MODEL 610

MULTI-PURPOSE ELECTROMETER

AND ACCESSORIES

KEITHLEY INSTRUMENTS, INC.

CLEVELAND, OHIO

CONTENTS

SECTION I INTRODUCTION

The Keithley Model 610 Electrometer is an ultra-high impedance voltmeter with full-scale ranges of 0.01, 0.03, 0.10, 0.30, 1.0, 3.0, 10, 30, and 100 volts. Accuracy is within 2% of full scale on all ranges.

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 610 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 610 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. Accuracy is within 3% of full scale from 3 amperes to 10^{-8} ampere, and 4% of full scale from 3×10^{-9} to 10^{-13} ampere.

Two current measuring methods are available to the user of the 610. They are selected by a slide switch at the back of the instrument. Normally, current is determined by measuring the voltage drop across a resistor shunted from input to ground. Alternately, on the 10^{-4} 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 610 measures 0.2 ohm to 10^{11} ohms with a two-terminal input. With a guarded input, its range is extended to 10^{14} ohms. A 1000-volt external supply would further extend the range to 10^{16} ohms. Unlike conventional ohmmeters, information is presented on the same linear scales used for current and voltage readings. Accuracy is within 3% of full scale up to 3×10^{8} ohms, within 5% beyond.

As a dc preamplifier, the 610 has a maximum gain of 1000, obtainable in 9 steps of 01, 0.3, 1, 3, 10, 30, 100, 300, and 1000. Gain accuracy is within 1% on all gain steps. The continuing stability of the gain is assured by a feedback factor in excess of 100 on any range.

The output is either 10 volts for driving high impedance devices such as oscilloscopes or pen recorder amplifiers, or 1 ma for driving low impedance recorders or similar devices. A calibration potentiometer is provided with the 1 ma position for calibrating recorders. A slide switch next to the output connector permits selecting the desired output.

SECTION II SPECIFICATION AND DESCRIPTION

SPECIFICATIONS

Ranges:

(a) Voltage: 0.01, 0.03, 0.1, 0.3, 1, 3, 10, 30, and 100 volts full scale.
(b) Current: 3 amperes to 10^{-13} amperes full scale in 1x and 3x overlapping ranges.
(c) Ohms: 10 ohms to 10^{14} ohms full scale on linear 1x and 3x overlapping ranges.

Accuracy:

(a) Voltage: 2% of full scale on all ranges.
(b) Current: 3% of full scale from 3 amperes to 10^{-10} amperes. 4% of full scale from 3 x 10^{-10} to 10^{-13} amperes.
(c) Ohms: 3% of full scale from 10 ohms to 10^{10} ohms. 5% of full scale from 3 x 10^{10} ohms to 10^{14} ohms.

Resistance Standards:

1, 10, 100, 1000, 10^4, 10^5, 10^6, 10^7, 10^8 ohms, 1% accuracy; 10^9, 10^{10}, and 10^{11} ohms, 2% accuracy.
The 10^9 and 10^{10} ohm and 10^{11} resistors may be expected to change slightly in value with age.

Input Impedance:

On the VOLTS position the input impedance is greater than 10^{14} ohms resistive, shunted by approximately 30 micromicrofarads.

Drift:

Less than 2 millivolts per hour after a 30 minute warm-up.

Recorder Output:

1 milliampere or 10 volts for full scale meter deflection, selected by a rear panel switch.

Amplifier:

Frequency response is DC to 500 cycles on the most sensitive range, rising to 10kc on the least sensitive range. Maximum gain is 1000. Noise is less than 3% (peak to peak) of full scale.

Line Regulation:

A ten percent change in line voltage in the range of 100 to 130 or 200 to 260 volts will cause a change of less than 200 micro-volts equivalent input.

Tubes:

Two 5886, two EF86, one 6BH8, two 12AX7, one 12B4A, one OG3, one OA2, one OB2.

Cabinet:

$7\frac{1}{4}$ wide by 11-1/8 high by $13\frac{1}{4}$ deep. Weight 17 lbs.

Power Supply:

100 to 130 (or 200 to 260) volts, 50 to 60 cycles at approximately 50 watts.

DESCRIPTION

The Keithley Model 610 is a line operated multipurpose dc measureing instrument of extremely wide range. The measuring ranges are summarized below:

VOLTAGE: 10 millivolts to 100 volts full scale. The input impedance is greater than 10^{14} ohms shunted by approximately 30 micromicrofarads on the VOLTS position of the function switch. The input resistance may be varied from 10^{11} ohms to 1 ohm in decade steps by rotating the function switch in the AMPERES range marking.

HIGH VOLTAGE WITH ACCESSORIES: The Model 6102 10:1 divider probe extends the measuring range to 1000 volts. The divider resistance is 10^{10} ohms and its division accuracy is 1%.

The Model 6103 1000:1 divider probe extends the measuring range to 30 KV. Its input resistance is 10^{12} ohms and its division accuracy is 3%.

CURRENT: 3 amperes to 10^{-13} amperes full scale. From 3 amperes to 3 x 10^{-3} amperes the current is measured by measuring the drop across a resistor shunted across the input. From 10^{-4} to 10^{-13} amperes, the method above may be used or, by placing the FAST-NORMAL switch on the back panel in the FAST position, negative feedback is applied around the shunt resistor. This makes the input drop negligible and improves speed of response considerably on the low current ranges.

OHMS: 10 ohms to 10^{14} ohms full scale.

The linear ohms scale is achieved by measuring the unknown resistor with a known, constant current flowing through it. The voltage drop across the sample is then proportional to the resistance. Resistance from 10 ohms to 10^{11} ohms full scale is measured by a two terminal method. From 10^{11} to 10^{14} ohms, use of the GUARD terminal available at the rear of the instrument is recommended. An auxiliary 100 volt supply at the rear of the instrument is provided when measuring objects with appreciable capacitance or when it is desired to extend the measuring range. With the 100 volt potential, the leakage current is read on AMPERES and the resistance calculated.

DC AMPLIFIER: The frequency response of the Model 610 as an amplifier is from dc to 500 cycles on the 10 millivolt range rising to 10kc on the 100 volt range. The output is either 10 volts or 1 milliampere for full scale meter deflection. In the NORMAL micro-microammeter position, one side of the output is grounded; in the FAST micro-microammeter position the output is not grounded. For directions pertaining to the use of recorders see Section IV-G.

CONTROLS AND TERMINALS: The input connector is Amphenol 83-798. The mating connector is supplied as well as an accessory binding post which plugs into the center of the connector. A ground binding post is mounted on the panel above the input connector.

Front Panel controls are:

FUNCTION 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.

VOLT FULL SCALE switch, located at the left under the meter, determines the voltage sensitivity of the dc amplifier, and sets the voltage range when the FUNCTION is set on VOLTS. On OHMS or AMPERES, the setting of this knob multiplied by the OHMS or AMPERES setting gives the meter scale factor.

The ZERO control, located in the center of the front panel directly under the meter, is used to set the meter to zero.

The METER switch, at the right under the meter, turns the instrument on, determines meter polarity, and tests the potentials used in measuring ohms.

The OPERATE switch, located at the bottom right, selects normal operation or one of the two check positions.

In the ZERO CHECK position, the input terminals are shorted through 1 megohm, while the amplifier input is shorted. In the RES CHECK position, the internal high megohm resistance standards are measured.

Rear Panel controls are:

FUSE, at the upper right. With 117 volt AC power use 1.5 ampere fuse; with 230 volt power use 1 amp fuse.

POWER INPUT. Unless indicated, instrument is wired for 117 volts 50-60 cps. For 230 volt operation, consult the circuit schematic diagram.

SET 100V. Used to adjust the 100 volt internal test potential if meter indicates correction is needed.

SET 225V. Same as for Set 100V.

RECORDER CAL. Used to calibrate 1 ma. recorders, so their scale corresponds with the panel meter.

1 MA - 10V. In the 1 MA position, OUTPUT will drive 1 milliampere recorders. In the 10V position, the output is 10 volts for full scale panel meter deflection.

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.

100V. This test potential is used when it is desired to test leakage resistances with constant relatively high, potential applied across the unknown.

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

SECTION III CIRCUIT DISCUSSION

The basic element of the Model 610 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 amperes and ohms measurements will be discussed following the detailed description of the amplifier.

A. VOLTMETER

Refer to DR 11861 D at the rear of the manual.

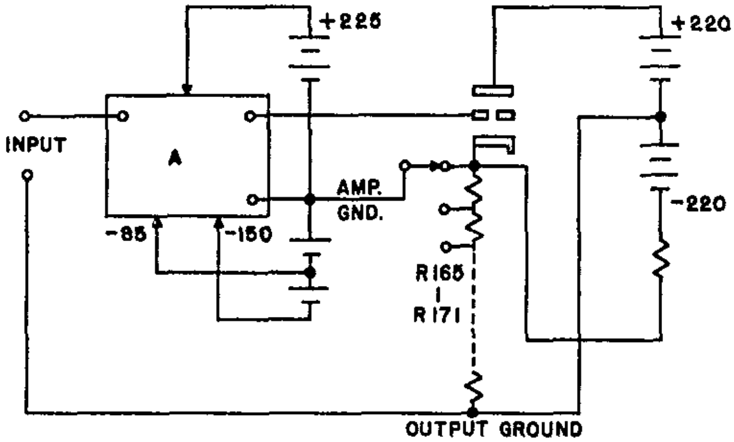


FIGURE 610-1

The amplifier proper consists of V1 through V5-A. V5-B 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 either directly or through divider R165 through R171 to the output cathode follower. Fig. 610-1 shows this diagramatically. The amplifier A is driven by the cathode follower. If it is desired to have unity gain, the amplifier is connected directly to the cathode. To increase the voltage gain, a fraction of the output voltage rather than all of it is fed back.

The purpose of this arrangement is to allow the input to accept relatively large input voltages without use of input dividers, which are neither stable nor accurate at high impedance. Consequently, the Model 610 will accept 100 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 220 volt supplies for the cathode follower are referred to input ground while the +225 volt and the -85 and -150 volt supplies for the amplifer 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 through a dropping resistor from the regulated B-plus supply. The control grid of V1, the active electrometer tube, is protected by R123, a one megohm resistor, bypassed for high frequencies by C101. The control grid of V2, the "dummy" tube, is returned to floating ground. The input switch, SW3, connects the grid of V1 to the input terminal on the OPERATE position and connects it to ground, through the 1 megohm protective resistor, on ZERO CHECK.

The screen grids of V1 and V2 are returned, in effect, to the cathodes of V3 and V4 through SW4 (COARSE BALANCE) and R180 (ZERO). The balance controls function by adjusting the dc voltages of the electrometer tube screens. Since the cathode of V3 and V4 are free to move, the result is that a negative feedback loop for signals in phase at the electrometer tubes exists through the cathode circuit of V3 and V4 back to the screens of V1 and V2. This connection stabilizes the plate potential of the input tubes, and causes the first stage gain to be much greater for signals arriving at the active tube control grid than spurious signals at both electrometer tubes, such as variation in the plate supply and changes in transconductance due to filament temperature changes. Also due to this stabilization, electrometer tube operating points are maintained even though 10 meg plate load resistors are used to assure a large voltage gain in this stage. This obviates the need for regulation of the filaments of subsequent stages.

V3 and V4 form an ordinary differential amplifier and their output is taken single ended into V5-A. V6-A drives the output cathode follower.

The voltmeter sensitivity is determined by the fraction of the cathode follower voltage fed back via the divider, R165 through R171. 10 volts appears at the V5-B cathode for full scale meter deflection for the ranges from 10 millivolts through 10 volts. On the 30 and 100 volt ranges, 30 and 100 volts respectively are fed directly back to floating ground. R161 is the meter multiplier resistor from 10 millivolts to 10 volts. On the 30 and 100 volt ranges, R162 and R163 are used.

The OUTPUT is derived directly from the 6BH8 cathode except on the 30 and 100 volt ranges, where R158 and R159 are interposed. If the output switch is set at 10 V, R158 and R159 form a divider with R177 to attenuate the output to 10 volts. If the output switch is set at 1 ma, these resistors in combination with R164 and R160 are used to provide enough series resistance so that 1 milliampere flows into the recorder terminals. R164 and R160 calibrate the recorder on all ranges.

The feedback loop is stabilized against oscillation by C102 and C103 together with R172 through R176. Insertion of R172 through R176 in the cathode of V5-A, or the omission of a resistor by the range switch, determines the loop gain. The gain is kept high enough so that there is a feedback factor of at least 100 on all ranges, but the gain is not allowed to become high enough to cause oscillation. C102 and C103 provide a 6 db per octave dominant lag cut-off characteristic.

B. <u>AMMETER</u>

Grid current of the input electrometer tube fixes the minimum current that may be measured. The Model 610 grid current will usually be less than 2×10^{-14} amperes. On low current ranges, the grid current will be apparent and may be balanced out with the ZERO control or subtracted from the final reading.

(1) Shunt Resistor Method (NORMAL)

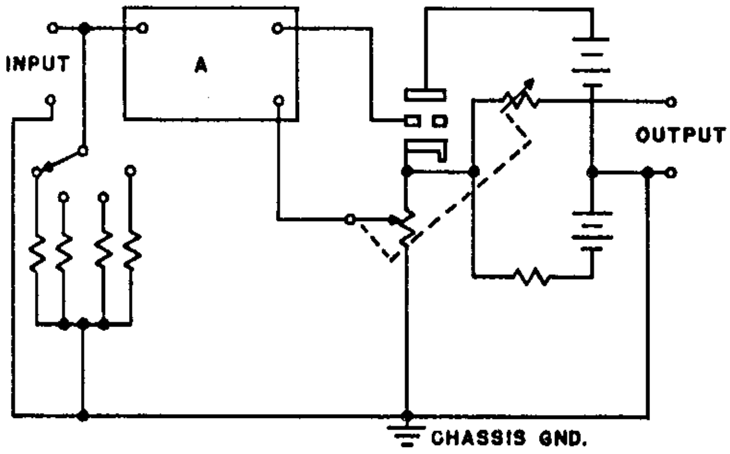


FIGURE 610-2A

In the normal operating connection as shown in Fig. 610-2A, 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 VOLTS switch; the setting is the input voltage drop for full-scale meter deflection.

(2) Feedback Method (FAST)

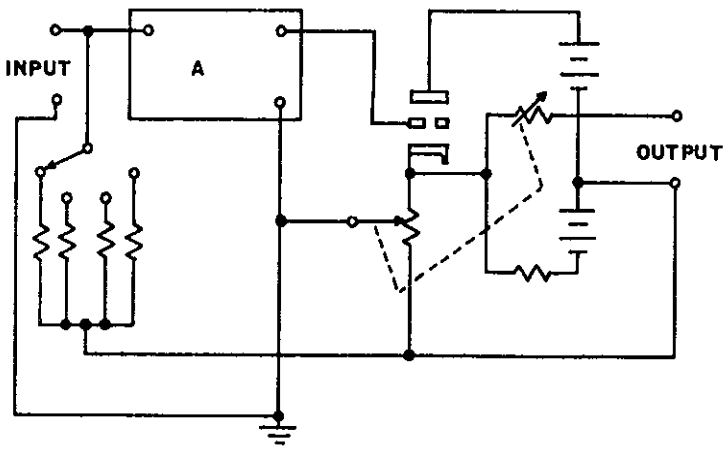


FIGURE 610-2B

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. 610-2B, 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 610, it is possible to use this connection with currents of 100 microamperes or less. To change the connection, remove the lock from the 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 at least 100 times.

If Fig. 610-2B is again consulted, it will be seen that this connection converts the 610 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 a 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 100 microamperes.

C. OHMMETER

(1) Two Terminal Method.

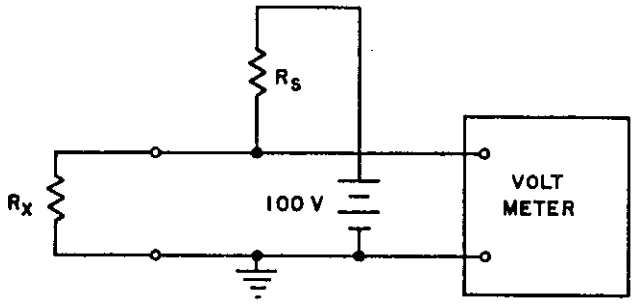


FIGURE 610-3

The Model 610 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. One method is shown in Fig. 610-3.

The constant current source can consist of a high voltage and a large resistor of known value. As long as the drop across the unknown resistor is of the order of 1% of the total voltage, the current can be considered constant. In the Model 610 on the 10^3 and 10^4 ranges, the current is supplied in this manner from a 100 volt supply with the appropriate dropping resistor as illustrated in Fig. 610-3. For example, with a current of one milliampere, the voltage drop across a one ohm resistor will be one millivolt. Thus this value can be read on the 10 millivolt range of the 610.

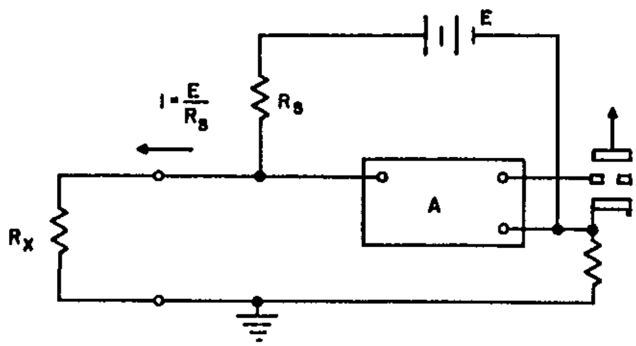


FIGURE 610-4

On the 10^5 range and higher, a second method is used to obtain a constant current. This is illustrated in Fig. 610-4. The ground connections are in the NORMAL position, that is, the amplifier ground is driven and the cathode-follower ground is attached to the input ground. The voltage source is only one volt. However, it is attached between floating ground and the grid of the voltmeter while, as before, the test sample is attached between input ground and the voltmeter grid. Since feedback to the amplifier ground keeps it at virtually the same potential as the input grid regardless of the input voltage, the voltage across the current source resistor cannot change.

Therefore this arrangement provides a true current source regardless of the input voltage. Thus, resistances may be measured using any voltmeter range on the 10^6 to 10^{12} ohmmeter ranges as opposed to the limit of 1 volt maximum on the 10^3 to 10^5 ohmmeter ranges.

(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.

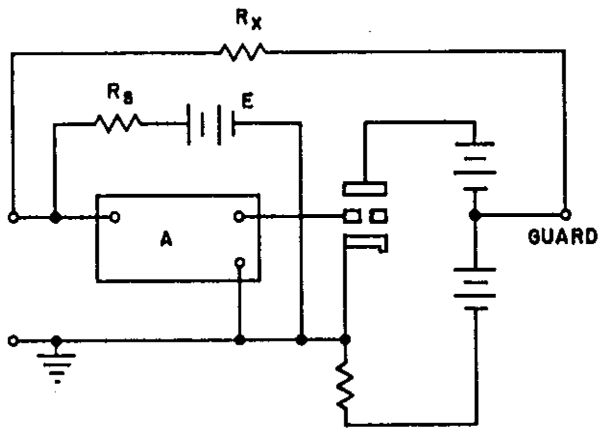


FIGURE 610-5

The switch at the rear of the instrument is moved from NORMAL to FAST and the low impedance end of the resistance sample is connected to the GUARD terminal. Fig. 610-5 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 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.

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).

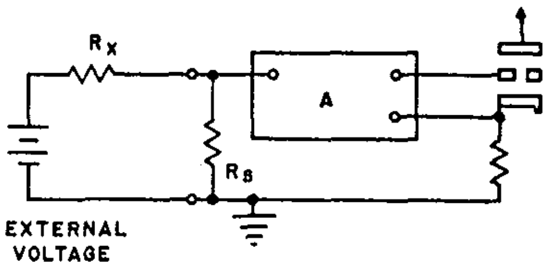


FIGURE 610-6

The unknown is connected between the input terminal of the electrometer and the source of voltage. This is shown in Fig. 610-6. 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 610.

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 610 input switch on ZERO CHECK, the input is shorted to ground through 1 megohm, providing a discharge path for the capacitor. Simultaneously the 100 volt test potential at the rear of the instrument is disconnected. The reading time may be shortened if the capacitor is allowed to charge through a low impedance position on the AMPERE 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.

D. STANDARD RESISTOR CHECK

The resistance standards used in the Model 610 have been described in the specification section. In general the resistors from 1 ohm to 10^8 ohms can be expected to retain a 1% accuracy throughout the life of the instrument. The high megohm resistors are correct to 2% when installed, and will usually be between 1% and 2% above the nominal value. Since they always decrease in value with time, they are likely to remain within specifications for three to six years after the instrument is delivered.

However, to determine the accuracy of these resistors, a resistance check position is provided on the input switch. Thus corrections can be made in the readings of small current and high resistance.

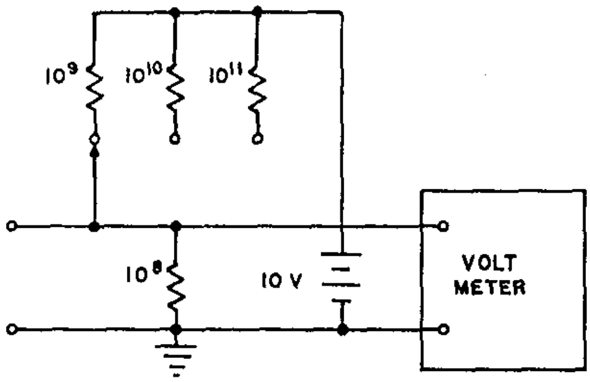


FIGURE 610-7

The method used in checking the resistors is outlined in Fig. 610-7. The ohmmeter is used in the standard manner except that the input switch is turned to RES CHECK. In this position a 1% 10^8 ohm resistor is placed across the input. In turn, 10^9, 10^{10} and 10^{11} ohm resistors are used to supply current through this resistor from 10 volts. Thus if the 10^{11} position on the OHMS segment of the function switch is used, the meter should read full scale on the .01 position of the OHMS-AMPS MULTIPLIER. Correspondingly, the reading is full scale on the 0.1 position for the 10^{10} ohm resistor and the 1.0 position for the 10^9 ohm resistor. If the reading is not correct, a correction factor can be applied to the ohms and amperes reading.

Due to the fact that the current through the resistor is the reciprocal of the resistance value, if the reading is low, the correction is subtracted on AMPERES and added on OHMS. If the reading is high, the opposite is done.

E. THE REGULATED POWER SUPPLIES

The negative regulator consists of cascaded voltage regulator tubes V11 and V10. This combination provides a well-regulated supply for the negative return of the second amplifier stage and reference for the positive supply. The maximum current supplied by this regulator combination is about 2.5 milliamperes so that the regulator tubes are able to operate satisfactorily over a 100 to 130 volt range of line voltage. V11, type OA2, supplies a minus 150 volt potential for the amplifier interstage dividers.

The positive 225 volt regulator is a three tube regular circuit consisting of V8, the series tube, and V6 and V7 which form the feedback amplifier. This circuit operates satisfactorily from 100 to 130 volts and is largely responsible for the extreme freedom from line transients which the Model 610 exhibits.

SECTION IV OPERATION

A. PREPARING THE INSTRUMENT FOR OPERATION

(1) Connect to power line of proper voltage and frequency. Due to the extreme sensitivity of the Model 610, the appearance of 60 cps noise at the output terminals is sometimes encountered. IF THIS NOISE IS FOUND TO BE HIGHER THAN 2% OF FULL SCALE, THE POWER PLUG MAY BE REVERSED TO REDUCE THE NOISE. It may also help to ground the case of the instrument to a water pipe or similar earth ground. Unless otherwise indicated at rear of instrument, the Model 610 is wired for 100 to 130 volts 50 to 60 cps. If it is desired to operate on 200 to 260 volts 50 to 60 cps, consult DR 11861 D at rear of the manual for instructions.

(2) Set controls as follows:

VOLTS SWITCH:	100 volts.
FUNCTION SWITCH:	VOLTS
OPERATE SWITCH:	ZERO CHECK
INPUT TERMINAL:	Shield with cap.

(3) Turn the Power switch to meter +. The instrument should come to zero in approximately 30 seconds.

(4) Rotate the VOLTS 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 BAL control on rear panel to bring the instrument within range of the ZERO control.

(5) 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 610 may be used.

If the impedance is low and leads can be kept short, the binding post adapter furnished with the instrument may be used.

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

B. MEASURING VOLTAGE

Place FUNCTION switch at VOLTS. Turn VOLTS switch to expected sensitivity and check meter zero. Turn OPERATE switch to OPERATE and read. If the sensitivity of the instrument is increased, recheck the zero reading.

For voltages greater than 100 volts, use the Model 6102-10:1 Divider Probe, or the Model 6103-1000:1 Divider Probe and measure as above.

C. MEASURING [illegible]

(1) NORMAL [illegible] [illegible]peres to 10^{-13} amperes full scale).

Turn FUNC[illegible] [illegible] desired AMPERES range. Make sure the switch at the re[illegible] [illegible] [illegible]rument is on the NORMAL position. Connect current s[illegible] [illegible]. The product of the reading on the FUNCTION switch an[illegible] [illegible]S MULTIPLIER gives the meter scale factor. Check zer[illegible] [illegible] [illegible]ERATE switch and then read unknown current. The volta[illegible] [illegible] [illegible] the instrument is the meter reading multiplied by [illegible] [illegible] the OHMS-AMPS MULTIPLIER.

(2) FAST [illegible] [illegible] to 10^{-13} amperes full scale).

Proceed as [illegible] [illegible]t move the FAST-NORMAL switch at the rear of the instr[illegible] [illegible] [illegible]AST position. The input drop is now negligible and [illegible] [illegible] response is increased approximately 100 times. However [illegible] [illegible] [illegible]lowing cautions:

(a) [illegible] [illegible] [illegible]put switch to check zero; DO NOT SHORT INPUT.

(b) [illegible] [illegible] [illegible] the output is no longer grounded.

Therefo[illegible] [illegible] [illegible]nstrument is being used with an output recorder t[illegible] [illegible]st not be grounded to the case of the 610.

(c) [illegible] [illegible] [illegible] position for the measurement of capacitor leaka[illegible].

D. MEASURING [illegible]

(1) NORMAL [illegible] [illegible] [illegible]hms to 10^{11} ohms full scale).

Turn functi[illegible] [illegible] desired OHMS range. Make sure that NORMAL-FAST switc[illegible] [illegible] [illegible]ORMAL position.

Connect re[illegible] [illegible]e to be measured only after OPERATE switch has been [illegible] [illegible] CHECK. Do not open-circuit instrument when on OHMS, [illegible] [illegible] [illegible] will develop a large voltage due to its constant [illegible] [illegible]eristic. However, if the sample is first connected [illegible] [illegible] [illegible]PERATE switch is turned to OPERATE the input volta[illegible] [illegible] [illegible] value read on the meter scale multiplied by the se[illegible] [illegible] [illegible]MS-AMPS MULTIPLIER.

Before re[illegible] [illegible] [illegible] FUNCTION switch to the approximate range of the un[illegible] [illegible]ce. By manipulating the OHMS-AMPS MULTIPLIER and the F[illegible] [illegible], the sample can be tested at a number of test pote[illegible] [illegible]sired.

The full-sc[illegible] [illegible] [illegible]ge is the FUNCTION switch setting multiplied by the se[illegible] [illegible] [illegible]MS-AMPS MULTIPLIER.

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^{14} 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, or the 100 VOLT terminal on the back panel.

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) Turn input switch to ZERO CHECK.

(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. If the 100 volt tap at the rear of the 610 is used, the potential is turned off when input switch is in either ZERO CHECK or RESISTANCE CHECK position.

(c) FAST-NORMAL switch should be at NORMAL.

(d) Apply potential to sample before switching to OPERATE. Start the function 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 meter reading times the setting of the VOLTS FULL SCALE 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:

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

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

E. INTERNAL RESISTOR CHECK

(1) To check 10^9: Turn input switch to ZERO CHECK, function switch to OHMS x 10^9. Turn VOLTS FULL SCALE to 1.0 or 3.0. Turn input switch to RES CHECK. If reading is exactly one volt, resistor is 1.00 x 10^9. If reading is low, subtract the percent correction when measuring AMPERES and add the percent correction when measuring OHMS.

(2) To check 10^{10}: Turn VOLTS FULL SCALE to .1 or .3. Reading should be .1 volt.

(3) To check 10^{11}: Turn VOLTS FULL SCALE to .01 or .03. Reading should be .01 volts.

F. INTERNAL VOLTAGE CHECK

The internal 225-volt and 100-volt supplies are used to test resistance samples and therefore should be checked periodically and always before the high megohm standards are checked. To check, turn meter switch to CHECK 225v. The meter should point to 2.25 on the 3.0 scale.

Then turn meter to 100v. The meter should read exactly full scale. If either potential is not correct, set with the appropriate control at the back of the instrument.

G. USING EXTERNAL INDICATORS

The output of the Model 610 will drive one milliampere recorders and servo rebalance recorders, as well as higher impedance instruments such as pen recorder amplifiers and oscilloscopes.

(1) For use with one milliampere instruments such as Esterline Angus, General Electric, and Texas Instrument Rectiriter: Connect to output connector at rear of instrument, pin 1 is the positive terminal. Place output switch at 1 MA position. Output is approximately 1 ma for full scale meter deflection on any range and can be made exactly 1.00 ma. Turn to a voltage range such as 100 millivolts full scale, where zero control has enough latitude, and adjust ZERO until panel meter reads full scale. Then adjust RECORDER CAL at the rear until the recorder also reads full scale. Next check the zero of the recorder and the panel meter and repeat full scale calibration. The meter polarity switch does not reverse the recorder output.

(2) For use with servo rebalance recorders: On the 1 MA position, there is enough latitude in the RECORDER CAL pot so that even if the recorder terminals are short circuited, exactly one milliampere can be made to flow at full scale deflection of the panel meter. Therefore for servo rebalance recorders, place a resistor across the output terminals equal to 1 ohm per millivolt of span and adjust RECORDER CAL to make sensitivity equal to full scale meter deflection. For example, with a 50 millivolt recorder place 50 ohms across output terminals before connecting recorder.

(3) For use with oscilloscopes and pen recorder amplifiers, set output switch at the 10v position. Output is now 10 volts for full scale meter deflection on any range.

The frequency response is dc to 500 cycles on the 10 millivolt range rising to 10 kc on the 10, 30 and 100 volt ranges. The maximum amplitude which can be delivered by the amplifier is approximately 10 volts peak to peak. Maximum permissible load across the output terminals in this mode of operation is one megohm. to limit output error to 1%

With the FAST-NORMAL switch at the rear of the instrument in the NORMAL position, the negative side of the output is grounded to the case of the instrument. However in the FAST position neither side is grounded. Therefore, no difficulty will be experienced using oscilloscopes and pen amplifiers with the 610 in NORMAL operation. However if it is desired to use the FAST position, care must be taken that there is no common ground between the pen writer or the oscilloscope and the Model 610 case.

H. MISCELLANEOUS APPLICATIONS

CURRENT INTEGRATOR: The Model 610 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 FUNCTION switch is set at VOLTS so that there is no resistance placed across the capacity. Then if Fig. 610-2B is consulted, it can be seen that the standard resistor has been replaced by a capacitor and the 610 is now an integrator. The charge on the capacitor in coulombs is simply the product of the capacitor value chosen (in farads) and the setting of the VOLTS FULL SCALE 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: Turn input switch to ZERO CHECK, thus removing the charge from the capacitor and shorting the input. Zero if necessary. Turn to OPERATE. 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 function switch. Therefore the instrument may be used as a current source for calibration of other instruments if desired.

Turn OPERATE switch to ZERO CHECK and FUNCTION 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 VOLTS FULL SCALE 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 VOLTS switch.

STATIC CHARGE MEASUREMENTS: The instrument is zeroed and the FUNCTION switch placed on VOLTS. The voltage sensitivity is perhaps placed at 10 or 30 volts full scale. The charged object is then brought near the uncovered, unshielded input connector of the 610. 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.

SECTION V ACCESSORIES

MODEL 6101 ACCESSORY PROBE:

The Model 6101 probe 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 6102 - 10:1 DIVIDER PROBE:

The Model 6102 divider probe is intended for general purpose measurements where an extension of the upper voltage range of the 610 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 6103 - 1000:1 DIVIDER PROBE:

The Model 6103 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 ADAPTER:

The Model 6104 Test Adapter 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 accuracy of the polarization potentials and the high megohm resistors as provided for by the front panel controls. There are no internal batteries. The method of performing these checks is outlined in Section IV part E and F.

The calibration of the voltmeter is set by R179 located on the vertical chassis carrying the majority of the tubes. 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 III. 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 BAL control at the rear of the instrument will not bring the instrument back into balance. If this does not work remove the instrument case and if necessary the bottom plate just below the input compartment to gain access to all circuitry. Follow this procedure:

(1) Check for presence of regulated B-plus voltage by switching the meter to TEST +225v. If this voltage is not correct consult section following on servicing regulated power supply.

(2) If correct voltage is present, check the plus and minus 220 volt supplies which supply the output cathode follower. The plus voltage is present on pin 3 of V5. The minus voltage may be obtained from the bottom of the 30k cathode resistor of V5-B. It is a 10 watt power resistor located on the metal chassis next to the rectifier stacks. If this voltage is not correct consult the schematic and trouble shoot the supply in the usual manner.

(3) If no defects are found so far, proceed by shorting 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 VOLTS 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 however 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.

Trouble shooting the regulated supplies:

(1) Check the minus supply first since the positive supply is referenced to the negative supply. If the dc voltages seem correct and the trouble persists, check for excessive ripple which would indicate a bad rectifier or filter capacitor.

(2) If the negative voltages are correct, then check the positive unregulated supply voltages in the same way.

(3) If the above voltages are correct, check the tubes and components of the regulator circuit (V-6, V-7, V-8) for defects.

Miscellaneous troubles:

Trouble	Cause	Remedy
Excessive grid current	Defective electrometer tube	Replace V1 and V2 with matched set
Excessive drift	Power supply not regulating	See section above
Excessive microphonics	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.

REPLACEABLE PARTS LIST - MODEL 610

Circuit Desig.	Description	Part No.
C101	Capacitor, ceramic disc, 100 mmf, 600 VDCW	C22-100
C102	Capacitor, ceramic disc, .01 mfd, 600 VDCW	C22-.01
C103	Same as C102	
C104	Same as C101	
C105	Same as C101	
C106	Capacitor, ceramic disk, 47 mmf, 600 VDCW	C22-47
C107	Same as C106	
C108	Capacitor, ceramic disc, .005 mfd, 600 VDCW	C22-.005
C301	Capacitor, tubular, electrolytic, 40 mfd, 350 VDCW	C23-40
C302	Same as C301	
C303	Capacitor, tubular, electrolytic, 20 mfd, 600 VDCW	C35-20
C304	Capacitor, tubular, electrolytic, 20 mfd, 450 VDCW	C8-20L
C305	Capacitor, ceramic disc, .02 mfd, 600 VDCW	C22-.02
C306	Same as C305	
C307	Same as C304	
C308	Same as C305	
C309	Same as C303	
C310	Capacitor, ceramic disc, 300 mmf, 600 VDCW	C22-330
C311	Capacitor, ceramic disc, .02 mfd, 600 VDCW	C22-.02
D1	Diode, Silcon, IN482, Transitron	RF 14
D2	Same as D1	
F1	Fuse, 1½A, 3AG (110v), Fuse, 1A, 3AG (220v)	FU 8-FU 7
M	Meter, panel, 0-200UA	ME 7
R101	Resistor, wirewound, 1 ohm, 1%, 10W	R34-1
R102	Resistor, wirewound, 10 ohm, 1%, 10W	R34-10

REPLACEABLE PARTS LIST - MODEL 610

Circuit Desig.	Description	Part No.
R103	Resistor, wirewound, 100 ohm, 1%, 10W	R34-100
R104	Resistor, deposited carbon, 1K, 1%, ½W	R12-1K
R105	Resistor, deposited carbon, 10K, 1%, ½W	R12-10K
R106	Resistor, deposited carbon, 100K, 1%, ½W	R12-100K
R107	Resistor, deposited carbon, 1M, 1%, ½W	R12-1M
R108	Resistor, deposited carbon, 10M, 1%, 1W	R13-10M
R109	Resistor, deposited carbon, 100M, 1%, 2W	R14-100M
R110	Resistor, hi-meg, 10^{9} ohm	R20-10^{9}
R111	Resistor, hi-meg, 10^{10} ohm	R20-10^{10}
R112	Resistor, hi-meg, 10^{11} ohm	R20-10^{11}
R115	Resistor, composition, 1M, 10%, ½W	R1-1M
R116	Same as R109	
R117	Same as R115	
R118	Resistor, deposited carbon, 1M, 1%, ½W	R12-1M
R119	Resistor, composition, 470 ohm, 5%, ½W	R19-470
R120	Same as R106	
R121	Potentiometer, wirewound, 15K	RP3-15K
R122	Resistor, composition, 47K, 5%, ½W	R19-47K
R123	Resistor, composition, 10M, 10%, ½W	R1-10M
R124	Resistor, deposited carbon, 100 ohm, 1%, ½W	R12-100
R125	Resistor, deposited carbon, 900 ohm, 1%, ½W	R12-900
R126	Resistor, deposited carbon, 9K, 1%, ½W	R12-9K
R127	Resistor, deposited carbon, 215K, 1%, 1W	R13-215K
R128	Resistor, wirewound, 135 ohm, 1%, ½W	R18-10-135
R129	Resistor, power, 12K, 3%, 25W	R30-12K

Circuit Desig.	Description	Part No.
R130	Resistor, deposited carbon, 33.3K, 1%, ½W	R12-33.3K
R131	Resistor, deposited carbon, 20K, 1%, ½W	R12-20K
R132	Resistor, deposited carbon, 5K, 1%, ½W	R12-5K
R133	Same as R132	
R134	Same as R132	
R135	Same as R132	
R136	Same as R132	
R137	Same as R132	
R138	Same as R131	
R139	Same as R104	
R140	Resistor, deposited carbon, 200 ohms, 1%, ½W	R12-200
R141	Same as R104	
R142	Same as R108	
R143	Same as R108	
R144	Resistor, composition, 100K, 5%, ½W	R19-100K
R145	Same as R144	
R146	Same as R106	
R147	Resistor, composition, 1M, 5%, ½W	R19-1M
R148	Resistor, deposited carbon, 1.5M, 1%, ½W	R12-1.5M
R149	Resistor, composition, 330K, 5%, ½W	R19-330K
R150	Resistor, composition, 1K, 5%, ½W	R19-150K
R151	Same as R122	
R152	Resistor, composition, 100K, 5%, 2W	R33-120K
R153	Resistor, composition, 390K, 5%, ½W	R19-390K
R154	Resistor, composition, 330K, 5%, ½W	R19-330K
R155	Resistor, wirewound, 30K, 10%, 10W	R5-30K

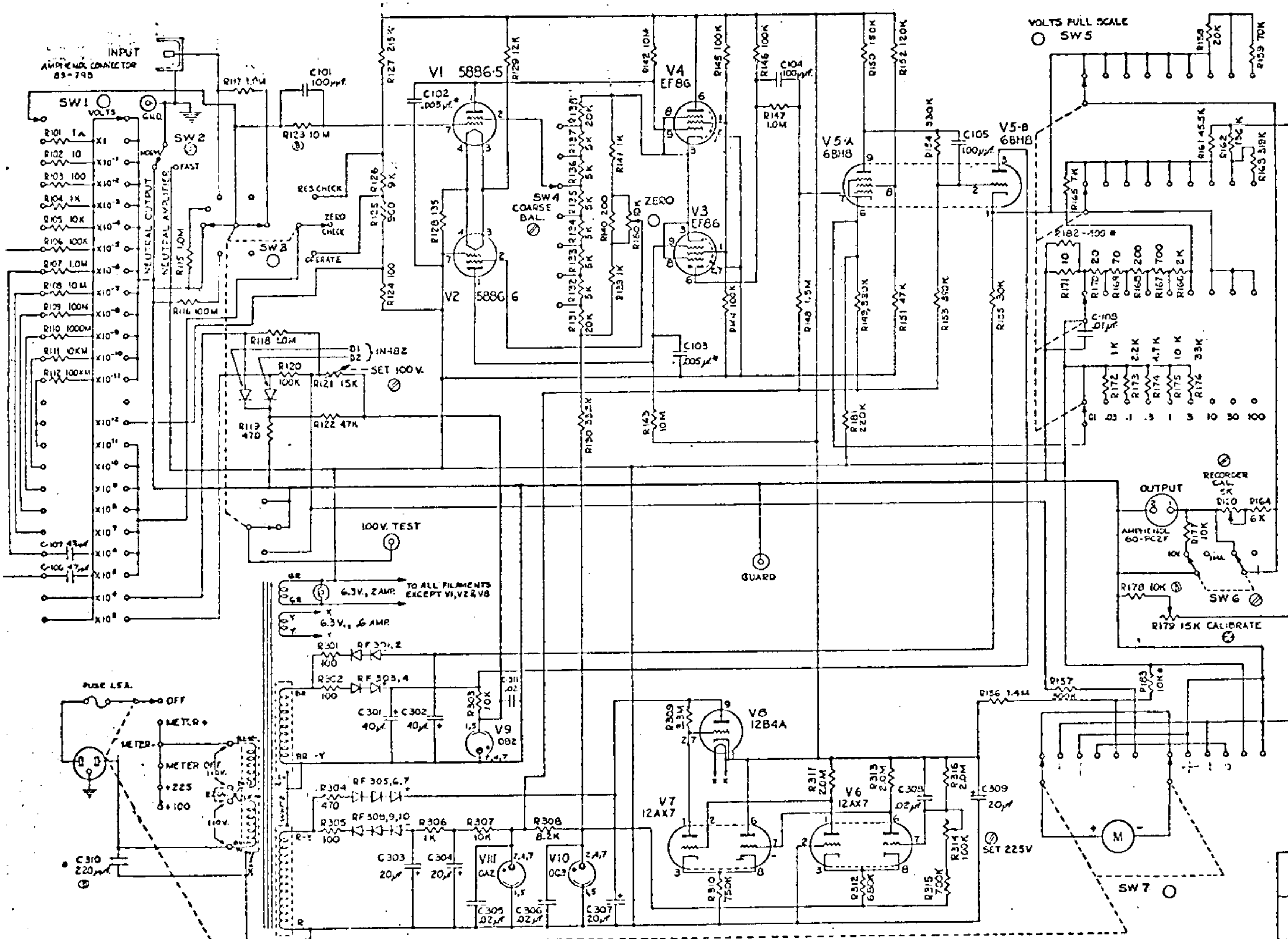
Circuit Desig.	Description	Part No.
R156	Resistor, deposited carbon, 1.4M, 1%, ½W	R12-1.4M
R157	Resistor, deposited carbon, 500K, 1%, ½W	R12-500K
R158	Same as R131	
R159	Resistor, deposited carbon, 70K, 1%, ½W	R12-70K
R160	Potentiometer, wirewound, 5K	RP3-5K
R161	Resistor, deposited carbon, 45.5K, 1%, ½W	R12-45.5K
R162	Resistor, deposited carbon, 133.6K, 1%, ½W	R12-133.6K
R163	Resistor, deposited carbon, 312K, 1%, ½W	R12-312K
R164	Resistor, deposited carbon, 6K, 1%, ½W	R12-6K
R165	Resistor, deposited carbon, 7K, 1%, ½W	R12-7K
R166	Resistor, deposited carbon, 2K, 1%, ½W	R12-2K
R167	Resistor, deposited carbon, 700 ohm, 1%, ½W	R12-700
R168	Same as R140	
R169	Resistor, deposited carbon, 70 ohm, 1%, ½W	R12-70
R170	Resistor, deposited carbon, 20 ohm, 1%, ½W	R12-20
R171	Resistor, deposited carbon, 10 ohm, 1%, ½W	R12-10
R172	Resistor, composition, 1K, 10%, ½W	R1-1K
R173	Resistor, composition, 2.2K, 10%, ½W	R1-2.2K
R174	Resistor, composition, 4.7K, 10%, ½W	R1-4.7K
R175	Resistor, composition, 10K, 10%, ½W	R1-10K
R176	Resistor, composition, 33K, 10%, ½W	R1-33K
R177	Same as R105	
R178	Same as R105	
R179	Same as R121	
R180	Potentiometer, 10K	RP4-10K
R181	Resistor, deposited carbon, 220K, 1%, ½W	R12-220K

REPLACEABLE PARTS LIST - MODEL 610

Circuit Desig.	Description	Part No.
R182	Resistor, deposited carbon, 400 ohm, 1%, ½W	R12-400
R183	Resistor, composition, 10K, 10%, ½W	R1-10K
R301	Resistor, composition, 100 ohm, 10%, ½W	R1-100
R302	Same as R301	
R303	Resistor, wirewound, 10K, 10%, 10W	R5-10K
R304	Resistor, composition, 470 ohm, 10%, ½W	R1-470
R305	Same a R301	
R306	Resistor, composition, 1K, 10K, 1W	R2-1K
R307	Resistor, wirewound, 10K, 10%, 10W	R5-10K
R308	Resistor, composition, 8.2K, 10%, 2W	R3-8.2K
R309	Resistor, composition, 3.3M, 5%, ½W	R19-3.3M
R310	Resistor, composition, 750K, 5%, ½W	R19-750K
R311	Resistor, deposited carbon, 2M, 1%, ½W	R12-2M
R312	Resistor, deposited carbon, 680K, 1%, ½W	R12-680K
R313	Same as R311	
R314	Potentiometer, carbon, 100K, 3W	RP15-100K
R315	Resistor, deposited carbon, 700K, 1%, ½W	R12-700K
R316	Same as R311	
RF301, 2	Rectifier, selenium, 130V, 65Ma	RF8
RF303, 4	Same as RF 301, 2	
RF305, 6, 7	Same as RF 301, 2	
RF308, 9, 10	Same as RF 301, 2	
SW 1	Range switch 24 position	
SW 2	Slide switch, DPDT	SW 45
SW 3	Operate switch, 3 position	

REPLACEABLE PARTS LIST - MODEL 610

Circuit Desig.	Description	Part No.
SW 4	Coarse-balance switch, 7 position	
SW 5	Volt switch, 9 position	
SW 6	Same as SW 2	
SW 7	Meter switch, 6 position	
	Power transformer, Central Transformer Co., K1-127	TR 123
	Pilot Lamp 6.3 v, 0.15 amp miniature bayonet base G. E. type #47	PL-4
V1	Vacuum tube, type 5886	EV 5886-5
V2	Vacuum tube, type 5886	EV 5886-6
V3	Vacuum tube, type EF86	EV EF86
V4	Same as V3	
V5	Same as V3, type 6BH8	EV 6BH8
V6	Same as V3, type 12AX7	EV 12AX7
V7	Same as V6	
V8	Vacuum tube, type 12B4A	EV 12B4A
V9	Vacuum tube, type OB2	EV OB2
V10	Vacuum tube, type OG3	EV OG3
V11	Vacuum tube, type OA2	EV OA2



CHANGES		DATE
A	[illegible]	[illegible]
B	[illegible]	[illegible]
C	[illegible]	[illegible]

LEGEND

○ PANEL CONTROL

⊙ REAR PANEL ADJUSTMENT

⊘ INTERNAL ADJUSTMENT

NOTE: RESISTORS IN OHMS
K = 1000 OHMS
M = MEGOHMS

* NOMINAL VALUE

MODEL 610 ELECTROMETER
SCHEMATIC DIAGRAM

KEITHLEY INSTRUMENTS
CLEVELAND OHIO

DR.	DATE	CH.	DATE		
RLC	4-8-59			DR 11861	D

MODEL 610
VOLTAGE AND RESISTANCE CHART

DR 11968 - C

MEASUREMENTS MADE FROM TUBE PIN TO CHASSIS GROUND WITH CONTROLS SET AS FOLLOWS; "OPERATE" SW. - ZERO CHECK POSITION
VOLTS FULL SCALE SW. - .01 POSITION
METER SW. - +POSITION

READINGS TAKEN WITH 11 MEGOHM INPUT RESISTANCE VTVM.
ALL READINGS ARE APPROXIMATE. RESISTANCES ARE GIVEN IN OHMS.
K=1000, M=MEGOHMS.