INSTRUCTION MANUAL

MODEL 621, 621R

MULTI-PURPOSE ELECTROMETER
AND ACCESSORIES

CONTENTS

The Keithley Model 621 Electrometer is an ultra-high impedance voltmeter with full-scale ranges of 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 10^{6} ohm to 10^{10} ohms by means of the shunt resistors built into the instrument. Thus, the 621 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 621 may be used as a direct-reading ammeter from 10^{-4} to 10^{-11} ampere full scale. This seven decade range is covered in overlapping 3 x and 10 x scales. Accuracy is within 3% of full scale from 10^{-4} to 10^{-9} ampere, and 4% of full scale from 3×10^{-9} to 10^{-11} ampere.

Two current measuring methods are available to the user of the 621. 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, 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 621 measures 10^{5} to 10^{12} ohms with a two-terminal input. A 1000-volt external supply would further extend the range to 10^{14} 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^{10} ohms, within 5% beyond.

As a dc preamplifier, the 621 has gains of 0.1, 0.3, 1, 3, 10, 30, and 100. Gain accuracy is within 1% on all gain steps. The continuing stability of the gain is assured by a large feedback factor on all ranges.

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.

MODEL 621R: Although this manual specifically describes the 621, the instructions also apply to the Model 621R Electrometer. The principal difference between the two models is the 621R is designed for rack mounting. (See Figure 1) Both models have the same performance specifications, operating and maintenance procedures, circuit and components. Besides the cabinet dimensions, the models differ in the placement of two switches (see section II) and the layout of components within the chassis.

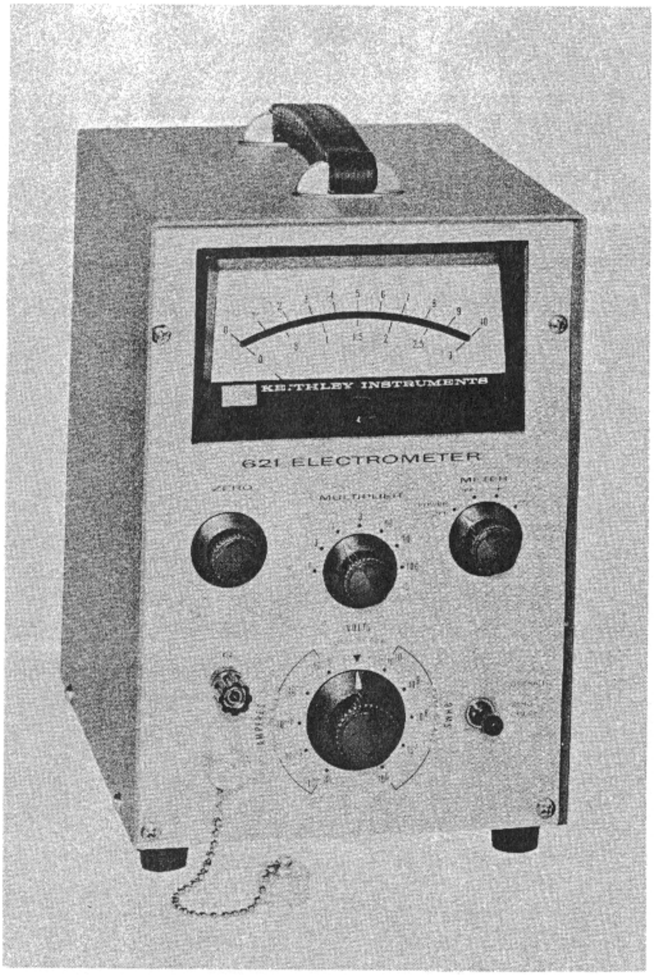
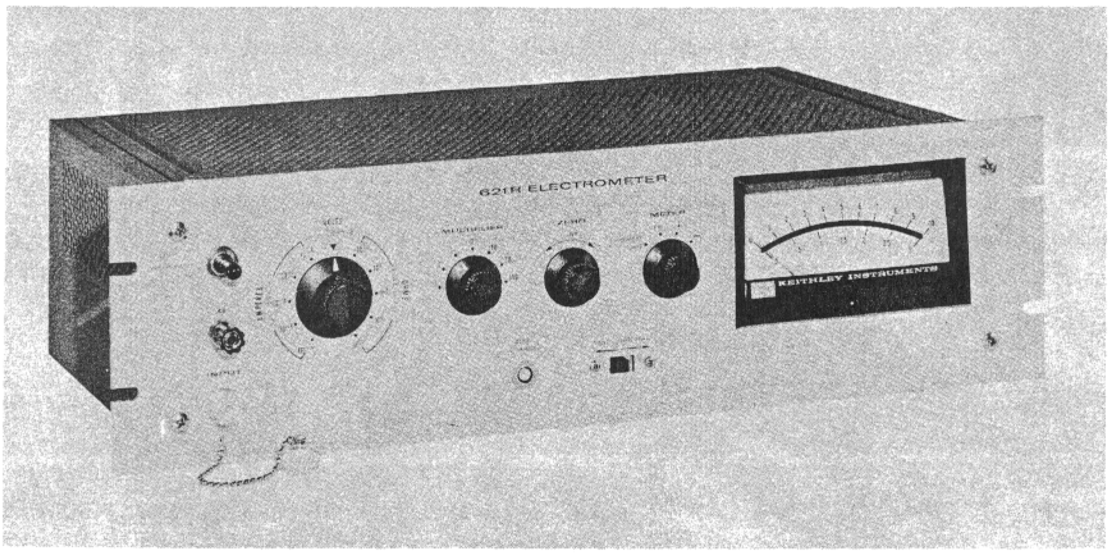


FIGURE 1. The Model 621 Electro
is shown at left. The Model 621
pictured below has the same spec
ations as the Model 621, but it
designed for rack mounting.



SECTION II - SPECIFICATIONS AND DESCRIPTION

SPECIFICATIONS:

Ranges:

(a) Voltage: 0.1, 0.3, 10, 30, and 100 volts full scale.
(b) Current: 10^{-4} to 10^{-11} amperes full scale in 1 x and 3 x overlapping ranges.
Ohms: 10^{5} to 10^{12} ohms full scale on linear 1 x and 3 x overlapping ranges.
Meter Scales: Left zero, 0 to 3 and 0 to 10.

Accuracy:

(a) Voltage: 2% of full scale on all ranges.
(b) Current: 3% of full scale from 10^{-4} to 10^{-9} amperes.
4% of full scale from 3×10^{-9} to 10^{-11} amperes.
(c) Ohms: 3% of full scale from 10^{5} to 10^{10} ohms.
5% of full scale from 3×10^{10} ohms to 10^{12} ohms.

Resistance Standards:

10^{6}, 10^{7}, 10^{8} ohms, 1% accuracy; 10^{9}, 10^{10} ohms, 2% accuracy. The 10^{9} and 10^{10} ohm resistors may be expected to decrease in value at about 1% per year.

Input Impedance:

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

Drift:

Less than 3 millivolts per hour after 2 hours 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 200 cycles on all ranges. Maximum gain is 100. Noise is less than 3% peak-to-peak of full scale.

Tubes:

One, 5886; one, 6CM6; one 6BH8; two, OA2; one, OB2.

Cabinet:

Dimensions (621): 6-3/8 in. wide by 9-3/4 in. high by 6-½ in. deep.
(621R): 19-in. wide by 5-¼ in. high by 10-½ in. deep.

Weight (621): 12 pounds.
(621R): 16 pounds.

Power Supply:

100 to 130 (or 200 to 260) volts, 50 to 60 cycles at approximately 35 watts.

DESCRIPTION:

The Keithley Model 621 is a line operated multipurpose DC measuring instrument of extremely wide range. The measuring ranges are summarized below:

VOLTAGE: 100 millivolts to 100 volts full scale. The input impedance is greater than 10^{14} ohms shunted by approximately 30 micro-microfarads on the VOLTS position of the RANGE switch. The input resistance may be varied from 10^{10} ohms to 10^{6} ohms in decade steps by rotating the RANGE switch in the AMPERES range marking.

HIGH VOLTAGE WITH ACCESSORIES: The Model 6102A, 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 6103A, 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: 10^{-4} amperes to 10^{-11} amperes full scale. The current is measured either by measuring the drop across a resistor shunted across the input, or by placing the NORMAL-FAST switch on the back panel in the FAST position, and applying negative feedback around the shunt resistor. This makes the input drop negligible and improves speed of response considerably on the low current ranges.

OHMS: 10^{5} ohms to 10^{12} 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^{5} ohms to 10^{12} ohms full scale is measured by a two terminal method.

DC AMPLIFIER: The frequency response of the Model 621 as an amplifier is from DC to 200 cycles on all ranges. The output is either 10 volts or 1 milliampere for full scale meter deflection. In the NORMAL micro-microammeter position the output is not grounded.

For directions pertaining to the use of recorders see section IV-E.

Front panel controls and terminals are:

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 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 range.

ZERO control, located to the left of the MULTIPLIER switch under the meter, is used to set the meter to zero.

METER switch, at the right under the meter, turns the instrument on and determines meter polarity.

OPERATE - ZERO CHECK switch, located at the bottom right, selects normal operation or zero check position. In the ZERO CHECK position, the input terminals are shorted through 4.7 megohms, while the amplifier input is shorted.

INPUT terminal is a teflon-insulated UHF type receptacle located in the lower left corner of the front panel. The mating connector and an accessory binding post which plugs into the center of the connector are supplied with the 621. A ground binding post labeled G is mounted on the front panel above the input terminal.

Rear panel controls and terminals are:

FUSE at the upper left. With 117 volt AC power use .5 ampere SLO-BLO fuse; with 230 volt power use .4 ampere fuse.

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

RECORDER CALIBRATION. 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 is an Amphenol type 80-PC2F receptacle. The mating connector is an Amphenol type 80 MC2M.

NORMAL-FAST. This control is locked in NORMAL position. In FAST position, current measurements are made with feed-back around the shunt resistor.

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

MODEL 621R: The specifications and controls described for the 621 in this section are the same for the 621R except for the location of two switches. On the 621R, the ZERO COARSE and FAST-NORMAL switches are located on the front panel. The function and operation of the switches are the same as for the 621.

The basic element of the Model 621, is a highly accurate, stable dc voltmeter with a full scale sensitivity of 100 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 13515-D at the rear of the manual. The amplifier proper consists of V-1 and V-2. V-3 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 R-201 through R-207 to the output cathode follower. Figure 2 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.

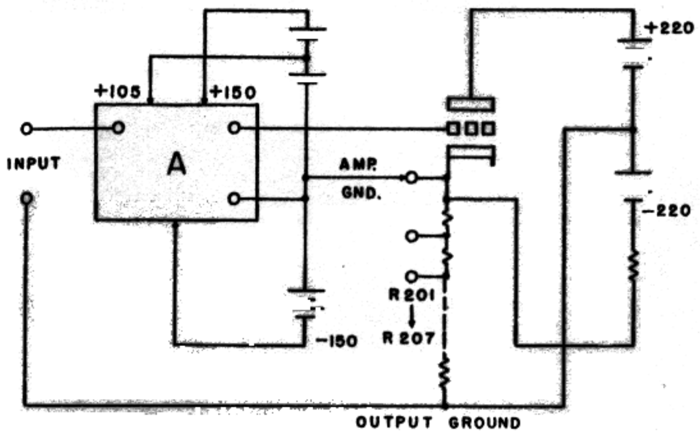


FIGURE 2. Voltmeter Schematic

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 621 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 +150 and +105 volt, and -150 volt 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 a 5886 electrometer tube. The filament is operated through a dropping resistor network from the regulated B plus supply. The control grid of V-1, the electrometer tube, is protected by R-102, a 4.7 megohm resistor, by-passed for high frequencies by C-102. The input switch, S-2 connects the grid of V-1 to the input terminal on the OPERATE position and connects it to ground, through the 4.7 megohm protective resistor, on ZERO CHECK.

The balance controls function by adjusting the dc voltages of the electrometer tube screen and the grid of V-2.

V-2 forms an ordinary differential amplifier and the output is taken into V-3 the output cathode follower.

The voltmeter sensitivity is determined by the fraction of the cathode follower voltage fed back via the divider, R-201 through R-207.

The OUTPUT is derived directly from the 6CM6 cathode. If the output switch (S-6) is set at 10 V, R-127 is set across the output terminals. If the output switch is set at 1 ma, R-127 in combination with R-128 are used to provide enough series resistance so that 1 milliampere flows into the recorder terminals. R-128 calibrates the recorder on all ranges.

The feedback loop is stabilized against oscillation by C-116 together with R-112. The gain is kept high enough so that there is a large feedback factor on all ranges, but the gain is not allowed to become high enough to cause oscillation.

B: AMMETER

Grid current of the input electrometer tube fixes the minimum current that may be measured. The Model 621 grid current will usually be less than 2 x 10^{-14} amperes.

1) Shunt Resistor Method (NORMAL) In the normal operating connection as shown in Figure 3 current is measured by placing a resistor across the input terminals and measuring the voltage drop. The voltage drop is selected by the MULTIPLIER switch; the setting is the input voltage drop for full-scale meter deflection.

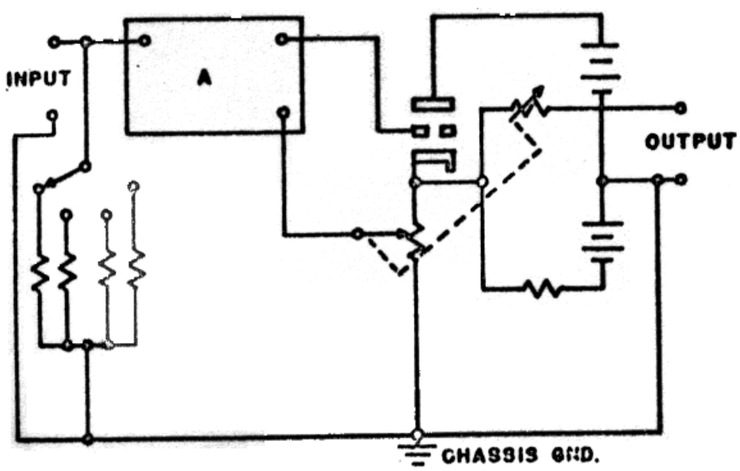


FIGURE 3. Normal Ammeter Operation Schematic

(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 Figure 4, 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

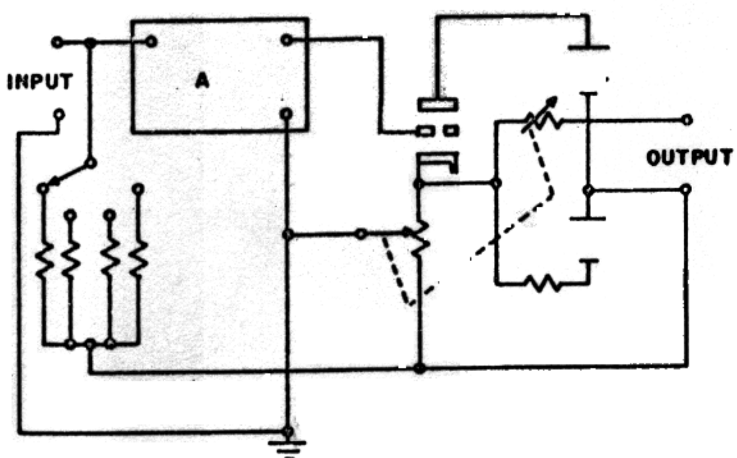


FIGURE 4. Fast Ammeter Operation Schematic

In the Model 621, 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 Figure 4 is again consulted it will be seen that this connection converts the 621 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.

C. <u>OHMMETER</u>

(1) <u>Normal Method</u>. The Model 621 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 used to obtain a constant current, is illustrated in Figure 5. 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.

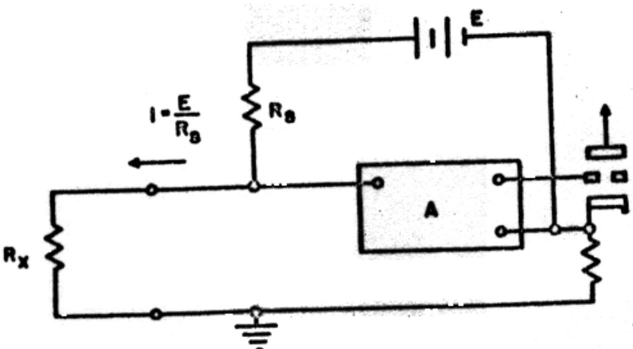


FIGURE 5. Normal Ohmmeter Operation Schematic.

(2) <u>Use of External Voltage Supply</u>. 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 log, 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 Figure 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 621.

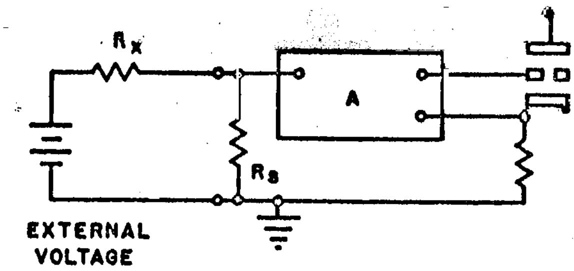


FIGURE 6. Ohmmeter with External Voltage Supply Schematic

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 621 input switch on ZERO CHECK, the input is shorted to ground through 4.7 megohms, providing a discharge path for the capacitor.

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 IV - OPERATION

A. PREPARING THE INSTRUMENT FOR OPERATION

(1) Connect to power line of proper voltage and frequency. Unless otherwise indicated at rear of instrument, the Model 621 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 13515-D at rear of the manual for instructions.

(2) Set controls as follows:

MULTIPLIER:	100
RANGE SWITCH:	VOLTS
OPERATE SWITCH:	ZERO CHECK
INPUT TERMINAL:	Shield with Cap.

(3) Turn the METER switch to meter +. The instrument should come to zero in approximately 30 seconds. Final stability within drift specifications will not be achieved for 2 hours.

(4) 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 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 621 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 6101A, Shielded Test Probe, will suffice for most measurements.

B. MEASURING VOLTAGE

Place RANGE switch at VOLTS. Turn MULTIPLIER switch to expected sensitivity and check meter zero. Move OPERATE switch up to OPERATE and read. If the sensitivity of the instrument is increased, recheck the zero setting.

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

C. MEASURING CURRENT

(1) NORMAL method

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 input. The product of the reading on the RANGE switch and the MULTIPLIER gives the full scale range. Check zero first with OPERATE switch and then read unknown current. The full scale voltage drop across the instrument is the setting of the MULTIPLIER.

(2) FAST method

Proceed as above, except move the FAST-NORMAL switch at the rear of the instrument to the FAST position. The input drop is now negligible and the speed of response is increased approximately 100 times. However, observe the following cautions:

(a) Use only the input switch to check zero; DO NOT SHORT INPUT.
(b) The low side of the output is no longer grounded. Therefore, if the instrument is being used with an output recorder, the recorder must not be grounded to the case of the 621.
(c) Do not use this position for the measurement of capacitor leakages.

D. MEASURING RESISTANCE.

NORMAL method (10^5 ohms to 10^{12} 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 OPERATE switch has been moved to ZERO CHECK. Do not open-circuit instrument when on OHMS, since the input will develop a large voltage due to its constant current characteristic. However, if the sample is first connected and then the OPERATE switch is moved to OPERATE, the full scale input voltage will be the setting of the MULTIPLIER.

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.

The full-scale ohms range is the RANGE switch setting times the MULTIPLIER.

(2) 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) 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.
(c) FAST-NORMAL switch should be at NORMAL
(d) Apply potential to sample before switching to OPERATE. 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 full scale ammeter drop (MULTIPLIER setting), 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. USING EXTERNAL INDICATORS

The output of the Model 621 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. 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 10 v position. Output is now 10 volts for full scale meter deflection on any range.

The frequency response is dc to 200 cycles on any range. 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.

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 621 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 621 case.

F. 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.

Move OPERATE switch to ZERO CHECK and 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 position of the MULTIPLIER switch.

G. <u>STATIC CHARGE MEASUREMENTS:</u> The instrument is zeroed and the RANGE 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 621-A. 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.