INSTRUCTION MANUAL

MODELS 301, 301K

SOLID STATE ELECTROMETER

OPERATIONAL AMPLIFIERS

KEITHLEY INSTRUMENTS

WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof which, within a year after shipment, proves defective upon examination. We will pay domestic surface freight costs.

To exercise this warranty, call your local field representative or the Cleveland factory, DDD 216-248-0400. You will be given assistance and shipping instructions.

REPAIRS AND RECALIBRATION

Keithley Instruments maintains a complete repair service and standards laboratory in Cleveland, and has an authorized field repair facility in Los Angeles and in all countries outside the United States having Keithley field representatives.

To insure prompt repair or recalibration service, please contact your local field representative or the plant directly before returning the instrument.

Estimates for repairs, normal recalibrations, and calibrations traceable to the National Bureau of Standards are available upon request.

SPECIFICATIONS

Specifications measured at 25°C.	MODELS 301 AND 301K
DC VOLTAGE GAIN, OPEN LOOP:	
Unloaded (Minimum)	50,000
Full Load (Minimum)	30,000
INPUT CHARACTERISTICS:	
Common Mode	
Resistance (Minimum)	$5X10^{12}$ ohms*
Shunt Capacitance (Maximum)	10 picofarads
Rejection (Minimum)	60 dB
Voltage Limit	±11 volts
Between Inputs	
Resistance (Minimum)	10^{12} ohms
Shunt Capacitance (Maximum)	10 picofarads
Overload Limit	±400 volts continuous either input to ground or between inputs
Current Stability	
Offset	10^{-14} ampere
vs. Time (worst case)	10^{-15} ampere/24 hours
vs. Temperature (worst case)	Doubles every 5°C
vs. Supply (worst case)	10^{-15} ampere/% (301K)
Voltage Stability	
Offset	Adjustable to zero
vs. Time (worst case)	2 millivolts/week after 1-hour warm-up
vs. Temperature (worst case)	150 microvolts/°C
vs. Supply (worst case)	300 microvolts/% (301K)
Current Noise	
0.1-10 Hz (Maximum peak-to-peak)	$5x10^{-15}$ ampere
Voltage Noise	
0.1-10 Hz (Maximum rms)	10 microvolts
10 Hz—500 kHz (Maximum rms)	100 microvolts
FREQUENCY:	
Gain Bandwidth Product (Minimum)	500 kHz
Slewing Rate (Minimum)	0.3 volt/microsecond
Rolloff (Nominal)	6 dB/octave
OUTPUT:	
Amplifier	±11 volts @ 11 milliamperes
Reference Voltage	±15 volts @ 5 milliamperes (301)
Regulation	±1.0% for 10% input change (301)
OPERATING TEMPERATURE:	—25°C to +85°C
CONNECTORS:	
Input	2 Push-on Teflon-insulated coaxial
All Other	15 terminal 1/16" card edge
POWER REQUIREMENTS:	
Voltage (positive and negative)	19 to 30 volts unregulated, 2 volts p-p maximum ripple (301). 15 V regulated ±0.1% (301 & 301K)
+Current (Plus output current)	16 milliamperes (301) 5 milliamperes (301K)
—Current (Plus output current)	16 milliamperes (301) 5 milliamperes (301K)
DIMENSIONS, WEIGHT:	3½" high x 4" wide x 1½" deep; 13 ounces
ACCESSORIES SUPPLIED:	Mating card-edge connector and 2 push-on coaxial connectors

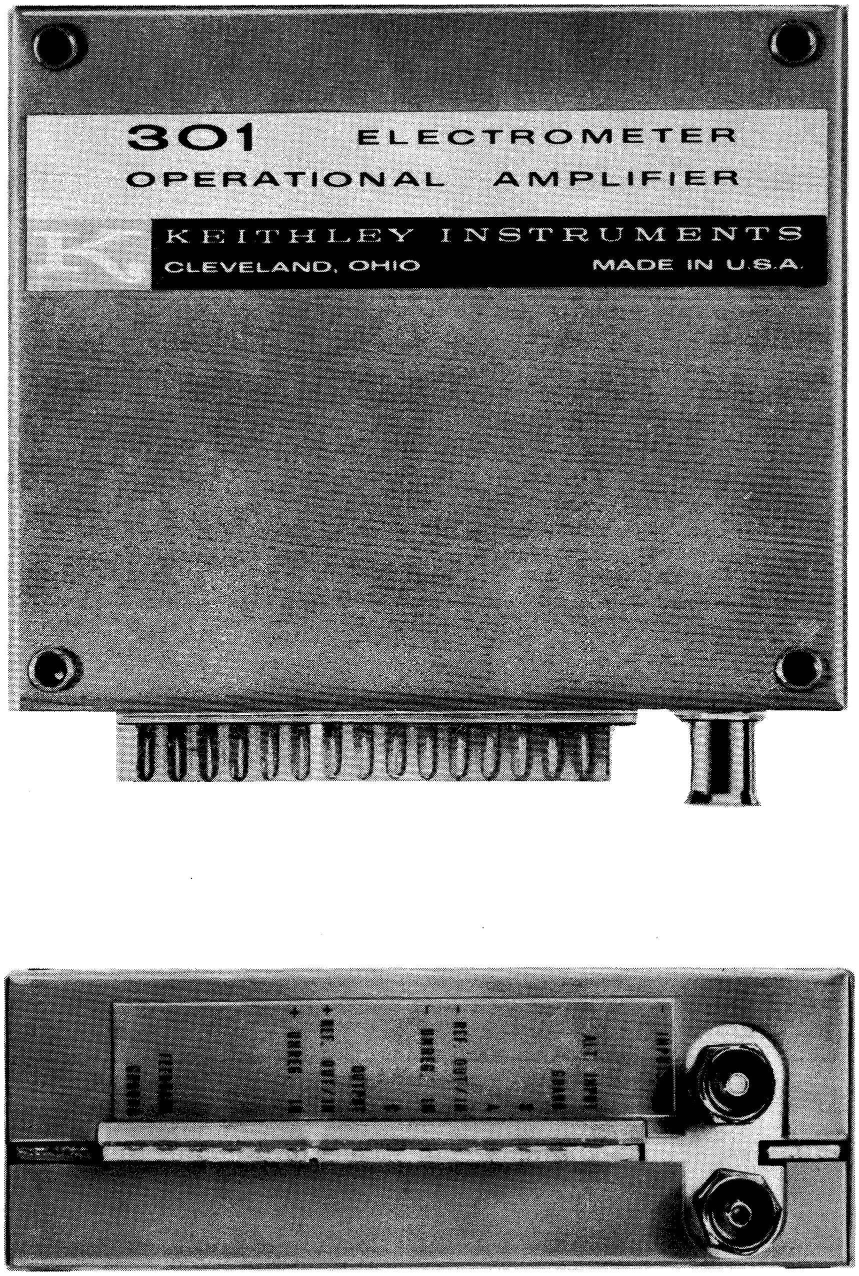


FIGURE 1. Top and Side Views of Case.

SECTION 1. GENERAL INFORMATION

The 301 Operational Amplifier offers better performance, more versatility and greater convenience than found in other high impedance amplifiers. It offers many features which make it easy to design into new or existing circuits.

Low offset current allows the use of resistors as high as 10^{13} ohms in the Model 301 feedback loop. This allows large voltage signals to be developed from very small currents, increasing the sensitivity and stability of the instrument. Increasing the feedback resistor also improves the signal-to-noise ratio for current measurements in proportion to the square root of the increase of resistance.

Common mode rejection is greater than 60 db. Common mode voltage limit is ±11 volts.

Drift due to offset current is very low: less than 10^{-15} ampere day. This allows much larger integration times than usually possible with other types of operational amplifiers.

The advantage of MOS FET input circuits is demonstrated by the outstanding voltage stability of the Model 301. Voltage stability is 0.02% of full output per week with the Amplifier connected in a unity-gain configuration. This stability is comparable to that obtained with varactor-type amplifiers without the problems of interference between units, intermodulation products, limited bandwidth and the necessity of shielding from modulation frequency. Also, the Model 301 has higher impedance between inputs, lower input capacitance and lower offset current by several orders of magnitude than varactor-type amplifiers.

The open loop frequency response of the Amplifier closely follows a 6 db/octave rolloff. This, coupled with a very low output impedance, allows the Amplifier to drive large capacitive loads with no instability even in a unity-gain configuration.

A unique input circuit provides complete overload protection without degrading the desirable features of the MOS FET input. The Model 301 will withstand continuous overloads up to ±400 volts—either input to ground or between inputs—without damage. Input circuit elements can not be damaged by induced static voltages.

The Model 301 will operate within specifications from unregulated power supplies, batteries or standard 15-volt regulated supplies. It has built-in voltage regulators to allow it to operate within specifications with unregulated supplies from ±19 to ±30 volts at ±16 milliamperes. The regulators have series input diodes to protect them from damage if the unregulated supply potentials are reversed. Short-circuit proof regulated potentials of ±15 volts at 5 milliamperes are available at the card-edge connector.

The inexpensive Keithley 3012 Power Supply is specially designed to power up to three 301 Amplifiers. The Model 3012 can also be used floating if it is desired to float the amplifier ground.

The Model 301K is identical to the Model 301 except it has no voltage regulators and requires regulated supplies. Specifications are based on ±15 volt supplies. The Model 301K can also be operated from ±12 to ±18 volt regulated supplies, but some specifications will be affected.

Besides its outstanding specifications, the Model 301 has many built-in features which aid in connecting and using the Amplifier in a circuit. It requires no accessory shields. Mating connectors are furnished at no extra cost.

The Model 301 saves time and trouble in providing high impedance connections. Teflon-insulated coaxial connectors are used for the input, and all high impedance points are mounted on guarded Teflon standoffs, providing maximum leakage resistance so essential in low current measurements. Feedback, input and output divider elements may be mounted within the unit, the case of which guards against external electrostatic and magnetic pickup.

When range switching is required, the 301 Amplifier can be used with the 3011 Shielded Switch, a 3-pole, 8-position, high impedance switch. The Model 3011 is constructed for low leakage and to provide shielding for the components. It can also be used with the 300 and 302 Amplifiers.

Voltage offset of the Model 301 is adjustable to zero. In addition to the internal control, an external potentiometer may be connected to allow remote zeroing.

The Model 301 can be used as a direct replacement for the Model 300 in most applications, resulting in improved or equal performance. It has the same dimensions as the Model 300.

SECTION 2. OPERATING INSTRUCTIONS

CONNECTIONS:

All wiring to the Models 301 or 301K should be made using the mating card-edge receptacle supplied with the amplifier. Input connections may be accomplished by using the coaxial inputs or the unshielded card-edge terminals (1 and 2). Mounting dimensions for Keithley part no. CS-175-15 is given in Figure 2.

POWER SUPPLY:

Model 301. This version may be powered by an unregulated voltage between ±19 and ±30 volts with less than 2 volts peak-to-peak ripple. Connections should be made between GROUND and +UNREG and -UNREG terminals.

Model 301K. This version requires a regulated supply of ±15 volts ±0.1%. Connections should be made between GROUND and +REF (pin 9) and -REF (pin 5).

Model 3012 Power Supply. This accessory is a full-wave rectified voltage supply which provides unregulated ±20 volts ±25% for use with the Model 301 (not useable with Model 301K).

Table 2.
Terminal Identification

Pin No.	Function
1	ALT. INPUT
2	GUARD
3	Remote zero control (B)
4	Remote zero control (A)
5	Negative reference voltage (-REF OUT/IN)
6	Negative unreg. voltage (-UNREG. IN)
7	Input protection drive (C)
8	Output voltage
9	Positive reference voltage (+REF OUT/IN)
10	Positive unreg. voltage (+UNREG. IN)
11	Not Used
12	Not Used
13	Not Used
14	FEEDBACK
15	GROUND

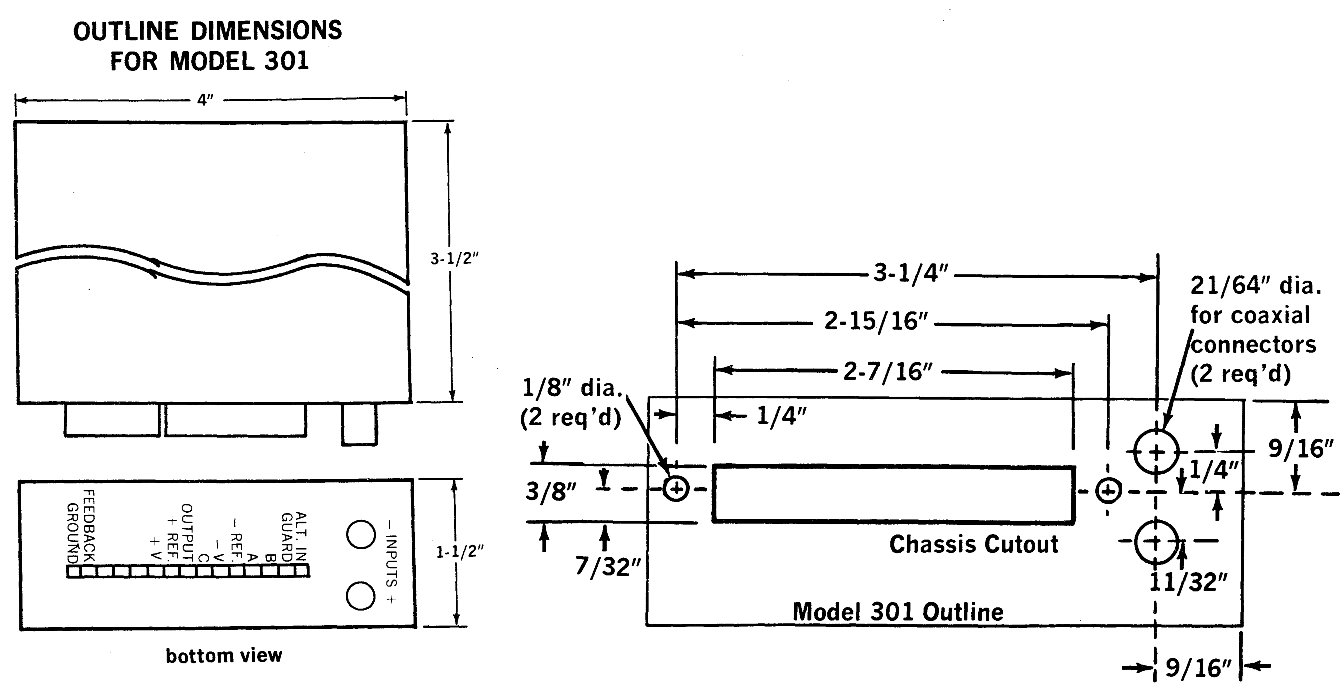


FIGURE 2. Outline Dimensions.

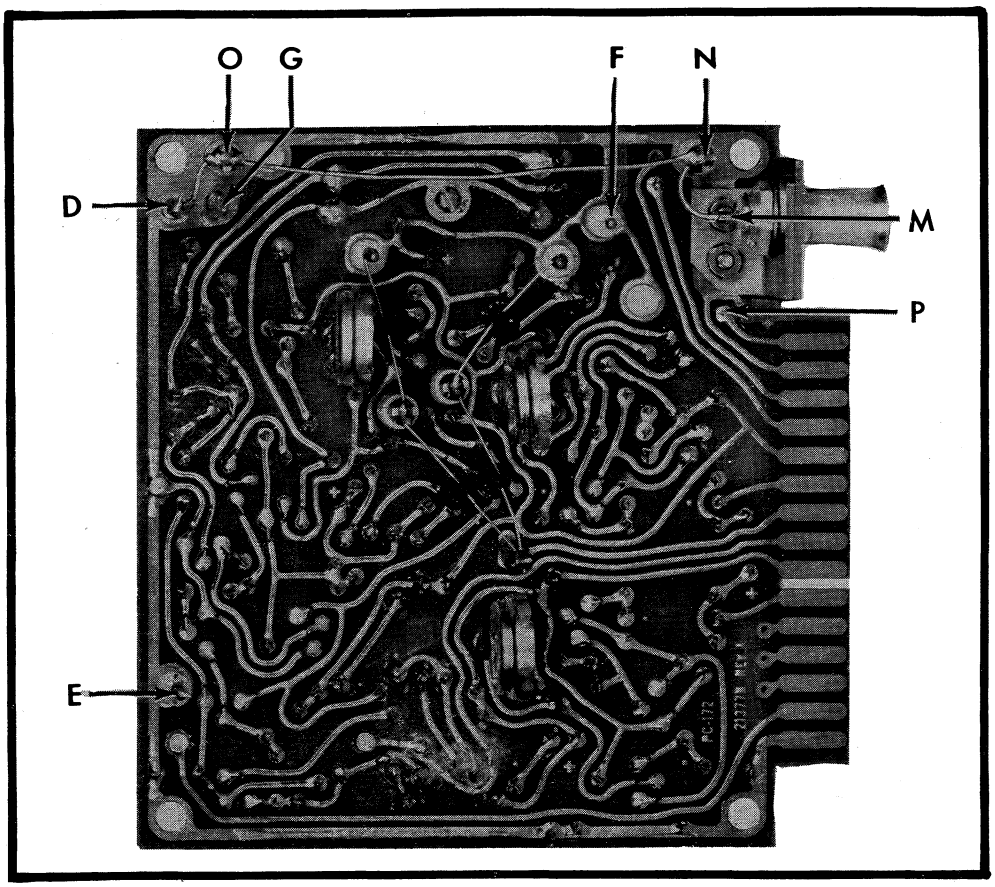


FIGURE 3. Circuit Points Within Models 301 and 301K. These points are the same in both models. Points are used to construct various circuits referred to in Figures 5 through 17.

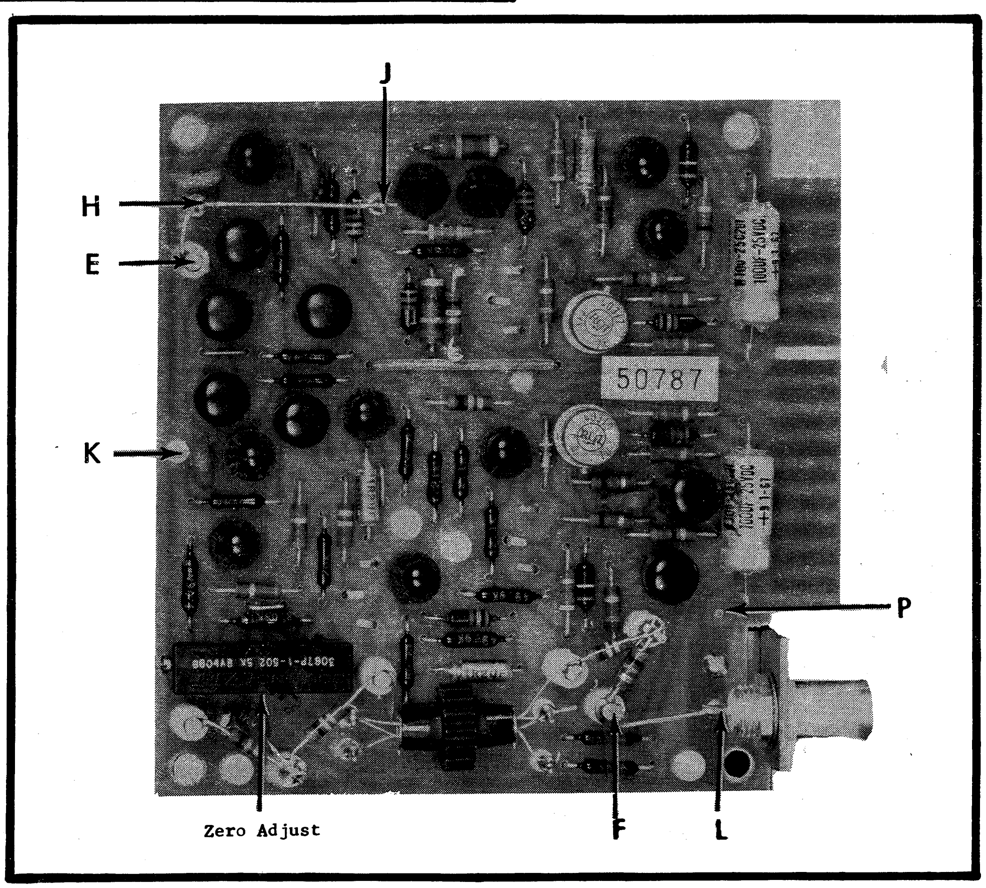


FIGURE 4. Circuit Points Within Models 301 and 301K. These points are the same in both models. Points are used to construct various circuits referred to in Figures 5 through 17.

MODES OF OPERATION:

(Refer to Figures 3 and 4 which indicate the various terminals and jumpers on the circuit board. The Models 301 and 301K are shipped from the factory wired for differential voltage operation with jumpers between terminals M-N, N-O, O-D, E-H, H-J, and F-L.)

1. Linear Current Amplifier (Without Fractional Feedback). In this mode a feedback resistor R_F is connected as shown in Figure 6. The output voltage is then proportional to the input current where $V_o = -I \times R_f$. When used in this mode check for jumpers between terminals M-N, N-O, O-D, E-H, H-J, and F-L. Add a new jumper between terminals G-F.

2. Linear Current Amplifier (With Fractional Feedback). In this mode the feedback resistor is connected as shown in Figure 7. Two additional resistors R_1 and R_2 are connected as shown in Figure 7. Resistor R_1 replaces the jumper between terminals J-H. With this connection the output voltage is proportional to the input current where $V_o = -I \times R_f\ [(R_1 + R_2)/R_2]$. The value of $R_1 + R_2$ should be greater than 1000 ohms so that the output current does not exceed 11 milliamperes.

3. Differential Current Amplifier (Without Fractional Feedback). In this mode two feedback resistors R_{f1} and R_{f2} are connected as shown in Figure 8. The output voltage is a function of the difference between input currents I_1 and I_2 where $V_o = (I_2 - I_1)R$ (assuming $R_{f1} = R_{f2} = R$).

4. Differential Current Amplifier (With Fractional Feedback). In this mode the output voltage is a function of the difference between input currents I_1 and I_2 where $V_o = (I_2 - I_1)R[(R_1 + R_2)/R_2]$ (assuming $R_{f1} = R_{f2} = R$). Resistor R_1 replaces the jumper between terminals J-H. The value of $R_1 + R_2$ should be greater than 1000 ohms so that the output current does not exceed 11 milliamperes. Connections should be made as shown in Figure 9.

5. Logarithmic Current Amplifier. In this mode a semiconductor junction (either a diode or transistor) is connected in the feedback path as shown in Figure 10. The output voltage is proportional to the logarithm of the input current where $V_o = -A \times$ logarithm (I). The value of A is determined by the particular characteristics of the diode junction. When using only one diode the amplifier responds to only one polarity of current. To measure positive and negative currents two diodes must be used wired in parallel and conducting in opposite directions. By adding two or more diodes in series the output voltage may be increased in direct proportion. Fractional feedback may be used to increase A where $V_o = -A\ [(R_1 + R_2)/2$ ln (I).

6. Differential Logarithmic Current Amplifier. In this mode two diodes are connected as shown in Figure 11. The output voltage is proportional to the difference of the logarithms of I_1 and I_2 where $V_o = A(\ln I_2 - \ln I_1) = A \ln [I_2/I_1]$.

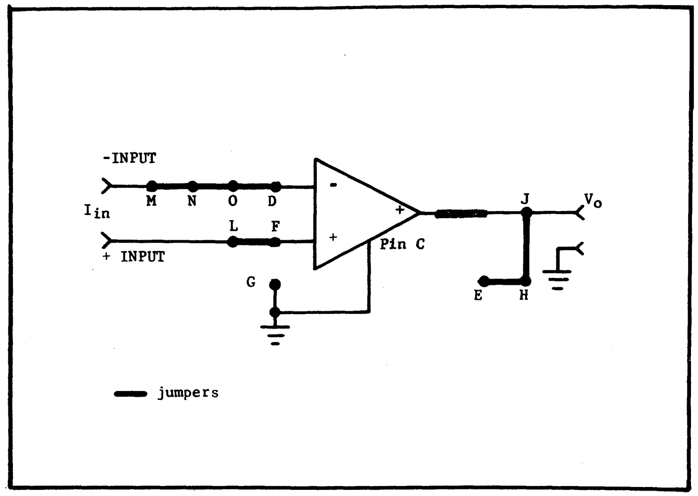


FIGURE 5. Factory Wired Amplifier

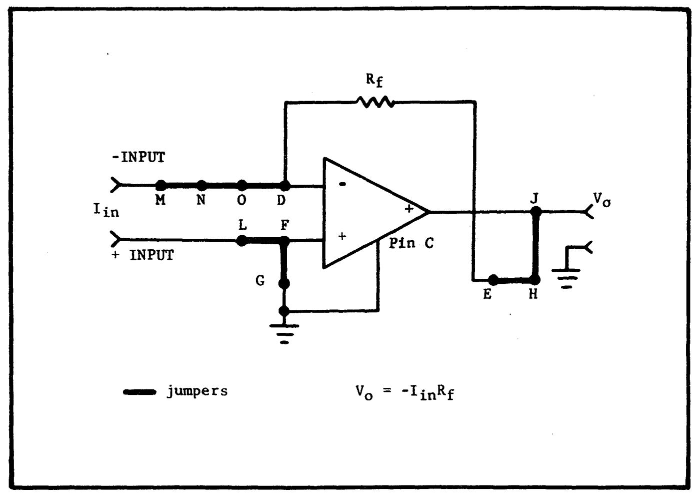


FIGURE 6. Current Amplifier

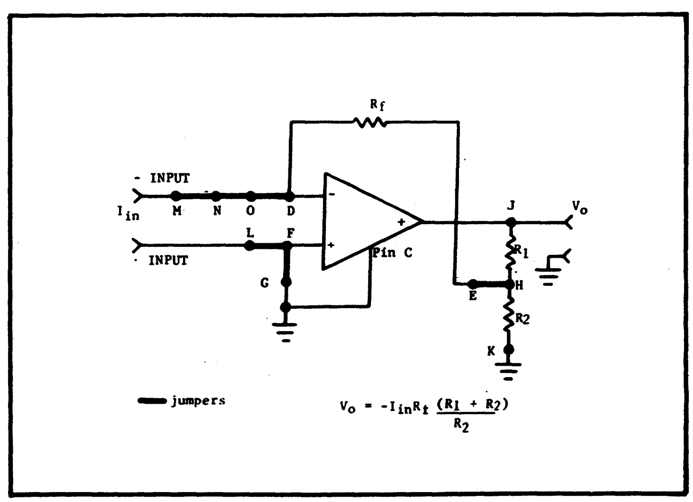


FIGURE 7. Current Amplifier

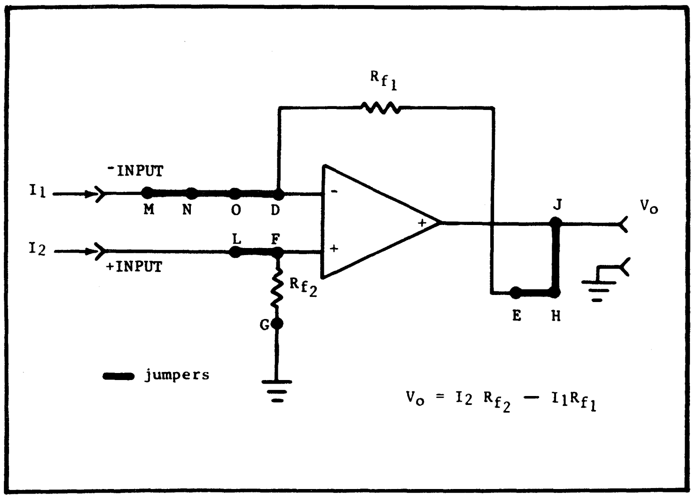


FIGURE 8. Differential Current Amplifier

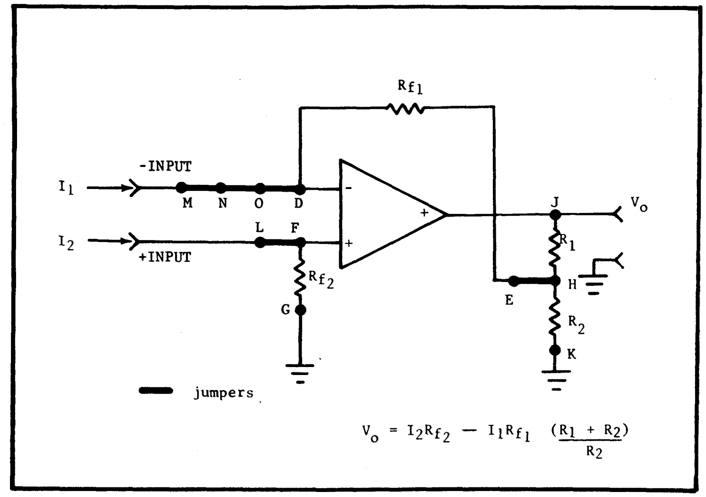


FIGURE 9. Differential Current Amplifier

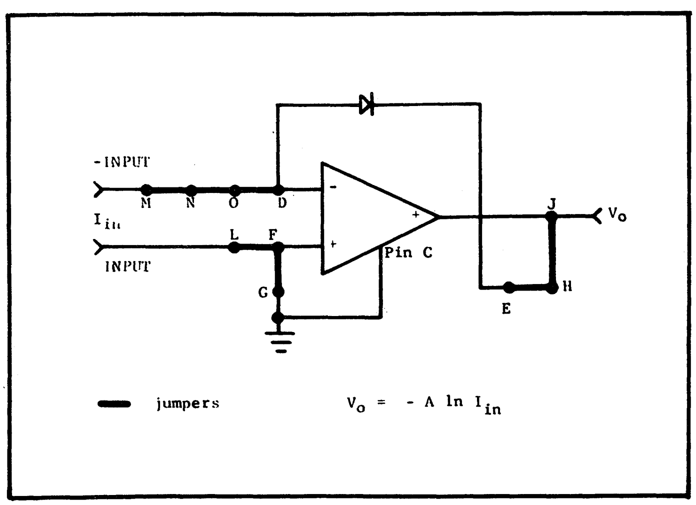


FIGURE 10. Logarithmic Current Amplifier

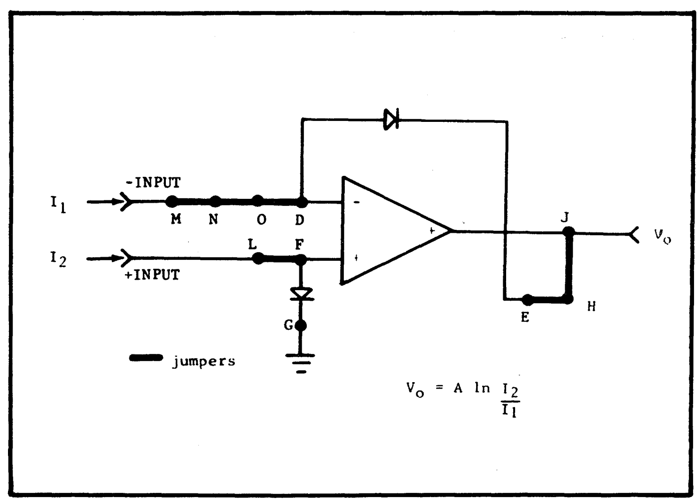


FIGURE 11. Logarithmic Current Amplifier

7. Current Integrator or Charge Amplifier. In this mode a capacitor C_f is connected in the feedback loop as shown in Figure 12. The output voltage is a function of the integral of current where

$$V_o = \frac{-1}{C_f} \int_o^t I\,dt$$

When making a measurement in terms of charge the output voltage is proportional to Q where

$$V_o = \frac{Q}{C_f} = \frac{It}{C_f}$$

8. Unity-Gain Voltage Amplifier. In this mode the output voltage is directly proportional to the input where

$$V_o = V_1 \left[1 \pm \frac{1}{CMRR}\right]$$

Since the CMRR (common mode rejection ratio) is 60 dB the common mode error is 0.1%. When using this mode connect a jumper between terminals D-E. Remove the jumper (if any) between terminals F-G. Apply the input voltage V_1 between the + INPUT and GROUND. Connections should be made as shown in Figure 13.

9. Unity Gain Voltage Amplifier (With Floating Input or Output). In this mode the input voltage is applied between -INPUT and OUTPUT such that the input is isolated from power supply ground. When using this connection either the power supply or the input must be floating. The gain accuracy is approximately 0.002% or 20 ppm. The Keithley Model 3012 Power Supply permits floating the input up to 500 volts off ground with greater than 10^8 ohms isolation between low and power supply ground. The output voltage is inverted with the voltage developed between OUTPUT and GROUND. Connections should be made as shown in Figure 14.

10. Voltage Amplifier (With Fractional Feedback). In this mode the output voltage is a function of the divider ratio established by R_1 and R_2 where $V_o = V_1\,[(R_1 + R_2)/R_2]$. The common mode error and gain error should be considered as additional sources of inaccuracy. Connections should be made as shown in Figure 15.

11. Voltage Amplifier (Summing Type). In this mode the output voltage is a function of resistors R_1 and R_f where

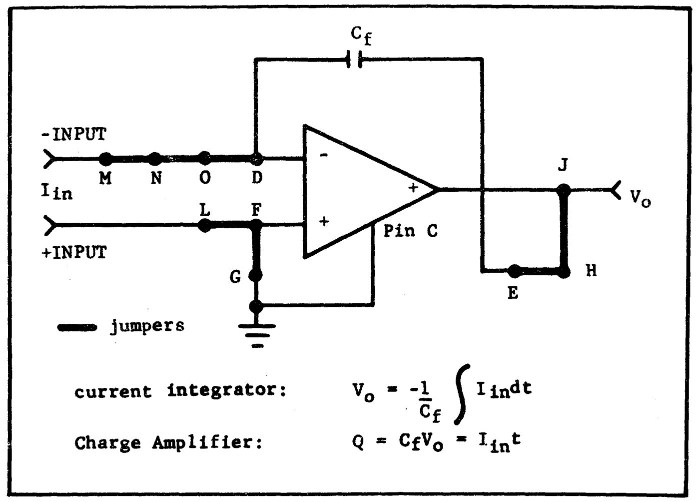
$$V_o = -V_1 \frac{R_f}{R_i}$$

Connections should be made as shown in Figure 16.

12. Voltage Amplifier (Differential Type). In this mode the output voltage is a function of the difference in voltages V_1 and V_2 where

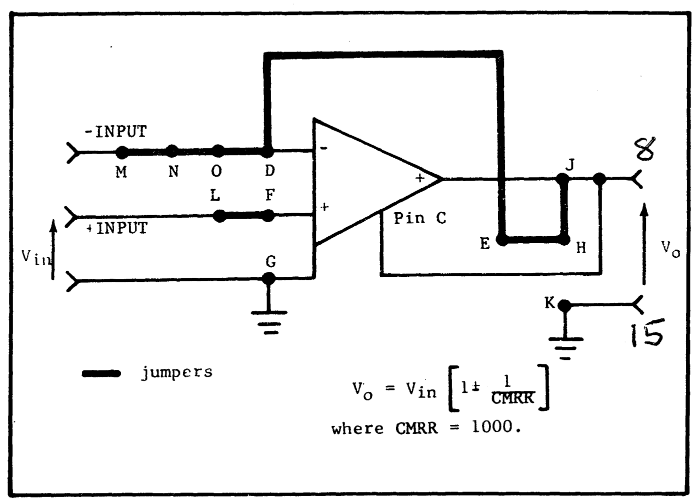
$$V_o = (V_2 - V_1)\frac{R_f}{R_i}$$

assuming $R_{f1} = R_{f2} = R_f$, $R_1 = R_2 = R_i$). Connections should be made as shown in Figure 17.



$V_o = \frac{-1}{C_f}\int I_{in}dt$; $Q = C_f V_o = I_{in}t$

FIGURE 12. Current/Charge Amplifier



$V_o = V_{in}\left[1 \pm \frac{1}{CMRR}\right]$

FIGURE 13. Unity-Gain Voltage Amplifier

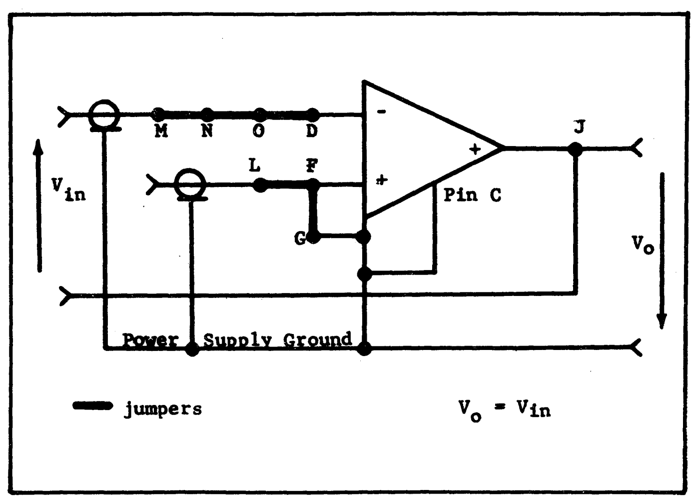


FIGURE 14. Unity-Gain Voltage Amplifier

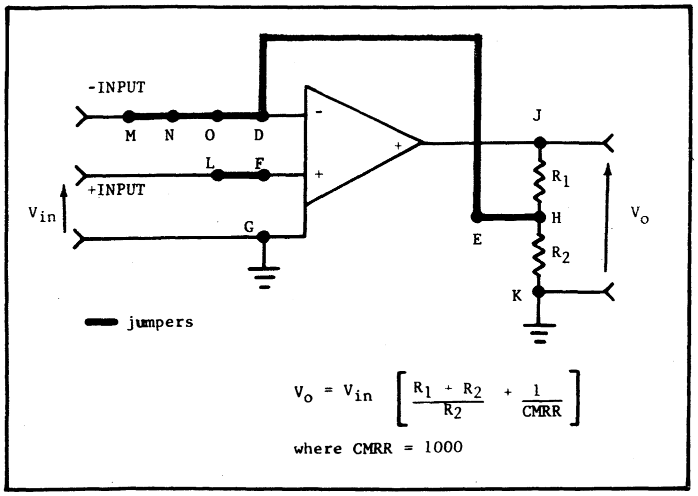


FIGURE 15. Voltage Amplifier

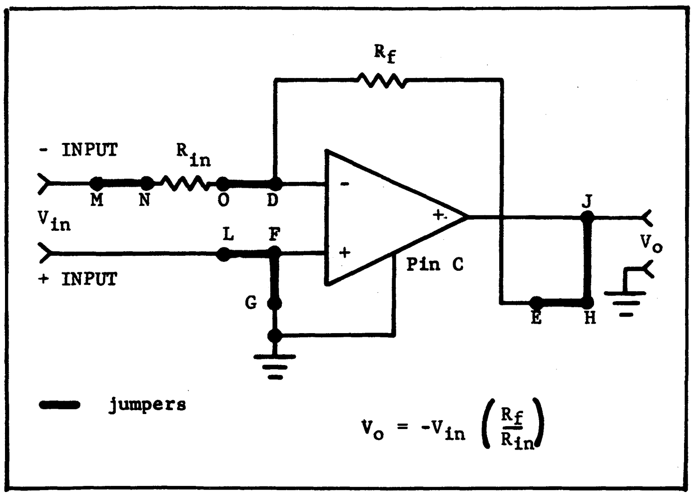


FIGURE 16. Voltage Amplifier (Summing)

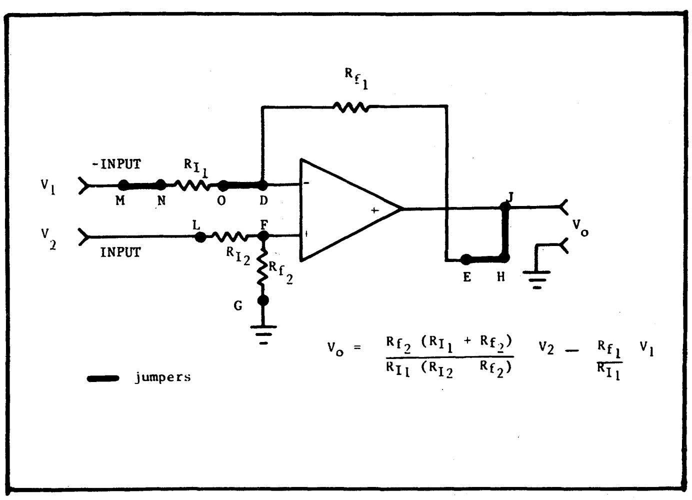


FIGURE 17. Voltage Amplifier (Differential)

ACCESSORY POWER SUPPLY (Model 3012)

The Model 3012 can be used to power up to three individual amplifiers (either Models 300 or 301). Connections to the Model 3012 can be made using a mating card-edge receptacle (supplied). The Model 3012 may be powered from line voltages over the ranges 105-125 volts or 210-250 volts.

Line Connections 105-125 volts:

Connect the line cord between terminals A and D. Add a jumper wire between A and B (which connects the primary BLK to BRN windings). Add a second jumper wire between C and D (which connects the primary BLK/WHT to BRN/WHT windings).

Line Connections 210-250 volts:

Connect the line cord between terminals A and D. Add a jumper wire between B and C (which connects the primary BLK/WHT to BRN windings).

Connections to Model 301 Amplifier:

Connect the positive output of the Model 3012 to the +UNREG IN terminal on the Model 301. Connect the negative output of the Model 3012 to the -UNREG IN terminal. Then make a connection between GROUND terminals on the Model 3012 and the Model 301. In floating operation the CASE terminal should be connected to circuit ground which is isolated from power GROUND for the amplifier.

NOTE
Two fuses are used in the primary windings of the Model 3012 (Type 8AG, 1/8A).

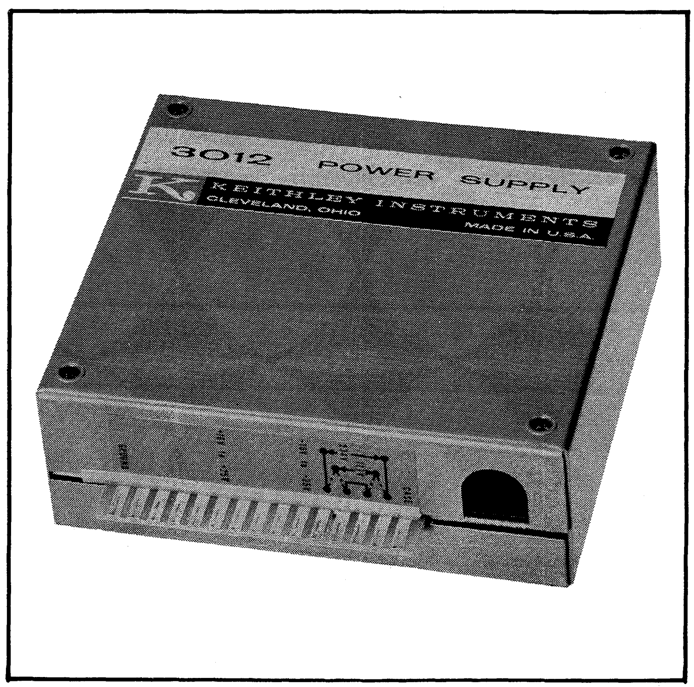


FIGURE 18. Model 3012 Power Supply

SECTION 3. THEORY OF OPERATION

3-1. GENERAL.

a. The Keithley Models 301 and 301K are differential input, single-ended output operational amplifiers. The Amplifiers use a pair of high impedance matched MOS FET's at their inputs followed by solid-state differential amplifier stages. The Model 301 has positive and negative power supply regulators that enable it to operate from a variety of inexpensive power supplies. The Model 301K is distinguished from the Model 301 by the fact that it does not have these regulators and it must operate from regulated supplies.

b. Use of negative feedback with the Models 301 and 301K achieves stable amplification. Negative feedback is accomplished by connecting components between the OUTPUT Terminal and the - INPUT Receptacle only. Connecting elements between the OUTPUT Terminal and the + INPUT Receptacle establishes positive feedback and the amplifier goes into saturation, cutoff or oscillation. Input and feedback elements are easily mounted within the case of the Amplifiers to provide shielding for the complete circuit, or may be externally mounted. By using different components — such as resistors, diodes, capacitors — in the feedback circuit, the Models 301 and 301K can operate in various modes: linear current amplifier, logarithmic current amplifier, current integrator and so forth.

NOTE

Circuit designations refer to schematic diagrams 21472E for the Model 301 and 21473D for the Model 301K.

3-2. MOS FET INPUTS.

a. Two matched MOS FET transistors, Q101 and Q102, are used for the Amplifier inputs. These transistors are selected for low noise and matched for threshold voltages, temperature coefficients and transconductances to assure stable, low noise, high common mode operation.

b. The MOS FET transistors are connected as a differential amplifier. Their sources are driven by a constant current amplifier, transistor Q103. This amplifier is driven by a common emitter stage, transistor Q108, which is driven by the emitter of the last differential stage, transistors Q111 and Q112. This arrangement provides a high common mode swing in both directions.

c. Transistor Q103 has its emitter connected directly to the power terminal. Stability for this stage is obtained through use of feedback rather than by emitter degeneration through a resistor.

3-3. PROTECTION CIRCUIT.

a. The input protection circuit, schematic designation 21728A, protects the MOS FETS from static voltages and overloads. This circuit, under normal operating conditions, allows almost full utilization of the MOS FETS' extremely high input impedance and low leakage current.

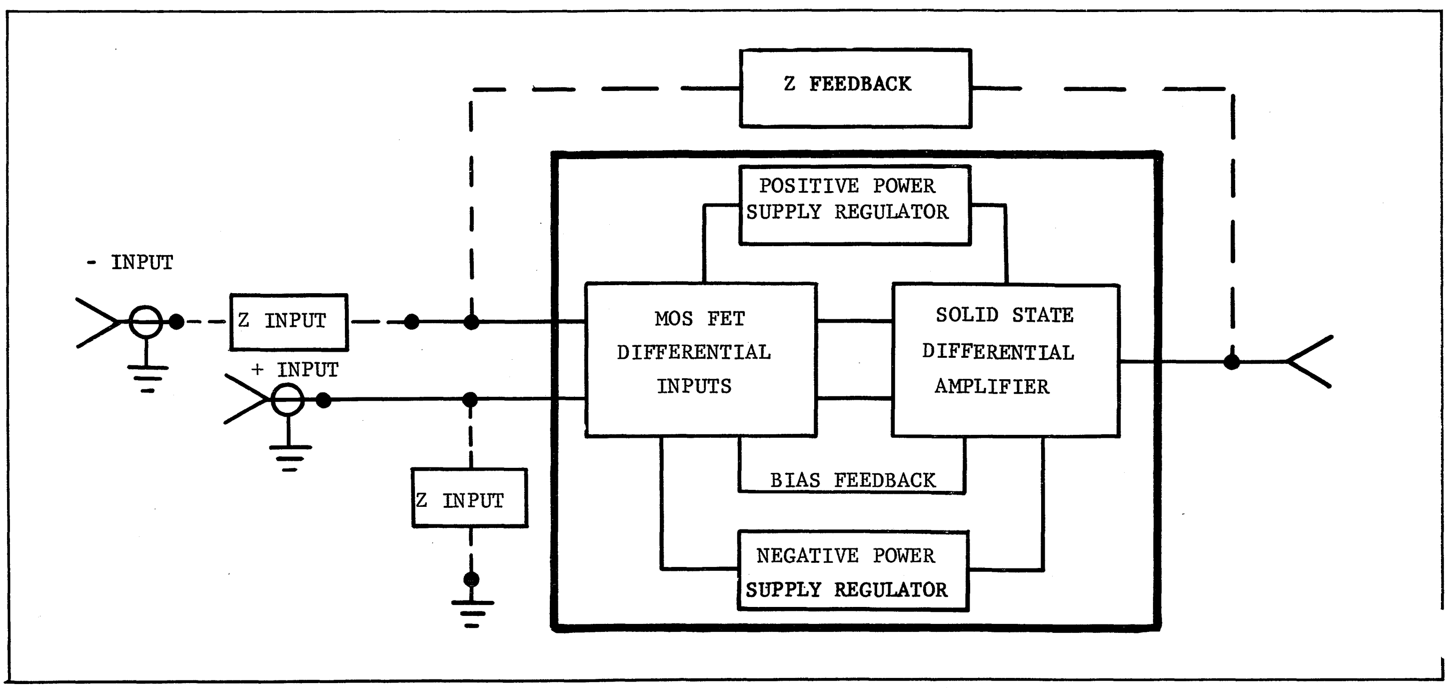


FIGURE 19. Block Diagram of Model 301.

b. Overloads of any form may be supplied to the inputs in any way for long periods of time without damaging the MOS FETS. Recovery from overloads to within several millivolts of before overload condition is immediate. This several millivolts change is due to slight heating effects in the protection circuit and possible polarization effects in the MOS FETS. Complete recovery is achieved after a few minutes of removal of overload condition.

c. The protection circuit, 21728A, is internally driven by a 10 kilohm source, R108. Even better conditions, however, can be obtained in many situations by driving the protection circuit externally. The internal drive voltage can be overriden by applying an external drive voltage from a low impedance source. The Models 301 and 301K have provisions for driving the protection circuit externally (See Section 2).

CAUTION

4 where?!!

The external drive voltage must not exceed ±15 volts with respect to Amplifier ground, or damage to the MOS FETS may result (See also paragraph 2-3).

3-4. DIFFERENTIAL AMPLIFIER.

a. MOS FETS Q101 and Q102 drive a differential amplifier stage, transistors Q106 and Q107, which in turn drives an emitter follower stage, transistors Q109 and Q110. The emitter followers drive a differential pair, transistors Q111 and Q112, which is the last voltage gain stage in the amplifier. The collector of Q112 drives an emitter follower stage, transistor Q113, which drives a complimentary symmetry output stage formed by transistors Q114 and Q115. Diodes D102 and D103 and resistor R131 eliminate any crossover distortion and provide excellent temperature compensation over the entire operating range of $-25^{\circ}C$ to $+85^{\circ}C$.

b. The output overload protection circuit is composed of resistors only, and is independent of power supply current limiting. The circuit is such that the output can be connected to ground or the plus or minus supply almost indefinitely without damaging the Amplifier. The only way to damage the output is to apply high voltage, high current signals back into it from an external source.

c. The Zero Adjust Potentiometer, R106, is located in the drain circuits of Q101 and Q102. It adjusts the drain load resistances to give equal gain to each side which adjusts the output to zero.

d. The Protection Drive Voltage Adjust Potentiometer, R114, adjusts the voltage across the input protection circuit to zero when the inputs are short circuited.

3-5. POSITIVE POWER SUPPLY REGULATOR (Model 301 only).

a. This circuit regulates the +19 and +30 volt unregulated power supply input to the Model 301. It provides a regulated +15 volts for the amplifier and can be used externally.

b. Diode D206 on the + UNREG. IN Terminal protects the supply regulator against damage if voltages of the wrong polarity are applied. The output of this regulator current limits at approximately 40 milliamperes and drives short circuits for a reasonable length of time with no damage to the regulator.

c. The positive power supply regulator consists of a pass transistor, Q205, and a dc amplifier, transistor Q206, which monitors the difference between an output divider, resistors R210 and R212, and zener diode D205. Any difference is amplified by Q206 and fed to the base of Q205. The base-emitter of current limiting transistor Q204 is connected across resistor R214 which is in series with the supply regulator output. The collector of Q204 is connected to the base of Q205. When the output current of the regulator becomes excessive, Q204 is saturated and tries to reverse bias the base of transistor Q205 and thus turn it off. If Q205 is turned off, however, no current flows through Q204 and it is turned off. A happy medium is reached and current is limited.

3-6. NEGATIVE POWER SUPPLY REGULATOR (Model 301 only).

The negative regulator is the same as the positive regulator except the voltages are negative and PNP transistors are used instead of NPN type.

SECTION 4. CALIBRATION

5-1. GENERAL.

a. The function of the calibration procedures is to provide a method of checking the Models 301 and 301K to make sure that they operate within the specifications

b. The following procedures are recommended for calibrating and adjusting the Models 301 and 301K. Use the equipment recommended in Table 5. If proper facilities are not available or if difficulty is encountered, contact Keithley Instruments, Inc., or its representatives to arrange for factory calibration.

NOTE

Unless otherwise stated, the tests herein described are to be performed with the Amplifier cover off.

c. If the Model 301 or 301K is not within specifications after the calibrations and adjustments, follow the troubleshooting procedures or contact Keithley Instruments, Inc., or its nearest representative.

NOTE

All the following procedures pertain to both the Models 301 and 301K unless otherwise stated.

5-2. PRELIMINARY CALIBRATION PROCEDURES.

a. Positive and negative power supply regulator checks (Model 301 only).

1. Set the Model 301 up as a voltage follower unity-gain amplifier (see paragraph 2-10). Connect a variable supply as described in paragraph 2-3 and apply +25 volts. Short the + INPUT Receptacle.

2. Connect the Model 662 between the Model 301 +REF. OUT/IN and GROUND Terminals and adjust potentiometer R211 for a +15 volts ±20 millivolts reading on the Model 662.

a) Vary the external supply voltage to +22.5 volts. The reading on the Model 662 should not change more than 150 millivolts.

b) Set the external supply to +25 volts and monitor the output current with the Model 602. It should be 20 milliamperes ±5 milliamperes.

3. Connect the Model 662 between the Model 301 - REF. OUT/IN and GROUND Terminals and adjust potentiometer R202 for a -15 volt ±20 millivolts reading on the Model 662.

a) Apply +22.5 volts with the external supply. The reading on the Model 662 should not change more than 150 millivolts.

b) Set the external supply to -25 volts and monitor the output current with the Model 602. It should be 20 milliamperes ±5 milliamperes.

b. Attach the Model 662 to the Amplifier OUTPUT Terminal. Adjust potentiometer R106 making sure the output voltage swings at least 50 millivolts either side of 0 volts.

1. Construct a 1% resolution Remote Zero Potentiometer as shown in paragraph 2-14. Set this potentiometer at mid-range.

2. Adjust R106 to within 1 millivolt of 0; closer if possible. Then use the Remote Zero Potentiometer to zero the output voltage within the limit of resolution.

TABLE 3.
Test Equipment Required.

Hewlett Packard Model 200CD Oscillator	Frequency response check.
Hewlett Packard Model 211B Square Wave Generator	Open loop gain and slewing rate checks.
Hewlett Packard Model 400GL AC Voltmeter	Frequency response check.
Keithley Instruments Model 153 Microvolt-Ammeter	Troubleshooting.
Keithley Instruments Model 602 Electrometer	Preliminary calibration and common mode check.
Keithley Instruments Model 662 Differential Voltmeter	Preliminary calibration and current offset check.
Tektronix 561 Oscilloscope	Open loop gain and slewing rate checks.
±10 V Batteries	Common mode rejection check.
1000:1 Voltage Divider	Open loop gain check.

c. Next, connect the Model 662 across resistor R132 and measure the voltage drop. It should be between 8.1 and 27 millivolts. If it is not, change the value of R131 to bring the voltage drop within the stated limits. Decreasing the value of R131 increases the voltage drop while increasing the resistance decreases the voltage drop.

d. Adjust potentiometer R114 for 0 volts ±5 millivolts at Terminal C. If this is not possible, select a value for resistor R113 between 10 kilohms and 22 kilohms which will allow R114 to adjust for 0 volts.

e. Put the cover on the Amplifier and perform the steps described in paragraphs 5-2b and 5-2c.

5-3. CURRENT OFFSET CHECK. (This check is a rather difficult check and may be by-passed if proper facilities are not available).

a. Inverting (-) input offset.

1. Keep the Amplifier in the same mode as in paragraph 5-2.

2. Check the voltage at Terminal C with the Model 662 for 0 volts ±5 millivolts. If necessary, adjust R114 for this value.

3. Attach Terminal C to GROUND Terminal.

4. Monitor the OUTPUT Terminal of the Amplifier with the Model 662 and adjust the Remote Zero Potentiometer for 0 volts ±0.1 millivolt at the output.

5. Set the Model 301 or 301K up as a single-ended linear current amplifier with a 10^{12} ohm resistor in the feedback loop (refer to paragraph 2-7). Monitor the output voltage to be 10 millivolts or less. A 10 millivolt output means that, with a 10^{12} ohm resistor in the feedback loop, the current offset is 10^{-14} ampere.

b. Non-inverting (+) input offset.

1. Connect the - INPUT Receptacle to the output and set the Model 301 or 301K up as a voltage follower amplifier.

2. Connect Terminal C to the OUTPUT Terminal.

3. Mount a 10^{12} ohm resistor from the + INPUT to ground.

4. Short the + INPUT and adjust the Remote Zero Control for 0 volts ±0.1 millivolt at the output.

5. Remove the short and measure the output. It should be 10 millivolts or less.

NOTE

If the current offset does not meet specifications, clean the Amplifier INPUT Receptacle and Terminal before attempting other corrective action.

5-4. COMMON MODE REJECTION.

a. Set the Amplifier up as in paragraph 5-2.

b. Connect Terminal C to GROUND Terminal.

c. Attach a battery to the Amplifier + INPUT Receptacle. Adjust the battery for 10 volts output then turn the battery off. Connect battery common to Amplifier GROUND Terminal.

d. Monitor the output from the Amplifier OUTPUT Terminal with the Model 602. Adjust the Remote Zero Potentiometer for a zero indication on the Model 602.

e. Apply 10 volts with the battery to the + INPUT Receptacle and measure the output with the Model 602. The output voltage should be less than 10 millivolts.

f. Repeat step e. using -10 volts.

5-5. OPEN LOOP GAIN.

a. Set up the Amplifier as in paragraph 5-2.

b. Apply a 0.2 volt peak-to-peak signal 1 Hz square wave with the Model 211B through a 1000:1 divider to the Amplifier - INPUT Receptacle. Monitor the output with the Model 561 Oscilloscope. Adjust the Remote Zero potentiometer, and potentiometer R106 if necessary, to obtain a non-saturated 1 Hz square wave at the output. The amplitude of the square wave observed at the output should be at least 10 volts peak-to-peak.

c. Short the - INPUT Receptacle, and repeat step b. applying a signal to the + INPUT Receptacle.

5-6. FREQUENCY RESPONSE.

a. Set the amplifier up as in paragraph 5-2.

b. Remove the short from the + INPUT Receptacle of the Amplifier.

c. Apply a 50 millivolt rms 100 Hz sine wave from the Model 200CD to the + INPUT Receptacle. Monitor the output with the Model 400GL and note the dB reading.

d. Increase the frequency to 500 kHz and readjust the 200CD output for 50 millivolts rms if necessary. At 500 kHz the output should be within 3 dB of the 100 Hz reading.

5-7. SLEWING RATE.

a. Keep the same set-up as in paragraph 5-6.

b. Apply an 8 to 10 volts peak-to-peak 20 Hz square wave signal with the Model 211B to the + INPUT Receptacle.

c. Monitor the output with the Model 561 Oscilloscope. The slope of the leading edge of the square wave observed at the output should be a minimum of 0.3-volt per microsecond.

NOTE

Read the slope in the linear portion of the leading edge. This is the portion that is at least 1 volt prior to the start or end of the leading edge.

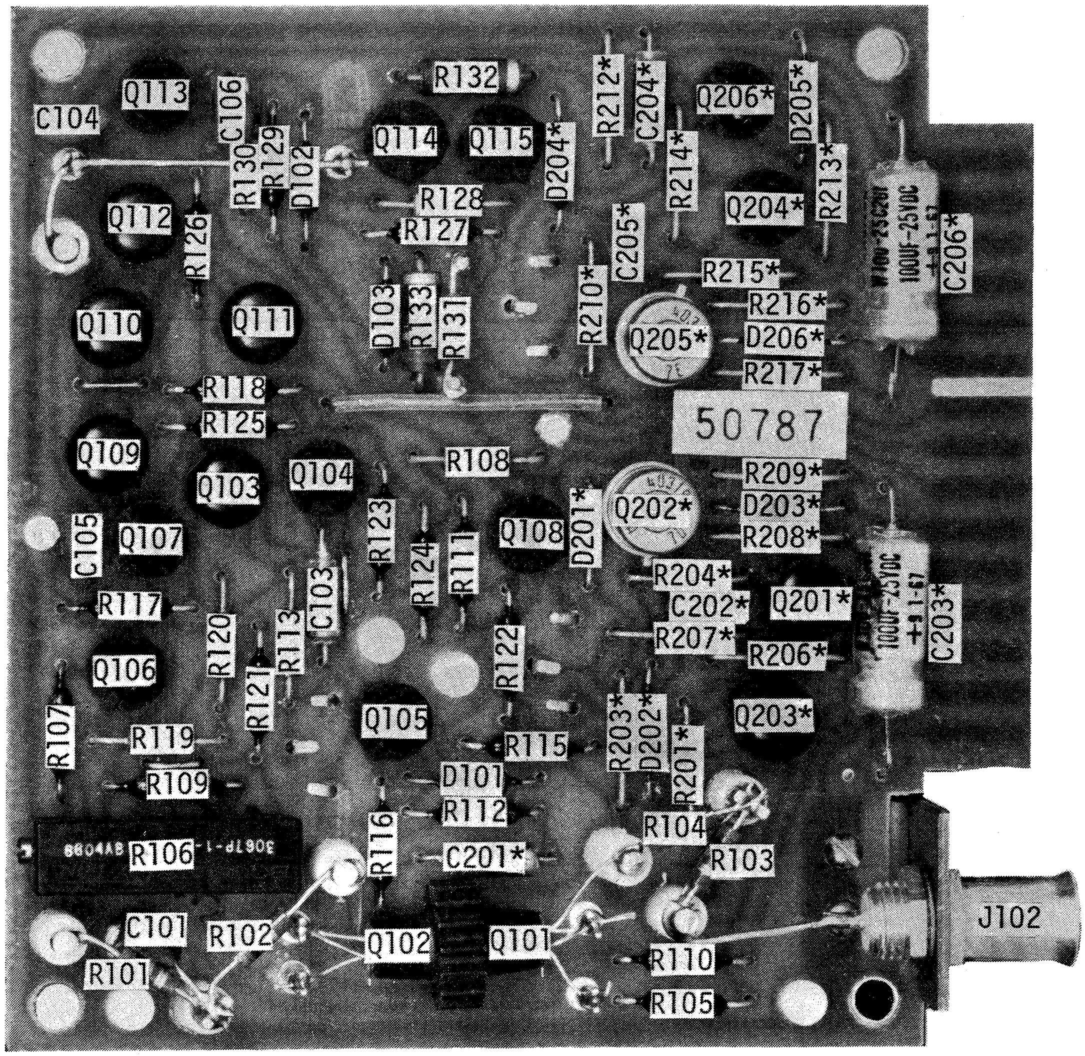


FIGURE 20. Component Location, Component Side of Board.

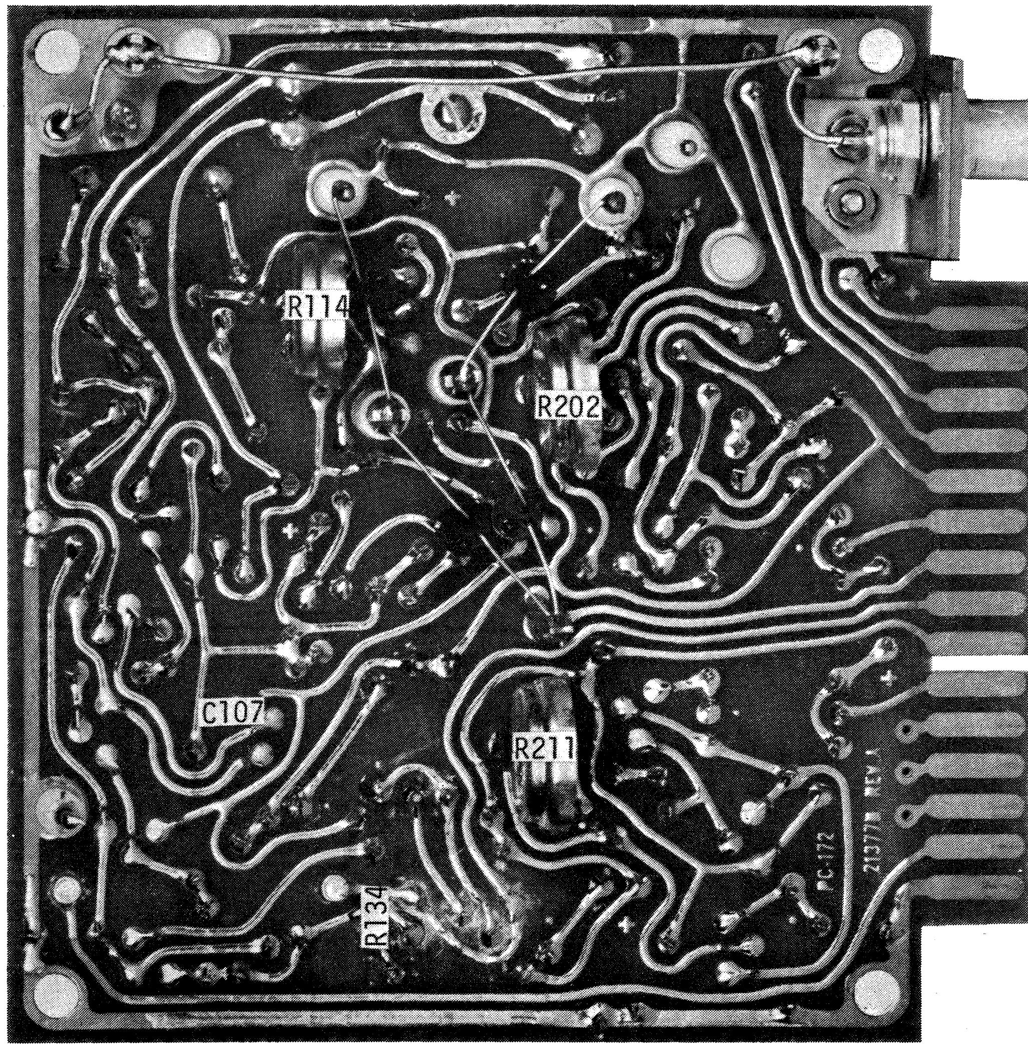


FIGURE 21. Component Location, Circuit Tape Side of Board.

SECTION 5. REPLACEABLE PARTS

MODELS 301, 301K REPLACEABLE PARTS LISTS

CAPACITORS

Circuit Desig.	Description	Mfr. Code	Mfr. Desig.	Keithley Part No.	Qty.
C101	150pF, 1000V, CerD.	CENLB	DD-151	C-64-150P	2
C102	150pF, 1000V, CerD.	CENLB	DD-151	C-64-150P	..
C103	1.2μF, 20V, ETT	COMPI	TSD120125	C-179-1.2M	1
C104	22pF, 1000V, CerD	CENLB	DD-220	C-64-22P	1
C105	220pF, 1000V, CerD.	CENLB	DD-221	C-64-220P	1
C106	.0033μF, 500V, CerD	ERIE	801-Z5U0-332M	C-22-.0033M	1
C107	.02μF, 500V, CerD	ERIE	811-Z5U0-203M	C-22-.02M	1
C201	1.2μF, 20V, ETT	KEMET	K1R2J20K	C-80-1.2M	2
C202	.001μF, 1000V, CerD	ERIE	808-000-Z5R0102K	C-64-.001M	2
C203	100μF, 25V, ETT	TEI	W100-25C2U1	C-96-100M	2
C204	1.2μF, 20V, ETT	KEMET	K1R2J20K	C-80-1.2M	..
C205	.001μF, 1000V, CerD	ERIE	808-000-Z5R0102K	C-64-.001M	..
C206	100μF, 25V, ETT	TEI	W100-25C2U1	C-96-100M	..

DIODES

Circuit Desig.	Description	Mfr. Code	Mfr. Desig.	Keithley Part No.	Qty.
D101	Silicon	TEXAS	1N645	RF-14	4
D102 }*	Silicon	TEXAS	1N914	RF-28 }*	1
D103	Silicon	TEXAS	1N914	RF-28	..
D201	Silicon	TEXAS	1N914	RF-28	1
D202	Zener, 6.2V	DICK	1N709	DZ-21	2
D203	Silicon	TEXAS	1N645	RF-14	..
D204	Silicon	TEXAS	1N645	RF-14	..
D205	Zener, 6.2V	DICK	1N709	DZ-21	..
D206	Silicon	TEXAS	1N645	RF-14	..

*Matched pair, order Keithley part no. 26607A.

MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfr. Code	Mfr. Desig.	Keithley Part No.	Qty.
J101	Coaxial Receptacle, - INPUT	AMPNL	FXR2175	CS-178	2
J102	Coaxial Receptacle, + INPUT	AMPNL	FXR2175	CS-178	..
----	(F) Plug, mate of J101 and J102, 2 req'd.	AMPNL	FXR30775	CS-179	1
----	(F) Hooded shield for CS-179, 2 req'd.	AMPNL	FXR2275	CS-180	1
----	(F) Connector, Card edge.	BURN	PSC44SS15-12	CS-175-9	1

RESISTORS

Circuit Desig.	Description	Mfr. Code	Mfr. Desig.	Keithley Part No.	Qty.M
R101	10MΩ, 10%, 1/4W, Comp	A-B	CB-105-10%	R-76-10M	2
R102	100kΩ, 10%, 1/4W, Comp.	A-B	CB-104-10%	R-76-100K	1
R103	10MΩ, 10%, 1/4W, Comp	A-B	CB-105-10%	R-76-10M	..
R104	100kΩ, 10%, 1/4W, Comp.	A-B	CB-104-10%	R-76-100K	..
R105	80.6kΩ, 1%, 1/8W, MtF	IRC	CEA-80.6K	R-88-80.6K	3
R106	10kΩ, 10%, 1/2W, WWVar.	BOURN	3067P-1-103	RP-39-10K	1
R107	15kΩ, 1%, 1/8W, MtF	IRC	CEA-15K	R-88-15K	2
R108	10kΩ, 10%, 1/4W, Comp	A-B	CB-103-10%	R-76-10K	1
R109	15kΩ, 1%, 1/8W, MtF	IRC	CEA-15K	R-88-15K	..
R110	80.6kΩ, 1%, 1/8W, MtF	IRC	CEA-80.6K	R-88-80.6K	..
R111	12.1kΩ, 1%, 1/8W, MtF	IRC	CEA-12.1K	R-88-12.1K	2
R112	49.9kΩ, 1%, 1/8W, MtF	IRC	CEA-49.9K	R-88-49.9K	3
R113	12kΩ, 10%, 1/4W, Comp	A-B	CB-123-10%	R-76-12K	3
R114	10kΩ, 1/4W, CbVar	MAL	MTC14L1	RP-59-10K	1
R115	49.9kΩ, 1%, 1/8W, MtF	IRC	CEA-49.9K	R-88-49.9K	..
R116	80.6kΩ, 1%, 1/8W, MtF	IRC	CEA-80.6K	R-88-80.6K	..
R117	60.4kΩ, 1%, 1/8W, MtF	IRC	CEA-60.4K	R-88-60.4K	2
R118	60.4kΩ, 1%, 1/8W, MtF	IRC	CEA-60.4K	R-88-60.4K	..
R119	1.2kΩ, 10%, 1/4W, Comp.	A-B	CB-122-10%	R-76-1.2K	2
R120	1.2kΩ, 10%, 1/4W, Comp.	A-B	CB-122-10%	R-76-1.2K	..
R121	49.9kΩ, 1%, 1/8W, MtF	IRC	CEA-49.9K	R-88-49.9K	..
R121	12.1kΩ, 1%, 1/8W, MtF	IRC	CEA-12.1K	R-88-12.1K	..
R123	18.2kΩ, 1%, 1/8W, MtF	IRC	CEA-18.2K	R-88-18.2K	1
R124	2.21kΩ, 1%, 1/8W, MtF	IRC	CEA-2.21K	R-88-2.21K	1
R125	10kΩ, 1%, 1/8W, MtF	IRC	CEA-10K	R-88-10K	2
R126	10kΩ, 1%, 1/8W, MtF	IRC	CEA-10K	R-88-10K	..
R127	2.8kΩ, 1%, 1/8W, MtF.	IRC	CEA-2.8K	R-88-2.8K	1
R128	470Ω, 10%, 1/4W, Comp	A-B	CB-471-10%	R-76-470	1
R129	56.2kΩ, 1%, 1/8W, MtF	IRC	CEA-56.2K	R-88-56.2K	1
R130	22kΩ, 10%, 1/4W, Comp	A-B	CB-223-10%	R-76-22K	1
R131	12kΩ*, 10%, 1/4W, Comp.	A-B	CB-123-10%	R-76-12K	..
R132	270Ω, 10%, 1/2W, Comp	A-B	EB-270	R-1-270	2
R133	270Ω, 10%, 1/2W, Comp	A-B	EB-270	R-1-270	..
R134	12kΩ, 10%, 1/4W, Comp	A-B	CB-123-10%	R-76-12K	..
R201	5.6kΩ, 10%, 1/4W, Comp.	A-B	CB-562-10%	R-76-5.6K	2
R202	2kΩ, 1/4W, CbVar.	MAL	MTC23L1	RP-59-2K	2
R203	4.7kΩ, 10%, 1/4W, Comp.	A-B	CB-472-10%	R-76-4.7K	2
R204	1kΩ, 10%, 1/4W, Comp.	A-B	CB-102-10%	R-76-1K	2
R205	Not Used.	.....	....	....	....
R206	15Ω, 10%, 1/4W, Comp.	A-B	CB-150-10%	R-76-15	2
R207	330Ω, 10%, 1/4W, Comp	A-B	CB-331-10%	R-76-330	3
R208	2.2kΩ, 10%, 1/4W, Comp.	A-B	CB-222-10%	R-76-2.2K	4
R209	2.2kΩ, 10%, 1/4W, Comp.	A-B	CB-222-10%	R-76-2.2K	..
R210	5.6kΩ, 10%, 1/4W, Comp.	A-B	CB-562-10%	R-76-5.6K	..
R211	2kΩ, 1/4W, CbVar.	MAL	MTC23L1	RP-59-2K	..
R212	4.7kΩ, 10%, 1/4W, Comp.	A-B	CB-472-10%	R-76-4.7K	..
R213	1kΩ, 10%, 1/4W, Comp.	A-B	CB-102-10%	R-76-1K	..
R214	15Ω, 10%, 1/4W, Comp.	A-B	CB-150-10%	R-76-15	..
R215	330Ω, 10%, 1/4W, Comp	A-B	CB-331-10%	R-76-330	..
R216	2.2kΩ, 10%, 1/4W, Comp.	A-B	CB-222-10%	R-76-2.2K	..
R217	2.2kΩ, 10%, 1/4W, Comp.	A-B	CB-222-10%	R-76-2.2K	..

TRANSISTORS

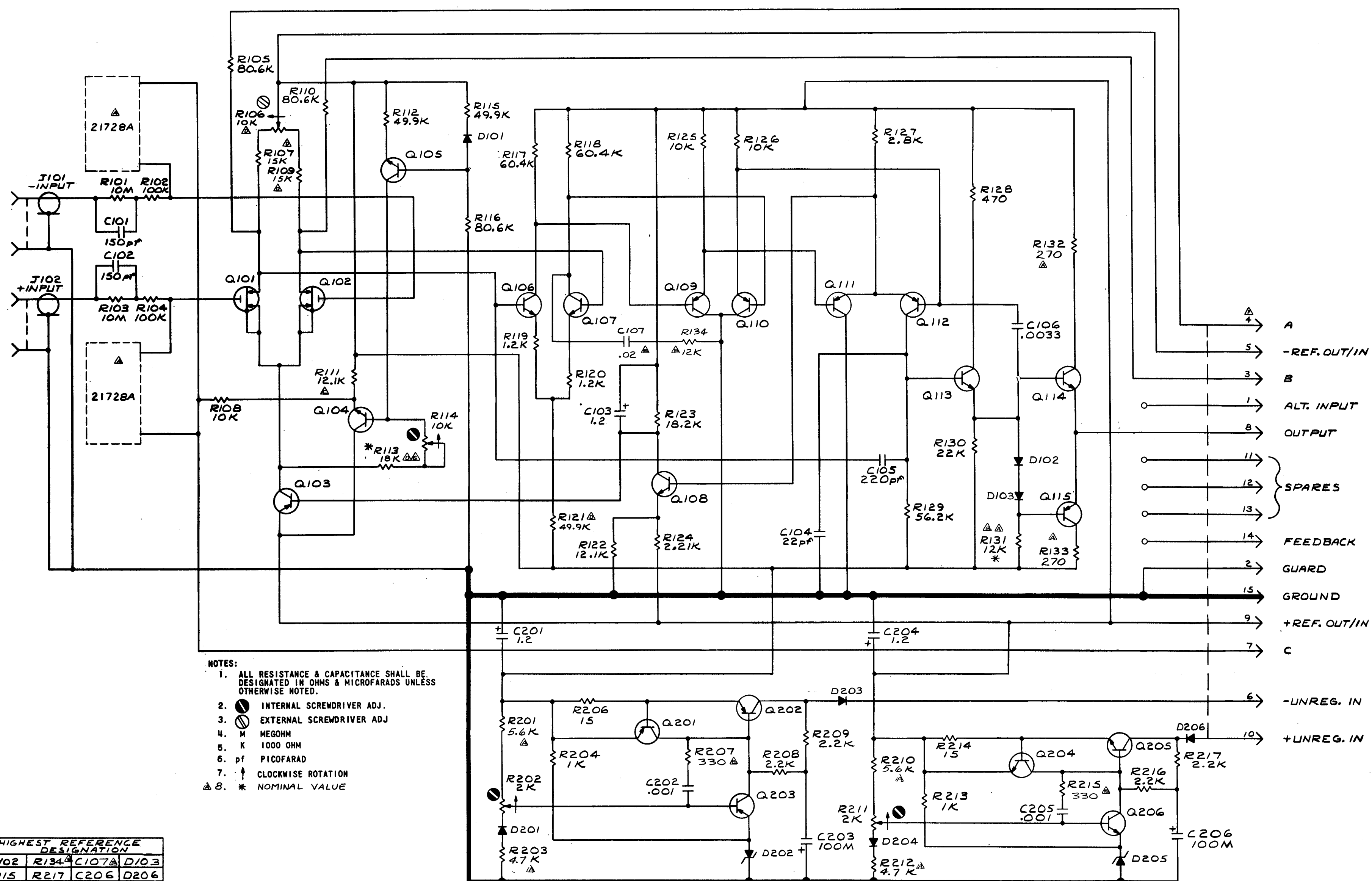
Circuit Desig.	Description	Mfr. Code	Mfr. Desig.	Keithley Part No.	Qty.
Q101	FET } Matched Pair	KI	....	22376A**	1
Q102	FET } Matched Pair	KI	....	22376A**	..
Q103	PNP, Case R-110	FAIR	S17638	TG-33	7
Q104	NPN, Case TO-106.	FAIR	2N3565	TG-39	9
Q105	NPN, Case TO-106.	FAIR	2N3565	TG-39	..
Q106	NPN, Case TO-106.	FAIR	2N3565	TG-39	..

TRANSISTORS (Cont'd.)

Circuit Desig.	Description	Mfr. Code	Mfr. Desig.	Keithley Part No.	Qty.
Q107	NPN, Case TO-106	FAIR	2N3565	TG-39	..
Q108	NPN, Case TO-106	FAIR	2N3565	TG-39	..
Q109	PNP, Case R-110	FAIR	S17638	TG-33	..
Q110	PNP, Case R-110	FAIR	S17638	TG-33	..
Q111	PNP, Case R-110	FAIR	S17638	TG-33	..
Q112	PNP, Case R-110	FAIR	S17638	TG-33	..
Q113	NPN, Case TO-106	FAIR	2N3565	TG-39	..
Q114	NPN, Case TO-106	MOT	2N3565	TG-39	..
Q115	PNP, Case TO-92	MOT	2N3905	TG-53	1
Q201	PNP, Case R-110	FAIR	S17638	TG-33	..
Q202	PNP, Case TO-5	RCA	40319	TG-50	1
Q203	PNP, Case R-110	FAIR	S17638	TG-33	..
Q204	NPN, Case TO-106	FAIR	2N3565	TG-39	..
Q205	NPN, Case TO-5	RCA	40317	TG-43	1
Q206	NPN, Case TO-106	FAIR	2N3565	TG-39	..

TABLE 10.
Code List of Suggested Manufacturers.
(Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)

ABREV.	NAME AND ADDRESS	ABREV.	NAME AND ADDRESS
A-B	Allen-Bradley Corp. Milwaukee, WI. 53204	FAIR	Fairchild Instrument Corp. Mountain View, CA. 94040
AMPNL	Amphenol Corp. Chicago, IL. 60153	IRC	IRC Division Burlington, IA. 52601
BOURN	Bourns, Inc. Riverside, CA. 92507	KI	Keithley Instruments, Inc. Cleveland, OH. 44139
BURN	Burndy Corp. Norwalk, CN. 06852	KEMET	Kemet Dept., Linde Division Cleveland, OH. 44107
CENLB	Centralab Division Milwaukee, WI. 53201	MAL	Mallory Capacitor Indianapolis, IN. 46206
COMPI	Components, Inc. Biddeford, ME. 04005	MOT	Motorola Semiconductor Products Inc. Phoenix, AZ. 85008
DICK	Dickson Electronics Corp. Scottsdale, AZ.. 85052	RCA	RCA Corporation Somerville, NJ. 08876
ERIE	Erie Technological Products, Inc. Erie, PA. 16512	TEXAS	Texas Instruments, Inc. Dallas, TX. 75231
		TEI	Transistor Electronics, Inc. Bennington, VT. 05201



NOTES:
1. ALL RESISTANCE & CAPACITANCE SHALL BE DESIGNATED IN OHMS & MICROFARADS UNLESS OTHERWISE NOTED.
2. INTERNAL SCREWDRIVER ADJ.
3. EXTERNAL SCREWDRIVER ADJ
4. M MEGOHM
5. K 1000 OHM
6. pf PICOFARAD
7. CLOCKWISE ROTATION
△8. * NOMINAL VALUE

HIGHEST REFERENCE DESIGNATION			
J102	R134△	C107△	D103
Q115	R217	C206	D206
Q206			

REFERENCE DESIGNATION NOT USED

REVISIONS			
LTR	ECO No.	APPR.	DATE
A	PCM 721		
B	PCM 722		
C	3430	WP	12-28-67
D	3475	WP	
E	3516		
F	3544	WP	7-11-68
G	3553	RGJ	7-18-68

KEITHLEY INSTRUMENTS CLEVELAND, OHIO

TITLE SCHEMATIC 301

301 — MODEL / NEXT ASSEMBLY / QUAN. — USED ON

PART NUMBER 21472E

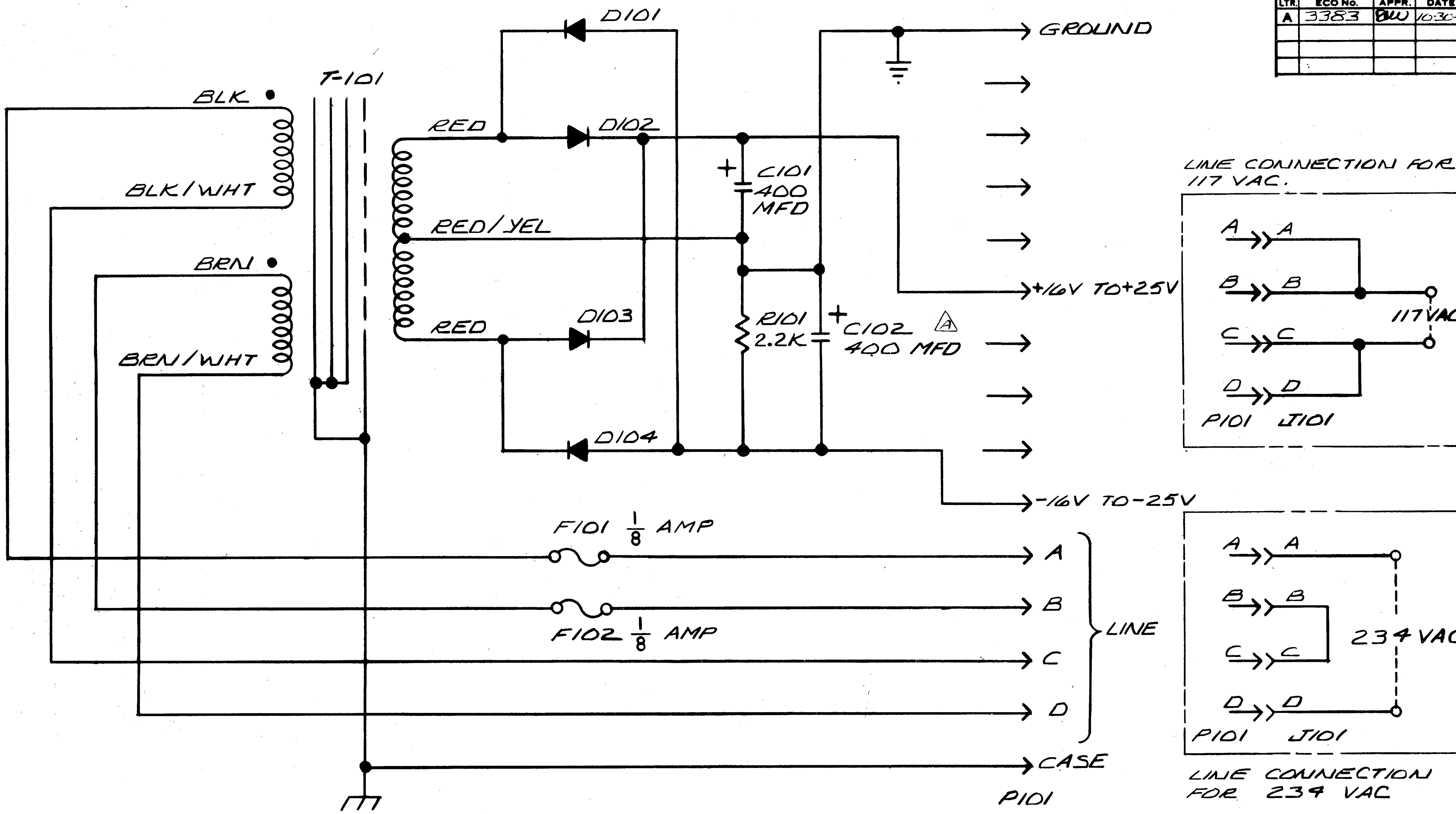
DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED: FRAC ± 1/64, DEC ± .005, ANG ± 1°

DO NOT SCALE

DRN WP DATE 7-6-67

TR-97 RF-38 C289-470

REVISIONS			
LTR.	ECO No.	APPR.	DATE
A	3383	BW	10-30-66



HIGHEST REF. DESIGNATION			REF. DESIGNATION NOT USED		
R101	C102	D104			
F102	J101	T101			
P101					

DIMENSIONAL TOLERANCES UNLESS OTHERWISE SPECIFIED		
FRAC.	DEC.	ANG.
± 1/64	± .005	± 1°
DO NOT SCALE		

DRN. GECHA	DATE 8-17-66
CKD. MM	DATE 9-14-66
ENG. APPR. MK	DATE 9-21-66
PILOT RELEASE MK	DATE 9-21-66
PROD. RELEASE MK	DATE 11/23/66

KEITHLEY INSTRUMENTS
CLEVELAND, OHIO

TITLE SCHEMATIC 3012

MATERIAL

FINISH

PART NUMBER 20351B

OGILVIE PRESS, INC., BROOKLYN 17 Y. ULTRAVEL NO. 4000 14000

KEITHLEY INSTRUMENTS, INC.

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