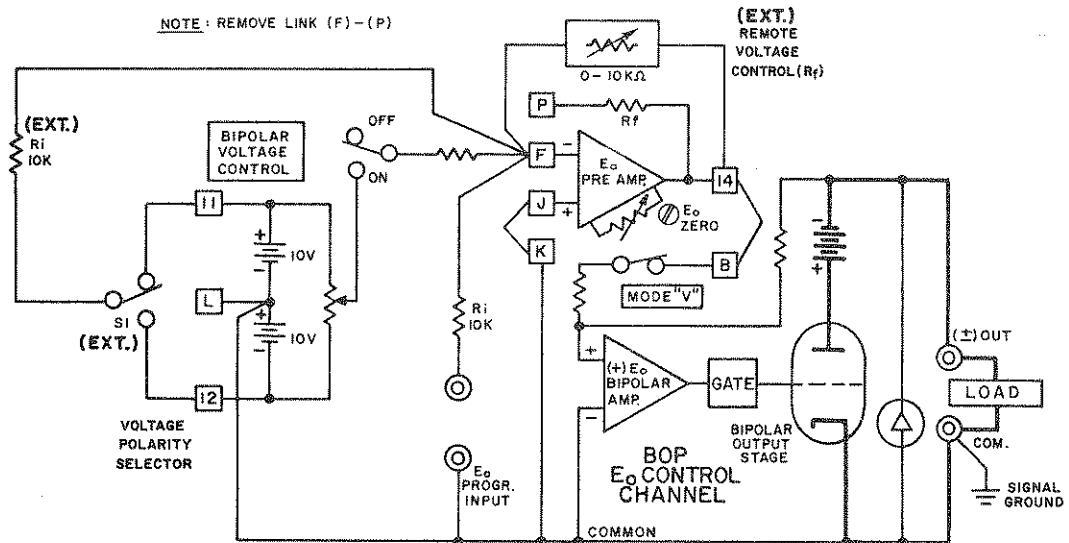


FIG. 3-5 REMOTE D-C OUTPUT VOLTAGE CONTROL BY MEANS OF A TWO-TERMINAL RESISTANCE (DECADE).

- 3-14 The external switch (S1), connected across the (±) reference voltage is used to pre-select either positive or negative output, by setting it to the applicable reference voltage polarity.
- 3-15 The E_o PRE-AMP functions here as an inverter. Its output can be expressed by the equation:

$$E_o \text{ (PRE-AMP)} = - E_{ref} (R_f/R_i). \quad \begin{array}{l} R_f = \text{Decade Resistor} \\ R_i = \text{Ext. Input Resistor} \end{array}$$

Since $E_{ref} = (\pm)10$ volts and the gain ratio R_f/R_i is variable from zero to one, its output voltage (E_o PRE-AMP) will vary linearly from zero to $(\pm)10$ volt, with the change in the decade resistance (R_f). As a consequence, the BOP output voltage will also vary linearly with the change in decade resistance.

- 3-16 This programming system can be calibrated very accurately by setting the REMOTE VOLTAGE CONTROL (Decade) to zero and adjusting zero output volts at the BOP E_o ZERO control, monitoring at the BOP output with a digital voltmeter. The maximum output voltage is calibrated by making all or part of R_i a rheostat and adjusting it, with the REMOTE VOLTAGE CONTROL at maximum resistance, to the maximum BOP output voltage.
- 3-17 REMOTE D-C VOLTAGE CONTROL BY MEANS OF D-C SIGNAL VOLTAGE.** The BOP d-c output voltage can be controlled directly by a $(\pm) 10V$ d-c signal, applied to the front panel E_o PROGRAM INPUT terminals. An interesting example of this application is the BOP output voltage control with a Kepco Model SN-12R Digital Programmer. The Model SN-12R responds to a complementary offset binary input coding and can be addressed either by a computer, or manually. The output signal of the Model SN-12R is from zero to $(\pm) 10$ volt and constitutes the input program for the BOP.

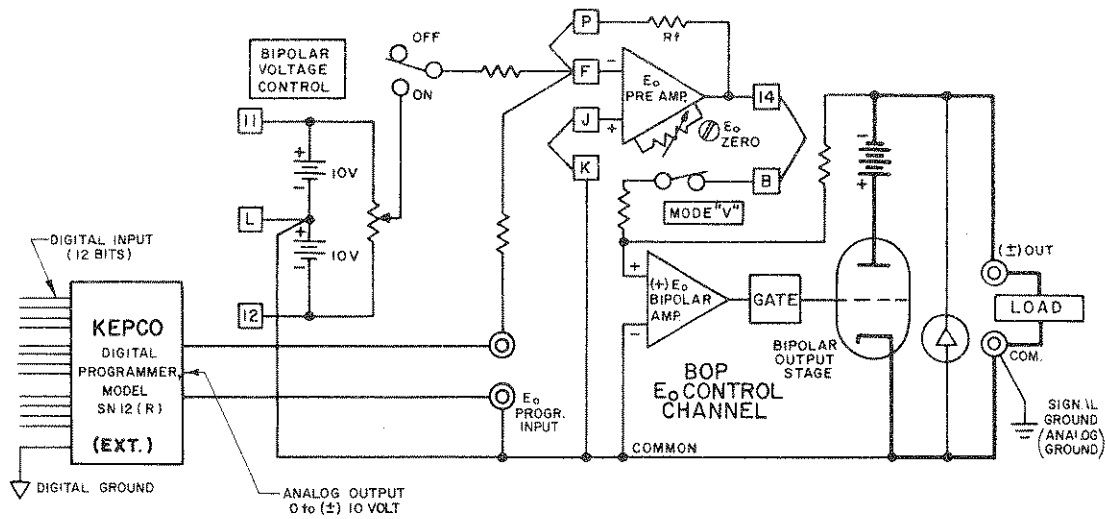


FIG. 3-6 DIGITAL CONTROL OF THE BOP D-C OUTPUT VOLTAGE

- 3-18 The connections between the SN-12R and the BOP are illustrated in FIG. 3-6. This programming system provides a resolution of 12-bits with a linearity of $(\pm) 0.01\%$. The digital and the power supply grounds are isolated (optical isolation) to 1000 volts. Calibration of the system is performed with the provided controls on the SN-12R Programmer
- 3-19 Since all terminals of the E_o PRE-AMP are available at the REAR PROGRAMMING CONNECTOR, d-c output voltage control can be exercised in many other ways. The E_o PRE-AMP can be treated as an uncommitted operational amplifier with its applicable transfer functions. Its initial offsets can be zeroed with the provided E_o ZERO Control, while the offset variations are specified in Section I of this manual (refer to Table 1-2). The basic principle of d-c output voltage control of the BOP is that a control voltage of $(\pm) 10$ volts at 1 mA at the E_o PROGRAM INPUT (with the built-in feedback/input resistors) will produce the full d-c output voltage swing of the BOP. If the selected control signal does not have the required amplitude or if the required control current cannot be supplied, the E_o PRE-AMP configuration can be altered to provide the proper interface for the application.
- 3-20 If, for example, the BOP d-c output voltage is to be controlled by means of a bipolar, 1 volt, high impedance source, it can be connected to the BOP as shown in FIG. 3-7.

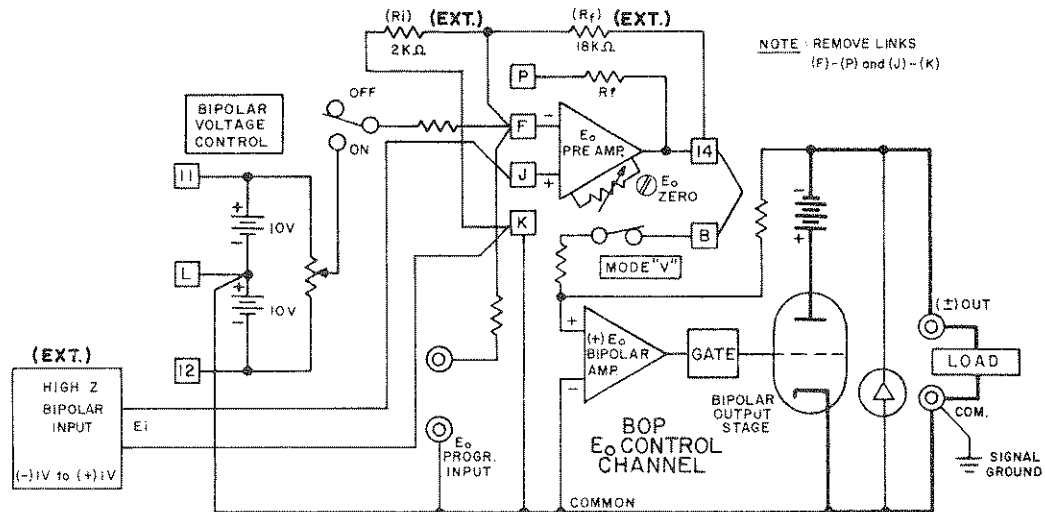


FIG. 3-7 BOP D-C OUTPUT VOLTAGE CONTROL WITH A HIGH IMPEDANCE, $(\pm) 1$ V SIGNAL SOURCE

- 3-21 As seen in FIG. 3-7, the original input feedback components of the E_O PRE-AMP have been bypassed and are replaced by external resistors (small, metal film or wirewound type resistors may be used and connected directly to the REAR PROGRAMMING CONNECTOR terminals as shown). The E_O PRE-AMP is used in the non-inverting configuration. Its output voltage (the necessary BOP control voltage) is given by:

$$E_O \text{ (PRE-AMP)} = E_i \left(\frac{R_f + R_i}{R_i} \right) = (\pm) 1V \left(\frac{18k + 2k}{2k} \right) = (\pm) 10V$$

Consequently, as the BIPOLAR INPUT VOLTAGE (E_i) is controlled from (-) 1V over zero to (+) 1V, the BOP output voltage will follow over its specified range. Calibration of the system can be performed at the programming source, or the E_O PRE-AMP zeroing control can be used for the low end, while the feedback resistor ($R_f = 18k$) can be trimmed to calibrate the high end of the range.

3-22 THE BOP AS AN AMPLIFIER

- 3-23 If, instead of the previously used d-c control signal, an a-c signal voltage is applied to the E_O PROGRAM INPUT, the BOP functions as a bipolar amplifier. As an amplifier, the BOP has a voltage gain of 50 (BOP-500M) and 100 (BOP-1000M) respectively, so that (as before with the d-c control signal) a bipolar a-c input signal with an amplitude of 20V (peak-to-peak) will drive the BOP output through its specified (\pm) output voltage range. All other dynamic specifications are given in Section I, Table 1-3.
- 3-24 The BOP can be used to amplify, sum or scale a variety of waveshapes, some of which are illustrated in FIG. 3-8. All input signals are shown in phase with their corresponding output waveshape. The latter can be readily produced 180° out of phase (i.e. with the output wave taking the exact opposite direction of the input signal) by addressing the non-inverting input of the E_O PRE-AMP instead of the front panel E_O PROGRAM INPUT (Inverting).

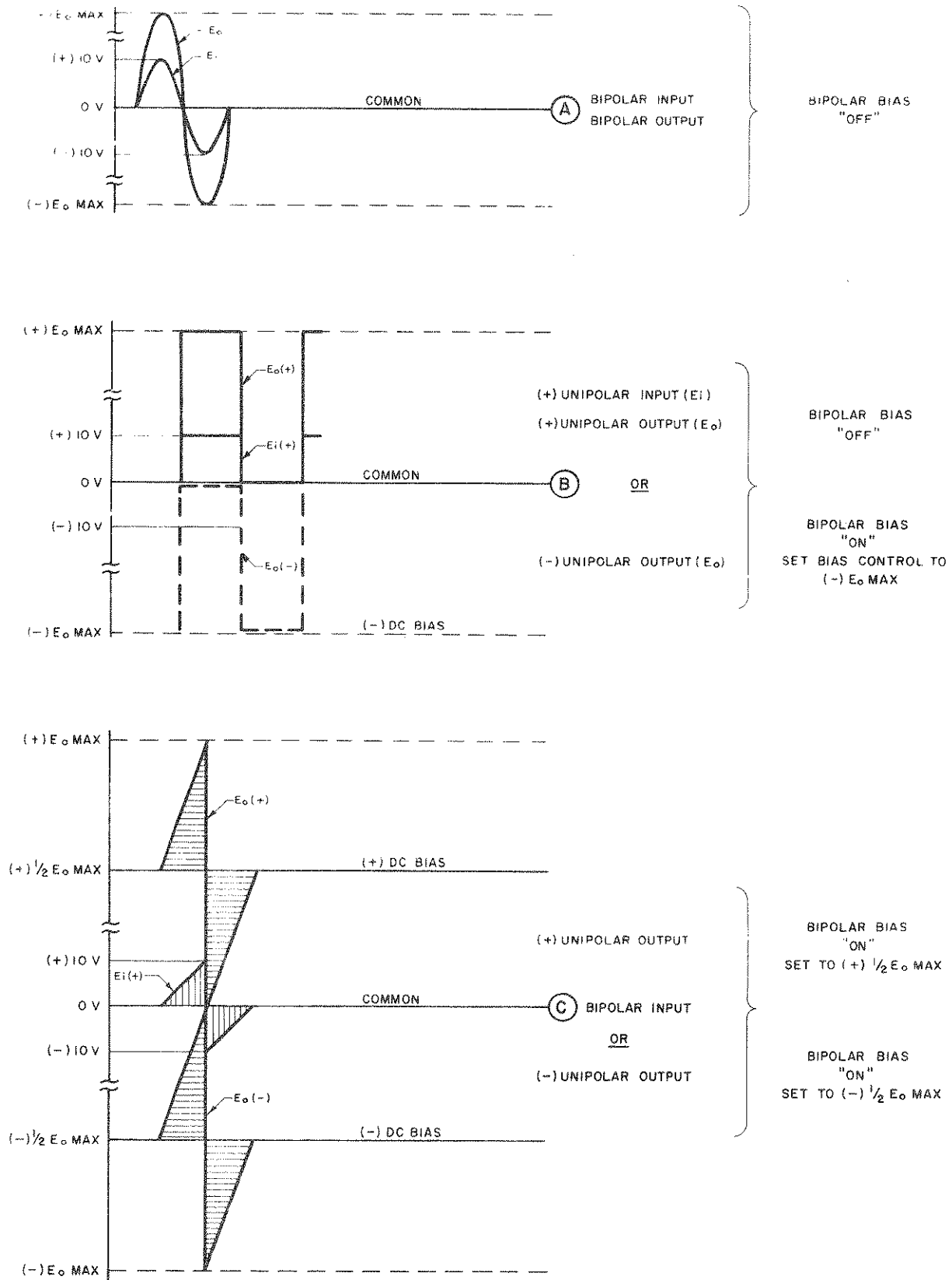


FIG. 3-8 GRAPHS OF POSSIBLE BOP INPUT/OUTPUT WAVE SHAPES

- 3-25 The basic programming circuit with which all the wave forms shown in FIG. 3-8 can be produced is shown in FIG. 3-9. Since all input signals in FIG. 3-8 are shown with a ± 10 volt amplitude, the basic programming circuit in FIG. 3-9 must be modified if the external signal source cannot produce 10 volts and if the full BOP output voltage swing is required.

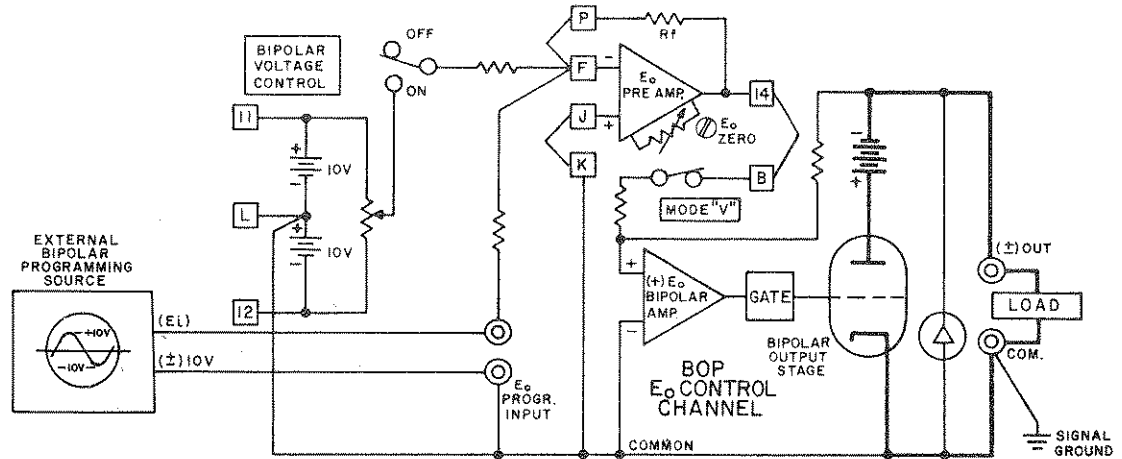


FIG. 3-9 BASIC PROGRAMMING CIRCUIT FOR USE OF THE BOP AS A BIPOLAR AMPLIFIER (VOLTAGE MODE)

- 3-26 If the EXT. PROGRAMMING SOURCE does not have sufficient amplitude to drive the BOP over its full output range, the gain of the E_0 PRE-AMP must be changed from the built-in 1V per volt value to suit the application. To calculate the required components for the new gain requirement, the output equation for the E_0 PRE-AMP in the inverting configuration is used:

$$E_0 \text{ (PRE-AMP)} = - E_i (R_f/R_i)$$

where $E_0 \text{ (PRE-AMP)} = \pm 10V$, and the values of R_f and R_i depend on the available amplitude of the programming source. If, for example, a ± 1 volt source is available, the ratio R_f/R_i must be 10, and the two resistor values can be 10k and 100k respectively. The built-in resistor ($R_i = 10k$) can be retained, and only R_f must be replaced with a 100k metal film (1/2 watt) unit. The necessary connections are illustrated in FIG. 3-10. Gain control (1 to 10) can be exercised by making R_f a rheostat instead of a fixed resistor.

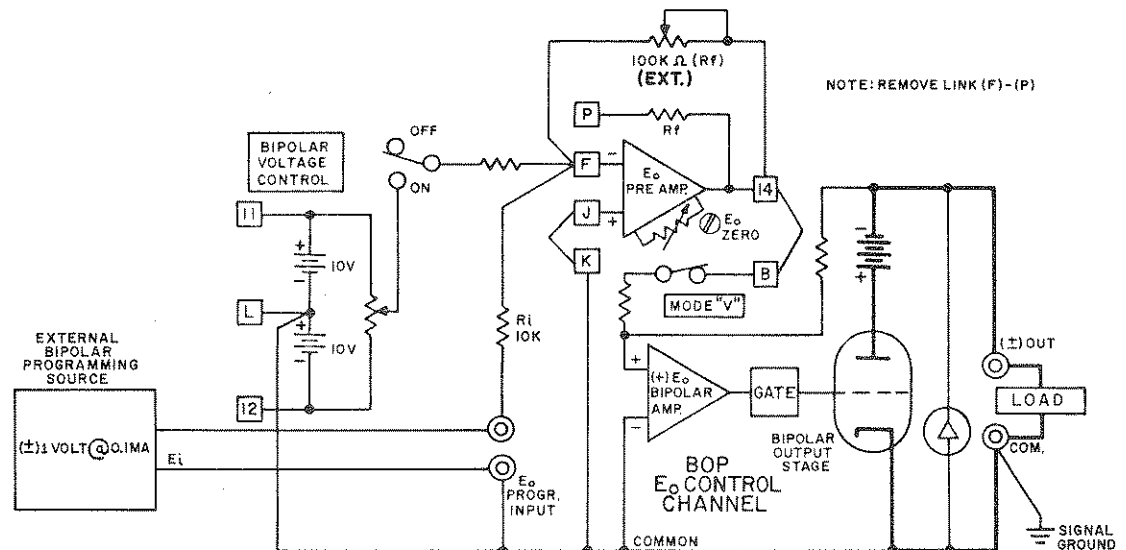


FIG. 3-10 PROGRAMMING CIRCUIT FOR DRIVING THE BOP OUTPUT VOLTAGE WITH A BIPOLAR ($\pm 1V$) SIGNAL

- 3-27 The non-inverting input of the E_o PRE-AMP is used for applications where the external programming source has a high impedance and/or cannot supply the necessary 0.1 mA drive current, or where a negative going output swing is desired for a positive going input signal. The necessary connections are illustrated in FIG. 3-11 for a E_o PRE-AMP GAIN of unity (with the built-in value for R_f retained and a short across R_f), although other gain configurations can be chosen, according to the output equation for the non-inverting configuration:

$$E_o \text{ (PRE-AMP)} = E_i \frac{R_f + R_i}{R_i}$$

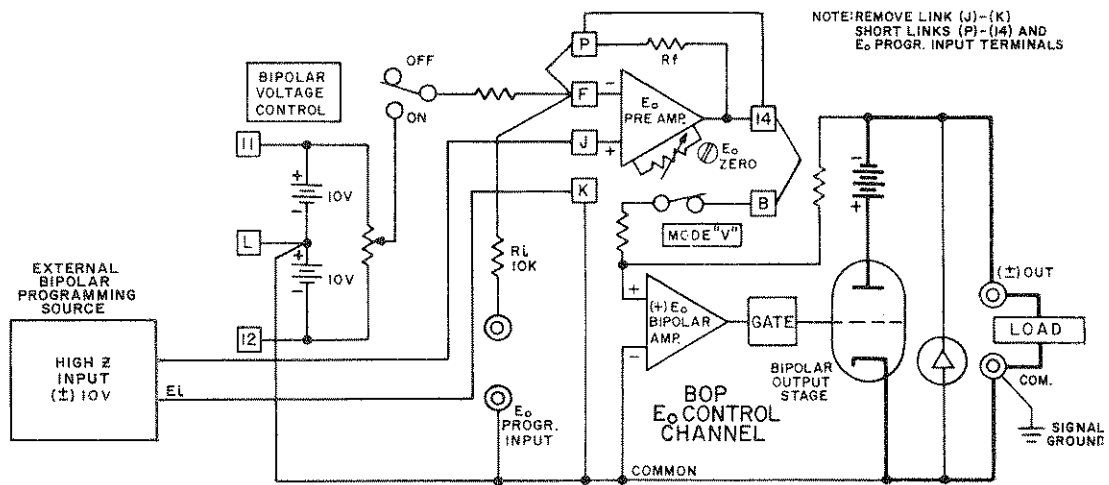


FIG. 3-11 PROGRAMMING CIRCUIT FOR DRIVING THE BOP OUTPUT VOLTAGE WITH A HIGH-IMPEDANCE SOURCE, USING THE NON-INVERTING INPUT OF THE PRE-AMPLIFIER

3-28 BOP OPERATION WITH REMOTE CONTROL OF THE CURRENT CONTROL CHANNEL

- 3-29 GENERAL: In the local (front panel) control mode, the BOP output current can be controlled by means of the BIPOLAR CURRENT CONTROL, with the BIPOLAR CURRENT CONTROL SWITCH closed, and the MODE SWITCH in the "CURRENT" position, over the full output range. The control potential zero to (\pm) 10V is applied to the I_o PRE-AMP, operating with unity gain, to the I_o BIPOLAR AMP which drives the BIPOLAR OUTPUT STAGE with a fixed gain of 8 mA per volt (BOP-500M) and 4 mA per volt (BOP-1000M) respectively. A d-c control signal from zero to (\pm) 10 volts will, therefore, control the BOP output current through its specified range (refer to FIG. 3-12).

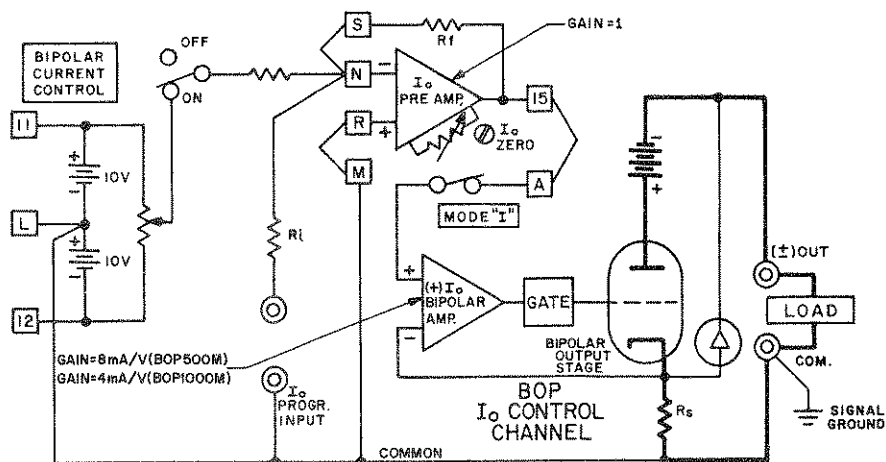


FIG. 3-12 LOCAL (FRONT PANEL) CONTROL OF THE BOP OUTPUT CURRENT WITH THE BIPOLAR CURRENT CONTROL.

3-30 REMOTE CONTROL OF THE BOP CURRENT CHANNEL. Since the requirements for the control of the BOP output current are the same as for programming the output voltage, and since the control circuitry is almost identical, all programming circuit descriptions for programming the output voltage of the BOP can be applied for current programming. The current programming circuits are illustrated in the following diagrams. Any exceptions with respect to current channel programming are noted on the diagrams. NOTE: Adjust the "zero" output current point by means of the built-in "I_o ZERO" control.

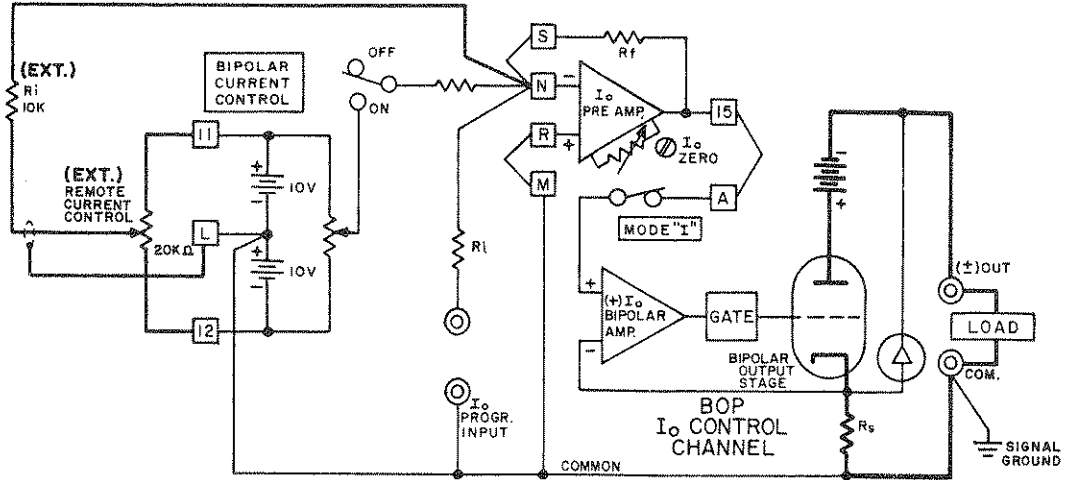


FIG. 3-13 REMOTE POTENTIOMETER CONTROL OF THE BOP OUTPUT CURRENT

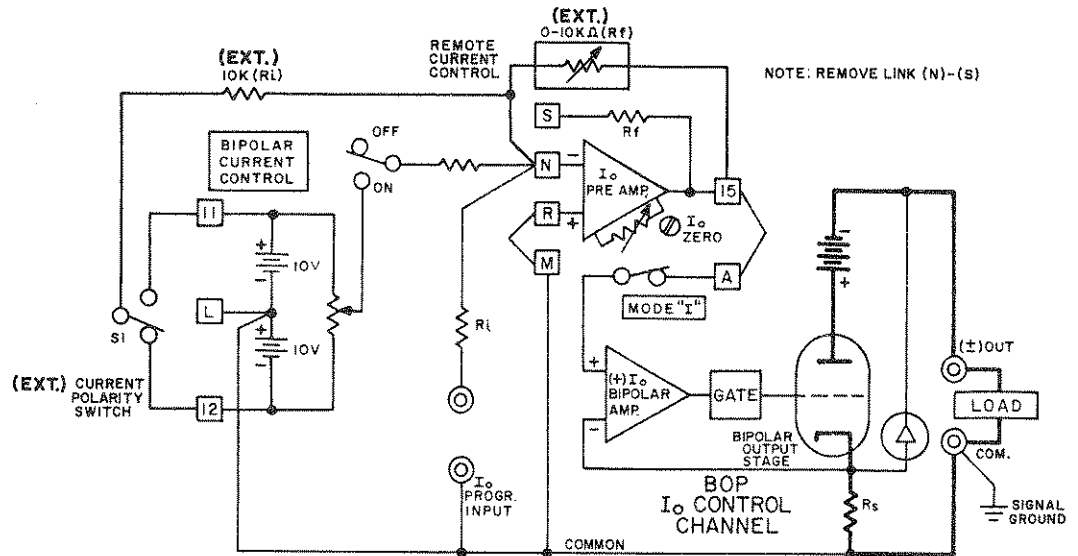


FIG. 3-14 REMOTE OUTPUT CURRENT CONTROL BY MEANS OF A TWO-TERMINAL RESISTANCE.

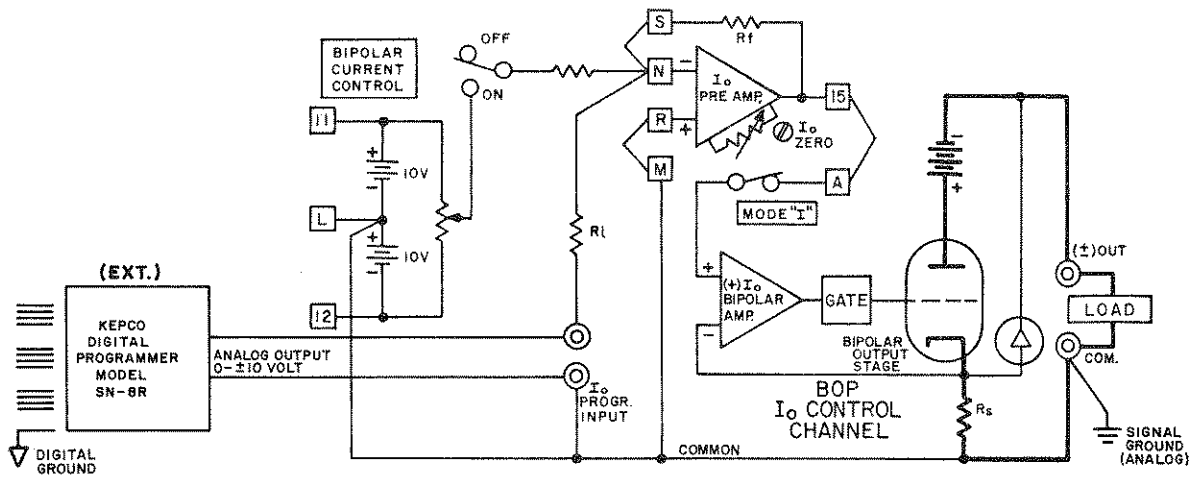


FIG. 3-15 DIGITAL CONTROL OF THE BOP OUTPUT CURRENT

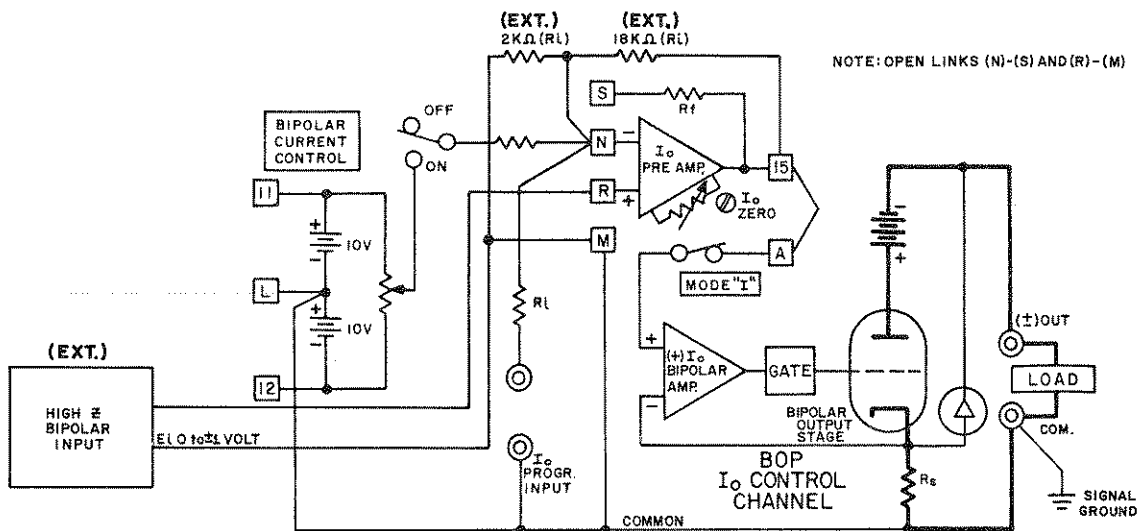


FIG. 3-16 BOP OUTPUT CURRENT CONTROL WITH A HIGH IMPEDANCE (± 1) VOLT SIGNAL SOURCE

Note: The non-inverting input of the Pre-amplifier is used to prevent loading of the input source.

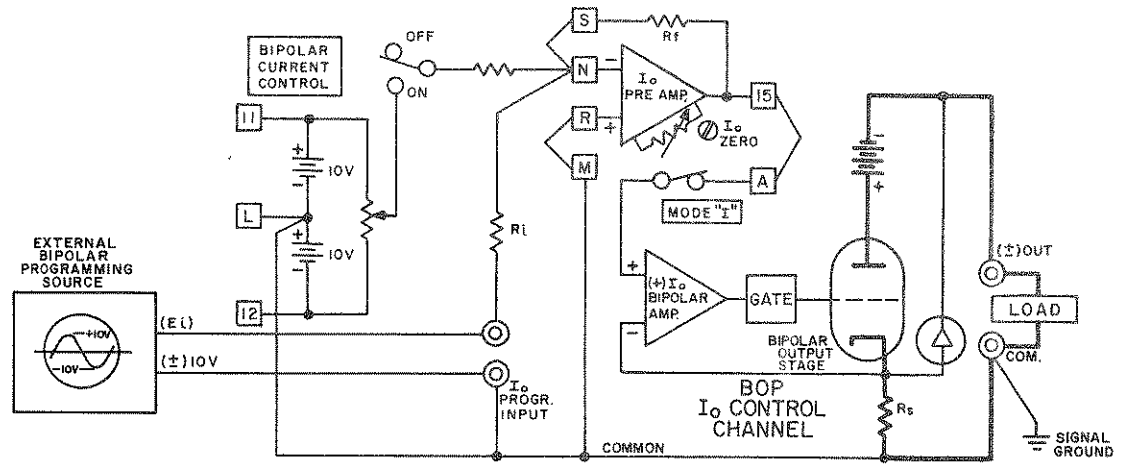


FIG. 3-17 BASIC PROGRAMMING CIRCUIT FOR USE OF THE BOP AS A BIPOLAR CURRENT-STABILIZED AMPLIFIER.

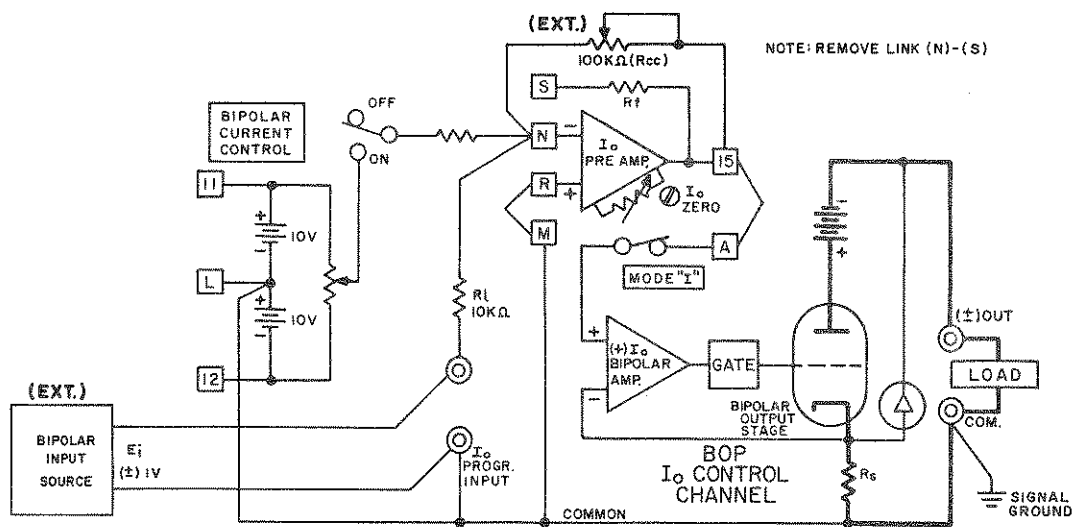


FIG. 3-18 PROGRAMMING CIRCUIT FOR DRIVING THE BOP OUTPUT CURRENT WITH A BIPOLAR SIGNAL LESS THAN $\pm 10V$ (EXAMPLE SHOWN: $\pm 1V$ SOURCE)

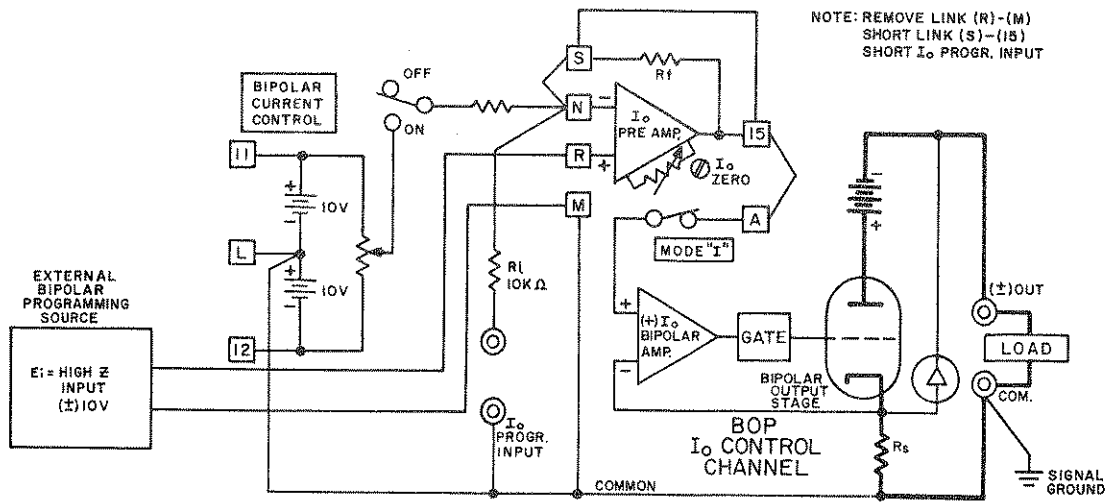


FIG. 3-19 PROGRAMMING CIRCUIT FOR DRIVING THE BOP OUTPUT CURRENT WITH A HIGH IMPEDANCE SOURCE

3-31 REMOTE CONTROL OF THE BOP CURRENT LIMIT

3-32 The BOP I_o LIMIT CIRCUIT in the local (front panel) control mode is shown in FIG. 3-20. A (+)10 volt reference voltage is repeated and inverted to obtain two reference voltages (+10V and -10V respectively). These references are applied at the input of the two $(\pm) I_o$ LIMIT CONTROL AMPS. Both control amplifiers operate in the inverting configuration and produce the control potential according to the output equation:

$$E_{Control} = (-) \frac{E_{ref}}{R_i} R_f$$

Since " R_f " is adjustable, the control voltage ($E_{CONTROL}$) can be varied from zero to (+)10V and (-)10V respectively, thus providing output current limit control over the full range of the BOP.

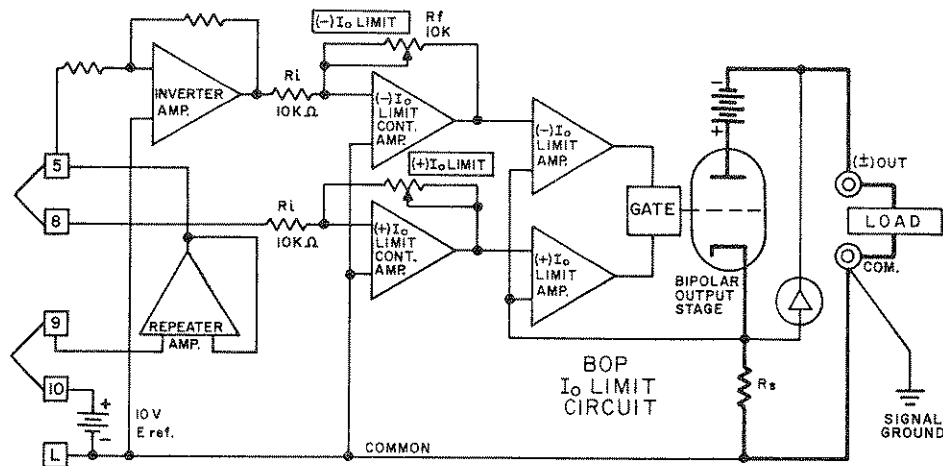


FIG. 3-20 LOCAL (FRONT PANEL) CONTROL OF THE BOP CURRENT LIMIT CIRCUIT.

3-33 The BOP current limits can be remotely controlled by disconnecting the fixed reference potential, setting the front panel controls to their maximum clockwise position, and substituting a variable (0 to 10 volt) reference potential. The two limits may be controlled simultaneously and symmetrically, or separately. The necessary connections are shown in FIG's 3-21 and 3-22 respectively.

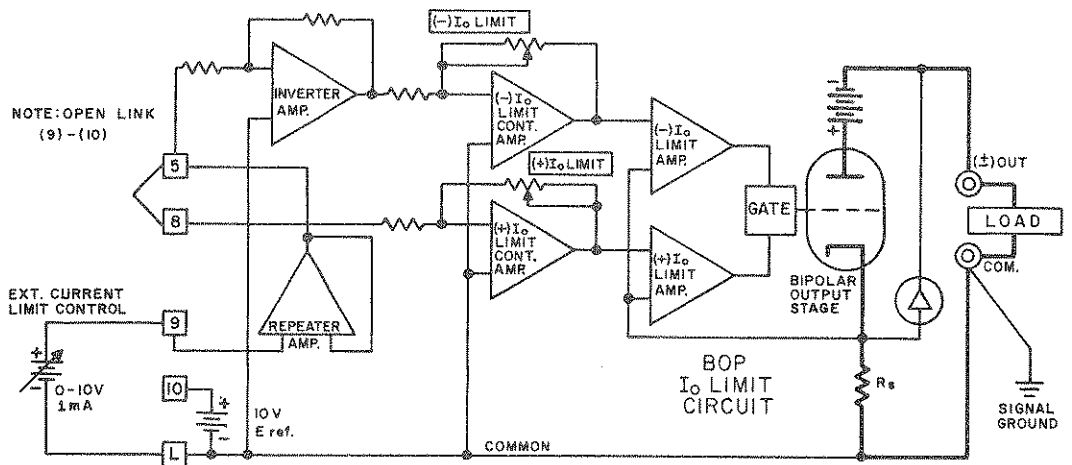


FIG. 3-21 SYMMETRICAL REMOTE CONTROL OF THE BOP CURRENT LIMITS

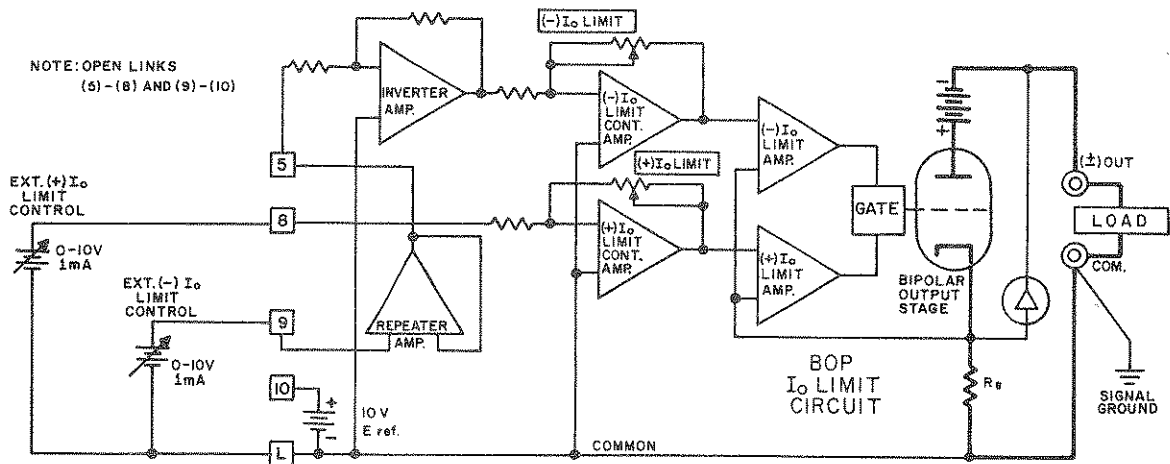


FIG. 3-22 INDEPENDENT REMOTE CONTROL OF THE BOP (+) I_o AND (-) I_o LIMIT

3-34 REMOTE CONTROL OF THE BOP VOLTAGE LIMIT

3-35 The BOP E_o LIMIT CIRCUIT in the local (front panel) control mode is shown in FIG. 3-23. The circuit functions in the same manner as the I_o LIMIT CIRCUIT described previously (refer to PAR. 3-31) and can be remotely controlled symmetrically with a 0 to 10V d-c source, or the (+) and (-) voltage limit can be controlled independently by individual 0 to 10V d-c sources. The necessary circuit connections are illustrated in FIG.'s 3-24 and 3-25. Note: The front panel VOLTAGE LIMIT CONTROLS serve as a "back-up" when remote controlling the voltage limits on the BOP. The front panel VOLTAGE LIMIT CONTROLS should be set to their maximum positions if full range remote control of the BOP voltage limits is desired.

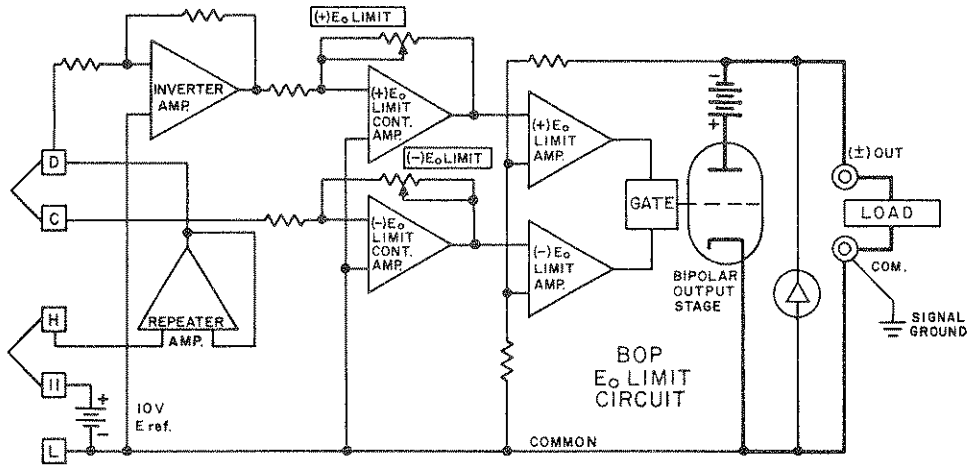


FIG.3-23 LOCAL (FRONT PANEL) CONTROL OF THE BOP VOLTAGE LIMIT CIRCUITS

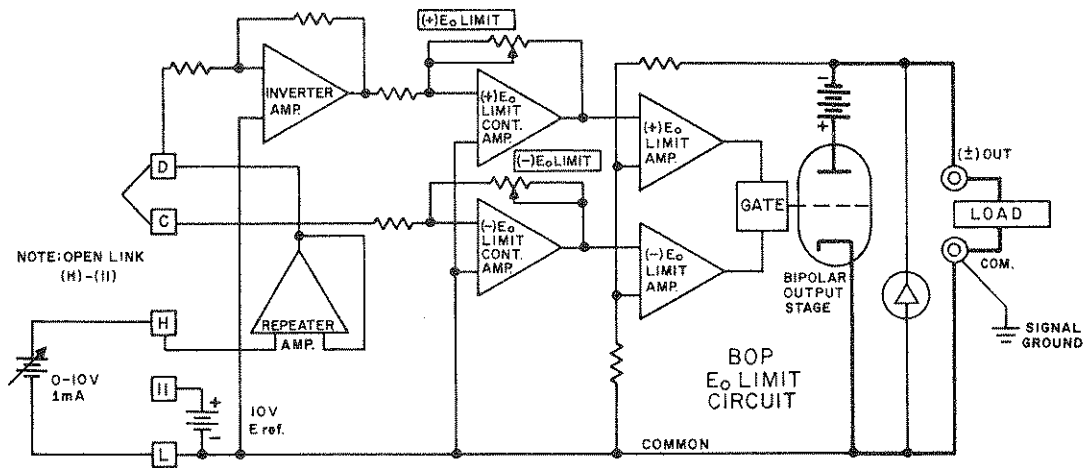


FIG. 3-24 SYMMETRICAL REMOTE CONTROL OF THE BOP VOLTAGE LIMIT CIRCUIT.

NOTE: REMOVE LINKS
(D)-(C) AND (H)-(II)

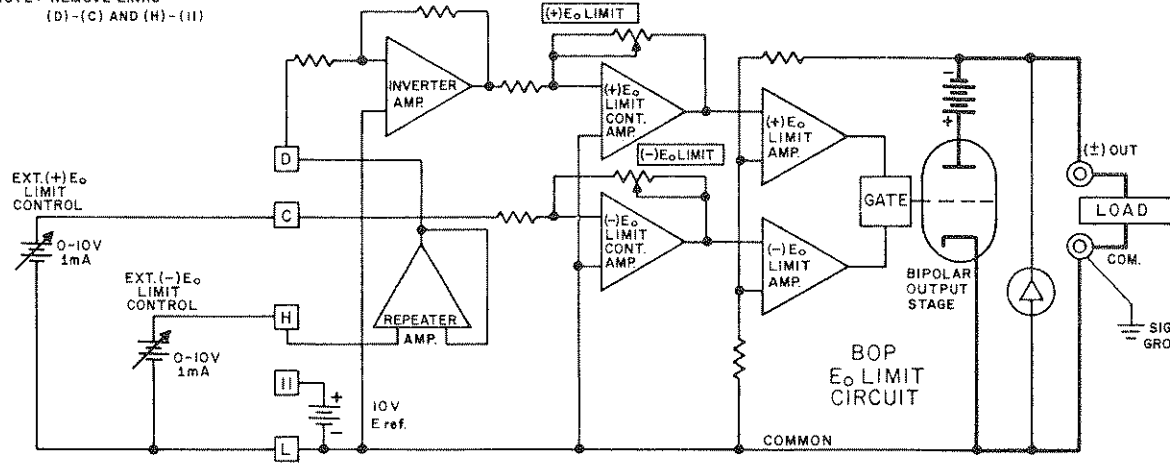


FIG. 3-25 INDEPENDENT REMOTE CONTROL OF THE BOP (+) AND (-) VOLTAGE LIMIT CIRCUIT.

SECTION IV – THEORY OF OPERATION

4-1 GENERAL

4-2 This section contains a brief analysis of the BOP circuitry by means of a simplified circuit diagram, discussion of the error equation and its application, and a circuit description based on the Main Schematic Diagram.

4-3 SIMPLIFIED DIAGRAM ANALYSIS (REFER TO FIG. 4-5)

4-4 The BOP Bipolar Operational Power Supply can be described as a stabilized d-c voltage or current source with either local (front panel) or remote control of its output. Its wide band characteristics permits operation as an amplifier, with or without d-c bias. The circuitry of the BOP consists of the following major sections:

- A) BIPOLAR OUTPUT STAGE
- B) GATE CIRCUIT
- C) VOLTAGE CHANNEL
- D) CURRENT CHANNEL
- E) BIPOLAR D-C BIAS SUPPLY
- F) VOLTAGE LIMIT CIRCUIT
- G) CURRENT LIMIT CIRCUIT

4-5 BIPOLAR OUTPUT STAGE. This stage consists of two groups of vacuum tubes (only two single tubes are shown in FIG. 4-1) connected effectively as a bridge circuit (refer to FIG. 4-1).

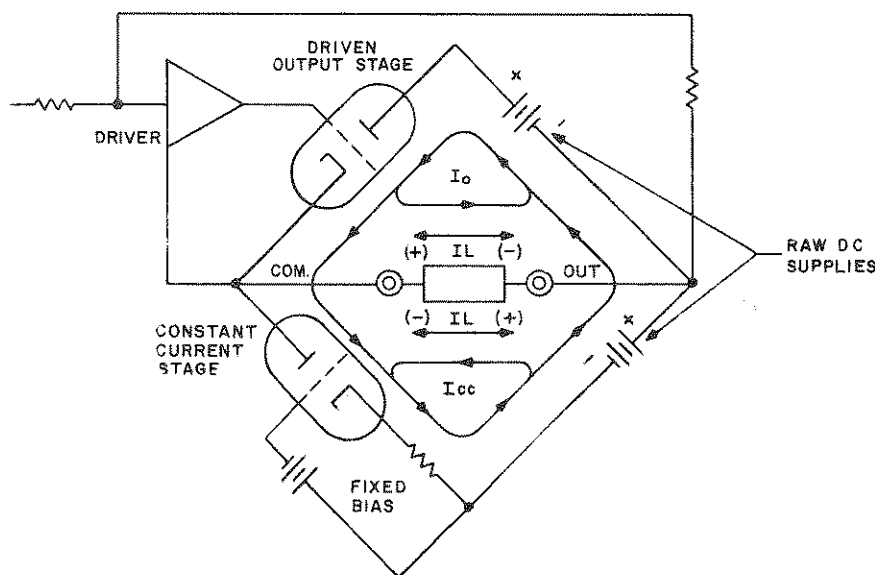


FIG. 4-1 BIPOLAR OUTPUT STAGE, BOP

4-6 The vacuum tube connected as a CONSTANT CURRENT STAGE establishes a bias current through the bridge circuit. The DRIVEN OUTPUT STAGE can be considered a variable impedance.

There are several operating conditions to be considered.

Let E_o = Output Voltage

Let I_o = Current from DRIVEN OUTPUT STAGE

Let I_{cc} = Current from CONSTANT CURRENT STAGE

Let I_L = Current through the LOAD

- A) NO LOAD ($I_L = 0$, $E_o = 0$, $I_o = I_{cc}$)

The impedances in both halves of the bridge are equal, therefore, the output voltage is zero

NO LOAD ($I_L = 0$, $E_o > 0$)

The impedance of the DRIVEN OUTPUT STAGE is larger, resulting in a positive output with reference to COMMON.

NO LOAD ($I_L = 0, E_o < 0$)

The impedance of the DRIVEN OUTPUT STAGE is smaller, resulting in a negative output with reference to COMMON.

- B) WITH LOAD, POSITIVE OUTPUT ($I_L \neq 0, E_o > 0, I_L = I_{CC} - I_o$)
 C) WITH LOAD, NEGATIVE OUTPUT ($I_L \neq 0, E_o < 0, I_L = I_o - I_{CC}$)

4-7 GATE CIRCUIT. The following amplifier's are connected to the DRIVER stage via the GATE circuit:

(-) E_o LIMIT	AMP
(+) E_o LIMIT	AMP
(-) I_o LIMIT	AMP
(+) I_o LIMIT	AMP
E_o BIPOLAR	AMP
I_o BIPOLAR	AMP

The GATE circuit operates as a dual "Exclusive OR" gate, permitting no more than a single amplifier to take control of the DRIVER and, thereby, the BOP output. All other amplifiers are biased off in the manner shown in FIG. 4-2.

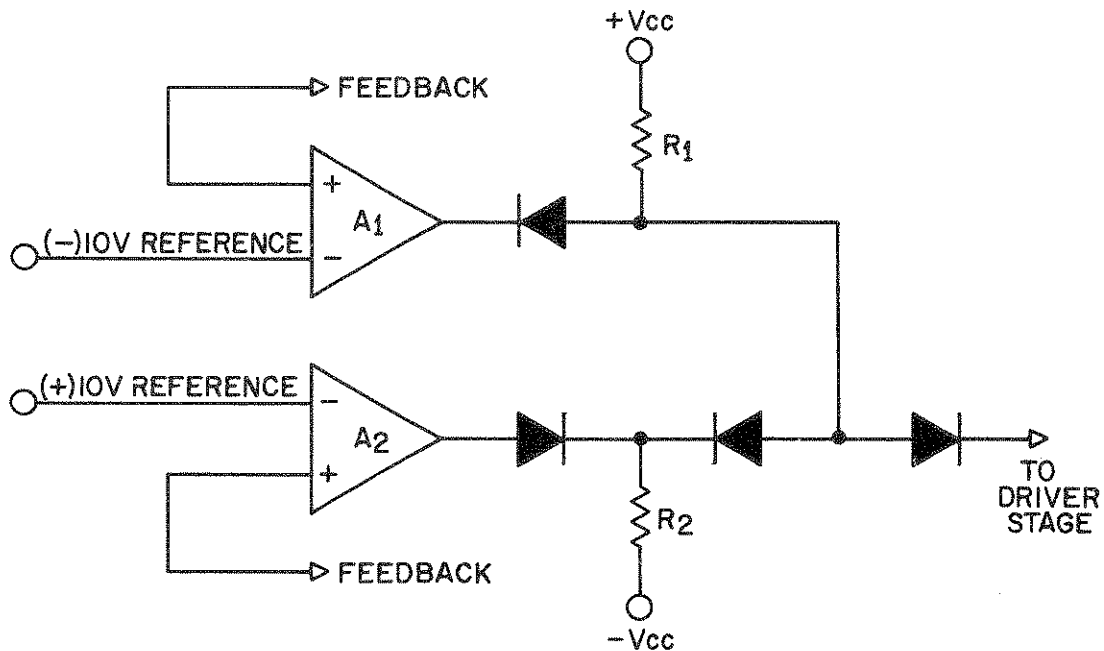


FIG. 4-2 DUAL OR-GATE, BOP

- 4-8 The presence of a feedback signal depends on the output configuration and the load condition. If, for example, the amplifier (A2) has sufficient feedback it is in control of the BOP output. Without a feedback signal applied to the amplifier (A1), its output voltage is driven by the (-) 10 volt reference signal to the level of (+) VCC and thereby cut-off. If load and/or output conditions now cause a feedback signal to be developed for A1, the feedback signal is simultaneously taken away from A2 and its output is driven by the (+) 10 volt reference signal to the level of (-) VCC and thereby cut-off, leaving A1 in control of the BOP output.
- 4-9 VOLTAGE CONTROL CHANNEL. With the MODE switch in the "E_o" position, the BOP d-c output voltage can be either controlled by connecting the E_o PRE-AMP to the BIPOLAR VOLTAGE Control, or by connecting an external ±10 volt (1 mA) signal to the E_o PROGRAM INPUT, or by summing the d-c bias with an external input signal. For input signals with an amplitude of less than 10 volts, the E_o PRE-AMP gain (unity with the built-in feedback and input resistors) can be altered to suit the available input signal. Signal sources not able to deliver 1 mA of signal current can be accommodated by using the (high impedance) non-inverting input of the E_o PRE-AMP. Since the gain of the following I_o BIPOLAR AMP/DRIVER/OUTPUT STAGE combination is a fixed 50 (BOP-500M) and 100 (BOP-1000M), a (+) ten volt drive signal, either via the E_o PRE-AMP, or directly applied to the E_o BIPOLAR AMP, will produce the rated BOP output voltage swing.

- 4-10 CURRENT CONTROL CHANNEL. With the MODE switch in the "I_O" position, the BOP d-c output current can be either controlled by connecting the I_O PRE-AMP to the BIPOLAR CURRENT control, or by connecting an external (±) 10 volt (1 mA) signal to the I_O PROGRAM INPUT, or by summing the d-c bias with an external input signal. For input signals with an amplitude of less than 10 volts, the I_O PRE-AMP gain (unity with the built-in feedback and input resistors) can be altered to suit the available input signal. Signal sources not able to deliver 1 mA of signal current can be accommodated by using the (high impedance) non-inverting input of the I_O PRE-AMP. Since the gain of the following E_O BIPO LAR AMP/DRIVER/OUTPUT STAGE combination is a fixed 8 mA/V (BOP-500M) and 4 mA/V (BOP-1000M), a (±) 10 volt drive signal, either via the I_O PRE-AMP, or directly applied to the I_O BIPO LAR AMP, will produce the rated BOP output current swing.
- 4-11 BIPO LAR D-C BIAS SUPPLY. The BOP bipolar d-c (±10V) bias and reference voltages (shown as batteries on the simplified schematic diagram, FIG. 4-5) are precision calibrated sources, derived from the highly stabilized amplifier power supply. The (±) 10 volt sources are available for external use on the REAR PROGRAMMING CONNECTOR with reference to COMMON. For internal biasing, they are connected to two 10-turn potentiometers (BIPO LAR control for VOLTAGE and CURRENT at the front panel). Connected via the "ON-OFF" switch to their respective control channel, the zero to (±) 10 volt d-c bias can control the BOP output voltage or current throughout its specified d-c output range.
- 4-12 VOLTAGE AND CURRENT LIMIT CIRCUITS. As seen from FIG. 4-5, the circuits for limiting the BOP output voltage and current to pre-adjustable operating points are identical, except that the feedback for the voltage limit is taken from the (±) OUTPUT terminal, while the current limit feedback originates from the voltage drop across the current sensing resistor (R_{S1}). Both feedback signals are dimensioned such that a zero to (±) 10 volt d-c signal will control the voltage, as well as the current limit range. The control signal is derived from the (+) 10 volt reference source and repeated by the E_O or I_O REPEATER AMP. It is applied directly to the (-) E_O and (+) I_O LIMIT CONTROL AMPS and via the E_O or I_O PROGRAM INVERTERS to the (+) E_O and (-) I_O LIMIT CONTROL AMPS. The control amplifiers are operational amplifiers in the inverting mode. Their feedback resistors are single turn controls, accessible from the BOP front panel, which allow the manual adjustments of all limits (±E_O, ±I_O) over the BOP output range. The limits can also be controlled externally, by means of a 0 to (+) 10 volt, 1 mA d-c signal. For simultaneous control of the (±) E_O or (±) I_O limit, the control voltage source is connected to the REAR PROGRAMMING CONNECTOR from pin H (±E_O) or pin 9 (±I_O) to common. For individual control of the (+) E_O or I_O and the (-) E_O or I_O limit, two control voltages (0 to (+) 10V @ 1 mA) are required. One is connected as described for simultaneous control. Then, the jumper (5 to 8 for for I_O limit, D to C for E_O limit) is removed and the second control voltage is connected from pin 8 (I_O limit) or pin C (E_O limit) to COMMON.

4-13 THE MEANING OF THE PRE-AMPLIFIER OFFSET SPECIFICATIONS

- 4-14 The OUTPUT EFFECTS of the BOP as a d-c source of voltage or current, for variations in the various INFLUENCE QUANTITIES are tabulated in Section I (Table 1-2). These output effects are largely due to the preamplifier offsets and the variations in the reference potential, multiplied by the closed loop gain of the bipolar voltage amplifier (Voltage Mode) or divided by the sensing resistor value (Current Mode). The published specifications are valid only for the built-in values of the preamplifier input/feedback resistors. If these values are altered by the user (as in remote programming) the BOP output effects must be calculated with the new values and the tabulated specifications for the PREAMPLIFIER OFFSETS (from Section I, Table 1-2). The expressions for the (worst case) BOP output effects are:

$$\text{(Voltage Mode)} \quad \Delta E_O = G \quad [\pm \Delta E_{I_O} (1 + R_f/R_i) \pm \Delta I_{I_O} (R_f)]$$

$$\text{(Current Mode)} \quad \Delta I_O = \frac{1}{R_S} \quad [\pm \Delta E_{I_O} (1 + R_f/R_i) \pm \Delta I_{I_O} (R_f)]$$

- where: ΔE_{I_O} = Pre-amp Offset Voltage Variation (from Section I, Table 1-3)
 ΔI_{I_O} = Pre-amp Offset Current Variation (from Section I, Table 1-3)
 G = Closed Loop Gain, Voltage Mode (BOP 500M = 50, BOP 1000M = 100)
 R_f = External Feedback Resistor Value
 R_i = External Input Resistor Value
 R_S = Current Sensing Resistor Value (BOP 500M = 125Ω, BOP 1000M = 250Ω)

- 4-15 As a practical example, let us assume that on a Model BOP-500M, the Voltage Pre-amplifier gain has been changed from the original unity to ten. This would mean the input resistor value (10k) has been maintained and the feedback resistor (R_f) has been changed from 10k to 100k. The BOP is used as a d-c voltage source and the output variations over a 10°C temperature change are to be predicted.
- A) From Section I, Table 1-2; the PREAMPLIFIER OFFSETS are: $\Delta E_{iO} = 20 \mu\text{V}$, $\Delta I_{iO} = 1 \text{ nA}$. The input/feedback resistors are: $R_i = 10\text{k}$, $R_f = 100\text{k}$.
- B) Inserting the offsets and the values of the feedback/input resistors into the given equation:

$$\Delta E_O = 50 [20 \mu\text{V} (1 + 10) + 1 \text{ nA} (100\text{k}\Omega)]$$

$$\Delta E_O = 50 (220 \mu\text{V} + 100 \mu\text{V})$$

$$\Delta E_O = 15.6 \text{ mV per } ^\circ\text{C} \text{ (maximum output voltage change)}$$
- C) For a temperature change of 10°C , therefore, a 156 mV change in output voltage is the maximum variation to be expected.
 NOTE: If the internal BIPOLAR BIAS (Reference) Voltage is used to produce the output voltage, its tabulated variation (0.0005% of 10 volts = $50 \mu\text{V}$ per $^\circ\text{C}$) must be added to the calculated result. If an *external* voltage source is used to program the BOP, *its* variations with temperature must be added.

4-16 BOP CIRCUIT DESCRIPTION (SEE MAIN SCHEMATIC, SECTION VI, FIG. 6-5)

- 4-17 GENERAL. This section contains a description of the major circuitry of the Kepco Model BOP-500M and Model BOP-1000M Bipolar Operational Power Supplies. The BOP consists of a MAIN CHASSIS ASSEMBLY (A2) with attached FRONT PANEL and contains a total of four (4) subassemblies:
- 1) MAIN CHASSIS ASSEMBLY WITH FRONT PANEL (A2), Component Numbers 101-199 and 201-299
 - 2) CONTROL CIRCUIT AND REFERENCE ASSEMBLY (A1), Component Numbers 1-99
 - 3) REAR TERMINAL ASSEMBLY (A3), Component Numbers 301-399
 - 4) OUTPUT STAGE AND BIAS SUPPLY ASSEMBLY (A4), Component Numbers 401-499
 - 5) A-C DELAY AND SOURCE SELECTOR ASSEMBLY (A5), Component Numbers 501-599
- 4-18 The subassemblies and the main chassis assembly are interconnected by printed circuit connectors as shown on the Interconnecting Diagram (refer to Section VI, FIG. 6-1). The identification of all connectors in FIG. 6-1 coincides with the reference designations on the Main Schematic (Section VI, FIG. 6-5). Any component on 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.

4-19 A-C INPUT CIRCUIT

- 4-20 A-C source power is introduced via the three-wire line cord which connects to the A-C POWER INPUT connector (P201). The center contact of P201 is connected to the BOP metal chassis. If the supplied three-wire line cord with safety plug is used to connect the BOP to a properly grounded power outlet, safety (a-c) grounding is automatically accomplished.
- 4-21 Once the A-C POWER switch (SDS101) is placed in the "on" position, and the INTERLOCK switch (S301, part of the REAR TERMINALS ASSEMBLY A3) is closed, the front panel POWER indicator lamp (part of the A-C POWER switch SDS101) is energized and a-c power is applied to the FILAMENT TRANSFORMER (T202). This transformer, besides providing the filament power for the OUTPUT STAGE vacuum tubes (V401 through V408), contains a winding which produces the d-c operating voltage for the DELAY circuit, by means of the bridge rectifier (CR501) and filtered with a capacitor (C501). The DELAY circuit provides an approximately 25-second delay for the turn-on of the HIGH VOLTAGE and the AUXILIARY TRANSFORMERS (T201, T203). The delay circuit consists of a programmable unijunction transistor (Q501), a silicon controlled rectifier (CR503) and their auxiliary components, which determine the delay time following a-c turn-on. Once the output is delivered to the triac (CR201) and the triac conducts, the HIGH VOLTAGE and the AUXILIARY TRANSFORMERS (T201, T203) are powered and the HIGH VOLTAGE front panel light (DS101) is "on".
- 4-22 The A-C SOURCE SELECTOR switch (S501) connects the primaries of all transformers (T201, T202, T203) either in parallel (115V POSITION) or in series (230V POSITION). The A-C SOURCE SELECTOR is accessible from the left side of the BOP.

4-23 MAIN D-C SUPPLIES AND OUTPUT STAGE WITH DRIVER

4-24 The dual Main D-C Supply which delivers the output power for the OUTPUT STAGE (V401 through V408) is derived from the centertapped secondary winding on the HIGH VOLTAGE TRANSFORMER (T201). Rectified by the bridge rectifier circuit (CR401 through CR404), the two equal (positive and negative) d-c potentials are filtered by capacitors C201, 202 and C203 respectively. All filter capacitors are paralleled by bleeder resistors (R201, 202, 203). The dual Main D-C Supply is connected to the output stage as indicated in the simplified partial schematic diagram (FIG. 4-3).

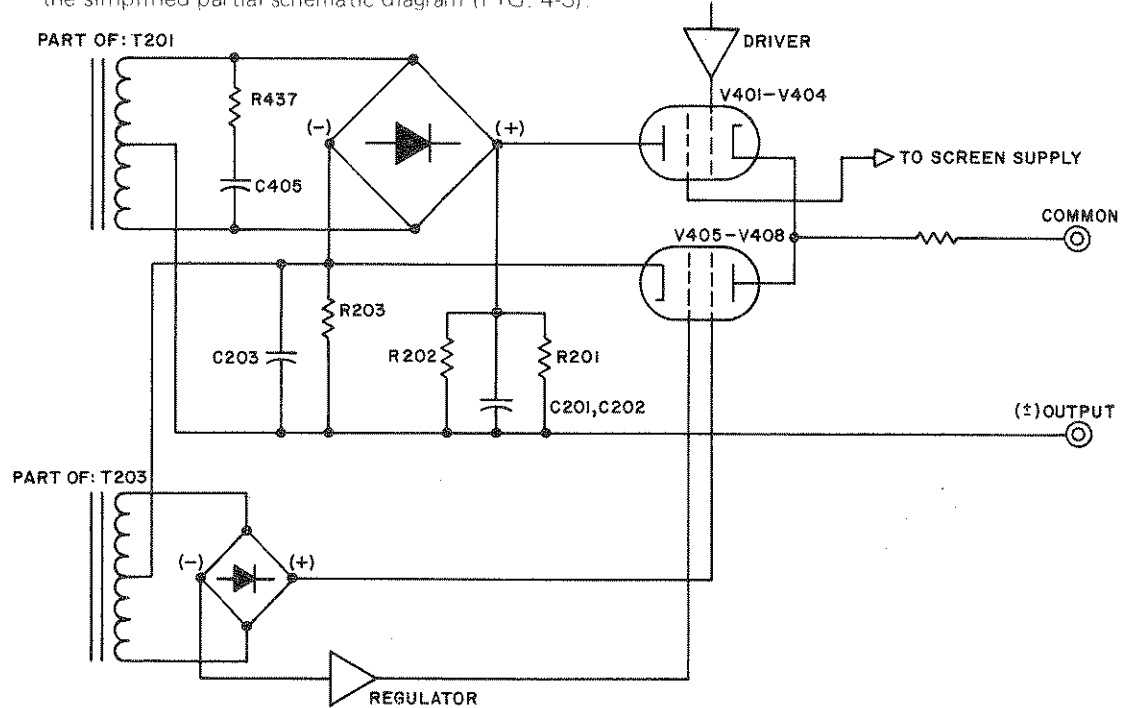


FIG. 4-3 SIMPLIFIED DIAGRAM, BOP MAIN D-C SUPPLIES AND OUTPUT STAGE

4-25 The OUTPUT STAGE consists of two groups of four vacuum tubes, each connected as shown in FIG. 4-3). The group connected as a constant current stage (V405 to V408) receives its fixed grid bias from the CONTROL GRID AND SCREEN SUPPLY, a dual (\pm) d-c source, which is derived from a center-tapped secondary winding on T203, rectified by the bridge rectifier (CR405) and filtered by C401 (negative) and C402 (positive). While the positive voltage is connected (via R412-415) to the screen grids of the constant current stage, the negative voltage is applied (via R421-426) to the control grid of the same group of vacuum tubes (V405-V408). The REGULATOR for the negative grid potential consists of the operational amplifier (IC401) with a driver stage (Q401). The regulator reference potential is derived from the zener diode (CR406) and the voltage divider resistors (R406, R407) and is compared to the feedback voltage across R405 at the input of IC401. The power for IC401 is obtained from zener regulators CR406 and CR407, and its output biases the driver stage (Q401 with resistors R417, R418, R419, lag network R420, C404). The second group vacuum tubes (V401-V404) is driven from the DRIVER STAGE (Q3, Q4 with associated components) via the series resistors (R429-R432). The screen voltage for the driven output stage (V401-V404) is derived from a secondary winding on T203, rectified by the bridge rectifier (CR1) and filtered by C1, paralleled by the bleeder resistor (R1). It is applied via the series resistors (R433-R436). The resistors in series with the cathodes of all vacuum tubes (R401-R404 and R408-R411) are matching resistors for equal output current distribution between the individual tubes. The Collector Voltage for the DRIVER STAGE (Q3, Q4) is derived from a secondary winding on T203, rectified by the bridge rectifier (CR2), filtered by C2 and applied via R6 to the transistor stage (Q3). Resistor R69 serves as a collector load for Q4.

4-26 THE REFERENCE AND AUXILIARY POWER SUPPLIES

4-27 The bipolar d-c source for the operation of the control amplifiers and the generation of the reference potentials are derived from a center-tapped winding on T201, rectified by the bridge rectifier (CR3) and filtered by C3 (positive) and C4 (negative). The positive section of the dual (± 15 volt) supply is regulated by IC-1 and Q1, and filtered by C7. A zener potential, created by R11 and CR4 serves as a reference for both, the 15 volt and the 10 volt regulator (IC1, 1/4 IC-3). The gain of the 10 volt regulator is adjustable (R18), so that the 10 volt reference potential can be calibrated. A separate 12 volt zener potential, established by CR6 (via R17) serves as a return for the protective diodes (CR8 to CR11, CR18, CR19) of the control amplifiers. The

negative section of the dual supply is identical to the positive side (except for component reference designations). Both reference potentials (± 10 volts) are connected to the BIPOLAR controls for voltage and current (R101 and R102 so that a 0 to (\pm) 10V reference voltage can be applied (via S102 and S103) to either the voltage mode or the current mode pre-amplifiers (IC-4, IC-7). The reference potentials (± 10 volt) are also available on the REAR PROGRAMMING CONNECTOR (terminals 10, 11, 12, 13) with reference to COMMON (terminal L). The maximum reference current from these d-c sources is 1 milliampere.

4-28 THE VOLTAGE AND CURRENT CONTROL CHANNELS

- 4-29 These two control channels are identical, except for component reference designations and the terminations on the REAR PROGRAMMING CONNECTOR (J214). Only the VOLTAGE CONTROL CHANNEL will be described here. The VOLTAGE CONTROL CHANNEL consists of the voltage pre-amplifier (E_O PRE-AMP - IC4) and the bipolar voltage amplifier (E_O BIPOLAR AMP - IC8), interconnected via the MODE SWITCH (S104) and operating into the driver stage (Q3) via the gating diodes (CR28, CR34, CR37). The pre-amplifier input and output terminals are brought to the REAR PROGRAMMING CONNECTOR (J214, terminals F, J, and 14). The inverting input of the pre-amplifier is also connected (via R22) to the E_O PROGRAM INPUT terminal at the front panel, as well as (via R21 and S102) to the BIPOLAR VOLTAGE control (R101). The offset of the pre-amplifier (IC-4) can be zeroed by means of the E_O ZERO control (R31). The pre-amplifier output is connected (via J214 - terminals 14 and B) to the MODE SWITCH (S104). In the "V" position of the MODE switch, the pre-amplifier output goes (via R51) to the non-inverting input of the E_O BIPOLAR AMP (IC-8) to which the voltage feedback from the (\pm) OUTPUT terminal is connected (feedback resistor R301 with parallel feedback capacitor C301, in series with protective resistor R302). The gain of the VOLTAGE CONTROL CHANNEL is designed to produce the rated BOP output voltage for a (\pm) 10 volt input signal applied to the E_O PROGRAM INPUT terminals at the front panel. This input is non-inverting, i.e., the BOP output voltage is *positive* for a *positive* input signal and *negative* for a *negative* input signal.

4-30 THE VOLTAGE AND CURRENT LIMIT CIRCUITS

- 4-31 The (\pm) E_O and the (\pm) I_O LIMIT CIRCUITS are identical, except for component reference designations, the origin of the feedback signal and the terminations on the REAR PROGRAMMING CONNECTOR (J214). Only the VOLTAGE LIMIT (E_O LIMIT) circuit will be described here. The VOLTAGE LIMIT circuit consists of the E_O PROGRAM REPEATER AMPLIFIER (1/4 IC-5, PINS 1,2,3), the E_O PROGRAM INVERTER (1/4 IC-5, PINS 5,6,7), the (-) E_O LIMIT CONTROL AMPLIFIER (1/4 IC-5, PINS 12,13,14), the (+) E_O LIMIT CONTROL AMPLIFIER (1/4 IC-5, PINS 8,9,10), the (-) E_O LIMIT AMPLIFIER (1/4 IC-9, PINS 1,2,3) and the (+) E_O LIMIT AMPLIFIER (1/4 W IC-9, PINS 5,6,7).
- 4-32 In the standard local (front panel) control mode, the current or voltage limit points ($\pm E_O$, $\pm I_O$) are individually pre-adjustable over the full BOP output range by means of the front panel controls: R103 (+) I_O LIMIT CONTROL, R104 (-) I_O LIMIT CONTROL, R105 (+) E_O LIMIT CONTROL, R106 (-) E_O LIMIT CONTROL. In the normal operating mode, the negative, as well as the positive voltage and current limit circuits are biased off. While the negative voltage limit is biased off from the control of the gate via CR33 and R65 connected to the (+) 15 volt supply, the positive voltage limit is biased off from the control of the gate via CR29 and R64 connected to the (-) 15 volt source. The limit circuit becomes active if an (external) load condition produces a feedback signal via the voltage divider (R308, R309) applied to the (+) E_O LIMIT and simultaneously to the (-) E_O LIMIT AMPLIFIER. The feedback signal is compared with the control signal derived as described in par. 4-33. If the feedback signal magnitude approaches that of the control voltage, the amplifiers will turn-on and take control over the output, by overriding the back-bias on its gate diode. The overvoltage range is approximately from zero to 15% beyond the maximum rated output voltage.
- 4-33 The Control Voltage to the (\pm) E_O LIMIT AMPLIFIERS is derived from the positive (+ 10 volt) reference source, and repeated via the E_O PROGRAM REPEATER AMPLIFIER (1/4 IC-5, PINS 1,2,3). It is applied directly to the (-) E_O LIMIT CONTROL AMPLIFIER (1/4 IC-5, PINS 12,13,14) and via an inverting stage (E_O PROGRAM INVERTER, 1/4 IC-5, PINS 5,6,7) to the (+) E_O LIMIT CONTROL AMPLIFIER (1/4 IC-5, PINS 8,9,10). By means of the feedback control resistors ($\pm E_O$ LIMIT CONTROLS, R105, R106) the control voltage is adjusted from zero to (\pm) 10 volts and compared at the input of the (\pm) E_O LIMIT AMPLIFIERS (1/4 IC-9, PINS 1,2,3 negative and 1/4 IC-9, PINS 5,6,7, positive) with the feedback signal as described in PAR. 4-32.

4-34 THE INDICATOR LIGHT AND FLAG SIGNAL CIRCUITS

4-35 There are four (4) indicator/flag signal circuits to signal the BOP operating mode at the front panel by means of a light and at the REAR PROGRAMMING CONNECTOR (J214) by means of a flag signal:

- A) VOLTAGE MODE INDICATOR CIRCUIT
- B) CURRENT MODE INDICATOR CIRCUIT
- C) VOLTAGE LIMIT INDICATOR CIRCUIT
- D) CURRENT LIMIT INDICATOR CIRCUIT

All four circuits are similar, except for component reference and rear terminal designations. Only the circuit for the VOLTAGE MODE will be described.

4-36 Once the E_O BIPOLAR AMPLIFIER (IC-8) takes control of the BOP output, its output signal serves as a turn-on for the E_O MODE FLAG AMPLIFIER (1/4 IC-11, PINS 1,2,3). The signal is inverted and energizes the zener diode (CR46) and the front panel VOLTAGE MODE light (DS102) via R82. Simultaneously, the output from the E_O MODE FLAG AMPLIFIER is used to turn-on the flag signal transistor (Q5), the output of which is connected to the REAR PROGRAMMING CONNECTOR J214 pin 3 with reference to COMMON from the saturation potential of Q5 (approximately 0.5V) to the zener voltage of CR5 (approximately 4.5V), to the saturation potential of Q5 (approximately 0.5V).

4-37 THE METERING AND COMPENSATING CIRCUITS

4-38 The output voltmeter (M102) is connected in series with the meter multiplier resistor(s) (R311 and R312, the latter is *not* used in Model BOP-500M) directly across the output terminals of the BOP. In current mode operation, the voltmeter (M102), the feedback resistors for the E_O BIPOLAR and for the E_O LIMIT AMPLIFIERS constitute a shunt load, in parallel with the external load. This shunt load produces an error current, in phase with the actual load current. A compensating circuit has been provided in the BOP consisting of a voltage divider network (R303 I_O COMPENSATING CONTROL, R304, R305) producing a compensating current which opposes the direction of and is proportional to the error current. The error and compensating circuit at the BOP output can be represented by the simplified illustration (FIG. 4-4).

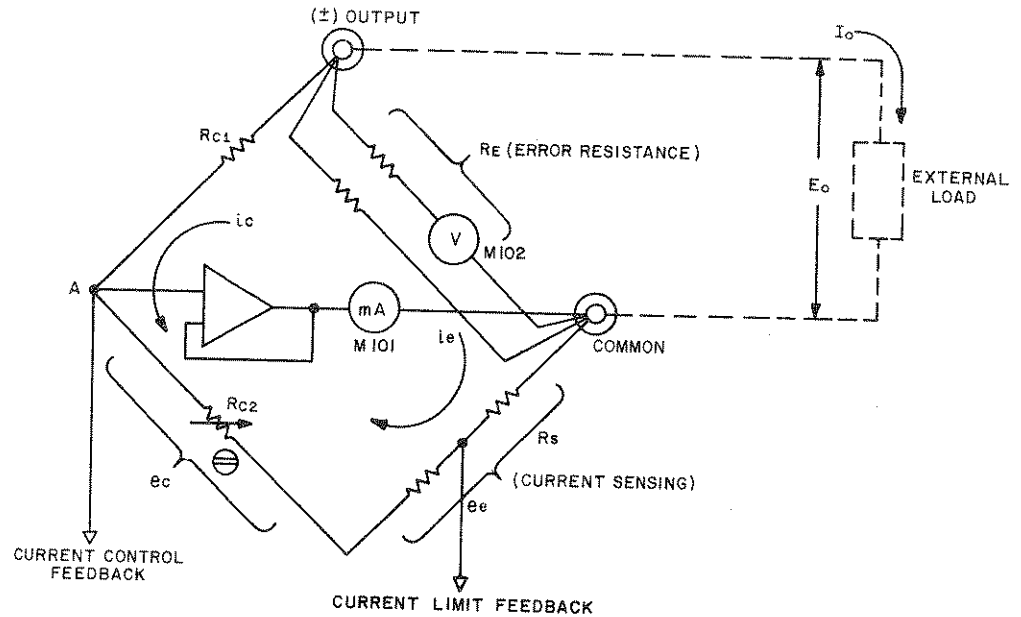


FIG. 4-4 BOP CURRENT STABILIZATION COMPENSATION CIRCUIT

4-39 The compensating circuit can be analyzed as a bridge circuit as shown in FIG. 4-4. The error resistance (R_E) produces an error current (i_e) due to the BOP compliance (output) voltage (E_O). A proportional and opposite compensating current (i_c) is produced by R_C . The error current (i_e) and the compensating current (i_c) produce the indicated voltage drops (e_e and e_c) across R_S and R_C2 as shown. The effect of the error current is cancelled if R_C2 is adjusted such that $e_e = e_c = 0$. The output current meter (M101) is driven by the METER AMPLIFIER (1/4 IC-3, PINS 8,9,10) and connected to the balanced compensating circuit (see FIG. 4-4) so that its reading is not affected by the error current, but will read only the voltage drop across R_S due to and proportional to the output current (I_O).

4

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 non-congested 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 DISASSEMBLY

5-4 Remove the wrap-around cover and disassemble the printed circuit board cards as described and illustrated in FIG. 5-1 below.

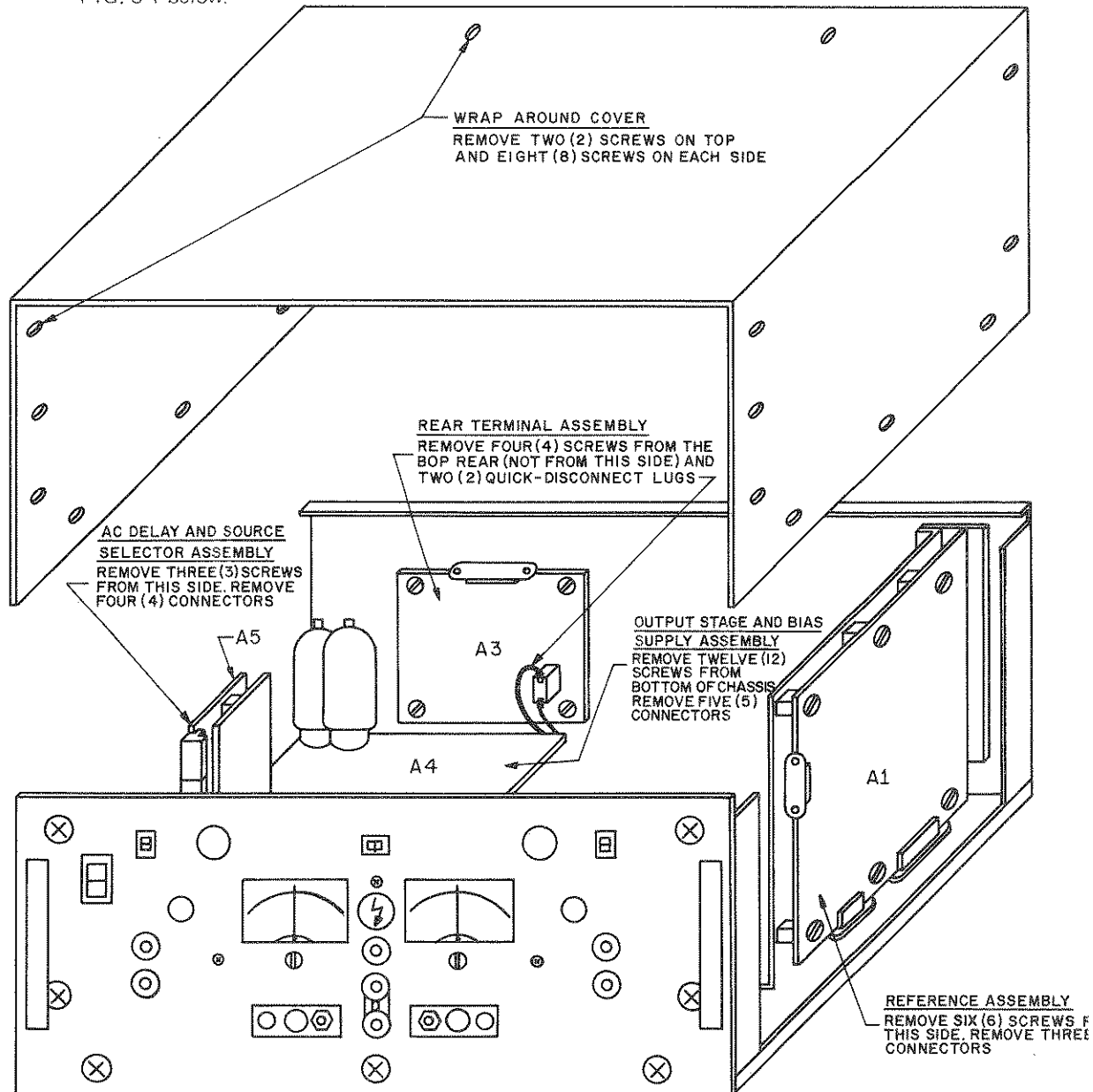


FIG. 5-1 COVER REMOVAL AND PC BOARD DISASSEMBLY, BOP

5-5 PERIODIC MAINTENANCE

- 5-6 The inside of the BOP should be periodically cleaned of dust and grime to ensure cooling efficiency. In normal laboratory environments, the recommended maintenance interval is six (6) months.

5-7 INTERNAL ADJUSTMENTS AND CALIBRATIONS

- 5-8 The location of all internal controls is illustrated in Section II, FIG. 2-1. The use of the zeroing controls for the BOP output voltage and current has been described in Section III. The adjustment for the two (2) remaining controls is described below:

Note: These controls are factory calibrated. Re-calibration is necessary only if components, related to the circuitry involving these controls must be replaced.

A) ADJUSTMENT OF THE (\pm) 10 VOLT CALIBRATION CONTROL

- 1) Connect a precision digital voltmeter to the REAR PROGRAMMING CONNECTOR (J214, from COMMON pin L, M or K to pin 10 or 11 for +10 volts).
- 2) Turn the BOP "on" and locate the calibrating controls (see Section II, FIG. 2-1).
- 3) Adjust control to exactly 10 volts as readout on the digital voltmeter. NOTE: This adjustment calibrates the (-)10V simultaneously. Check for (-)10V on pin 12 or 13 with reference to common.

B) ADJUSTMENT OF THE I_O COMPENSATING CONTROL

- 1) Set-up a test circuit similar to that shown in FIG. 5-4.
- 2) Turn BOP "on" and open and close the load switch (S1). Note the deviation on the digital voltmeter across R_M .
- 3) Locate the " I_{OX} " control and adjust for the smallest deviation on the digital voltmeter as S1 is opened and closed.

5-9 TROUBLE SHOOTING

- 5-10 Trouble analysis of precision power supplies with 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.

Instead, a systematic approach to trouble analysis is presented. Follow the flow diagram (FIG. 5-2) and refer to the applicable paragraphs. For further help in circuit analysis, refer to Section IV (Operational Theory and Circuit Description) and to the Main Schematic Diagram, Section VI (FIG. 6-5). For the actual repair and replacement of components, refer to the Parts Location Diagram the Connection Diagram and the Replacement Parts List, all in Section VI of this manual.

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

5-11 TROUBLE ANALYSIS

STEP No. 1: Disconnect BOP from the a-c input source, from the load and from all auxiliary sources such as input signal generators, etc.

STEP No. 2: Restore ALL jumper links on the rear barrier-strip and on the REAR PROGRAMMING CONNECTOR (J214) to those for Standard Power Supply operation (see Section IV, FIG. 4-5).

STEP No. 3: 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, proceed to Step No. 4.

STEP No. 4: Follow the FLOW CHART (FIG. 5-2) and refer to the appropriate paragraphs.

5-12 DISCONNECT BOP FROM THE A-C POWER SOURCE and:

- A) Check if the SOURCE SELECTOR SWITCH is set to the correct a-c line voltage (see Section II, FIG. 2-3).
- B) Check if the FUSE (F201) is open (see Section II, FIG. 2-2).
- C) Check if the INTERLOCK switch (S301) is open (see Section II, FIG. 2-2).

Note: Replace the fuse (F201) only once. If it opens again, localize the problem by connecting an ammeter across the fuse terminals. Disconnect all PC connectors from the A-C SELECTOR/DELA ASSEMBLY and re-insert them serially to trace the transformer circuit causing the overcurrent. Then check the secondary circuits, especially rectifier circuits and replace any defective components.

5-13 DISCONNECT BOP FROM THE A-C POWER SOURCE and:

- A) Check the IC timer (IC-501) by substitution of a new IC.
- B) Check the TRIAC (CR201) and replace if defective.
- C) Check the lamp (DS101) and replace if defective.

5-14 Check if the d-c control voltage reaches the input of the E_o BIPOLAR AMPLIFIER, (IC-8). Connect voltmeter at the REAR PROGRAMMING CONNECTOR (J214 - from pin "L" to pin "B"). As the BIPOLAR VOLTAGE CONTROL is turned through its range, the control voltage should go from (-) 10 volts through zero to (+) 10 volts. If it does, investigate the OUTPUT STAGE of the BOP as follows:

- A) If there is no (+) output voltage: The voltage drop across resistors R405 must be approximately 9 volts in normal operation. If it is not, investigate the BIAS SUPPLY, starting with rectifier CR405, and test the vacuum tubes (V405 to V408) and the associated circuitry. Replace any defective components.
- B) If there is higher than the maximum rated (+) output voltage and the output cannot be controlled, remove vacuum tubes V405, V406, V407 and V408 one after another, always leaving three (3) tubes in the circuit. Replace the shorted vacuum tube.
- C) If there is no (-) output voltage, investigate the driver circuit, consisting of Q3 and Q4 with the associated components. Check the collector voltage at Q3 and check the collector supply, starting with CR2. Check the BIPOLAR (VOLTAGE) AMP (IC-8) and its associated circuitry, as well as the feedback resistors (R301, R302). Replace defective components.
- D) If there is higher than the maximum rated (-) output voltage and the output cannot be controlled, remove vacuum tubes (V401 to V404) one after another, always leaving three (3) tubes in the circuit. Replace the shorted vacuum tube.

5-15 If the control voltage does not go through its specified range, or if it is not present, investigate the E_o PREAMP (IC-4) and its associated circuitry. Measure the control voltage on the REAR PROGRAMMING CONNECTOR [J214 - from pin "L" to pins 10, 11 = (+) 10 volt and to pins 12,13 = (-) 10 volts]. Check the reference supply, starting with CR3, if the reference voltage is incorrect or not present. Take the voltage readings given on the Main Schematic Diagram (Sect. VI - FIG. 6-5). Replace defective components and recalibrate the reference potential (see PAR. 5-7).

5-16 If the BOP functions correctly after the load has been removed (VOLTAGE MODE), or after a short circuit has been placed across the output terminals (CURRENT MODE), investigate your load condition:

NOTE: FOR VOLTAGE MODE OPERATION, YOUR MINIMUM LOAD RESISTANCE IS GIVEN BY:

$$R_L \text{ (MIN) (K}\Omega\text{)} = \frac{\text{OUTPUT VOLTAGE SETTING (VOLTS)}}{\text{CURRENT LIMIT SETTING (mA)}}$$

ANY LOAD RESISTANCE SMALLER THAN R_L (MIN) WILL TRANSFER THE BOP INTO THE CURRENT LIMIT MODE (CURRENT LIMIT LIGHT "ON").

FOR CURRENT MODE OPERATION, YOUR MAXIMUM LOAD RESISTANCE IS GIVEN BY:

$$R_L \text{ (MAX)} \text{ (K}\Omega\text{)} = \frac{\text{VOLTAGE LIMIT SETTING (VOLTS)}}{\text{OUTPUT CURRENT SETTING (mA)}}$$

ANY LOAD RESISTANCE **GREATER** THAN R_L (MAX) WILL TRANSFER THE BOP INTO THE VOLTAGE LIMIT MODE (VOLTAGE LIMIT LIGHT "ON").

- 5-17 Check if the d-c control voltage reaches the input of the I_O BIPOLAR AMPLIFIER (IC-10): Connect a voltmeter at the REAR PROGRAMMING CONNECTOR (J214 - from pin "L" to pin "A"). As the BIPOLAR CURRENT CONTROL is turned through its range, the control voltage should go from (-) 10 volts, through zero, to (+) 10 volts. If it does, investigate the drop across the feedback resistors (R306, R307), it should be approximately 10 volts at the rated output current. Check the I_O BIPOLAR AMP (IC-10) and the associated circuitry. Check the output stage as described in PAR. 5-14A to 5-14D. Replace any defective components.
- 5-18 If the control voltage does *not* go through its specified range, or if it is not present, investigate the I_O PRE-AMP (IC-7) and its associated circuitry. Measure the control voltage on the REAR PROGRAMMING CONNECTOR (J214 - from pin "L" to pins 10, 11 - (+) 10 volt and to pins 12, 13 = (-) 10 volts). Check the reference supply, starting with CR3, if the reference voltage is incorrect or not present. Take the voltage readings given on the Main Schematic Diagram (Sect. VI - FIG. 6-5). Replace defective components and recalibrate the reference potential (see PAR. 5-7).

5-19 OPERATIONAL POWER SUPPLY PERFORMANCE MEASUREMENTS

5-20 GENERAL. Measurements to verify the performance specifications are a frequent requirement of "Inco Inspection" departments, as a part of a routine maintenance program or as a part of repair procedures. Some operational power supply measurements (OUTPUT IMPEDANCE, DRIFT, TEMPERATURE COEFFICIENT, etc.) require specialized test equipment and/or a controlled environment, and are therefore not described here. For information on these measurements, consult the Kepco Engineering Test Department. The measurements described in the following paragraphs, require only a minimum of equipment, and are generally sufficient to verify the most important d-c and dynamic performance specifications.

5-21 REQUIRED INSTRUMENTATION

- a) STABILIZED A-C INPUT SOURCE, with provisions for "stepping" the voltage over the specified input range (105 to 125V or 210 to 250V). A variable AUTOTRANSFORMER is generally adequate if it can deliver the required a-c input current.
- b) RESISTOR LOAD, variable, capable of dissipating the full d-c output power of the unit under test equipped with "on-off" and "shorting" switch (S1).
- c) D-C VOLTAGE MONITOR, digital or differential voltmeter with a suitable voltage range for the meter under test and able to resolve at least 1 microvolt (M1).
- d) OSCILLOSCOPE, vertical sensitivity at least 10 mV/cm and with a minimum bandwidth of 10 megahertz. **NOTE: HIGH VOLTAGE PROBE (1000V MIN. RATING) REQUIRED!**
- e) SQUARE-WAVE GENERATOR, with a variable output amplitude of 0–10 volts into 600 ohms rise time of at least 0.1 microseconds. A "floating output", where the signal is available either positive or in the negative direction is desirable.

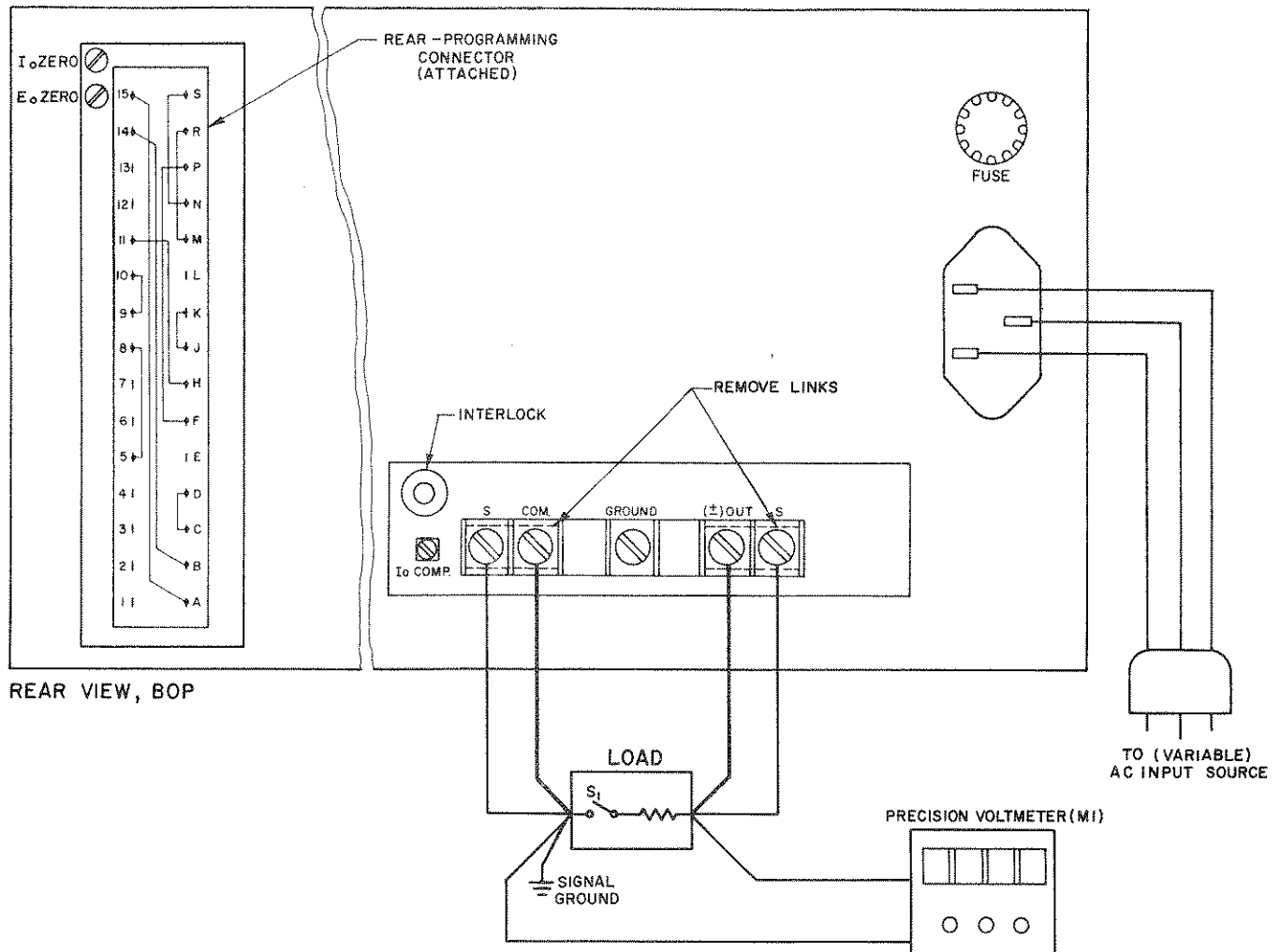


FIG. 5-3 OUTPUT EFFECT MEASUREMENTS, VOLTAGE CONTROL CHANNEL (TEST CIRCUIT).

5-22 **OUTPUT EFFECT MEASUREMENTS, VOLTAGE CONTROL CHANNEL.** The output effects due to load, or a-c input source changes in the voltage mode can be measured with the circuit shown in FIG. 5-3. These output effects ("SOURCE EFFECT", "LOAD EFFECT") are defined as the amount of output voltage change resulting from specified variations in the a-c source voltage, or from a change in load resistance (see Section I, Table 1-2). The output effects can be expressed as an absolute change (ΔE_o) or as a percentage of the total output voltage (E_o):

$$\% \text{ OUTPUT EFFECT (Source or Load Effect)} = \frac{\Delta E_o}{E_o} \times 100\% \text{ (Eq. 5-1)}$$

where: ΔE_o = Change in output voltage
 E_o = Total output voltage

5-23 PROCEDURE (Refer to FIG. 5-3)

- 1) Connect the BOP to a metered a-c input source, such as described in PAR. 5-21a.
- 2) To measure the SOURCE EFFECT, vary the a-c source voltage over the specified range (105 to 125V or 210 to 250V) and note the deviation (ΔE_o) on the PRECISION VOLTMETER (M1).
- 3) To measure the LOAD EFFECT, open and close the load switch (S1) and note the deviation (ΔE_o) on the PRECISION VOLTMETER (M1).
- 4) From the results of the two previous measurements, calculate the Source Effect and the Load Effect by means of equation (5-1).

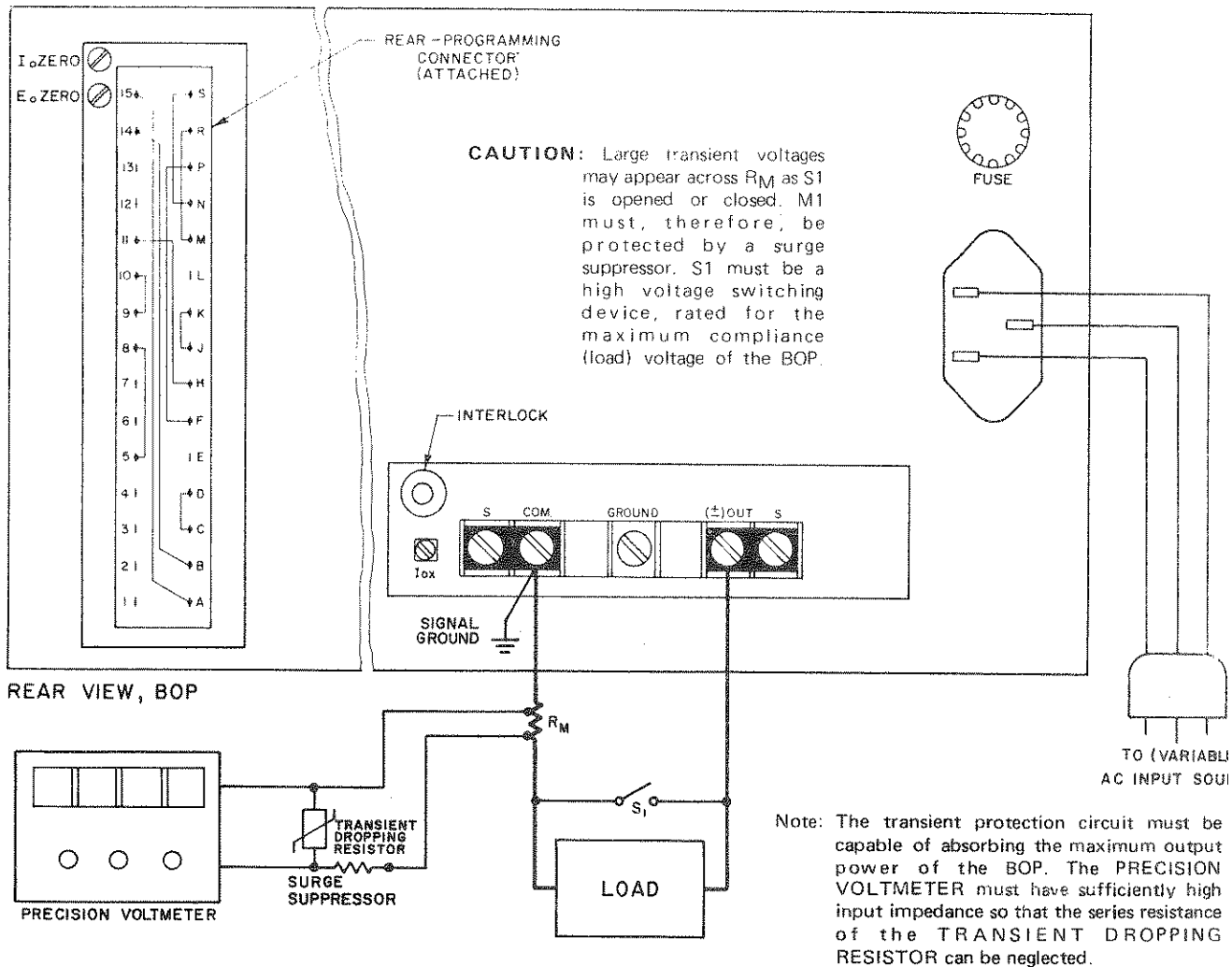


FIG. 5-4 OUTPUT EFFECT MEASUREMENTS, CURRENT CONTROL CHANNEL (TEST CIRCUIT)

5-24 **OUTPUT EFFECT MEASUREMENTS, CURRENT CONTROL CHANNEL.** The output effects due to a-c source or d-c load variations in the current mode can be measured with the circuit shown in FIG. 5-4. These output effects ("SOURCE" and "LOAD" EFFECT) are defined as the amount of output current change resulting from the specified variation in a-c source voltage, or from a change in load resistance. (See Section 1, Table 1-2). The output effects can be expressed as an absolute change (ΔI_O), or as a percentage of the total output current (I_O):

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

(Source or Load Effect)

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

5-25 PROCEDURE (Refer to FIG. 5-4)

- 1) Connect the BOP to a metered and adjustable a-c input source such as described in PAR. 5-21a.
- 2) To measure the SOURCE EFFECT, vary the a-c source voltage over the specified range (105 to 125V or 210 to 250V) and note the deviation (ΔV divided by $R_M = \Delta I_O$) on the voltmeter (M1 across R_M).
- 3) To measure the LOAD EFFECT, close the load switch (S1) and note the deviation ($\Delta V/R_M$) on the voltmeter (M1 across R_M).
- 4) From the results of the two previous measurements, calculate the Source Effect and the Load Effect by means of equation (5-2). Note: $\Delta I_O = \Delta V/R_M$.

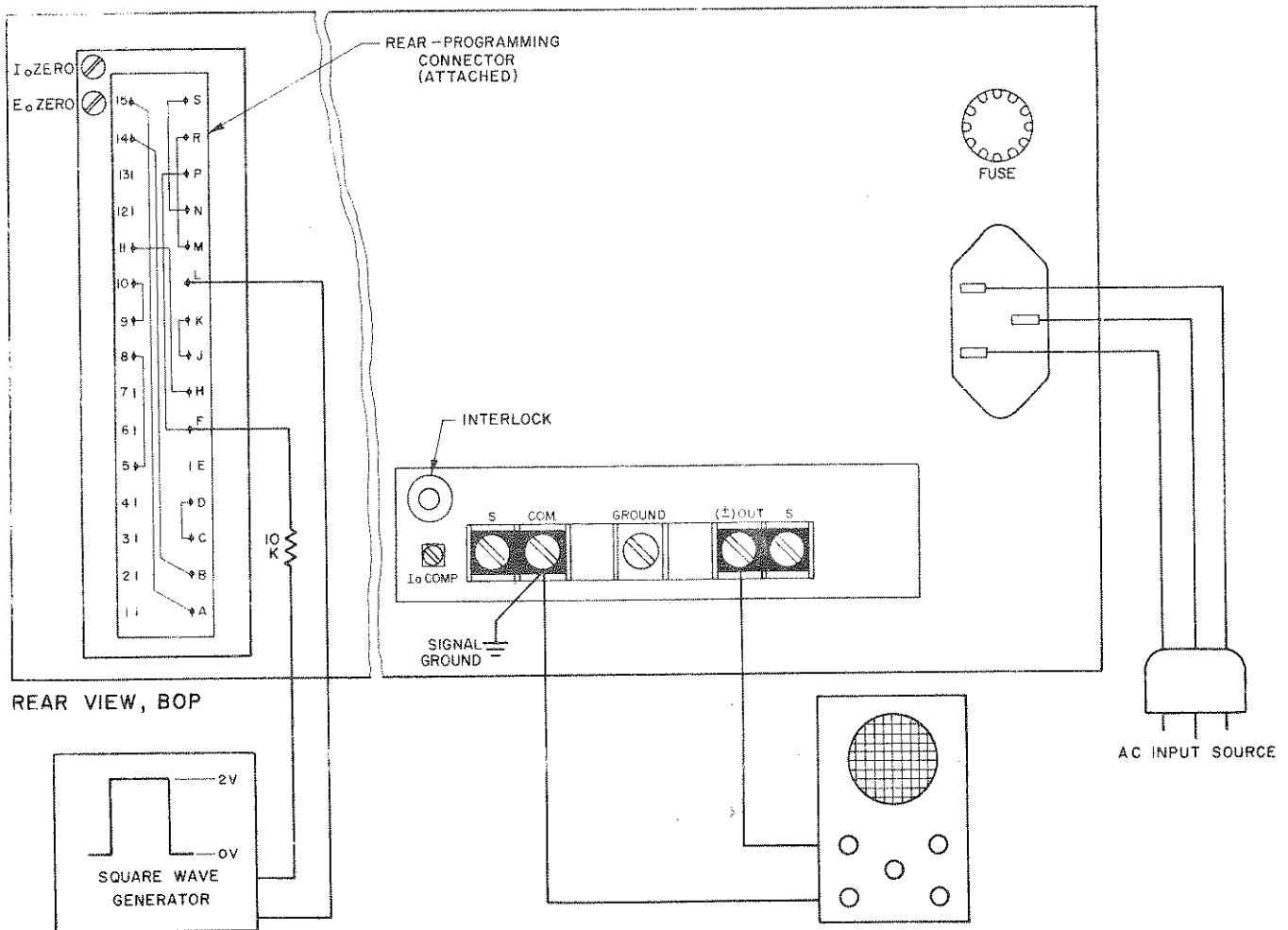


FIG. 5-5 MEASUREMENT OF THE PROGRAMMING TIME CONSTANT.

5-26 **DYNAMIC MEASUREMENTS.** The verification of the specification for the PROGRAMMING TIME CONSTANT are an excellent means of checking the dynamic performance of the BOP. In this test, the output voltage rise time of the BOP is measured in response to a square wave input.

5-27 PROCEDURE (REFER TO FIG. 5-5)

- 1) Connect the BOP and the external instrumentation as shown in FIG. 5-5. Note: The Signal Generator may be connected (without the 10KΩ resistor) to the BOP front panel E₀ PROGRAM input terminals.
- 2) Turn BOP "on". Adjust the gain of the SQUARE WAVE GENERATOR until the output wave form, displayed on the OSCILLOSCOPE shows a peak amplitude of 200 volts.
- 3) Measure the rise time of the displayed wave form from zero to 63% of the displayed amplitude. This rise time represents the PROGRAMMING TIME CONSTANT.

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: KEPKO 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 KEPKO REPRESENTATIVE OR THE KEPKO 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)	μ	= Micro (μ) (10 ⁻⁶)
MFR	= Manufacturer	V	= Volt
		W	= Watt
		WW	= Wire Wound



KEPCO. REPLACEMENT PARTS LIST

BOP 500M

CONTROL CIRCUIT AND REFERENCE ASSEMBLY (A1)

CoJe 1-1678

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C1	1	Cap. Elect., Axial Leads 85uF, 200V, +50 -10%	Sprague Electric Type 43D	117-0853	1
C2	1	Cap. Elect., Axial Leads 10uF, 100V, +50 -10%	Sangamo Type 556	117-0439	1
C3,4,7,8	4	Cap. Elect., Axial Leads 240uF, 25V, +75 -10%	Sangamo Electric Type 052	117-0640	1
C5,6,9, 10,18	5	Cap., Ceramic Disc 100pF, 500V, ±10%	Radio Materials Corp. Type JK	117-0754	1
C13	1	Cap., Mylar, Axial Leads 0.01uF, 200V, ±20%	Sprague Electric Type 192P	117-0353	1
C14,15	2	Cap., Mylar, Axial Leads 0.033uF, 200V, ±10%	Sprague Electric Type 192P	117-0347	1
C19	1	Cap., Ceramic Disc 500pF, 500V, 10%	Radio Materials Corp. Type JG	117-0755	1
C20	1	Cap., Mylar, Axial Leads 0.0022uF, 200V, ±10%	Sprague Electric Type 192P	117-0659	1
C21,22	2	Cap., Mylar, Axial Leads 560pF, 200V, 10%	Sprague Electric Type 192P	117-0569	1
CR1,2,3	3	Rect., Bridge, Rad. Leads 200V (PIV), 1A	General Instruments Type W-02	124-0346	1
CR4,5	2	Zener Diode 6.2V ±5%	Motorola 1N827	121-0062	1
CR6,7	2	Zener Diode 12V ±1%, 1W	International Rect. 69-3626	121-0012	1
CR8-30 and CR32-45	37	Switching Diode 75V (PIV), 400mA	American Power Devices IN4148	124-0437	2
CR46,47, 48,49	4	Zener Diode 6.8V ±5%, 0.5W	Motorola IN5235B	121-0080	1
CR50,51, 52,53	4	Zener Diode 4.3V, ±5%, 0.5W	Motorola IN5229B	121-0059	1
CR54	1	Rect., H.V. Axial Leads 1000V (PIV), 400mA	Semicon Inc. SI-10	124-0094	1
IC1,2,4,7	4	IC Operational Amplifier Type 741	Motorola MC1741P	250-0025	1
IC3,5,6,9,11	5	IC Operational Amplifier Type 324	RCA CA324E	250-0050	1
IC8,10	2	IC Operational Amplifier Type 723	Texas Instruments SN72307P	250-0039	1
Q1	1	Transistor, Silicon, NPN Small Signal, TO-5	RCA 2N3053	119-0059	1
Q2,3	2	Transistor, Silicon, PNP Small Signal, TO-5	RCA 2N4036	119-0074	1
Q4,5,6,7,8	5	Transistor, Silicon, NPN Small Signal, TO-18	Texas Instruments 2N5450	119-0093	1
R1	1	Res. Fixed, Molded 39k, 1W, 5%	Allen Bradley GB3935	115-0111	1
R2,5	2	Res. Fixed, Molded 220 ohm, 2W, 5%	Allen Bradley HB2205	115-2114	1

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

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KEPCO. REPLACEMENT PARTS LIST

BOP 500M

CONTROL CIRCUIT AND REFERENCE ASSEMBLY (A1)

Code 12-1977

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
R3,4,54, 55,58	5	Res. Fixed, Molded 100 ohm, 1/4W, 10%	TRW Type GBT-1/4	115-2231	1
R6	1	Res. Fixed, Molded 47k, 1/4W, 10%	TRW Type GBT-1/4	115-2237	1
R7,10	2	Res. Fixed, Precision, M.F. 8.06k, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2445	1
R8,9	2	Res. Fixed, Precision, M.F. 5.62k, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2409	1
R11,12	2	Res. Fixed, Precision, M.F. 1.21k, 1/4W, 1%	Dale Electric Type MFF-1/4	115-1937	1
R13,15,16	3	Res. Fixed, Precision, M.F. 18.2k, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2275	1
R14	1	Res. Fixed, Precision, M.F. 35.7k, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2454	1
R17,20	2	Res. Fixed, Molded 330 ohm, 1/4W, 10%	TRW Type GBT-1/4	115-2233	1
R18,31,36	3	Res. Variable, Cermet 10k, 3/4W, 10%	Bourns Type 3009P	115-2481	1
R21,22,23,29, 32,33,34,35, 37,38,39,50,52	13	Res. Fixed, Precision, M.F. 10k, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2174	2
R24,26,27,30, 42,46,47,48, 49,53,56,57, 60,61,99	15	Res. Fixed, Precision, M.F. 1k, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2180	2
R25,28	2	Res. Fixed, Precision, M.F. 4.99k, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2401	1
R40,41	2	Res. Fixed, Precision, M.F. 11k ohm, 1/4W, 1%	Dale Electric Type MFF-1/4	115-1804	1
R51	1	Res. Fixed, Precision, W.W. 10k, 1W, 1%	Tepro Electric Type TS-1W	115-1232	1
R63,67,69	3	Res. Fixed, Molded 1k, 1/4W, 10%	TRW Type GBT-1/4	115-2238	1
R64,65,68	3	Res. Fixed, Molded 10k, 1/4W, 10%	TRW Type GBT-1/4	115-2211	1
R66	1	Res. Fixed, Molded 5.6k, 1/4W, 10%	Allen Bradley CB5621	115-2491	1
R70,71,72,73, 74,75,78,81, 91,93,95,97	12	Res. Fixed, Molded 15k, 1/4W, 10%	TRW Type GBT-1/4	115-2497	2
R76,77,79,80	4	Res. Fixed, Molded 4.7k, 1/4W, 10%	TRW Type GBT-1/4	115-2383	1
R82,85	2	Res. Fixed, Molded 470 ohm, 1/4W, 10%	TRW Type GBT-1/4	115-2235	1
R83,84	2	Res. Fixed, Molded 120 ohm, 1/4W, 10%	TRW Type GBT-1/4	115-2232	1
R87,88,89,90	4	Res. Fixed, Molded 8.2k, 1/4W, 10%	TRW Type GBT-1/4	115-2482	1
R92,94,96,98	4	Resistor, Fixed, Molded 2.4k, 1/4W, 10%	TRW Type GBT-1/4	115-2394	1

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KEPCO. REPLACEMENT PARTS LIST

BOP 500M

MAIN CHASSIS ASSEMBLY (A2), WITH FRONT PANEL

Code 1-1579

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
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FRONT PANEL ASSEMBLY CONTAINS:

DS101	1	Pilot Light (H.V. Warning)	Industrial Devices 152-0095	152-0095	1
DS102,103, 104,105	4	LED Indicator	Littlefuse 971-660X-02WRN	152-0096	2
M101	1	Ammeter 80 mA—0—80 mA, D.C.	Modutec 2W Series	135-0495	0
M102	1	Voltmeter 500V—0—500V D.C.	Modutec 2W Series	135-0497	0
R101,102	2	Res. Variable, W.W. 20k, 2W, 5%	Bourns, Inc. Type 3507	115-1224	1
R103,104, 105,106	4	Res. Variable, Cermet 10k, 2W, 10%	Bourns, Inc. 3852E-16-2-103A	115-2612	1
RC101	1	R/C Network 0.1uF, 400V, 20% and 100 ohm, 1/2W, 10%	Sprague Electric Type 288P	245-0003	1
SDS101	1	Toggle Paddle Switch SPST, Illum.	Carling Switch 127-0322	127-0322	0
S102,103,104	3	Toggle Paddle Switch DPDT	Carling Switch SGD0410	127-0325	0

MAIN CHASSIS ASSEMBLY CONTAINS:

C201,202,203	3	Cap., Paper, Oval 12uF, 1KV, 10%	General Electric Type 21L	117-0920	1
C204	1	Cap. Elect., Axial Leads 150uF, 3V, +75 -10%	Sangamo Electric Type 556	117-0512	1
C205,206	2	Capacitor, Ceramic, Disc. 0.005uF, 2kV	Radio Mat. Corp. Type Z5U	117-0079	1
CR201	1	Triac 400V (V_{DRM}), 30A (I_T -RMS)	Motorola Semi. 2N6164	124-0469	1
F201	1	Fuse, Fast Acting 4A, 250V	Bussmann Type MTH	141-0003	5
L201,202	2	Choke, R.F.	J.W. Miller 6302	176-0052	1
R201,202,203	3	Res. Fixed, Power Axial 1.5M ohm, 2W, ±20%	TRW Type MVX-2	115-1342	1
T201	1	Transformer, Main	Kepeco Magnetics 100-2052	100-2052	1
T202	1	Transformer, Fil.	Kepeco Magnetics 100-2053	100-2053	1
T203	1	Transformer, Aux.	Kepeco Magnetics 100-2118	100-2118	1

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KEPCO. REPLACEMENT PARTS LIST

BOP 500M

REAR TERMINAL ASSEMBLY (A3)

Code 12-1575

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C301	1	Cap., Ceramic Disc 100pF, 2000V, ±10%	Radio Materials Corp. Type U	117-0056	1
C302	1	Cap., Ceramic Disc 22pF, 2000V, 10%	Radio Material Corp. Type U	117-0071	1
C303	1	Cap., Mylar, Axial Leads 0.01uF, 200V, 20%	Sprague Type 192P	117-0353	1
C304	1	Cap., Mylar, Metal Ax. Lds. 0.5uF, 600V, ±10%	Wesco Elect. Type 33MM	117-0208	1
R301	1	Res. Fixed, Precision, W.W. 500 ohm, 2.5W, 1%	General Resistance Type 16S64A	115-2410	1
R302	1	Res. Fixed, W.W. 1k, 5W, 5%	Tepro Electric Type TS-5W	115-0512	1
R303	1	Res. Variable, Cermet 2k, 1/2W, 10%	TRW Type 750-2k	115-2617	1
R304	1	Res. Fixed, Precision, M.F. 6.81k, 1/2W, 1%	Dale Electric Type MFF-1/2	115-1802	1
R305,308	2	Res. Fixed, Thick Film 20M, 1W, 2%	KDI Pyrofilm Corp. PVC 7020M-2%	115-2618	1
R306	1	Res. Fixed, W.W. 25 ohm, 3W, 1%	Tepro Electric Type TS-3C	115-2606	1
R307	1	Res. Fixed, W.W. 100 ohm, 5W, 1%	Tepro Electric Type TS-5W	115-2607	1
R309	1	Res. Fixed, Precision 348k, 1/2W, 1%	Dale Electric Type MFF-1/2	115-2007	1
R310	1	Res. Fixed, W.W. 1k, 3W, 5%	Tepro Electric Type TS-3W	115-1302	1
R311	1	Res. Fixed, Precision, M.F. 1M, 1/2W, 0.5%	Dale Electric Type MFS-1/2	115-2605	1
R313	1	Res. Fixed, Molded 2.2M ohm, 2W, 10%	Allen Bradley HB2251	115-0238	1
S301	1	Interlock Switch, SPDT 125V a-c, 10A	Cherry Electrical Prod. AE69-30A	127-0324	0

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KEPCO. REPLACEMENT PARTS LIST

BOP 500M

OUTPUT STAGE AND BIAS ASSEMBLY (A4)

Code 10-477

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C401,402	2	Cap., Elect., Axial 120uF, 150V, +100% -10%	Sangamo Type 052	117-0823	1
C403	1	Cap., Mylar, Axial 0.01uF, 200V, ±20%	Gudeman Co. Type 356	117-0353	1
C404	1	Cap., Ceramic Disc 0.005uF, 500V, ±20%	Radio Materials Corp. Type 5M	117-0061	1
C405	1	Cap., Ceramic Disc 200pF, 6kV, ±20%	Centralab Type DD60-201	117-0075	1
CR401,402, 403,404	4	Rect., H.V. Axial Leads 2000V (PIV), 500mA	Semicon, Inc. HV-20	124-0299	1
CR405	1	Rectifier, Bridge 400V, 1A	General Instrument Type W-04	124-0450	1
CR406,407	2	Zener Diode, Axial Leads 15V ±5%, 1W	IRC 1N3024-B	121-0057	1
CR408	1	Zener Diode, Axial Leads 12V ±10%, 1W	IRC Type 69-3626	121-0012	1
IC401	1	IC Operational Amplifier Type 741	Motorola Type MC741P	250-0025	1
Q401	1	Transistor, Silicon, NPN Small Signal, TO-5	Fairchild 2N4888	119-0085	1
R401,402	2	Res. Fixed, Molded 39k ohm, 1W, 5%	Allen Bradley GB3935	115-0111	1
R403,404	2	Res. Fixed, W.W. 7.5k ohm, 5W, 5%	Tepro Type TS-5W	115-2443	1
R405	1	Res. Fixed, Power Axial 100 ohm, 3W, 5%	Hardwick Hindle Type 718	115-0471	1
R406	1	Res. Fixed, Precision, M.F. 6.04k ohm, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2175	1
R407	1	Res. Fixed, Precision, M.F. 8.66k ohm, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2511	1
R408,409, 410,411	4	Res. Fixed, Molded 100 ohm, 1/2W, 5%	Allen Bradley EB1015	115-0341	1
R412,413, 414,415,433, 434,435,436	8	Res. Fixed, Molded 100 ohm, 1/2W, 10%	Allen Bradley EB1011	115-0626	2
R416	1	Res. Fixed, Molded 1k ohm, 1/2W, 5%	Allen Bradley EB1025	115-0340	1
R417	1	Res. Fixed, Molded 47k ohm, 1/4W, 10%	Allen Bradley CB4731	115-2237	1
R418	1	Res. Fixed, Molded 2.2k ohm, 1/4W, 10%	Allen Bradley CB2221	115-2382	1
R419,420	2	Res. Fixed, Molded 1k ohm, 1/4W, 10%	Allen Bradley CB1021	115-2238	1
R421,422, 423,424,429, 430,431,432	8	Res. Fixed, Molded 560 ohm, 1/2W, 10%	Allen Bradley EB5611	115-0451	2

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KEPCO. REPLACEMENT PARTS LIST

BOP 500M

OUTPUT STAGE AND BIAS ASSEMBLY (A4)

Code 12-1575

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
R425,426, 427,428	4	Res. Fixed, Molded 51 ohm, 1/2W, 5%	Allen Bradley EB5105	115-0940	1
R437	1	Res. Fixed, Molded 39k ohm, 1/4W, 10%	Allen Bradley CB3931	115-2469	1
V401,402, 403,404,405, 406,407,408	8	Tube, Vacuum Beam Power Pentode	General Electric Type 8068	126-0096	9

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1. The first step is to identify the problem or goal. This involves understanding the current situation and what needs to be achieved.

2. Next, you need to gather information and resources. This includes identifying the people, tools, and materials needed to complete the task.

3. Once you have the information and resources, you can begin to plan the solution. This involves breaking the problem down into smaller, manageable tasks.

4. The next step is to execute the plan. This involves carrying out the tasks in the order they were planned.

5. Finally, you need to evaluate the results. This involves comparing the actual outcome to the original goal and identifying any areas for improvement.

6. The last step is to reflect on the process. This involves thinking about what worked well and what could be done better next time.

7. Once you have completed the process, you can move on to the next task or project.

8. The final step is to document the process. This involves writing down the steps you took and the results you achieved.

9. The last step is to share the results. This involves presenting the findings to the relevant stakeholders.

10. The final step is to review the process. This involves looking back at the entire process and identifying any lessons learned.

11. The last step is to implement the improvements. This involves putting the lessons learned into practice for the next time.

12. The final step is to celebrate the success. This involves acknowledging the hard work and achievements of the team.

13. The last step is to maintain the results. This involves ensuring that the improvements are sustained over time.

14. The final step is to evaluate the overall process. This involves assessing the effectiveness of the entire process and identifying any areas for further improvement.



KEPCO. REPLACEMENT PARTS LIST

BOP 500M

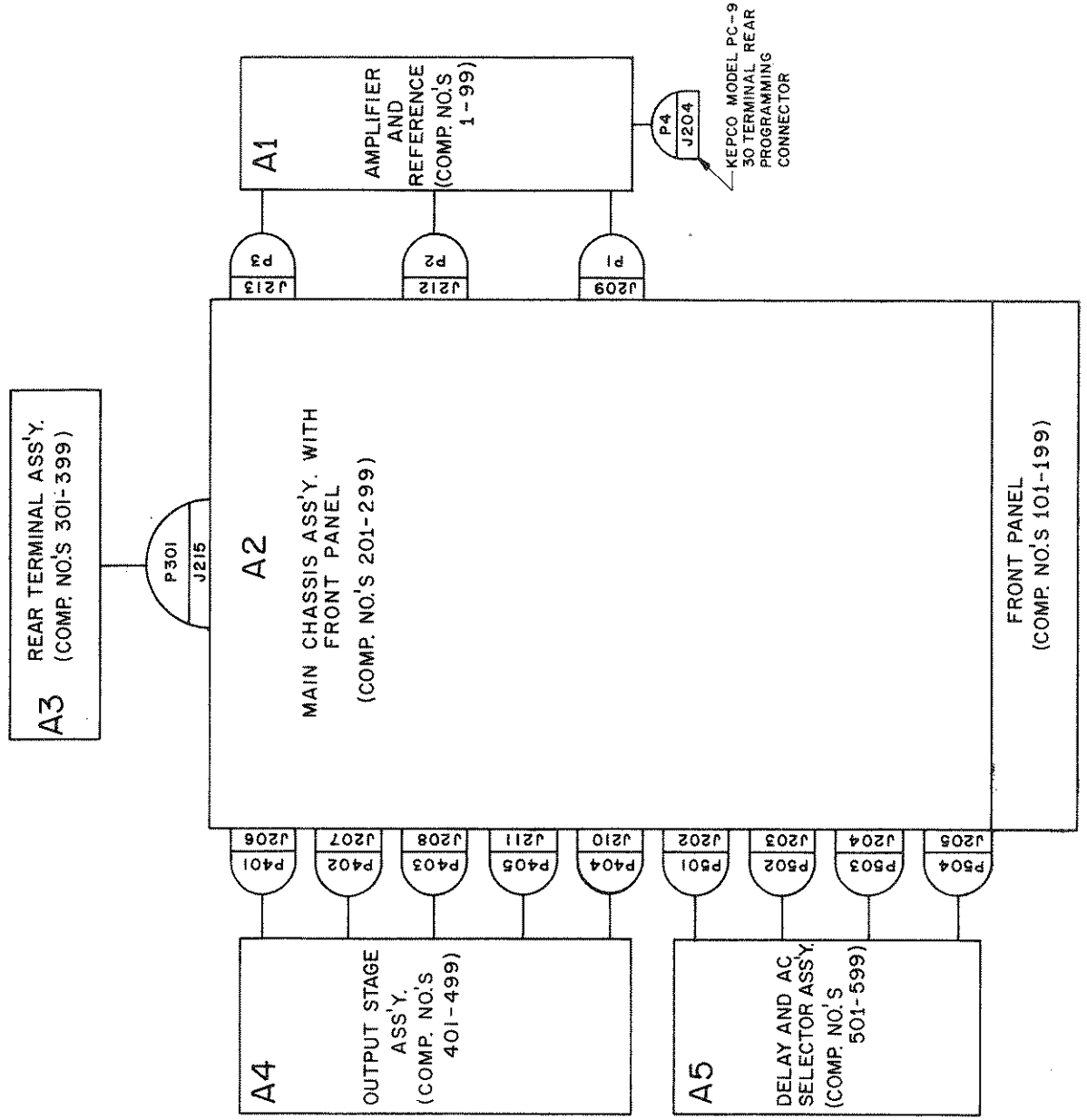
A-C DELAY AND SOURCE SELECTOR ASSEMBLY (A5)

Code 6-2276

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C501	1	Cap., Elect., Axial Leads 950uF, 15V, +150 -10%	Sangamo Electric Type 052	117-0821	1
C502	1	Cap., Ceramic Disc 0.005uF, 500V, ±20%	Radio Materials Corp. Type SM	117-0061	1
C503	1	Cap., Elect., Axial Leads 150uF, 15V, +75 -10%	Sangamo Electric Type 556	117-0677	1
CR501	1	Rectifier Bridge, Rad. Leads 200V (PIV), 1A	General Instruments Type W-02	124-0346	1
CR502	1	Rect., Diode, Axial Leads 100V (PIV), 1.5A	Semcion, Inc. SI-1	124-0133	1
CR503	1	Rect., Silicon Controlled 50V (PIV), 8A	Motorola 2N4441	124-0349	1
Q501	1	Transistor, PNP, Silicon Unijunction	General Electric 2N6027	119-0111	1
R501	1	Res. Fixed, Molded 100 ohm, 1/4W, 10%	Allen Bradley CB1011	115-2231	1
R502	1	Res. Fixed, Molded 33 ohm, 2W, 5%	Allen Bradley HB3305	115-1027	1
R503	1	Res. Fixed, Precision, M.F. 18.2k ohm, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2275	1
R504	1	Res. Fixed, Precision, M.F. 30.1k ohm, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2541	1
R505	1	Res. Fixed, Molded 120 ohm, 1/4W, 10%	Allen Bradley CB1211	115-2232	1
R506	1	Res. Fixed, Precision, M.F. 150k ohm, 1/8W, 1%	Dale Electric Type MFF-1/8	115-2597	1
R507	1	Res. Fixed, Molded 47 ohm, 1/4W, 10%	Allen Bradley CB4701	115-2273	1
S501	1	Switch, Slide, 4-pole, 2 pos. 125V a-c, 6A	Switchcraft 47227LFR	127-0314	0

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JACK-PLUG NO.	ASSEMBLY AND TOTAL PINS	PINS NOT USED
J202/P501	A5 - 6P	ALL USED
J203/P502	A5 - 5P	No. 2
J204/P503	A5 - 9P	No. 1,3,6,8,9
J205/P504	A5 - 9P	No. 2,5
J206/P401	A4 - 18P	No. 3,4,5,6,8 to 17
J207/P402	A4 - 15P	No. 7,8,9
J208/P403	A4 - 6P	No. 2,4,6
J210/P404	A4 - 12P	No. 1,2,4,5,6,7,9,10,11
J211/P405	A4 - 18P	No. 2,3,4,6,7,8,9,10,12,15,16,17
J209/P1	A1 - 9P	No. 5,7
J212/P2	A1 - 12P	ALL USED
J213/P3	A1 - 22P	ALL USED
J214/P4	A1 - 30P	REMOTE PROGRAMMING CONNECTOR
J215/P301	A3 - 22P	No. 8,10,12,14,15,17,18,20,21

FIG. 6-1 BOP-H.V. PLUG-IN DIAGRAM

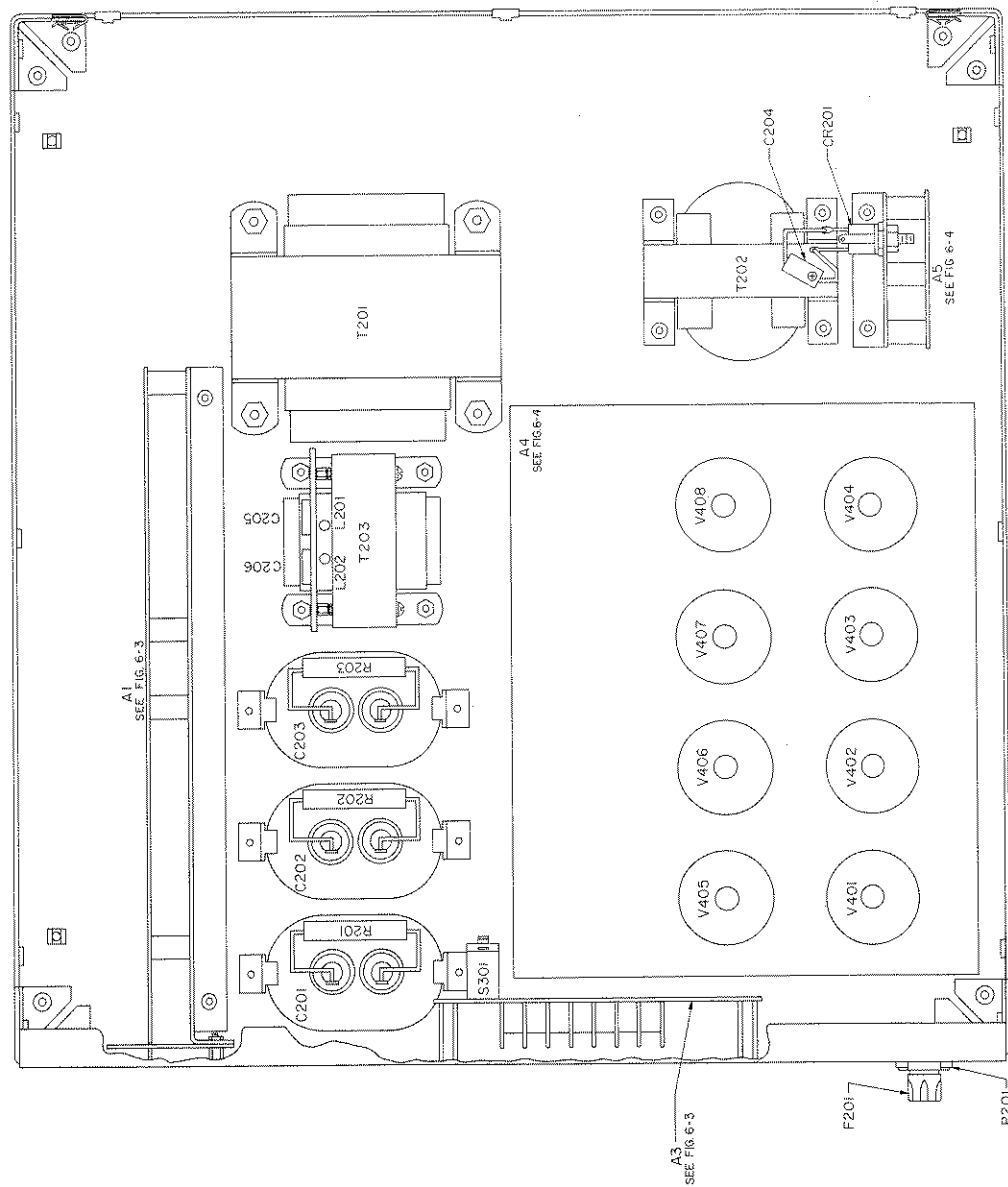
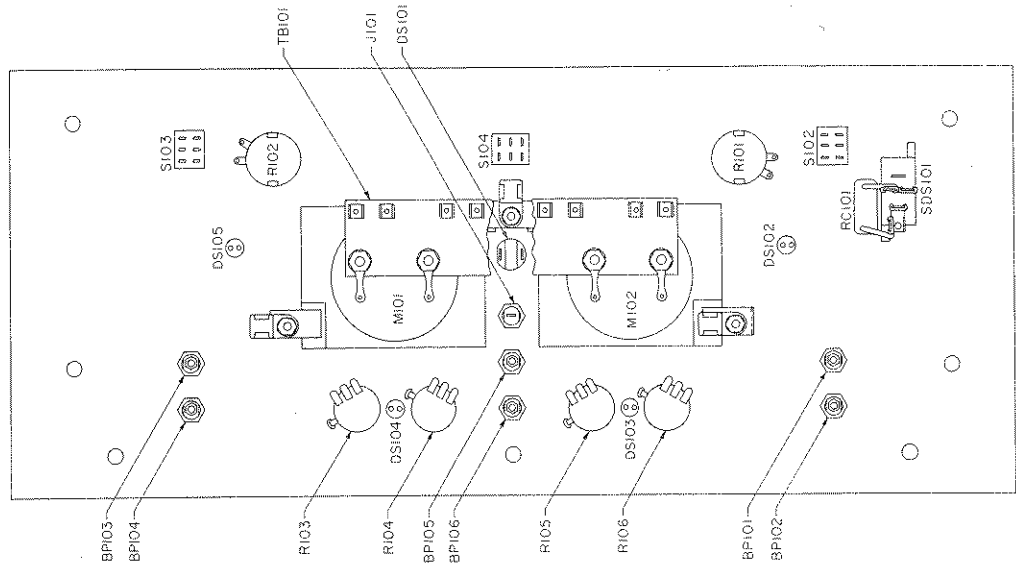
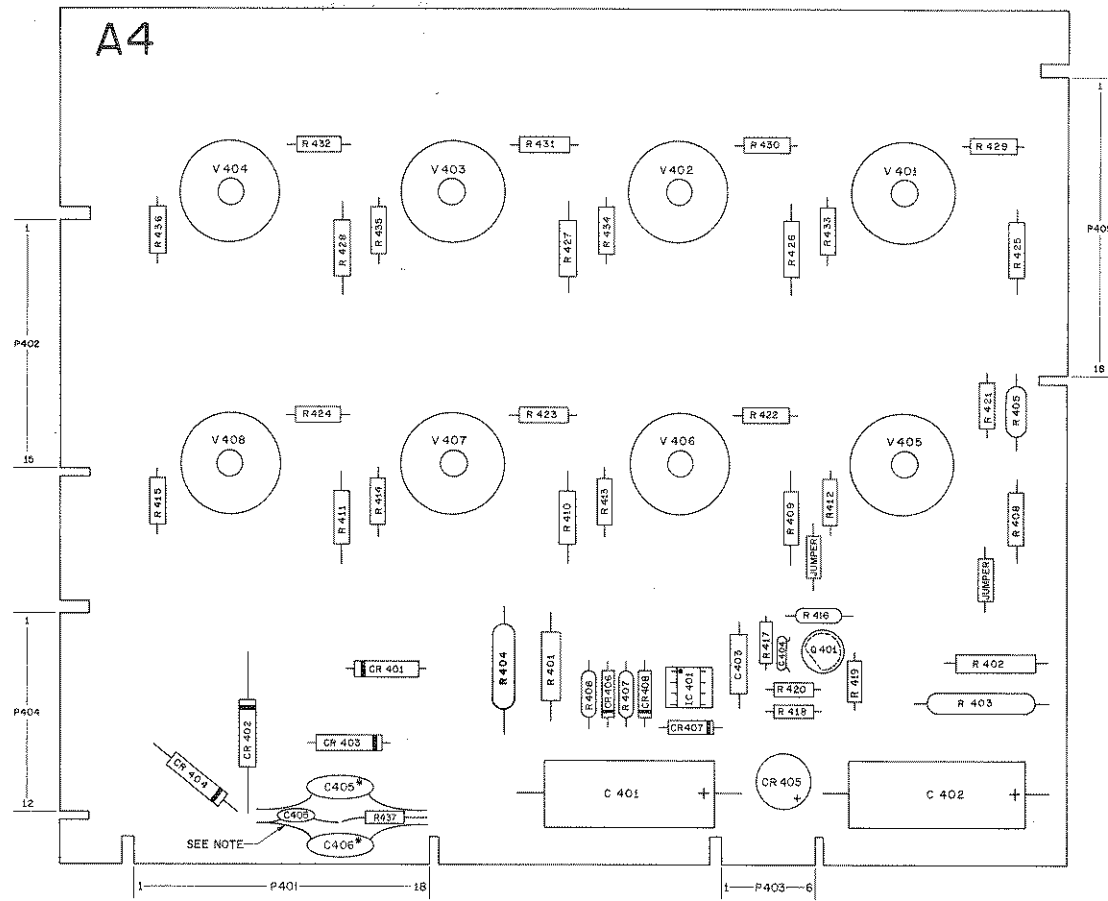


FIG. 6-2 COMPONENT LOCATION, MAIN CHASSIS AND FRONT PANEL (A2).



NOTE: 1) * C405 AND * C406 USED IN MODEL BOP1000M
 2) R437 USED IN MODEL BOP500M AND C405 IS RELOCATED IN SERIES WITH R437.

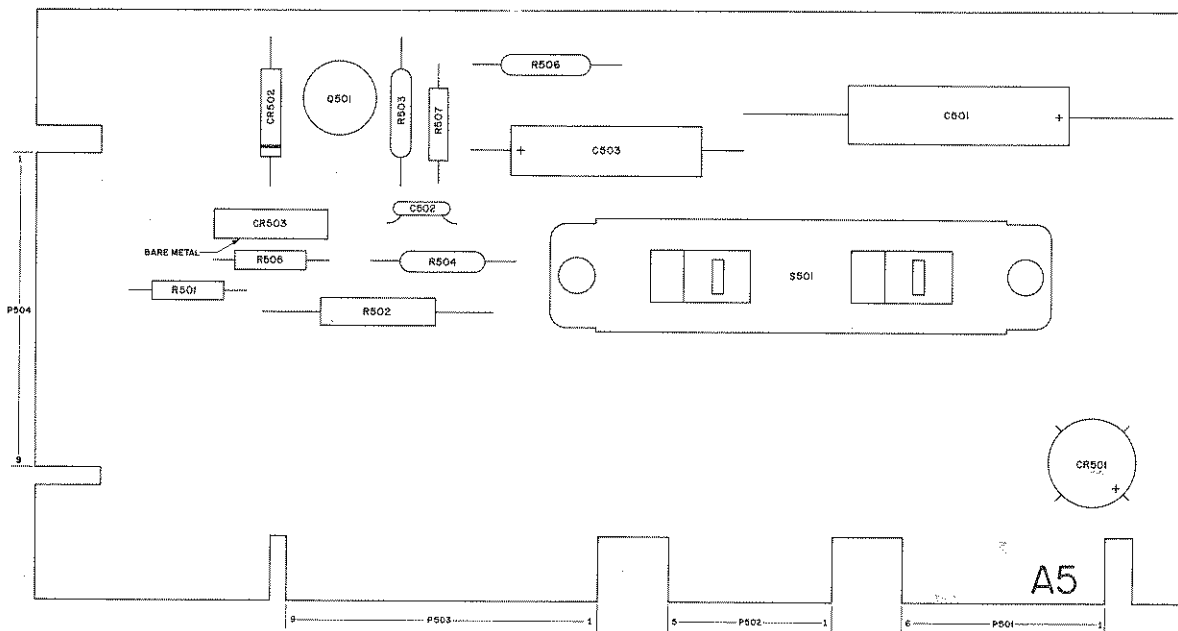


FIG. 6-4 COMPONENT LOCATION, ASSEMBLIES A4 AND A5.



