

# Model 600A

Electrometer  
Instruction Manual

Contains Operating and Servicing Information

**KEITHLEY**

# WARRANTY

Keithley Instruments, Inc. warrants this product to be free from defects in material and workmanship for a period of 1 year from date of shipment.

Keithley Instruments, Inc. warrants the following items for 90 days from the date of shipment: probes, cables, rechargeable batteries, diskettes, and documentation.

During the warranty period, we will, at our option, either repair or replace any product that proves to be defective.

To exercise this warranty, write or call your local Keithley representative, or contact Keithley headquarters in Cleveland, Ohio. You will be given prompt assistance and return instructions. Send the product, transportation prepaid, to the indicated service facility. Repairs will be made and the product returned, transportation prepaid. Repaired or replaced products are warranted for the balance of the original warranty period, or at least 90 days.

## LIMITATION OF WARRANTY

This warranty does not apply to defects resulting from product modification without Keithley's express written consent, or misuse of any product or part. This warranty also does not apply to fuses, software, non-rechargeable batteries, damage from battery leakage, or problems arising from normal wear or failure to follow instructions.

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# Safety Precautions

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The following safety precautions should be observed before using this product and any associated instrumentation. Although some instruments and accessories would normally be used with non-hazardous voltages, there are situations where hazardous conditions may be present.

This product is intended for use by qualified personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read the operating information carefully before using the product.

The types of product users are:

**Responsible body** is the individual or group responsible for the use and maintenance of equipment, for ensuring that the equipment is operated within its specifications and operating limits, and for ensuring that operators are adequately trained.

**Operators** use the product for its intended function. They must be trained in electrical safety procedures and proper use of the instrument. They must be protected from electric shock and contact with hazardous live circuits.

**Maintenance personnel** perform routine procedures on the product to keep it operating, for example, setting the line voltage or replacing consumable materials. Maintenance procedures are described in the manual. The procedures explicitly state if the operator may perform them. Otherwise, they should be performed only by service personnel.

**Service personnel** are trained to work on live circuits, and perform safe installations and repairs of products. Only properly trained service personnel may perform installation and service procedures.

Exercise extreme caution when a shock hazard is present. Lethal voltage may be present on cable connector jacks or test fixtures. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30V RMS, 42.4V peak, or 60VDC are present. **A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.**

Users of this product must be protected from electric shock at all times. The responsible body must ensure that users are prevented access and/or insulated from every connection point. In some cases, connections must be exposed to potential human contact. Product users in these circumstances must be trained to protect themselves from the risk of electric shock. If the circuit is capable of operating at or above 1000 volts, **no conductive part of the circuit may be exposed.**

As described in the International Electrotechnical Commission (IEC) Standard IEC 664, digital multimeter measuring circuits (e.g., Keithley Models 175A, 199, 2000, 2001, 2002, and 2010) are Installation Category II. All other instruments' signal terminals are Installation Category I and must not be connected to mains.

Do not connect switching cards directly to unlimited power circuits. They are intended to be used with impedance limited sources. NEVER connect switching cards directly to AC mains. When connecting sources to switching cards, install protective devices to limit fault current and voltage to the card.

Before operating an instrument, make sure the line cord is connected to a properly grounded power receptacle. Inspect the connecting cables, test leads, and jumpers for possible wear, cracks, or breaks before each use.

For maximum safety, do not touch the product, test cables, or any other instruments while power is applied to the circuit under test. ALWAYS remove power from the entire test system and discharge any capacitors before: connecting or disconnecting cables or jumpers, installing or removing switching cards, or making internal changes, such as installing or removing jumpers.

Do not touch any object that could provide a current path to the common side of the circuit under test or power line (earth) ground. Always make measurements with dry hands while standing on a dry, insulated surface capable of withstanding the voltage being measured.


The instrument and accessories must be used in accordance with its specifications and operating instructions or the safety of the equipment may be impaired.


Do not exceed the maximum signal levels of the instruments and accessories, as defined in the specifications and operating information, and as shown on the instrument or test fixture panels, or switching card.


When fuses are used in a product, replace with same type and rating for continued protection against fire hazard.

Chassis connections must only be used as shield connections for measuring circuits, NOT as safety earth ground connections.

If you are using a test fixture, keep the lid closed while power is applied to the device under test. Safe operation requires the use of a lid interlock.

If a  screw is present, connect it to safety earth ground using the wire recommended in the user documentation.

The  symbol on an instrument indicates that the user should refer to the operating instructions located in the manual.

The  symbol on an instrument shows that it can source or measure 1000 volts or more, including the combined effect of normal and common mode voltages. Use standard safety precautions to avoid personal contact with these voltages.

The **WARNING** heading in a manual explains dangers that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading in a manual explains hazards that could damage the instrument. Such damage may invalidate the warranty.

Instrumentation and accessories shall not be connected to humans.

Before performing any maintenance, disconnect the line cord and all test cables.

To maintain protection from electric shock and fire, replacement components in mains circuits, including the power transformer, test leads, and input jacks, must be purchased from Keithley Instruments. Standard fuses, with applicable national safety approvals, may be used if the rating and type are the same. Other components that are not safety related may be purchased from other suppliers as long as they are equivalent to the original component. (Note that selected parts should be purchased only through Keithley Instruments to maintain accuracy and functionality of the product.) If you are unsure about the applicability of a replacement component, call a Keithley Instruments office for information.

To clean an instrument, use a damp cloth or mild, water based cleaner. Clean the exterior of the instrument only. Do not apply cleaner directly to the instrument or allow liquids to enter or spill on the instrument. Products that consist of a circuit board with no case or chassis (e.g., data acquisition board for installation into a computer) should never require cleaning if handled according to instructions. If the board becomes contaminated and operation is affected, the board should be returned to the factory for proper cleaning/servicing.

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\*The yellow Change Notice sheet is included only if the instrument contains modifications which affect the instruction manual.



SECTION I - INTRODUCTION

The Keithley Model 600A Electrometer is an ultra-high impedance voltmeter with full-scale ranges of 0.01, 0.03, 0.10, 0.30, 1.0, 3.0 and 10 volts.

The maximum input resistance is greater than  $10^{14}$  ohms; in addition, the input resistance may be varied in decade steps from one ohm to  $10^{11}$  ohms by means of the shunt resistors built into the instrument. Thus, the 600A is not only appropriate for measurement in high-impedance circuits, but also can be used where a high input impedance would merely introduce unwanted pickup.

The 600A may be used as a direct-reading ammeter from 3 amperes to  $10^{-13}$  ampere full scale. This 14-decade range is covered in overlapping 3x and 10x scales. Two current measuring methods are available to the user of the 600A. Normally, current is determined by measuring the voltage drop across a resistor shunted from input to ground. Alternately, on the  $10^{-7}$  to  $10^{-13}$  ampere ranges, negative feedback can be applied to the input of the voltmeter through the current measuring resistor. This largely eliminates the input drop and increases measuring speed, particularly on the more sensitive ranges.

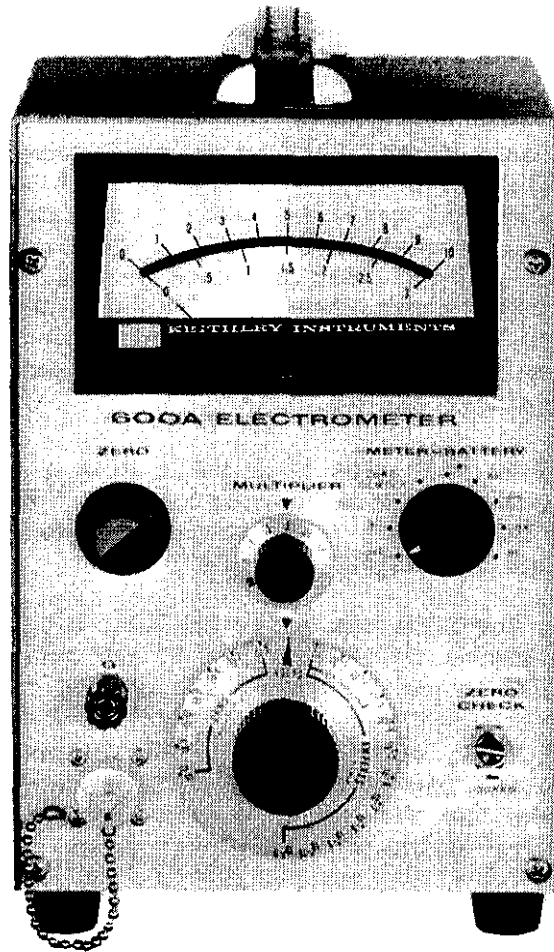
The 600A measures 10K to  $10^{12}$  ohms full scale with a two-terminal input. With a guarded input, its range is extended to  $10^{13}$  ohms. Unlike conventional ohmmeters, information is presented on the linear scales used for current and voltage readings.

As a dc preamplifier, the 600A has gains of 0.1, 0.3, 1, 3, 10, 30 and 100. The continuing stability of the gain is assured by a feedback factor in excess of 100 on any range.

The output is minus 1 volt, open circuit, with an internal resistance of 17K. Thus, the output may be used for driving oscilloscopes or pen recorder amplifiers, or the output may be shunted down to provide 10- or 50-mv outputs for servo-rebalance recorders.

## NOTE

When the Model 600A is shipped from the factory, an angle bracket (Keithley Part No. 13766A) supports the printed circuit board (PC-29). The bracket is fastened to the rear panel with a #6 x 5/16 sheet metal screw. The bracket and screw may be removed after the Model 600A is received. WHEN SHIPPING THE INSTRUMENT TO ANOTHER DESTINATION, REPLACE THE BRACKET TO FIRMLY SUPPORT THE PRINTED CIRCUIT BOARD.



KEITHLEY MODEL 600A ELECTROMETER



## SECTION II - SPECIFICATIONS

AS A VOLTMETER:

RANGE: 0.01 volt full scale to 10 volts in seven 1x and 3x ranges.

ACCURACY:  $\pm 2\%$  of full scale on all ranges exclusive of drift.

ZERO DRIFT: Less than 2 millivolts per hour after 1-hour warm-up.

INPUT IMPEDANCE: Greater than  $10^{14}$  ohms shunted by 30 picofarads. Input resistance may be selected in decade steps from 1 ohm to  $10^{11}$  ohms.

AS AN AMMETER:

RANGE:  $10^{-13}$  ampere full scale to 3 amperes in twenty-eight 1x and 3x ranges.

ACCURACY:  $\pm 3\%$  of full scale on 3-ampere to  $10^{-10}$  ampere ranges, using smallest available MULTIPLIER Switch setting;  $\pm 5\%$  of full scale on  $3 \times 10^{-11}$  to  $10^{-13}$  ampere ranges.

GRID CURRENT: Less than  $5 \times 10^{-14}$  ampere.

AS AN OHMMETER:

RANGE:  $10^4$  ohms full scale to  $10^{13}$  ohms in nineteen linear 1x and 3x ranges.

ACCURACY:  $\pm 3\%$  of full scale on  $10^4$  to  $10^{10}$  ohm ranges, using largest available MULTIPLIER Switch setting;  $\pm 5\%$  of full scale on  $3 \times 10^{10}$  to  $10^{13}$  ohm ranges.

AS AN AMPLIFIER:

GAIN: 0.1, 0.3, etc., to 100.

FREQUENCY RESPONSE (Within 3 db): dc to 100 cps at a gain of 100, rising to 1.5 kc at a gain of 0.1.

NOISE: Less than 3% peak-to-peak of full scale.

INPUT IMPEDANCE: Greater than  $10^{14}$  ohms shunted by 30 picofarads. Input resistance may be selected in decade steps from 1 ohm to  $10^{11}$  ohms.

OUTPUT:  $\pm 1$  volt for full-scale input. Internal resistance is 17 kilohms. Output polarity is opposite input polarity.

GENERAL:

POLARITY: METER Switch selects left-zero (positive or negative) or center-zero scales. Output polarity is not reversed.

CONNECTORS: Input: uhf type; ground binding post. Output: Amphenol 80-PC2F.

BATTERIES: Two 413 (30 volts), four E146 (8.4 volts), two RM42R (1.34 volts). 500 hours minimum battery life.

DIMENSIONS, WEIGHT: 10-1/4 inches high x 6-1/2 inches wide x 6-1/2 inches deep; net weight, 7-1/2 pounds.

ACCESSORIES SUPPLIED: Mating input and output connectors; binding post adapter.

## SECTION III - OPERATION

A. CONTROLS AND TERMINALS

Controls and Terminals: The input connector is a UHF type receptacle. An accessory binding post which plugs into the center of the connector is furnished. A ground binding post is mounted on the panel above the input connector.

## Front Panel Controls:

RANGE switch, located in the center of the front panel under the meter. This control selects VOLTS, OHMS, or AMPERES. On the AMPERES position, a shunt resistor whose value is the reciprocal of the designated range may be used to decrease the input resistance as well as to measure current.

MULTIPLIER switch, located in the center of the front panel directly under the meter, determines the voltage sensitivity of the dc amplifier, and sets the voltage range when the RANGE is set on VOLTS. On OHMS or AMPERES, the setting of this knob multiplied by the OHMS or AMPERES setting gives the full scale meter reading.

ZERO control, located at the left under the meter, is used to set the meter to zero.

METER-BATTERY switch, at the right under the meter, turns the instrument on, determines meter polarity or zero center operation, and tests the batteries.

ZERO CHECK switch, located at the bottom right, shorts the input terminal through one megohm, while the amplifier input is shorted.

## Rear Panel Controls:

OUTPUT connector for external recorders.

NORMAL-FAST. This control is locked in NORMAL position. In FAST position, current measurements are made with feedback around the shunt resistor. On OHMS, the FAST position is used when the INPUT GUARD terminal is used.

INPUT GUARD. With the NORMAL - FAST switch on FAST, the low impedance end of the test sample is returned to this terminal when it is desired to measure the resistance of a guarded sample.

COARSE ZERO. If the amplifier is quite badly unbalanced, the COARSE ZERO switch is used to bring the front panel ZERO control in range.

ZERO CENTER When meter cannot be centered with ZERO control it may be brought within range with this control.

**B. PREPARING THE INSTRUMENT FOR OPERATION**

(1) Set controls as follows:

MULTIPLIER: 10

RANGE SWITCH: VOLTS

ZERO CHECK SWITCH: Locked

INPUT TERMINAL: Shield with cap

(2) Turn the METER switch to meter +. The instrument should come to zero in approximately 5 seconds.

(3) Rotate the MULTIPLIER switch toward the high sensitivity end, adjusting ZERO as required. If it is impossible to zero the meter with the front panel ZERO control, use COARSE ZERO control on rear panel to bring the instrument within range of the ZERO control.

(4) Connect leads as required for measurement. If high impedance is involved, the input should be shielded using a coaxial connection or shielded enclosure. The various accessories for the Model 600A may be used.

If the impedance is low (below about  $10^{10}$  ohms) and leads can be kept short, the binding post adapter furnished with the instrument may be used.

The Keithley Model 6101A Shielded Test Lead will suffice for most measurements.

**C. MEASURING VOLTAGE**

Place RANGE switch at VOLTS. Turn MULTIPLIER switch to expected sensitivity and check meter zero. Release ZERO check, and read. If the sensitivity of the instrument is increased, recheck the zero reading.

**D. MEASURING CURRENT**

(1) NORMAL method (3 amperes to  $10^{-13}$  amperes full scale)

Turn RANGE switch to desired AMPERES range. Make sure the switch at the rear of the instrument is on the NORMAL position. Connect current source to the input. Full scale sensitivity is the product of the settings of the RANGE switch and MULTIPLIER. Check zero with the ZERO CHECK switch and then read the unknown current. The full scale voltage drop is the setting of the MULTIPLIER switch.

- (2) FAST method ( $10^{-7}$  to  $10^{-13}$  amperes full scale).

Proceed as above except with the FAST-NORMAL switch at FAST. The input drop is now negligible and the input circuit time constant is reduced at least 100 times. Observe the following cautions:

- (a) Use only the ZERO CHECK switch to check zero. Do not short the input.
- (b) The low side of the output is no longer at ground. Therefore, a recorder attached to the output must not be grounded to the Model 600A.
- (c) Do not use this method for the measurement of capacitor leakage.

#### E. MEASURING OHMS

- (1) NORMAL method (10K to  $10^{11}$  ohms full scale).

Turn RANGE switch to desired OHMS range. Make sure that NORMAL-FAST switch is in the NORMAL position.

Connect resistance sample to be measured only after ZERO CHECK switch has been locked. The test voltage at full scale is the setting of the MULTIPLIER switch. Before reading OHMS, turn RANGE switch to the approximate range of the unknown resistance. By manipulating the MULTIPLIER and the RANGE switch, the sample can be tested at a number of test potentials, if desired.

This two terminal method is the simplest and will work quite satisfactorily up to about  $10^{11}$  ohms. At resistances greater than  $10^{11}$  ohms, it is desirable to employ a GUARD connection both to speed up the response of the instrument and to nullify the error of leakage across the electrometer input insulation.

- (2) GUARDED method ( $10^{11}$  to  $10^{13}$  ohms full scale).

Proceed as with the two terminal method with the exception that the sample is connected between the INPUT terminal and the GUARD terminal on the rear panel. The FAST-NORMAL switch must be set at FAST.

- (3) EXTERNAL VOLTAGE method.

Any external voltage may be used. The unknown is connected between the test potential and the INPUT terminal of the electrometer. The current is then measured, using the NORMAL or FAST method, and the resistance calculated.

Proceed as follows:

- (a) Lock the ZERO CHECK Switch.
- (b) Connect unknown between INPUT terminal and source of potential. A switch should be connected in the high voltage line so that when the sample is disconnected from the potential, the low impedance end of the sample is grounded.
- (c) FAST-NORMAL switch should be at NORMAL.
- (d) Apply potential to sample before unlocking ZERO CHECK. Start the RANGE switch at low current sensitivities and advance the sensitivity until a reading is obtained.

If the potential applied is at least 100 times the ammeter drop (the setting of the MULTIPLIER switch), the resistance is equal to:

$$\frac{\text{POTENTIAL APPLIED}}{\text{CURRENT READING}}$$

If the potential applied is not large compared to the ammeter drop, the resistance is equal to:

$$\frac{\text{POTENTIAL APPLIED} - \text{INPUT DROP (VOLTS)}}{\text{CURRENT READING}}$$

- (e) If it is possible to operate on FAST micro-microammeter, the input drop need not be considered in the calculation.

#### F. BATTERY CHECK

Turn METER-BATTERY switch to B1, B2, etc. All batteries should read half scale or higher on the meter.

B1, B3, B4, and B5 are tested directly. B2a and B2b are tested in series on position B2. Since the battery drains are nearly identical in B2a and B2b, both should be changed when the series arrangement reads low.

B6 and B7 are not tested because they are operated under virtually shelf-life conditions. They may be replaced yearly as preventive maintenance or may be tested at any time by removing the case and measuring with a voltmeter. They should be replaced if they test less than eight volts.

### G. USING EXTERNAL INDICATORS

The output of the Model 600A may be used to drive servo rebalance recorders as well as high impedance devices such as oscilloscopes and pen drive amplifiers.

- (1) For use with servo rebalance recorders:

The output circuit consists of a 16.67K resistor through which 60 microamperes flow for full scale deflection of the panel meter. Shorting the output does not affect the meter reading of the Model 600A, but low impedances placed across the output terminals lower the terminal voltage for full scale deflection. Thus, if it is desired that the output voltage for full scale be 10 millivolts, a 168 ohm resistor should be connected across the output terminals. If a full scale of 50 millivolts is required, 878 ohms should be used.

- (2) For use with oscilloscopes and pen recorder amplifiers, the output is minus one volt for full scale meter deflection on any range.

The frequency response is dc to 100 cycles on the 10 millivolt range rising to 1 kc on the 10 volt range. The maximum amplitude which can be delivered by the amplifier is approximately 2 volts peak to peak.

### H. MISCELLANEOUS APPLICATIONS

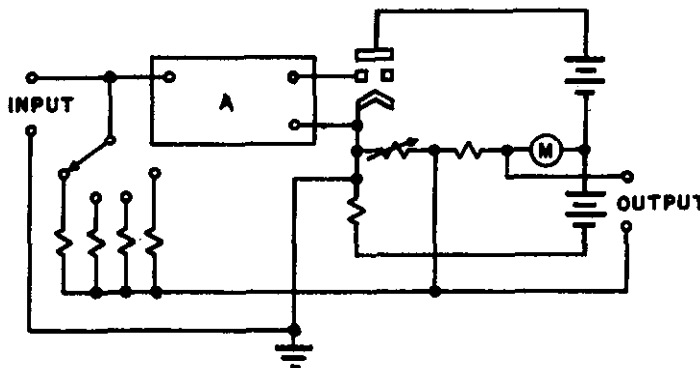


FIGURE 600-1

#### CURRENT INTEGRATOR:

The Model 600A may be used as an integrator for small currents such as cyclotron and mass spectrometer beam currents, since it is basically an operational amplifier with electrometer input when the FAST-NORMAL switch at the rear is placed in the FAST position.

To integrate current, connect a polystyrene capacitor of suitable value between the GUARD terminal and the input. The RANGE switch

is set at VOLTS so that there is no resistance placed across the capacity. Then if Fig. 600-1 is consulted, it can be seen that the standard resistor has been replaced by a capacitor and the 600A is now an integrator. The full scale charge on the capacitor in coulombs is simply the product of the capacitor value chosen (in farads) and the setting of the MULTIPLIER

switch (in volts). If it is desired that a time constant be introduced into the integrating circuit the appropriate shunt resistor may be selected by the function switch.

Practically, it is suggested that the capacitor be enclosed in a grounded can. The connection to the GUARD terminal may be made by a simple unshielded lead. The connection to the input terminal should be made by means of a coaxial connection to one side of a "tee" adapter. The current input is made to the other side of the "tee".

The following procedure is suggested: Depress the ZERO CHECK switch, thus removing the charge from the capacitor and shorting the input. Zero if necessary. Release the ZERO CHECK switch. If the integration is to take place over a long period of time it is suggested that the instrument be used on the one volt range or higher so that zero drift and grid current will not be factors.

CURRENT SOURCE: When measuring ohms, the instrument is designed to supply a constant current to any device placed across its input terminals. The magnitude of the current is equal to the reciprocal of the designation on the OHMS segment of the RANGE switch. Therefore the instrument may be used as a current source for calibration of other instruments if desired.

Depress ZERO CHECK and turn RANGE switch to OHMS. The current that is supplied on each range is the reciprocal of the OHMS setting, and is not affected by the setting of the MULTIPLIER switch. However, for the current to be accurate, the amplifier should be in balance. It will be sufficient to balance the amplifier on the .1 volt range of the MULTIPLIER Switch.

STATIC CHARGE MEASUREMENTS: The instrument is zeroed and the RANGE switch placed on VOLTS. The voltage sensitivity is perhaps placed at 3 or 10 volts full scale. The charged object is then brought near the uncovered, unshielded input connector of the 600A. Depending on the distance between the charge and the instrument a voltage will be induced on the input terminal and can be read on the panel meter. The instrument zero should be checked frequently since accumulation of charge due to the electrometer tube grid current will cause a slow drift of input voltage.

Connecting a capacitor across the input reduces the drift due to grid current and also the sensitivity to charge. An electrode connected to the INPUT terminal which increases the capacitance between the INPUT terminal and the charged object will increase the sensitivity to charges.

#### I. ZERO CENTER OPERATION

In some applications, such as null indication or in measuring voltages of either polarity near zero, it may be desirable to use the ZERO CENTER position on the METER-BATTERY switch. On this position, operation is just the same as for left-zero (normal), except that for zero input voltage or current, the meter pointer is at center scale.

The ZERO CENTER control on the rear panel is used to set the meter pointer to zero for zero center operation. It should require only infrequent attention.



SECTION IV - CIRCUIT DISCUSSION

The basic element of the Model 600A is a highly accurate, stable dc voltmeter with a full scale sensitivity of 10 millivolts and an input impedance greater than  $10^{14}$  ohms shunted by 30 micro-microfarads. Amperes and ohms are measured by the use of resistance standards. The various connections necessary for ampere and ohms measurements will be discussed following the detailed description of the amplifier.

A. VOLTMETER

Refer to DR12014C at the rear of the manual.

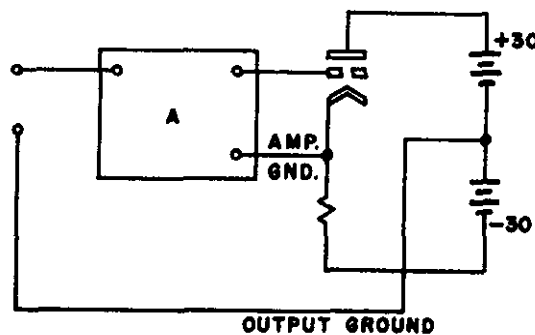


FIGURE 600-2

The amplifier proper consists of V1, V2, and V3. V4 is a cathode follower which drives the amplifier at the same instantaneous potential as the input signal. In other words the neutral or ground terminal of the amplifier is not grounded to the chassis but is attached to the output cathode follower. Fig. 600-2 shows this diagrammatically. The amplifier A is driven by the cathode follower.

Input dividers are neither stable nor accurate at high impedance. Consequently the Model 600A will accept 10 volts without the use of input dividers, preserving the high input impedance and accuracy of the amplifier. Accessory probes are available for extending the voltage range at reduced input resistance and accuracy.

Since the amplifier proper is driven by the cathode follower, the plus and minus 30 volt batteries for the cathode follower are referred to input ground while the battery supplies for the amplifier are referred to amplifier ground which is "floating". In subsequent discussion, reference will be made to the amplifier ground as "floating ground" and to cathode follower ground as "output ground".

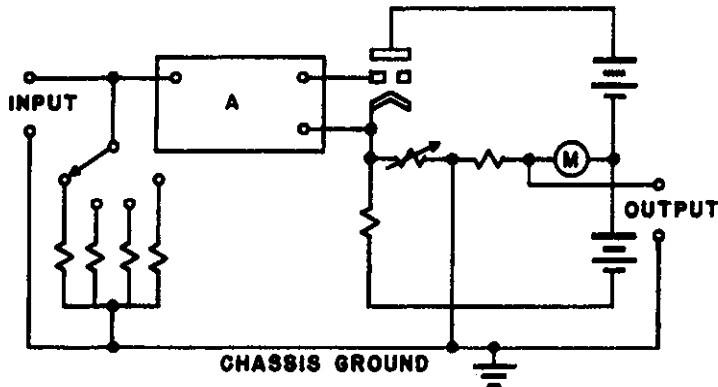
The amplifier input consists of two balanced 5886 electrometer tubes. The filaments are operated in parallel from battery B1. The control grid of V1, the active electrometer tube, is protected by R2, a  $10^9$  ohm resistor, bypassed for high frequencies by C2. The control grid of V2, the "dummy" tube, is returned through a variable voltage to floating ground. This variable supply is made up from B2a, B2b, R15 (ZERO on the front panel) and R11, R28, R29, R30, R31, R32 on SW-4 (COARSE ZERO on rear panel).

The ZERO controls function by adjusting the dc voltage of the dummy electrometer tube grid.

The voltmeter sensitivity is determined by the resistor placed in series with the meter, R33 through R39. Meter current passing through R42 develops the constant one volt output for any range.

C3 and R6 serve to stabilize the feedback loop against oscillation.

## B. AMMETER



Grid current of the input electrometer tube fixes the minimum current that may be measured. The Model 600A grid current will usually be less than  $2 \times 10^{-14}$  amperes. On low current ranges, the grid current will be apparent and may be balanced out with ZERO control or subtracted from the final reading.

FIGURE 600-3

### (1) Shunt Resistor Method (NORMAL)

In the normal operating connection as shown in Fig. 600-3, current is measured by placing a resistor across the input terminals and measuring the voltage drop. Currents from 3 amperes to  $10^{-13}$  amperes may be measured by this method since the range switch selects resistors ranging from one ohm to  $10^{11}$  ohms in decade steps. The voltage drop is selected by the MULTIPLIER switch; the setting is the input voltage drop for full-scale meter deflection.

### (2) Feedback Method (FAST)

In the voltmeter discussion above, floating ground has been driven by the cathode follower and output ground has been connected to the low impedance side of the input connector. In the FAST connection, shown in Fig. 600-1, the amplifier ground is connected to the low impedance side of the input; the cathode follower ground floats, and negative feedback is applied through the shunt resistor.

In the Model 600A, it is possible to use this connection with currents of 0.1 microamperes or less. To change the connection, remove the lock from NORMAL-FAST switch at the bottom of the rear panel and change it to the FAST position. The advantages of this connection are:

- (a) The effect of input capacity is largely neutralized, that is, the time constant of the input and cable capacity and the shunt resistor used will be decreased at least 100 times as

compared to the NORMAL connection, corresponding to a 100-fold increase in response speed.

(b) The input drop will be reduced about 100 times.

If Fig. 600-1 is again consulted, it will be seen that this connection converts the 600A into an operational amplifier with a resistor from the output to the input. Therefore, the following cautions apply:

(a) The input cannot be shorted since this will remove the feedback.

(b) The internal impedance of the current source being measured should not be less than about one-tenth of the value of the feedback resistor used for measurement.

(c) This connection should not be used for measuring the leakage current of capacitors since the connection of the capacitor to the input causes the circuit to be transformed into a differentiator with the resultant extreme sensitivity to very small voltage transients. For this measurement the NORMAL should be used.

(d) Do not attempt to use the FAST connection for currents exceeding 0.1 microamperes.

### C. OHMMETER

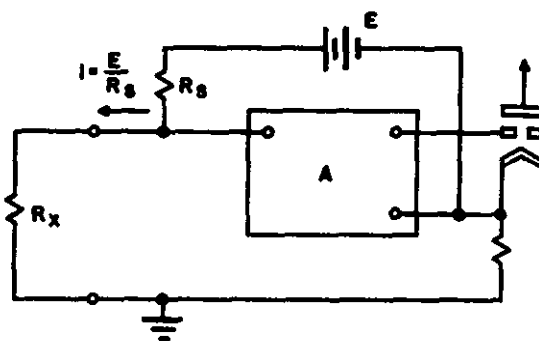


FIGURE 600-4

#### (1) Two Terminal Method

The Model 600A employs a linear scale to provide a megohmmeter of high accuracy. The linear ohms scale is achieved by supplying a constant current to the sample and measuring the voltage drop across it. The method is shown in Fig. 600-4.

#### (2) Ohms measurement using GUARD terminal:

There are two disadvantages with the method just outlined:

(a) When measuring resistances greater than  $10^{11}$  ohms, input capacity causes the meter reading to be annoyingly slow.

(b) If it is desired to use large voltages across the sample, this same voltage will appear across the input insulation of the electrometer and the input insulation will contribute error to the reading because of the current also flowing in it.

For these reasons a second connection for measuring ohms is provided.

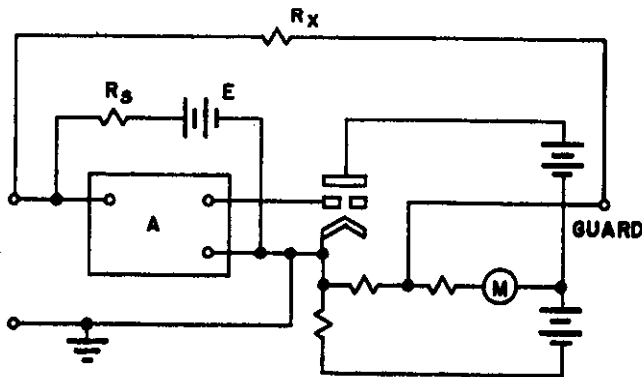


FIGURE 600-5

slowing effect of instrument input capacity. Also, since the potential across the input terminal is small, the leakage error is reduced.

### (3) Use of External Voltage Supply

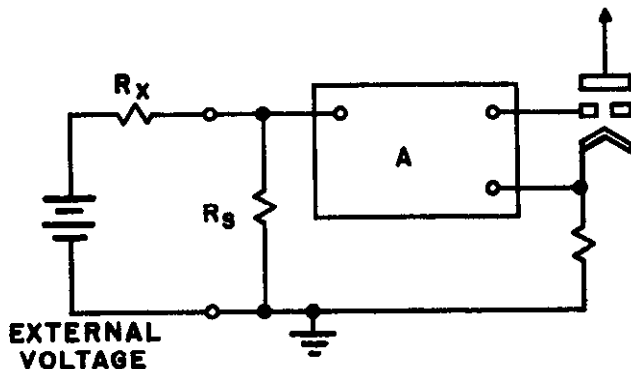


FIGURE 600-6

The switch at the rear of the instrument is moved from NORMAL to FAST and the resistance sample is connected to the GUARD terminal. Fig. 600-5 shows the arrangement. Now, as with measuring amperes with the FAST method, the amplifier ground is attached to the input ground and the cathode-follower ground is floating. The result is that feedback is applied through the unknown resistance to reduce the

With the constant current method of measuring resistance, the voltage across the unknown may not be arbitrarily selected, and the time of measuring capacitor leakage tends to be long, since constant-current charging is slower than the exponential charge available with an RC circuit.

Due to these facts, it may be desirable to use an external voltage supply and measure the leakage current on the AMPERES scale (NORMAL operation).

The unknown is connected between the input terminal of the electrometer and the source of voltage. This is shown in Fig. 600-6. If the applied voltage is large compared to the voltage drop across the electrometer (so that the voltage across the sample is substantially the applied voltage) the resistance is simply equal to the voltage applied divided by the current measured. If the voltage drop is an appreciable fraction of the applied voltage, the resistance equals the voltage applied minus the input

drop divided by the current measured. It will be rarely necessary to correct for the input drop of the electrometer due to the excellent voltage sensitivity of the Model 600A.

It is advisable to use the NORMAL micro-microammeter connection for the measurement of leakage resistance of capacitors in this manner, since instability is likely to occur using the FAST connection. However, in cases where the capacity shunted across the sample is small, it will be possible to realize a considerable increase in speed of response by utilizing the FAST connection.

Some precautions are recommended when testing capacitors. Be sure that capacitors have discharged before removing from test circuit. With the ZERO CHECK switch depressed, the input is shorted to ground through 1 megohm, providing a discharge path for the capacitor. The reading time may be shortened if the capacitor is allowed to charge through a low impedance position on the AMPERES switch before the appropriate measuring resistor is inserted in the circuit.

It should be further noted that capacitor measurement is likely to be a slow process in any case due to the fact that it may take considerable time for the molecular orientation of the dielectric to take place at the testing potential. It may take minutes or even hours in some cases to achieve a stable reading.

SECTION V - ACCESSORIES

## MODEL 6101A SHIELDED TEST LEAD:

The Model 6101A Lead consists of an input connector, 3 feet of low noise cable and a shielded probe head. Its purpose is to allow convenient connection to the electrometer input.

## MODEL 6102A - 10:1 VOLTAGE-DIVIDER PROBE:

The Model 6102A divider probe is intended for general purpose measurements where an extension of the upper voltage range of the 600A is desired. The division ratio is 10:1 correct to 1% and the probe input resistance is  $10^{10}$  ohms. The probe is supplied with a mating connector and 3 feet of cable.

## MODEL 6103A - 1000:1 VOLTAGE-DIVIDER PROBE:

The Model 6103A probe is intended for very high voltage measurements at high impedance. The division ratio is 1000:1 correct to 3% and the probe input resistance is  $10^{12}$  ohms. The probe is supplied with a mating connector and 3 feet of cable.

## MODEL 6104 TEST SHIELD:

The Model 6104 Test Shield is intended for use in making measurements wherein complete shielding of the component under test is required. External terminals are provided for either grounded tests, or a test requiring an external voltage source.

## SECTION VI - MAINTENANCE

No periodic maintenance is required other than checking the batteries as provided for by the front panel control. The method of performing these checks is outlined in Section III-E.

The calibration of the voltmeter is set by R41 located on the horizontal chassis carrying B1, B3, B4 and B5. This is set at the factory and should not require adjustment. If recalibration is performed, an accurate voltage source should be used.

A. Trouble Shooting

The circuit is completely described in Section IV. Study of that section will facilitate any trouble shooting.

The most usual trouble encountered is that on the most sensitive voltage range, with the input shorted, it is not possible to bring the meter pointer to zero. However before assuming that the instrument is at fault make sure that resetting the COARSE ZERO control at the rear of the instrument will not bring the instrument back into balance. If this does not work it will be necessary to remove the instrument cover to gain access to all circuitry. The instrument cover is removed by unscrewing the three screws on both sides of the instrument and lifting the cover upward. With the cover removed, follow this procedure:

Short floating ground to output ground to remove the negative feedback. This is most conveniently accomplished by shorting the two ends of the FAST-NORMAL switch on the rear panel. In this condition the instrument will become very sensitive and, in operating the zero control, the meter will be very difficult to hold on scale. However, the indication that the circuit is operating satisfactorily is that it is possible to swing the voltage through the correct operating point as indicated on the voltage-resistance diagram.

Now with the MULTIPLIER switch at .01 volts, proceed to check the operating points of the tube electrodes.

Regardless of the condition of the amplifier balance, the filament or cathode, and screen potentials should be reasonably close to the values on the circuit diagram. The plate and grid potentials will depend on the setting of the ZERO control. However if it is possible to swing the voltage through the correct value it may be assumed that the stage is working. Proceed in this manner until the point is found where the voltage cannot be swung through the value marked on the diagram. At this point it will be relatively easy to find the fault. First check the tube involved and then check the components.

## Miscellaneous troubles:

| <u>Trouble</u>            | <u>Cause</u>                | <u>Remedy</u>                      |
|---------------------------|-----------------------------|------------------------------------|
| Excessive grid current    | Defective electrometer tube | Replace V1 and V2 with matched set |
| Excessive drift           | Battery failing             | Replace battery                    |
| Excessive micro-phonics   | Defective electrometer tube | Replace V1 and V2 with matched set |
| Instrument does not zero. | See section above           | See section above                  |

The proper method of inserting electrometer tubes is shown in the voltage-resistance diagram. When inserting do not touch the glass base, where the leads emerge, with the fingers.



## SECTION 7. REPLACEABLE PARTS

7-1. REPLACEABLE PARTS LIST. The Replaceable Parts List describes the components of the Model 600A. The List gives the circuit designation, the part description, a suggested manufacturer, the manufacturer's part number and the Keithley Part Number. The name and address of the manufacturers listed in the "Mfg. Code" column are contained in Table 2.

## 7-2. HOW TO ORDER PARTS.

a. For parts orders, include the instrument's model and serial number, the Keithley Part Number, the circuit designation and a description of the part. All structural parts and those parts coded for Keithley manufacture (80164) must be ordered from Keithley Instruments, Inc. In ordering a part not listed in the Replaceable Parts List, completely describe the part, its function and its location.

b. Order parts through your nearest Keithley distributor or the Sales Service Department, Keithley Instruments, Inc.

| amp      | ampere                     | Mil No.  | Military Type Number |
|----------|----------------------------|----------|----------------------|
| CbVar    | Carbon Variable            | $\Omega$ | ohm                  |
| CerD     | Ceramic, Disc              |          |                      |
| Comp     | Composition                | p        | pico ( $10^{-12}$ )  |
| DCb      | Deposited Carbon           | $\mu$    | micro ( $10^{-6}$ )  |
| f        | farad                      | v        | volt                 |
| k        | kilo ( $10^3$ )            | Var      | Variable             |
| M or meg | mega ( $10^6$ ) or megohms | w        | watt                 |
| m        | milli ( $10^{-3}$ )        | WW       | Wirewound            |
| Mfg.     | Manufacturer               | WWVar    | Wirewound Variable   |

TABLE 1. Abbreviations and Symbols.

MODEL 600A REPLACEABLE PARTS LIST

(Refer to Schematic Diagram DR12014C for circuit designations.)

## BATTERIES

| Circuit Desig. | Description    | Mfg. Code | Mfg. Part No. | Keithley Part No. |
|----------------|----------------|-----------|---------------|-------------------|
| B1             | 1.34 v mercury | 37942     | RM42R         | BA-10             |
| B2a            | 8.4 v mercury  | 61637     | E146X         | BA-9              |
| B2b            | 8.4 v mercury  | 61637     | E146X         | BA-9              |
| B3             | 1.34 v mercury | 37942     | RM42R         | BA-10             |
| B4             | 30 v dry cell  | 61637     | 413           | BA-5              |
| B5             | 30 v dry cell  | 61637     | 413           | BA-5              |
| B6             | 8.4 v mercury  | 61637     | E146X         | BA-9              |
| B7             | 8.4 v mercury  | 61637     | E146X         | BA-9              |

## CAPACITORS

| Circuit Desig. | Value        | Rating | Type | Mfg. Code | Mfg. Part No. | Keithley Part No. |
|----------------|--------------|--------|------|-----------|---------------|-------------------|
| C101           | 100 pf       | 1000 v | CerD | 72982     | 831X5R101K    | C22-100P          |
| C102           | 100 pf       | 1000 v | CerD | 72982     | 831X5R101K    | C22-100P          |
| C103           | 0.02 $\mu$ f | 1000 v | CerD | 72982     | 841Z5V203P    | C22-.02M          |
| C104           | 0.02 $\mu$ f | 1000 v | CerD | 72982     | 841Z5V203P    | C22-.02M          |

## MISCELLANEOUS PARTS

| Circuit Desig. | Description   | Mfg. Code | Keithley Part No. |
|----------------|---|-----------|-------------------|
| J101           | Receptacle, uhf, Input, Mil. No. SO-239A (Mfg. No. 6804)                        | 91737     | CS-64             |
| ---            | Dust Cap for J101, n, Mil. No. MX-913/U (Mfg. No. 7901)                         | 91737     | CAP-4             |
| ---            | Plug, uhf, Mate for Input, Mil. No. 49190 (Mfg. No. 83-822)                     | 02660     | CS-49             |
| ---            | Reducing Adapter, uhf, for CS-64 and CS-49, Mil. No. UG-175/U (Mfg. No. 83-185) | 02660     | CS-36             |
| J102           | Binding Post, Black, G (Mfg. No. DF21BC)  | 58474     | BP-11B            |
| J103           | Receptacle, Microphone, Output (Mfg. No. 80-PC2F)                               | 02660     | CS-32             |
| ---            | Plug, Microphone, Mate for Output (Mfg. No. 80-MC2M)                            | 02660     | CS-33             |
| J104           | Binding Post, Red, INPUT GUARD (Mfg. No. DF21RC)                                | 58474     | BP-11R            |
| M101           | Meter   | 80164     | ME-16             |
| S101           | Rotary Switch less components, Range  | 80164     | SW-63             |
| ---            | Rotary Switch with components, Range  | 80164     | 12326B            |
| ---            | Knob Assembly, Range Switch   | 80164     | 15367A            |

## MISCELLANEOUS PARTS (Cont'd)

| Circuit<br>Desig. | Description                                  | Mfg.<br>Code | Keithley<br>Part No. |
|-------------------|--|--------------|----------------------|
| S102              | Push Button, ZERO CHECK                      | 80164        | 14376A               |
| S103              | Slide Switch, NORMAL-FAST (Mfg. No. G326)    | 79727        | SW-45                |
| S104              | Rotary Switch less components, COARSE ZERO   | 80164        | SW-51                |
| ---               | Rotary Switch with components, Coarse Zero   | 80164        | 12094B               |
| S105              | Rotary Switch less components, MULTIPLIER    | 80164        | SW-47                |
| ---               | Rotary Switch with components, Multiplier    | 80164        | 12093B               |
| ---               | Knob Assembly, Multiplier Switch             | 80164        | 15384A               |
| S106              | Rotary Switch less components, METER-BATTERY | 80164        | SW-62                |
| ---               | Rotary Switch with components, Meter-Battery | 80164        | 12092B               |
| ---               | Knob Assembly, Meter-Battery Switch          | 80164        | 14838A               |
| ---               | Knob Assembly, ZERO Control                  | 80164        | 15110A               |

## RESISTORS

| Circuit<br>Desig. | Value                     | Rating     | Type  | Mfg.<br>Code | Mfg.<br>Part No. | Keithley<br>Part No. |
|-------------------|---------------------------|------------|-------|--------------|------------------|----------------------|
| R101              | 1 M $\Omega$              | 10%, 1/2 w | Comp  | 01121        | EB               | R1-1M                |
| R102              | 10 <sup>9</sup> $\Omega$  | 20%, 1/2 w | Comp  | 75042        | BTS              | R37-10 <sup>9</sup>  |
| R103              | Not Used                  |            |       |              |                  |                      |
| R104              | Not Used                  |            |       |              |                  |                      |
| R105              | 10 M $\Omega$             | 1%, 1 w    | DCb   | 91637        | DC-1             | R13-10M              |
| R106              | *33 k $\Omega$            | 10%, 1/2 w | Comp  | 01121        | EB               | R1-33K               |
| R107              | 10 M $\Omega$             | 1%, 1 w    | DCb   | 91637        | DC-1             | R13-10M              |
| R108              | 312 k $\Omega$            | 1%, 1/2 w  | DCb   | 79727        | CFE-15           | R12-312K             |
| R109              | Not Used                  |            |       |              |                  |                      |
| R110              | 220 k $\Omega$            | 1%, 1/2 w  | DCb   | 79727        | CFE-15           | R12-220K             |
| R111              | 450 k $\Omega$            | 1%, 1/2 w  | DCb   | 79727        | CFE-15           | R12-450K             |
| R112              | 3.4 k $\Omega$            | 1%, 1 w    | DCb   | 91637        | DC-1             | R13-3.4K             |
| R113              | 9 k $\Omega$              | 1%, 1/2 w  | DCb   | 79727        | CFE-15           | R12-9K               |
| R114              | 1 k $\Omega$              | 1%, 1/2 w  | DCb   | 79727        | CFE-15           | R12-1K               |
| R115              | 10 k $\Omega$             | 3%, 5 w    | WWVar | 73138        | A                | RP4-10K              |
| R116              | 10 <sup>11</sup> $\Omega$ | 1%         | DCb   | 63060        | RX-1             | R20-10 <sup>11</sup> |
| R117              | 10 <sup>10</sup> $\Omega$ | 1%         | DCb   | 63060        | RX-1             | R20-10 <sup>10</sup> |
| R118              | 10 <sup>9</sup> $\Omega$  | 1%         | DCb   | 63060        | RX-1             | R20-10 <sup>9</sup>  |
| R119              | 100 M $\Omega$            | 1%, 2 w    | DCb   | 91637        | DC-2             | R14-100M             |
| R120              | 10 M $\Omega$             | 1%, 1 w    | DCb   | 91637        | DC-1             | R13-10M              |
| R121              | 1 M $\Omega$              | 1%, 1/2 w  | DCb   | 79727        | CFE-15           | R12-1M               |
| R122              | 100 k $\Omega$            | 1%, 1/2 w  | DCb   | 79727        | CFE-15           | R12-100K             |
| R123              | 10 k $\Omega$             | 1%, 1/2 w  | DCb   | 79727        | CFE-15           | R12-10K              |

\* Nominal value, factory set.

## RESISTORS (Cont'd)

| Circuit Desig. | Value            | Rating     | Type  | Mfg. Code | Mfg. Part No. | Keithley Part No. |
|----------------|------------------|------------|-------|-----------|---------------|-------------------|
| R124           | 1 k $\Omega$     | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-1K            |
| R125           | 100 $\Omega$     | 1%, 10 w   | WW    | 91637     | RSE-10        | R34-100           |
| R126           | 10 $\Omega$      | 1%, 10 w   | WW    | 91637     | RSE-10        | R34-10            |
| R127           | 1 $\Omega$       | 1%, 10 w   | WW    | 91637     | RSE-10        | R34-1             |
| (1)            | *20 $\Omega$     | .1%, 2 w   | WW    | 01686     | 7070          | R92-20            |
| R128           | 450 k $\Omega$   | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-450K          |
| R129           | 8.6 k $\Omega$   | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-8.6K          |
| R130           | 8.6 k $\Omega$   | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-8.6K          |
| R131           | 8.6 k $\Omega$   | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-8.6K          |
| R132           | 8.6 k $\Omega$   | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-8.6K          |
| R133           | 166.7 k $\Omega$ | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-166.7K        |
| R134           | 50 k $\Omega$    | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-50K           |
| R135           | 16.7 k $\Omega$  | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-16.7K         |
| R136           | 5 k $\Omega$     | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-5K            |
| R137           | 1.667 k $\Omega$ | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-1.667K        |
| R138           | 500 $\Omega$     | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-500           |
| R139           | 166.7 $\Omega$   | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-166.7         |
| (2)            | *10 k $\Omega$   | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-10K           |
| R140           | 9 k $\Omega$     | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-9K            |
| R141           | 10 k $\Omega$    | 10%, 2 w   | WWVar | 71450     | WP            | RP9-10K           |
| R142           | 16.67 k $\Omega$ | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-16.67K        |
| R143           | 47 k $\Omega$    | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-47K           |
| R144           | 600 k $\Omega$   | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-600K          |
| R145           | 47 k $\Omega$    | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-47K           |
| R146           | 1.14 M $\Omega$  | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-1.14M         |
| R147           | Not Used         |            |       |           |               |                   |
| R148           | 250 k $\Omega$   | 20%, 1/4 w | CbVar | 71450     | RQ11-130      | RP2-250K          |
| R149           | 900 k $\Omega$   | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-900K          |
| R150           | 1.14 M $\Omega$  | 1%, 1/2 w  | DCb   | 79727     | CFE-15        | R12-1.14M         |

## VACUUM TUBES

| Circuit Desig. | Number | Mfg. Code | Keithley Part No. |
|----------------|--------|-----------|-------------------|
| V101           | 5886   | 80164     | EV-5886-2         |
| V102           | 5886   | 80164     | EV-5886-2         |
| V103           | 6418   | 81453     | EV-6418           |
| V104           | 6418   | 81453     | EV-6418           |

\* Nominal value, factory set.

(1) If used, this resistor is in parallel with R127.

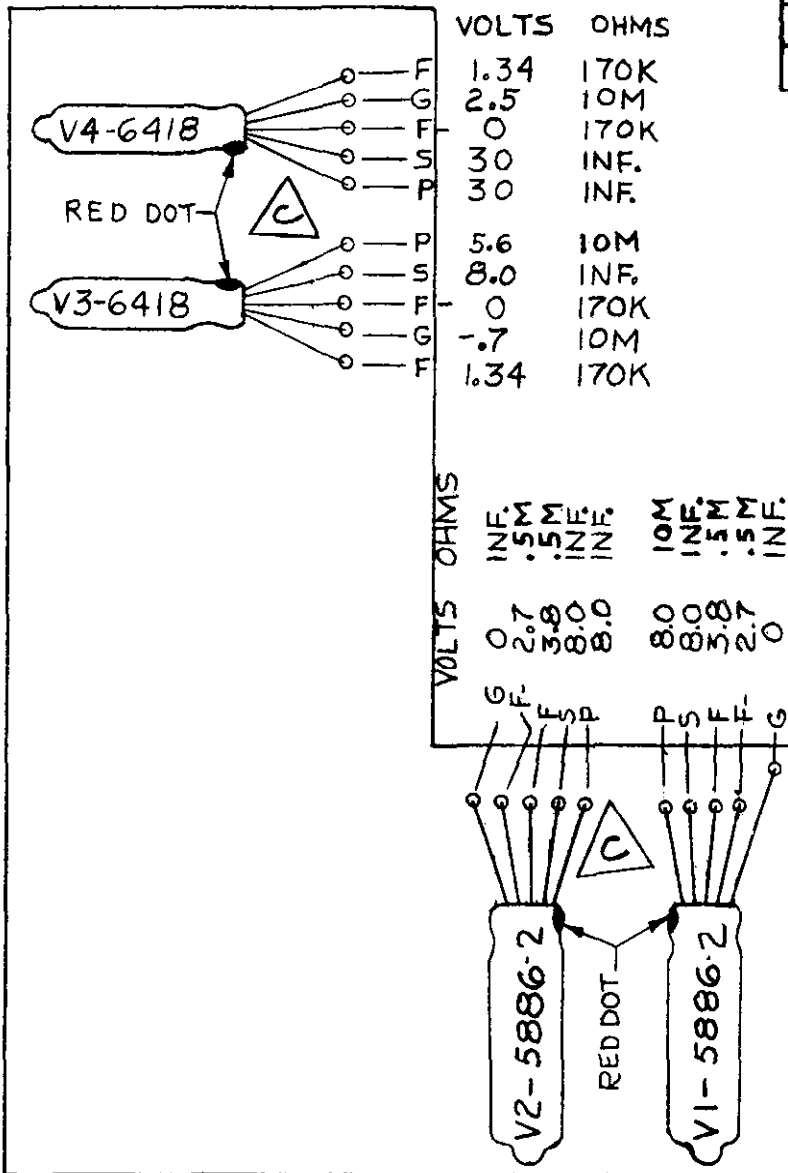
(2) If used, this resistor is in parallel with R139.

|       |   |       |  |
|-------|---|-------|--|
| 01121 | Allen-Bradley Corp.<br>Milwaukee, Wis.                          | 72982 | Erie Technological Products, Inc.<br>Erie, Pa.   |
| 02660 | Amphenol-Borg Electronics Corp.<br>Broadview, Chicago, Illinois | 75042 | International Resistance Co.<br>Philadelphia, Pa.  |
| 37942 | Mallory, P. R., and Co., Inc.<br>Indianapolis, Ind.             | 79727 | Continental-Wirt Electronics Corp.<br>Philadelphia, Pa.                                  |
| 44655 | Ohmite Mfg. Co.<br>Skokie, Ill.                                 | 80164 | Keithley Instruments, Inc.<br>Cleveland, Ohio  |
| 58474 | Superior Electric Co., The<br>Bristol, Conn.                    | 81453 | Raytheon Co.<br>Industrial Components Div.<br>Industrial Tube Operation<br>Newton, Mass. |
| 61637 | Union Carbide Corp.<br>New York, N. Y.                          | 91637 | Dale Electronics, Inc.<br>Columbus, Nebr.  |
| 63060 | Victoreen Instrument Co.<br>Cleveland, Ohio                     | 91737 | Greomar Mfg. Co., Inc.<br>Wakefield, Mass.   |
| 71450 | CTS Corp.<br>Elkhart, Ind.                                      |       |  |

TABLE 2. Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)

DR 12124 -A

|   |             |          |
|---|-------------|----------|
| A | ECO 1160 cm | 9-26-61  |
| B | ECO 1516 RR | 10-15-62 |
| C | ECO 1670    | 3-20-63  |



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 PROPERTY OF KEITHLEY INSTRUMENTS, INC.,  
 NOT TO BE USED OR REPRODUCED EXCEPT  
 AS AUTHORIZED BY THE COMPANY.

THE ABOVE VOLTAGE AND RESISTANCE READINGS  
 WERE TAKEN WITH CONTROLS SET AS FOLLOWS;

MULTIPLIER ON 10  
 METER SWITCH ON METER + FOR VOLTAGE MEASUREMENTS, OFF FOR OHMS MEASUREMENTS  
 RANGE SWITCH ON VOLTS  
 ZERO CHECK LOCKED  
 OUTPUT AT ZERO  
 FAST-NORMAL SWITCH IN  
 NORMAL POSITION

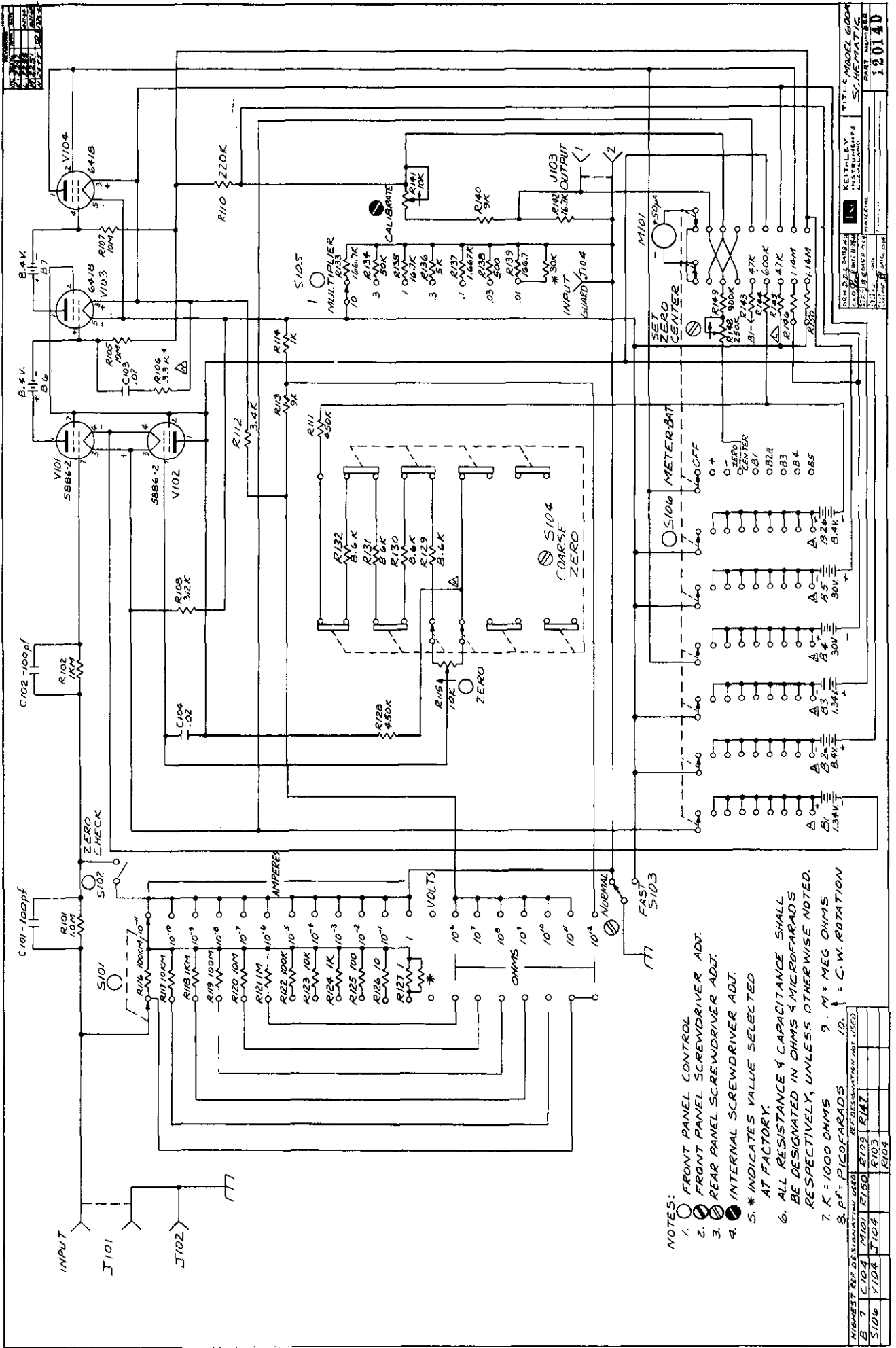
RESISTANCES ARE APPROXIMATE  
 READINGS TAKEN WITH VTVM  
 TO GROUND.

MODEL 600A ELECTROMETER  
 VOLTAGE - RESISTANCE DIAGRAM

KEITHLEY INSTRUMENTS

CLEVELAND, OHIO

|           |                  |           |                  |            |
|-----------|------------------|-----------|------------------|------------|
| DR<br>JAC | DATE<br>12-28-59 | CH<br>RMM | DATE<br>10-29-59 | DR12124 -A |
|-----------|------------------|-----------|------------------|------------|



- NOTES:
1. FRONT PANEL CONTROL SCREWDRIVER ADJ.
  2. FRONT PANEL SCREWDRIVER ADJ.
  3. REAR PANEL SCREWDRIVER ADJ.
  4. INTERNAL SCREWDRIVER ADJ.
  5. \* INDICATES VALUE SELECTED AT FACTORY.
  6. ALL RESISTANCE & CAPACITANCE SHALL BE DESIGNATED IN OHMS & MICROFARADS RESPECTIVELY, UNLESS OTHERWISE NOTED.
  7. K = 1000 OHMS
  8. PF = PICO FARADS
  9. M = MEG OHMS
  10. - C.W. ROTATION

| HIGHEST REF. DESIGNATION USED | REF. DESIGNATION NOT USED |
|-------------------------------|---------------------------|
| B 7                           | C104                      |
| S106                          | M101                      |
|                               | V104                      |
|                               | T104                      |
|                               | R103                      |
|                               | R104                      |

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