

INSTRUCTION MANUAL
MODEL 616
DIGITAL ELECTROMETER

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KEITHLEY INSTRUMENTS, INC.

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SPECIFICATIONS

AS AN AUTORANGING VOLTMETER

RANGE: ± 10 microvolts per digit (10mV full range) to ± 100 volts full range in five decade ranges. 100% overranging to 1999 on all ranges.

ACCURACY (20°C to 30°C): $\pm(0.2\%$ of reading $+0.1\%$ of range).

READING TIME: Less than 4 seconds to within 0.1% of final reading, except where limited by source characteristics.

ZERO DRIFT: Less than (50 microvolts $+0.01\%$ of range) per °C, and less than 100 microvolts per 24-hour period after two hours warm-up (during which drift does not exceed 500 microvolts).

NOISE: ± 10 microvolts with input shorted.

INPUT IMPEDANCE: Greater than 2×10^{14} ohms shunted by 20 picofarads. Input resistance may also be selected in decade steps from 10 to 10^{11} ohms.

NORMAL MODE REJECTION RATIO:

RANGE	NMRR	MAX. AC
10mV	94dB	2V p-p
100mV	80dB	2V p-p
1 V	80dB	20V p-p
10 V	60dB	20V p-p
100 V	60dB	200V p-p

For voltage of line frequency and at least 10% of full range dc reading. Maximum total input 200 volts peak ac + dc.

COMMON MODE REJECTION RATIO: Greater than 140 dB at line frequency with 300 volts peak-to-peak from circuit Lo to chassis ground, up to 10^{11} ohm source resistance, and at least 10% of full range dc reading.

AS AN AMMETER

RANGE: $\pm 10^{-16}$ ampere per digit (10^{-13} ampere full range) to ± 0.1 ampere full range in 13 decade ranges. 100% overranging to 1999 on all ranges.

ACCURACY (20°C to 30°C):

Range Switch Setting	Accuracy
10^{-1} to 10^{-7} A	$\pm(0.5\%$ of reading $+0.1\%$ of range)
10^{-8} A	$\pm(2\%$ of reading $+0.1\%$ of range)
10^{-9} to 10^{-11} A	$\pm(5\%$ of reading $+0.1\%$ of range)

NOISE: 2×10^{-15} ampere peak-to-peak on the most sensitive range, exclusive of alpha particle disturbance.

OFFSET CURRENT: Less than 5×10^{-15} ampere.

COMMON MODE REJECTION: 300 volts peak-to-peak at line frequency from circuit Lo to chassis ground on any range and with at least 10% of full range dc reading will not degrade accuracy more than 0.3% of range. (Equivalent to 140 dB CMRR).

AS AN OHMMETER

RANGE: 1 ohm per digit (1000 ohms full range) to 10^{14} ohms full range in 12 decade ranges. 100% overranging to 1999 on all ranges.

ACCURACY (20°C to 30°C):

Range Switch Setting	Accuracy
10^3 to $10^7 \Omega$	$\pm(0.5\%$ of reading $+0.1\%$ of range)
$10^8 \Omega$	$\pm(2\%$ of reading $+0.1\%$ of range)
10^9 to $10^{12} \Omega$	$\pm(5\%$ of reading $+0.1\%$ of range)

METHOD: Two-terminal constant-current. Current equals reciprocal of OHMS range.

AS A COULOMB METER

RANGE: $\pm 10^{-15}$ coulomb per digit (10^{-12} coulomb full range) to $\pm 10^{-5}$ coulomb full range in 8 decade ranges. 100% overranging to 1999 on all ranges.

ACCURACY (20°C to 30°C): $\pm(5\%$ of reading $+0.1\%$ of range) on all ranges.

AS A CONSTANT CURRENT SOURCE

RANGE: 8 currents in decade steps from 10^{-5} to 10^{-12} ampere using OHMS ranges. Hi terminal is positive.

COMPLIANCE: Up to 200 volts.

ACCURACY (20°C to 30°C): $\pm 0.5\%$ from 10^{-5} to 10^{-7} ampere. $\pm 2\%$ at 10^{-8} ampere. $\pm 5\%$ from 10^{-9} to 10^{-12} ampere.

LOAD REGULATION: Better than 0.1% for loads up to 10^{11} ohms.

GENERAL

DISPLAY: 3 digits plus 1 overrange digit; decimal position, polarity, and overload indication; 5 readings per second. Depending on sensitivity setting, 3 least-significant digits blink or blank when overload condition exists.

POLARITY SELECTION: Automatic

SENSITIVITY SELECTION: Automatic: Voltage sensitivity selection is fully automatic. Sensitivity selection is automatic two decades above and below range switch setting for resistance, charge, and most current measurements. Manual: Front panel switch. Remote: Programmable with the Model 6162 Output/Control (optional).

ISOLATION: Circuit Lo to chassis ground; greater than 10^9 ohms shunted by 500 picofarads (decreasing to 10^8 ohms at 30°C and 70% relative humidity). Circuit Lo may be floated up to ± 1000 volts with respect to chassis ground.

ANALOG OUTPUTS: Unity Gain: For dc inputs, output is equal to input within 20 ppm for output currents of 1mA or less. In the fast mode output polarity is opposite input polarity. 1 volt: ± 1 volt at up to 1mA with respect to circuit Lo for full range input; 100% overrange capability. In the normal mode the output polarity is opposite input polarity.

OPERATING ENVIRONMENT: 20°C to 30°C, 0% to 70% relative humidity. 10°C to 50°C with derated specifications. Storage: 0°C to 70°C.

CONNECTORS: Input: Teflon-insulated triaxial. Analog Outputs: Unity gain, 1 volt chassis, Lo, and guard; binding posts. BCD Output: Internal connectors for interfacing the Model 6162 Isolated Output/Control.

DIMENSIONS; WEIGHT: Style M 3-1/2 in. half-rack, overall bench size 4 in. high x 8-3/4 in. wide x 15-3/4 in. deep (100 x 220 x 400 mm); net weight, 11 pounds (4,8 kg).

POWER: Line Operation: 90-125 or 180-250 volts (switch selected), 50-60 Hz, 9 watts.

ACCESSORIES SUPPLIED: Model 6011 Input Cable: 3 ft. (1m) triaxial cable with triaxial connector and 3 alligator clips.

NOTE: All accuracy and gain specifications are exclusive of noise and zero offsets. Accuracies include temperature coefficient. On the 5% accuracy ranges as an Ammeter, Ohmmeter, and Constant Current Source the coefficient is less than 0.2% per °C.

SECTION 1. GENERAL INFORMATION

1-1. INTRODUCTION. The Model 616 Digital Electrometer is an automatic ranging, multipurpose electrometer featuring sensitivity to 10 microvolts per digit. Its 3-1/2 digit LED display provides 0.2% voltage accuracy for a wide range of measurements. The Model 616 is essentially a digital multimeter optimized for measurements from high source impedance. The 616 provides wide range capability when measuring current, resistance, and charge in addition to voltage.

1-2. WARRANTY INFORMATION. The warranty is stated on the inside front cover of the manual.

1-3. CHANGE NOTICE. Improvements or changes to the instrument not incorporated into the manual will be explained on a yellow Change Notice sheet attached to the inside back cover.

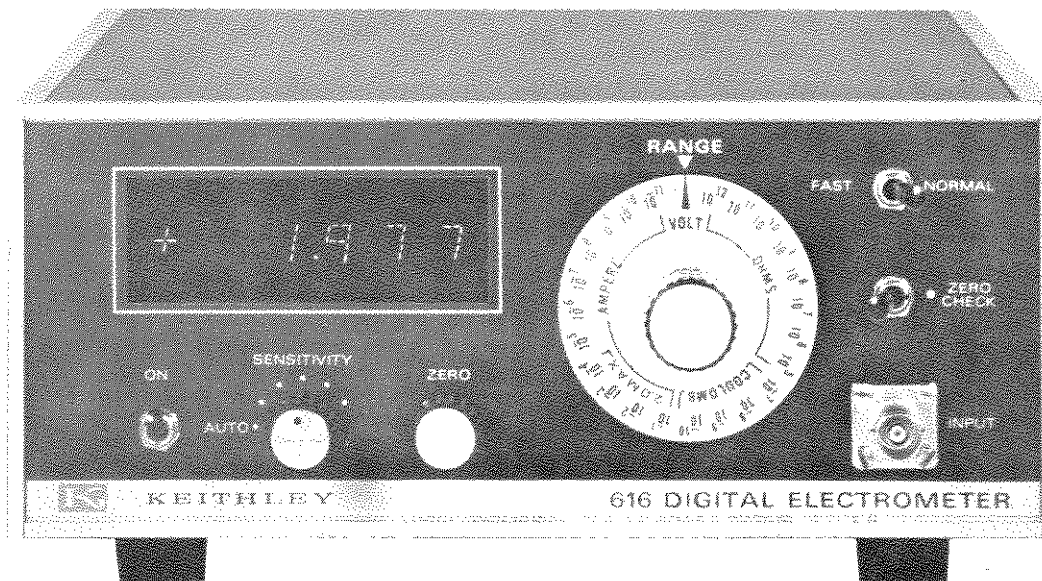


TABLE 1-1.
Front Panel Controls

Control	Functional Description	Paragraph
Power ON	Controls line power.	--
SENSITIVITY	Sets voltage sensitivity and decimal point.	3-4a
ZERO	Adjusts zero offset.	3-4a
RANGE	Sets range on a chosen function.	3-3
FAST/NORMAL	Sets instrument for either Feedback or Shunt Mode.	3-7b
ZERO CHECK	Places instrument in ZERO CHECK mode.	3-6
INPUT	Triaxial input receptacle.	3-2a

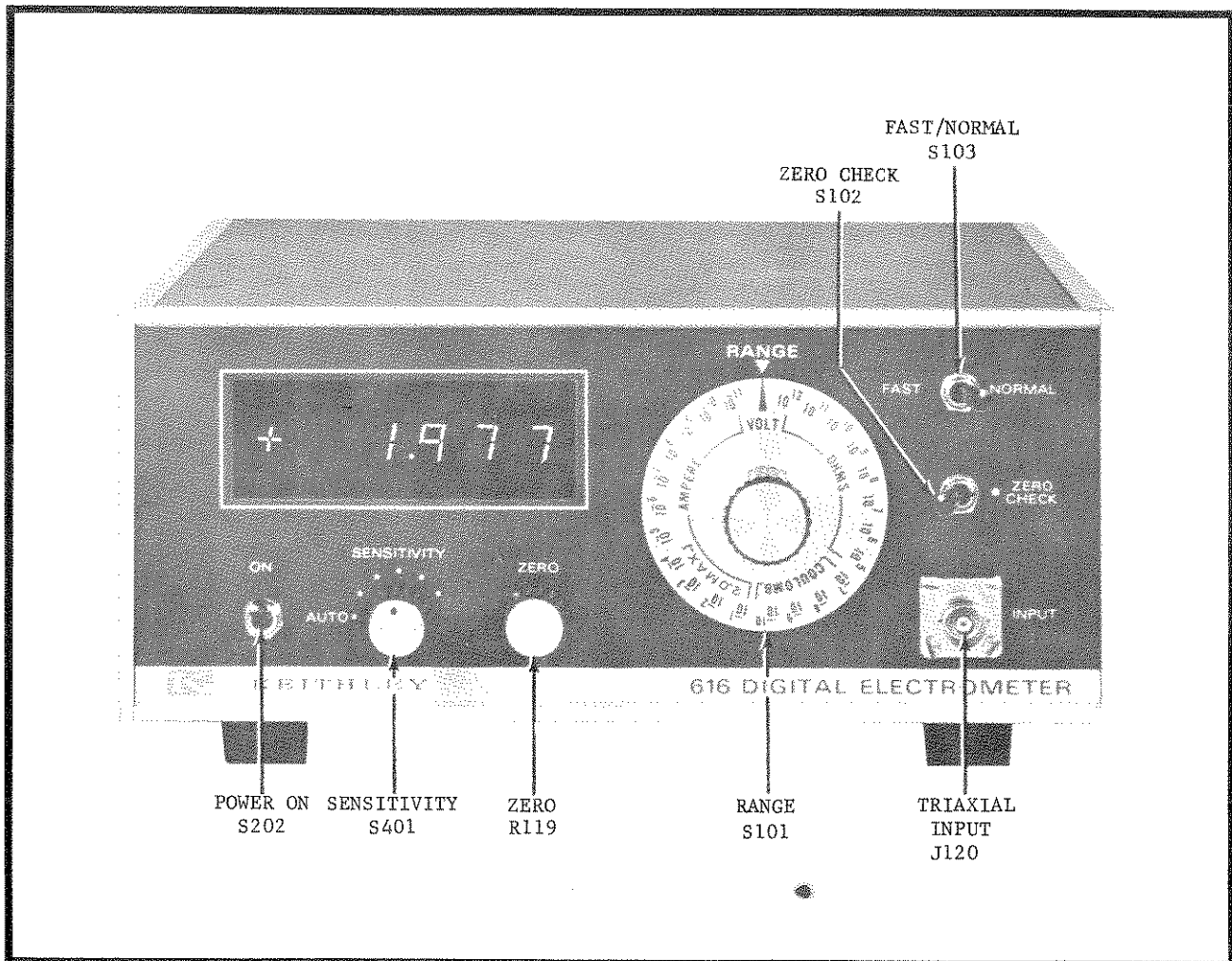


FIGURE 2. Front Panel Controls and Display.

TABLE 1-2.
Rear Panel Controls.

Control	Functional Description	Paragraph
Line Switch	Sets instrument for nominal 117V or 234V.	2-3a
Line Receptacle	Mates with 3-wire line cord.	2-3c
FUSE	117V: 3/16A 234V: 1/10A	2-3b
X1 (WHITE)	Unity-gain Output, 200V @ 1 mA maximum.	3-2c
1V (RED)	Recorder Output, 1V @ 1 mA full range.	3-2c
GUARD (BLUE)	Guard Output.	3-2c
LO (BLACK)	Circuit Low.	3-2c
GROUND (GREEN)	Chassis ground.	3-2c

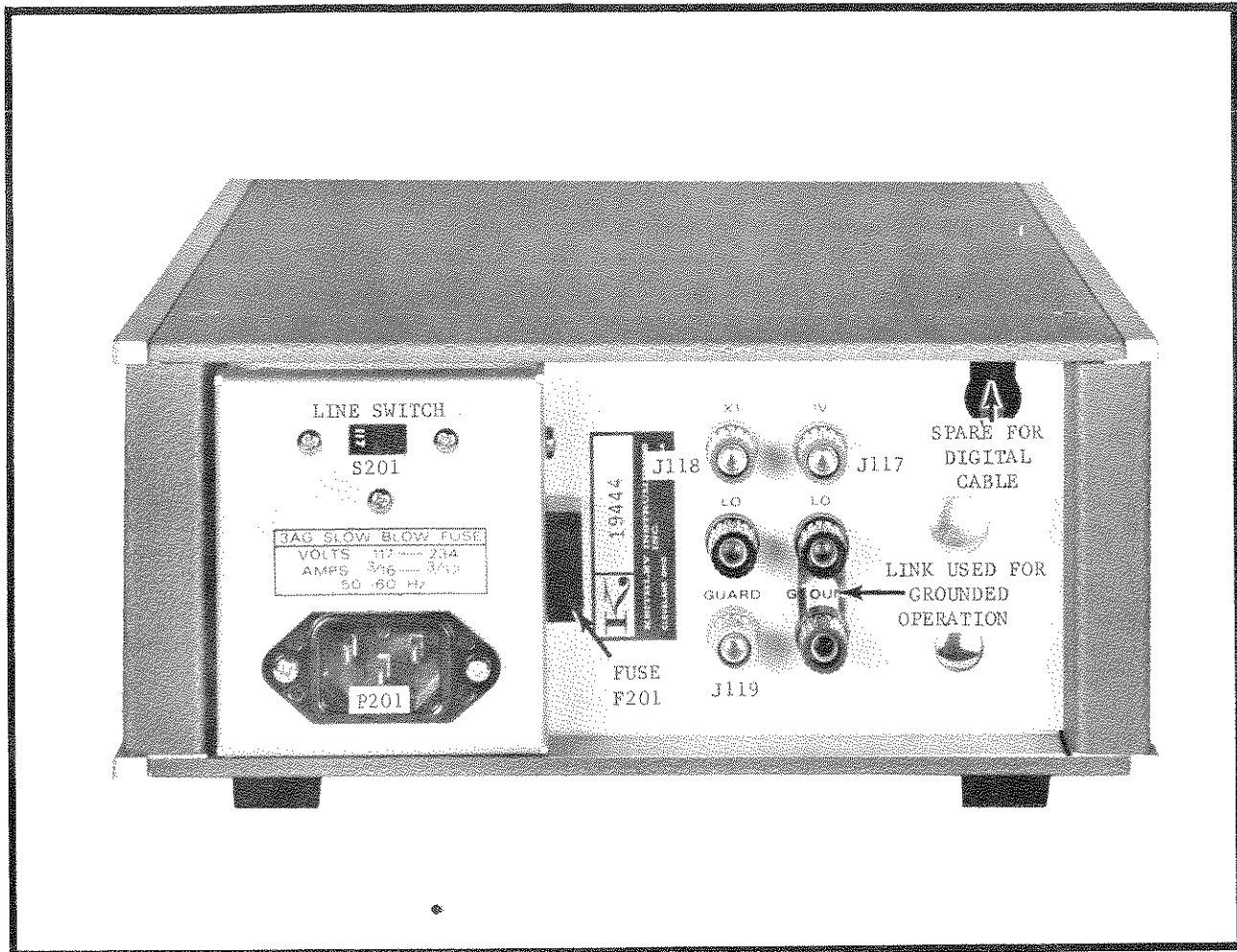


FIGURE 3. Rear Panel Connectors.

SECTION 2. INITIAL PREPARATION

2-1. GENERAL. This section describes procedures for incoming inspection and preparation for use.

2-2. INSPECTION. The Model 616 was carefully inspected both mechanically and electrically before shipment. Upon receiving the instrument, check for any obvious damage which may have occurred during transit. Report any damages to the shipping agent.

2-3. PREPARATION FOR USE.

a. Line Voltage. Before power is applied check the position of the LINE switch (S201) on the rear panel. Select the 117V position for operation from 50-60 Hz line voltages over the range 90V to 125V rms. Select the 234V position for operation from 50-60 Hz line voltages over the range 180V to 250V rms.

b. Fuse Installation. After the line voltage range is selected check for the proper fuse type and rating as follows:

117V: 3/16 ampere, type 3AG SLO-BLO

234V: 1/10 ampere, type 3AG SLO-BLO

c. Line Connections. This instrument requires a three-wire line cord (Keithley part no. CO-7) which provides connections to line voltage (high, common) and chassis ground. For operator safety, the chassis ground pin should be connected to earth ground.

CAUTION

If the instrument input LO is to be floated, above chassis ground, make certain that the "link" between LO and GROUND on the rear panel is removed.

SECTION 3. OPERATING INSTRUCTIONS

3-1. GENERAL. This section describes the procedures for operating the Model 616 as a voltmeter, ammeter, ohmmeter, and coulombmeter.

3-2. CONNECTIONS.

a. Input Receptacle. This receptacle is a Teflon insulated triaxial connector. The center terminal is the high impedance input; the inner shield is the low input; and the outer shield is case ground. The mating connector is a Keithley part no. CS-141 triaxial plug.

b. Model 6011 Input Cable. This cable is a 30 inch long triaxial cable terminated with 3 color-coded alligator clips. The input high is identified by the heavy wire with red insulator. The input low is identified by the thin wire with black insulator. The case ground is identified by the thin wire with green insulator.

c. Rear Panel Terminals. The rear panel has six binding posts which are used for making special connections to the Model 616.

1. X1 Terminal (White). This terminal provides an analog signal at unity gain.
2. 1V Terminal (Red). This terminal provides an analog signal with a scale factor of 1 volt for full range input.
3. LO Terminals (Black). These terminals provide a connection to input low. Either terminal may be used for system connections.
4. GUARD Terminal (Blue). This terminal provides a connection to the amplifier feedback when in the FAST mode.
5. GROUND Terminal (Green). This terminal provides a connection to chassis ground. A shorting link is provided for easy connections between low and chassis.

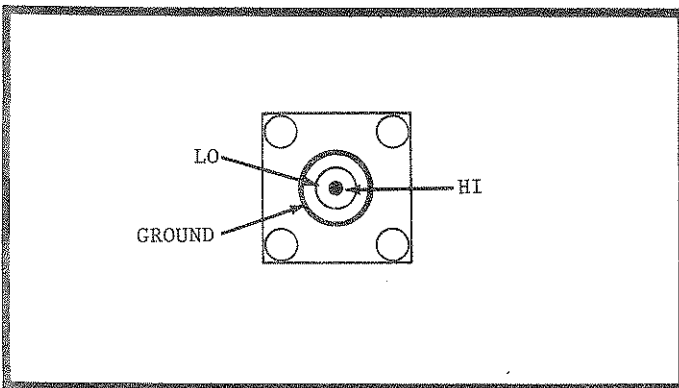


FIGURE 4. Triaxial Input.

3-3. FUNCTION SELECTION. The Model 616 provides a single front panel rotary switch for selection of function and range. The RANGE Switch (S101) permits manual selection of any of four functions, namely, VOLT, OHMS, COULOMB, and AMPERE.

3-4. VOLT FUNCTION. The Model 616 provides five decades of voltage sensitivity from .01000 volts to 100 volts full range. The VOLT function is selected by setting the RANGE switch to VOLT.

a. Manual Sensitivity Settings. The front panel SENSITIVITY switch has six positions. As the switch is rotated counter clockwise, the sensitivity is increased. These positions correspond to full range sensitivities of 100.0V, 10.00V, 1.000V, .1000V, and .01000V as in Table 3-1. Position six is the AUTO sensitivity mode which enables either automatic sensitivity or remotely selected sensitivity (when used with the Model 6162).

TABLE 3-1. Voltage Sensitivity Settings

Sensitivity Setting	Full Range Display	Maximum Display
10 mV	.01000 V	± .01999 V
100 mV	.1000 V	± .1999 V
1 V	1.000 V	± 1.999 V
10 V	10.00 V	± 19.99 V
100 V	100.0 V	± 199.9 V*

*The display indicates 000.0V at 200.0 volts input. The three least significant digits will flash on and off (blinking action) to indicate an over-voltage condition. The display will continue to read up to ±201.7 volts with blinking action. Beyond ±201.7 volts the display will indicate 001.7 volts with blinking action.

CAUTION

Voltage inputs greater than ±200 volts are not recommended since damage to the instrument may result.

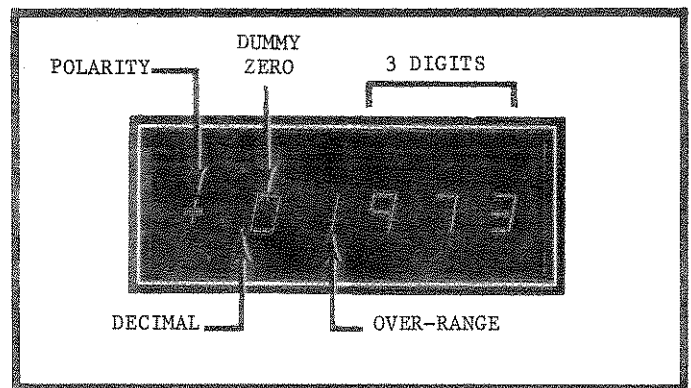


FIGURE 5. Typical Display on 10 mV Sensitivity.

b. Automatic Sensitivity Operation. In the AUTO mode, the Model 616 automatically selects the proper sensitivity in accordance with the following rules.

1. Upranging. If the display reading is between 0-1-8-0 and 1-9-9-9 and the input signal is increased beyond 1-9-9-9, the Model 616 automatically up-ranges to the next higher (less sensitive) range. The three least significant digits are blanked during range changing so as to prohibit incorrect readings from being displayed. If the input signal exceeds ± 199.9 volts the display will continue to indicate up to ± 201.7 volts but the three least significant digits will flash on and off to indicate an over voltage condition.

2. Down ranging. If the display reading is at least 0-1-8-0 and the input signal is decreased, the Model 616 automatically down ranges to the next lower (more sensitive) range.

c. Remote Sensitivity Selection. When the Model 616 is used with the Model 6162 Isolated Output/Control, the 616's voltage sensitivity may be remotely selected. The output connector on the rear panel of the 6162 provides four isolated control lines for the purpose of remote sensitivity programming. The lines are coded as shown in Table 3-2. The 616's front panel SENSITIVITY switch must be set to AUTO position.

TABLE 3-2.
Remote Sensitivity Programming Logic

Sensitivity	Control Lines			
	R ₀	R ₄	R ₂	R ₁
.01000 V	0	0	0	0
.1000 V	0	1	0	0
1.000 V	0	1	0	1
10.00 V	0	1	1	0
100.0 V	0	1	1	1

NOTE

The remote enable line R₀ is used to defeat the automatic sensitivity feature. When R₀ is open, the 616 returns to automatic operation. Logic 1 = open.

3-5. RANGE SELECTION. The front panel RANGE switch (S101) provides selection of four functions, VOLT, OHMS, COULOMB, and AMPERE as described in paragraph 3-3. For each function, a wide selection of ranges is provided; 8 ranges on OHMS, 4 ranges on COULOMB, and 11 ranges on AMPERE. Since the SENSITIVITY switch is used in conjunction with the RANGE Switch, the actual number of useable spans is 12 decades on OHMS, 8 decades on COULOMB, and 11 on AMPERE.

NOTE

On the 10⁻¹A to 10⁻⁴A ranges, the voltage developed must not exceed 2 volts, otherwise, overheating of a range resistor could result. As a result, the 10 volt and 100 volt sensitivity settings are not recommended for 10⁻¹A to 10⁻⁴A ranges.

To interpret a reading on OHMS, COULOMB, or AMPERE ranges both the digital display (with decimal location) and the RANGE setting (powers of ten) should be considered. For example, given a digital reading of 17.32 and a RANGE setting of 10⁻⁷ AMPERE, the actual measured value would be interpreted as 17.32 x 10⁻⁷ ampere. Since the decimal point is moveable, it is important to notice the position of the demimal point to determine the full range of the instrument. See Table 3-3 for typical range settings in the AMPERE function.

TABLE 3-3.
Typical Current Range Settings*

Input Current	Range Setting	Sensitivity Setting	Digital Display
10 ⁻¹⁵ A	10 ⁻¹¹ A	10 mV	.00010
10 ⁻¹⁴ A	10 ⁻¹¹ A	10 mV	.00100
10 ⁻¹³ A	10 ⁻¹¹ A	10 mV	.01000
10 ⁻¹² A	10 ⁻¹¹ A	100 mV	.1000
10 ⁻¹¹ A	10 ⁻¹¹ A	1 V	1.000

*The current reading is interpreted by multiplying the display reading times the range setting. Other currents not shown can be measured by selecting the appropriate RANGE switch setting in decade steps from 10⁻¹¹A to 10⁻¹A.

3-6. OPERATION AS A VOLTMETER. The Model 616 can be used to measure voltages from ± 10 microvolts to ± 200 volts. Although the Model 616 is useable as a general purpose digital voltmeter, it has certain characteristics which enable reliable measurements from very high source resistances. When used in the VOLT mode, the Model 616 has an input resistance greater than $2 \times 10^{14} \Omega$. As a result, the loading of the source circuitry is relatively insignificant when compared to typical digital voltmeters having 10⁸ ohms input resistance. The Model 616 has 20 picofarads of shunt capacitance (not including the input cable capacitance). Since a large amount of capacitance causes a slowing of response, the Model 616 input capacity is kept as small as possible.

a. Measurements From Very High Source Resistance.

To use the Model 616 as a voltmeter, set the front panel controls as follows:

- RANGE -- VOLT
- SENSITIVITY -- AUTO
- FAST/NORMAL -- NORMAL

(A complete explanation of the use of the FAST/NORMAL switch is given in paragraph 3-7b)

Make connections to the Model 616 using a shielded triaxial cable. Keep cable length as short as possible to reduce the slowing effects of cable capacitance. The zero control may need occasional adjustment to reduce any voltage offset which may occur due to temperature variations. To rezero the Model 616, set the ZERO CHECK switch to CHECK position and adjust the front panel ZERO control for a 0-0-0-0 display. (The recommended warm-up time for the Model 616 is two hours although it is useable immediately after power is turned on.) The Model 616 provides a direct reading voltage display with automatic decimal point position and polarity.

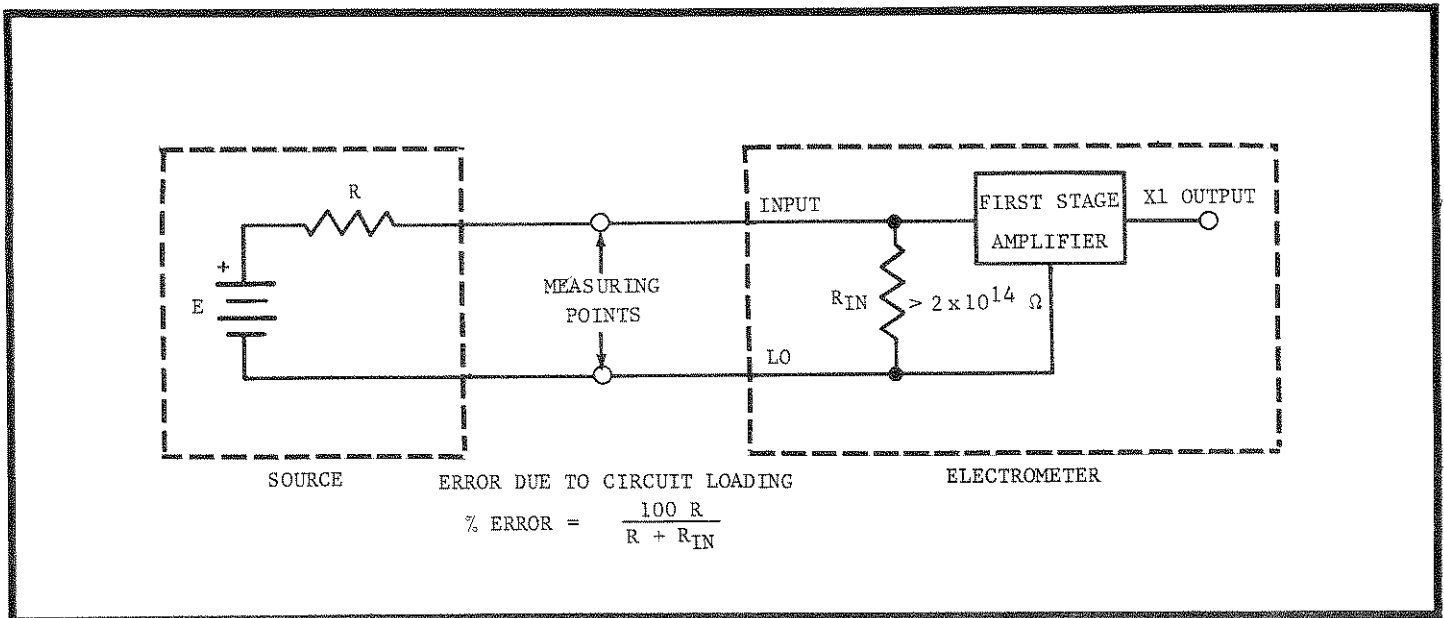


Figure 6. Operation As a Voltmeter in NORMAL Mode.

b. Measurements From Low Source Resistance. To use the Model 616 for voltage measurements from low source resistances, set the RANGE switch to the 10^{-11} AMPERE position. In this mode, the Model 616 input resistance is reduced to 10^{11} ohms; as a result the electrometer will be less sensitive to electrical noise pickup and input cable vibration. Voltage measurements can be made by following the same procedure given in paragraph 3-6a. The Model 616 can be used with the RANGE set at any position between 10^{-11} AMPERE to 10^{-1} AMPERE. The Model 616 input resistance can be determined by taking the reciprocal of the AMPERE setting. Significant loading error may result if the input resistance is reduced to less than 100x the source resistance.

c. Measurements Above 200 Volts. The Model 616 can be used with accessory divider probes to measure voltages up to 30 kilovolts. Range must be set to VOLT.

1. Model 6102A Divider Probe (10:1). This accessory extends the voltage measuring capability of the Model 616 to 1000 volts. The input resistance is 10^{10} ohms. The divider accuracy is $\pm 4\%$ to 1000 volts. (To use the Model 6102A an accessory Model 6012 Adapter is needed to mate the triaxial input with the UHF connector on the probe.)

2. Model 6601A Divider (100:1). This accessory extends the voltage measuring capability of the Model 616 to 5000 volts. The input resistance is 10^7 ohms. The divider accuracy is $\pm 0.01\%$.

3. Model 6103A Divider Probe (1000:1). This accessory extends the voltage measuring capability of the Model 616 to 30 kilovolts. The input resistance is 10^{12} ohms. The divider accuracy is $\pm 5\%$ to 30 kilovolts. (To use the Model 6103A an accessory Model 6012 Adapter is needed to mate the triaxial input with the UHF connector on the probe.)

NOTE

The Model 616 may exhibit a large amount of zero offset or drift immediately after an overload or a long period of storage. In addition, the offset current may exceed the specification for a short time until the Model 616 is sufficiently stabilized. Although the offset current of the Model 616 is well below offset found in conventional voltmeters, the effects of the offset current charging the input capacitance may be noticed when the input is open. Use the ZERO CHECK switch to discharge the offset charge.

CAUTION

The Model 616 should not be operated with circuit low floating by greater than 1000 volts with respect to chassis ground. If the Model 616 is to be used with circuit low floating make certain that no connection is made between the LOW and GROUND terminals on the rear panel. Do not connect a grounded recorder or other instrument to the X1 or IV outputs when the Model 616 is floated.

d. Voltage Measurements in FAST Mode. When the FAST/NORMAL Switch is set to FAST, the Model 616 is connected in a "FEEDBACK" amplifier configuration. In this configuration, the Model 616 requires special connections. To measure voltage, connect the source between input HI and GUARD. An easy way to accomplish this connection is to connect the link (on the rear panel) between "GUARD" (blue terminal) and "GROUND" (black terminal). Then use the triaxial cable for input connections with the input voltage applied between the "red" clip lead and the "green" clip lead.

NOTE

In this special voltage connection, the LO input (black clip lead) is not used since the voltage amplifier configuration has been changed. This "FAST" method significantly

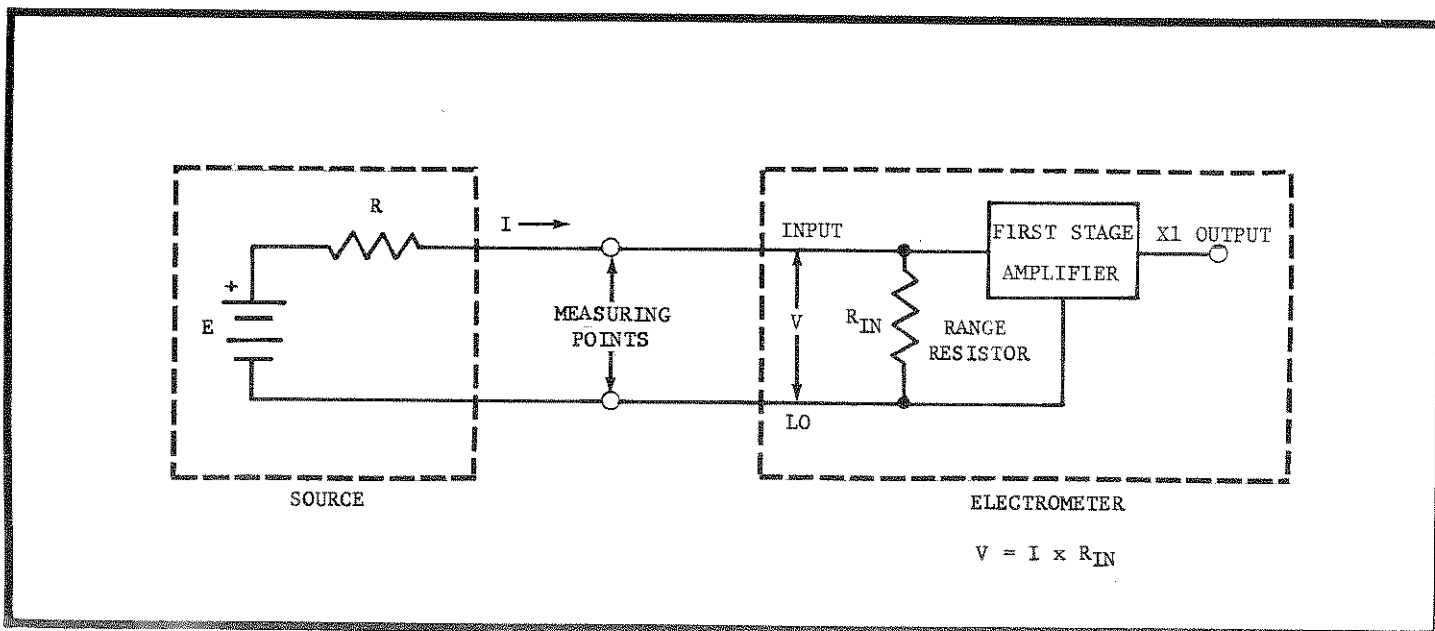


FIGURE 8. Operation As An Ammeter in NORMAL Mode.

3-7. OPERATION AS AN AMMETER. The Model 616 can be used to measure currents from $\pm 10^{-15}$ ampere to 200 milliamperes. Although the Model 616 is useable as a general purpose picoammeter, it has certain characteristics which enable reliable measurements of very small currents with fast response.

a. Normal Mode Current Measurements. In this mode, the Model 616 measures current over a wide range. When the FAST/NORMAL switch is set to NORMAL, the Model 616 operates as a shunt-type picoammeter in which a resistor is connected directly across the input terminals. The Model 616 measures the voltage drop across the shunt resistors where $V_{IN} = I_{IN} \times R_S$. This method of measurement is typical of most multimeter current measuring techniques. To use the Model 616 as a shunt-type picoammeter, set the front panel controls as follows:

- RANGE -- 10^{-5} AMPERE (or appropriate range)
- SENSITIVITY -- AUTO
- FAST/NORMAL -- NORMAL

NOTE

Full range is determined by the sensitivity setting and the AMPERE range setting.

Make connections to the Model 616 using a shielded triaxial cable. Keep cable length as short as possible to reduce the slowing effects of cable capacitance. The zero control may need occasional adjustment to reduce any voltage offset which may occur due to temperature variations. To rezero the Model 616, set the ZERO CHECK switch to CHECK position and adjust the front panel zero control for a 0-0-0-0 display. (The recommended warm-up time for the Model 616 is two hours although it is useable immediately after power is turned on.)

NOTE

The Model 616 may exhibit a large amount of zero offset or drift immediately after an overload or a long period of storage. In addition, the offset current may exceed the specification for a short time until the Model 616 is sufficiently stabilized. Although the offset current of the Model 616 is well below offset found in conventional voltmeters, the effects of the offset current charging the input capacitance may be noticed when the input is open. Use the ZERO CHECK switch to discharge the offset charge.

CAUTION

Do not use the 10 volt and 100 volt sensitivity settings for RANGE switch settings of 10^{-1} , 10^{-2} , 10^{-3} , and 10^{-4} ampere. If the voltage exceeds 2 volts on these ranges, overheating of the resistors could result with subsequent degradation of accuracy in the AMPERE mode.

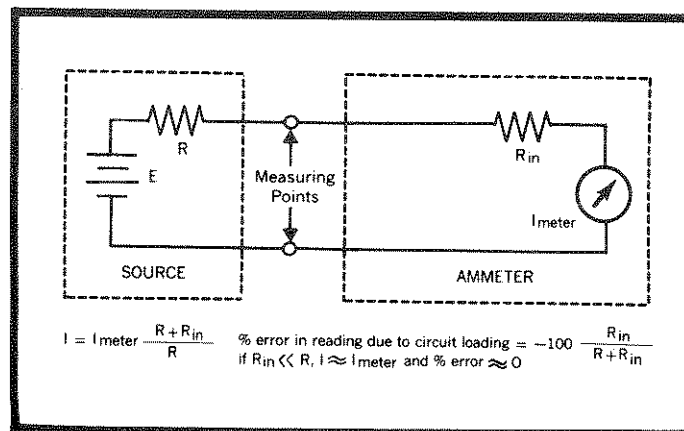


FIGURE 9. Loading Effects in Ammeter Function.

b. Fast Mode Current Measurements. (Useable for currents from 10^{-5} A and smaller.) In this mode, the Model 616 measures very small currents with fast response. When the FAST/NORMAL switch is set to FAST, the Model 616 operates as a feedback-type picoammeter in which the current flows through the feedback resistor of the voltage amplifier. The Model 616 indicates the voltage developed across the range resistor where $V_F = I_{IN} \times R_F$. This method of measurement provides fast response since the effect of the input capacitance from lengthy cables is diminished. To use the Model 616 as a feedback-type picoammeter, set the front panel controls as follows:

RANGE -- 10^{-11} AMPERE
 SENSITIVITY -- AUTO
 FAST/NORMAL -- FAST

Make connections to the Model 616 using a shielded triaxial cable. The zero control may need occasional adjustment to reduce any voltage offset which may occur due to temperature variations. To rezero the Model 616, set the ZERO CHECK switch to CHECK position and adjust the front panel ZERO control for a 0-0-0-0 display. (The recommended warm-up time for the Model 616 is two hours although it is useable immediately after power is turned on.)

NOTE

The Model 616 may exhibit a large amount of zero offset or drift immediately after an overload or a long period of storage. In addition, the offset current may exceed the specification for a short time until the Model 616 is well below offset found in conventional voltmeters, the effects of the offset current charging the input capacitance may be noticed when the input is open. Use the ZERO CHECK switch to discharge the offset charge.

c) Considerations When Measuring Current. When using the Model 616 in either the NORMAL or FAST modes, there are certain considerations which ensure optimum performance. In general, it is advantageous to use the smallest possible value of shunt resistance for a picoammeter. First, small value resistors are of higher quality compared to large values with respect to accuracy, time stability, temperature, and voltage coefficient. Second, ideal picoammeters require very small input resistance so that source loading does not affect the overall accuracy of the measurement. Since the input resistance in a shunt picoammeter is determined by the range resistor, the RANGE multiplier should be set at the lowest value. Third, the use of a low value resistor reduces the input RC time constant and results in faster response. However, since noise and zero drift become more significant when the voltage amplifier sensitivity is set to 10 or 100 millivolts,

the appropriate range multiplier should be selected with a one volt full scale sensitivity. The use of the Model 616 in the FAST mode enables measurements of very small currents while reducing the source loading and input RC time constant. Since the range resistor is connected in the feedback of the voltage amplifier, the effective input resistance is determined by the open-loop gain where $R_{IN} = R_F \div A$. (The value of A is typically 10,000.) Another advantage of the feedback mode is the reduced effect of input capacitance since the input RC time constant is decreased by the gain A ($RC_{EFFECTIVE} = RC \div A$). As a result, the measurement speed is governed by the feedback time constant which is a function of the feedback resistor and stray capacitance across the resistor (usually a few pF). Thus, when comparing shunt versus feedback modes, it is evident that the feedback measurement offers superior performance for most applications.

TABLE 3-4.
Current Settings

Input Current	Range Setting	Sensitivity Setting	Digital Display	Typical Accuracy*
10^{-15} A	10^{-11}	10 mV	.00010	± 2 d
10^{-14} A	10^{-11}	10 mV	.00100	± 6 d
10^{-13} A	10^{-11}	10 mV	.01000	± 51 d
10^{-12} A	10^{-11}	100 mV	.1000	± 51 d
10^{-11} A	10^{-11}	1 V	1.000	± 51 d
10^{-10} A	10^{-10}	1 V	1.000	± 51 d
10^{-9} A	10^{-9}	1 V	1.000	± 51 d
10^{-8} A	10^{-8}	1 V	1.000	± 21 d
10^{-7} A	10^{-7}	1 V	1.000	± 6 d
10^{-6} A	10^{-6}	1 V	1.000	± 6 d
10^{-5} A	10^{-5}	1 V	1.000	± 6 d
10^{-4} A	10^{-4}	1 V	1.000	± 6 d
10^{-3} A	10^{-3}	1 V	1.000	± 6 d
10^{-2} A	10^{-2}	1 V	1.000	± 6 d
10^{-1} A	10^{-1}	1 V	1.000	± 6 d

*exclusive of noise, zero drift, and loading error.

NOTE

The use of the FAST mode for current measurements is subject to certain restrictions as follows:

1. The range resistor value should not be greater than the source resistance, otherwise feedback division results in zero instability at the output.
2. The largest value of current measured should not exceed 10^{-5} ampere, otherwise the full feedback current cannot be developed. The NORMAL mode should be used for currents from 200 mA to 10^{-4} A.

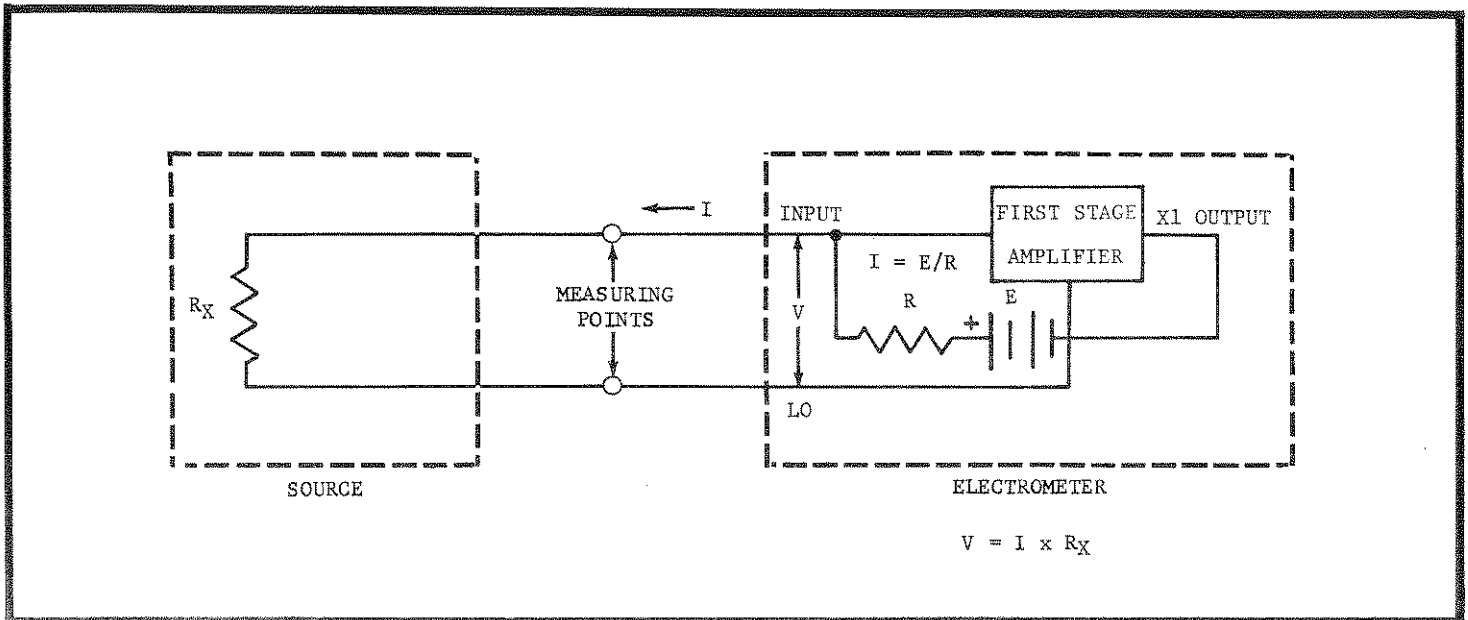


FIGURE 10. Operation As An Ohmmeter in NORMAL Mode

3-8. OPERATION AS AN OHMMETER. The Model 616 can be used to measure resistance from 1 ohm to 2×10^{14} ohms. Although the Model 616 is useable as a general purpose ohmmeter, it has certain characteristics which enable reliable measurements of very large resistances with fast response.

a. Normal Mode Ohms Measurements. In this mode, the Model 616 measures resistance over a wide range. The use of the NORMAL mode is recommended for measurements up to 10^{11} ohms (use the FAST mode for larger resistances). The Model 616 uses a constant current method for measuring resistance. Therefore, the digital readout is proportional to the voltage developed across the input terminals where $V = I \times R$ (the current I is selected in decade steps using the RANGE Switch). To use the Model 616 as an ohmmeter, set the front panel controls as follows:

- RANGE -- 10^5 OHMS (or other appropriate range)
- SENSITIVITY -- AUTO
- FAST/NORMAL -- NORMAL

TABLE 3-5.
Ohms Settings

Source Resistance	Range Setting	Sensitivity Setting	Digital Display	Typical Accuracy*
10^{14}	10^{12}	100 V	100.0	± 51 d
10^{13}	10^{12}	10 V	10.00	± 51 d
10^{12}	10^{12}	1 V	1.000	± 51 d
10^{11}	10^{11}	1 V	1.000	± 51 d
10^{10}	10^{10}	1 V	1.000	± 51 d
10^9	10^9	1 V	1.000	± 51 d
10^8	10^8	1 V	1.000	± 21 d
10^7	10^7	1 V	1.000	± 6 d
10^6	10^6	1 V	1.000	± 6 d
10^5	10^5	1 V	1.000	± 6 d
10^4	10^5	1 V	.1000	± 6 d
10^3	10^5	100 mV	.01000	± 6 d
10^2	10^5	10 mV	.00100	± 2 d

*exclusive of noise, zero drift, and loading error.

Make connections to the Model 616 using a shielded triaxial cable. Keep cable length as short as possible to reduce the slowing effects of cable capacitance. The zero control may need occasional adjustment to reduce any voltage offset which may occur due to the temperature variations. To rezero the Model 616, set the ZERO CHECK Switch to CHECK position and adjust the front panel ZERO control for a 0-0-0 display. (The recommended warmup time for the Model 616 is two hours, although it is useable immediately after power is turned on.) The Model 616 provides a direct reading display with automatic decimal point position.

b. Fast Mode Ohms Measurement. In this mode, the Model 616 measures very large resistances with fast response (use this mode for resistances larger than 10^{11} ohms). When the FAST/NORMAL switch is set to FAST, the unknown resistance (R_x) is floating with respect to the low side of the voltage amplifier. The unknown resistor is connected across the feedback so as to reduce the effects of capacitance and therefore speed up the measuring time. To use the Model 616 for FAST ohmmeter measurements, set the front panel controls as follows:

- RANGE -- 10^{12} OHMS
- SENSITIVITY -- AUTO
- FAST/NORMAL -- FAST

Connect the unknown resistance between input HI and GUARD (on the rear panel).

NOTE

When the FAST mode is used for resistance measurements, the unknown resistance sample is connected in feedback around the electrometer amplifier. Therefore the resistance must be floating and not referenced to LO.

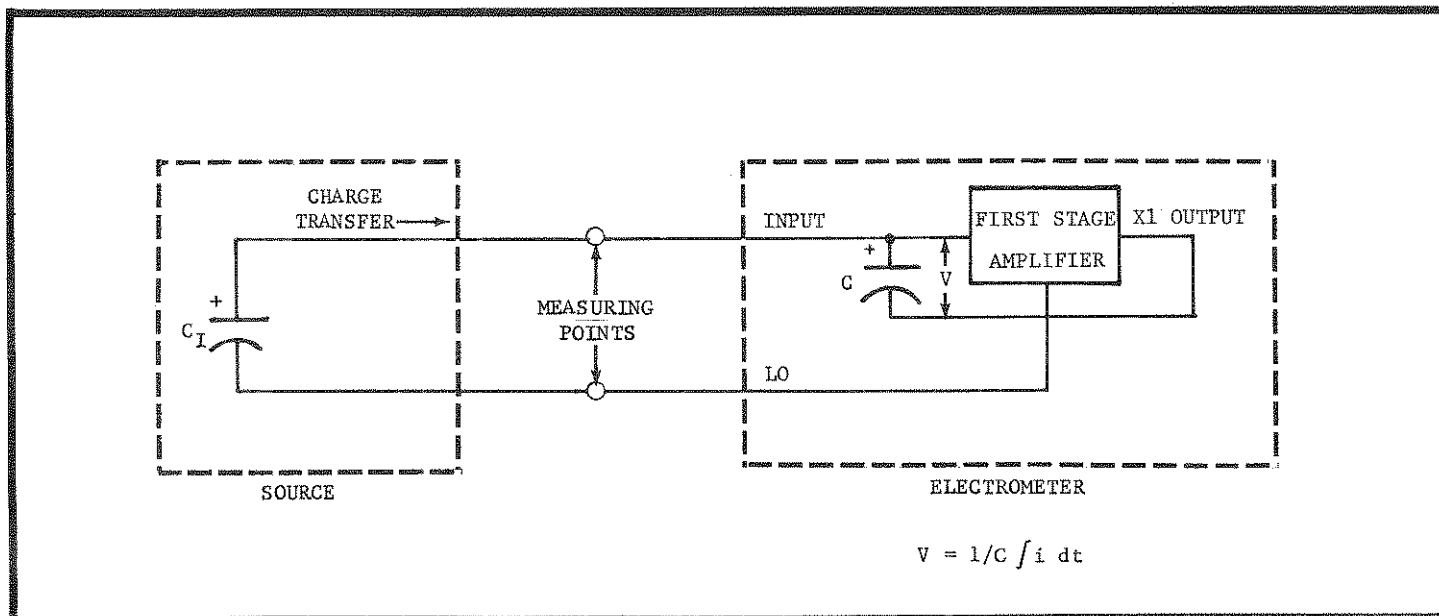


FIGURE 11. Operation As A Coulombmeter in FAST Mode.

3-9. OPERATION AS A COULOMBMETER. The Model 616 can be used to measure charge by means of a current integration technique. When the Model 616 is set to any one of the 4 coulomb ranges, an accurately known capacitor is connected in the feedback loop of the voltage amplifier so that the voltage developed is proportional to the integral of current where $V = Q/C$ or $V = 1/C \int i dt$. The Model 616 can also be used with accessory Models 2501 or 2503 for measurement of static charge on a dielectric surface. A discussion of static charge measurement is given in section 3-10c. To use the Model 616 as a coulombmeter, set the front panel controls as follows:

RANGE -- 10^{-10} COULOMB
 SENSITIVITY -- AUTO
 FAST/NORMAL -- FAST

Make connections to the Model 616 using a shielded triaxial cable. Keep cable length as short as possible to reduce the slowing effects of cable capacitance. The zero control may need occasional adjustment to reduce any voltage offset which may occur due to the temperature variations. To rezero the Model 616, set the ZERO CHECK Switch to CHECK position and adjust the front panel ZERO control for a 0-0-0-0 display. (The recommended warmup time for the Model 616 is two hours although it is useable immediately after power is turned on.) The Model 616 provides a direct reading display with automatic decimal point position.

NOTE

The input offset current of the Model 616 contributes a charge of 5×10^{-15} coulomb per second and should be subtracted from the actual reading.

3-10. ALTERNATE MEASUREMENTS. The Model 616 can also be used with Keithley accessories which extend the measuring capabilities of the electrometer.

a. Null Method for Current Measurements. The Model 616 can be used with an accurate current source such as Keithley Model 261 to measure small variations of current. When using this method, the Model 616 is operated as a current null detector in the FAST mode. The current source should be adjusted to obtain a null reading on the Model 616 (the electrometer should be set to an appropriate range and sensitivity depending on the magnitude of current variation).

b. Volt-Ammeter Resistance Measurements. The Model 616 can be used with an accurate voltage source such as Keithley Models 240A, 244, 245, or 246. When using this method, the Model 616 is operated as a picoammeter so that the current through the unknown resistance is measured by the electrometer. The resistance is then calculated in terms of the known voltage impressed and the resultant current measured on the electrometer.

c. Static Charge Measurements. The Model 616 can be used with Models 2501 or 2503 Static Detector Probes for measurement of static charge on a dielectric surface. When using this method, the Model 616 is operated as a voltmeter with a reading directly in volts. (Do not attempt to measure static charge with the Model 616 in the COULOMB mode.)

NOTE

For more information about Static Charge Measurements, request the Keithley Product Notes entitled "Electrometer Static Charge Measurements".

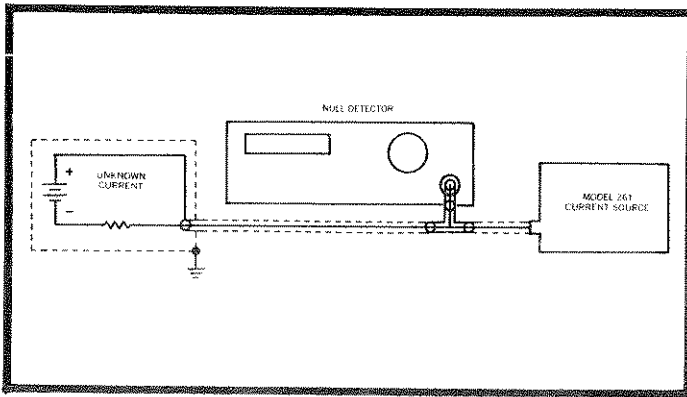


FIGURE 12. Null Method for Current Measurement.

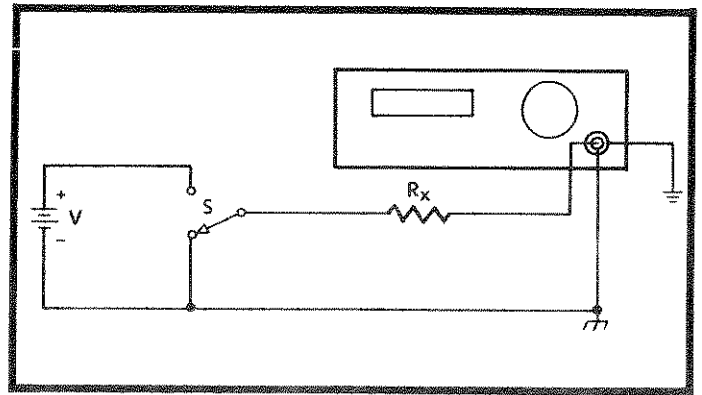


FIGURE 13. Volt-Ammeter Resistance Method.

3-11. RECORDER OUTPUTS. The Model 616 provides several outputs for monitoring an analog signal.

a. XI Output (Unity Gain). This output can be used for monitoring the input signal in applications requiring a buffer amplifier.

1. **NORMAL MODE.** In the NORMAL MODE, the signal at the XI OUTPUT (with respect to LO) is equal to the input within 20 ppm at dc. The XI OUTPUT can deliver up to 1 milliampere for outputs up to 200 volts.

2. **FAST MODE.** In the FAST MODE, the XI OUTPUT terminal is connected to input LO. For unity gain applications when in FAST mode the GUARD terminal should be used. Typical rise times for various current ranges is shown in Table 3-6. This data is representative of instrument response for unity gain operation.

b. 1 VOLT OUTPUT. This output provides a 1 volt analog output at up to 1 milliampere corresponding to a full scale input.

1. **NORMAL MODE.** In the NORMAL mode, the output polarity is opposite the input polarity.

2. **FAST MODE.** In the FAST MODE, the output polarity is the same as input.

c. GUARD OUTPUT. This output can be used with the XI output for recording purposes or special measuring techniques such as guarded resistance measurements.

1. **NORMAL MODE.** In this mode, the GUARD terminal is connected to the LO terminal.

2. **FAST MODE.** In this mode, the GUARD terminal can be used to monitor the input current when the Model 616 is used as a FAST mode picoammeter. The output of the GUARD terminal is proportional to the input current where $V_o = I_{input} \times R_{range}$. The GUARD terminal is also useful for making guarded resistance measurements. For this type of measurement, the unknown resistance is connected between input HI and GUARD. The voltage developed at the GUARD terminal is proportional to the unknown resistance, where $V_o = I_{ohms\ range} \times R_x$.

TABLE 3-6.

Response at GUARD (Unity Gain) OUTPUT for Fast Current*.

Range Setting	Rise Time 10-90%		
	1 V	10 V	100 V
1×10^{-5} A	50 μ S	100 μ S	500 μ S
1×10^{-6} A	300 μ S	500 μ S	1 mS
1×10^{-7} A	2 mS	3 mS	5 mS
1×10^{-8} A	10 mS	12 mS	15 mS
1×10^{-9} A	60 mS	60 mS	60 mS
1×10^{-10} A	300 mS	300 mS	300 mS
1×10^{-11} A	3 S	3 S	3 S

*Typical instrument performance (may vary from unit to unit).

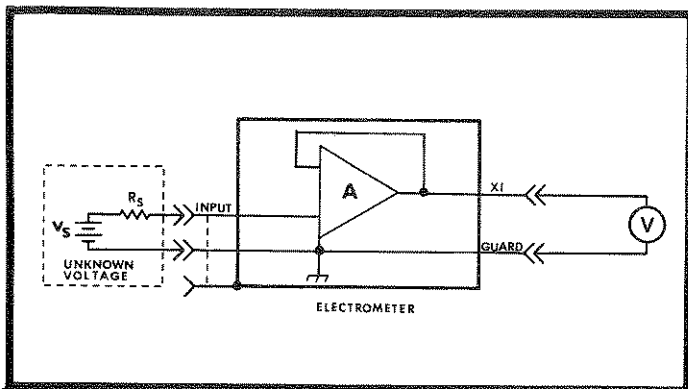


FIGURE 14. Unity-Gain (XI) Measurement.

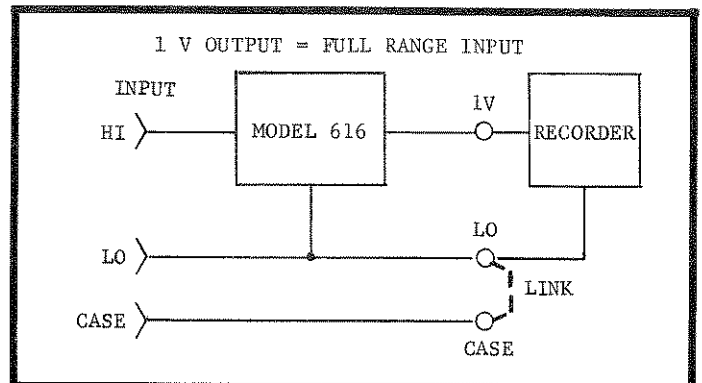


FIGURE 15. Use of 1V Recorder Output.

3-12. DIGITAL OUTPUT CONTROL.

a. General. The Model 6162 Isolated Output/Control provides isolated BCD outputs, remote controls, and remote programming lines for systems use of the Model 616. The Model 6162 has 32 bits of measurement information provided in parallel format. Strobe lines permit data transfer in 4 bit multiples which are compatible with 8, 12, or 16-bit data systems. Strobing of the "open collector" outputs also permit multiplexing of data from 2 or more 6162's on a single data bus. Print rate can be adjusted from 1/5 second to 7 seconds per reading to permit a transfer rate compatible with the speed of measurement and/or the acquisition system. Isolated Remote Controls are provided for Zero Check, Sensitivity, Display Hold, Output Hold, as well as Strobe. The 616's low to chassis ground isolation is maintained by the 6162 (greater than 10^{10} ohms). Digital output low is also isolated from chassis ground by 10^8 ohms.

b. Installation. The 6162 circuitry is housed in a separate 3-1/2 in. high half-rack chassis. It can be used on the bench adjacent to the 616 or rack mounted side-by-side in a standard 19 inch rack width using rack hardware provided (Model 1007).

1. Bench Mounting. Position the Model 6162 on the left side of the Model 616 as shown in Figure 19 since the interconnecting cable has been designed to mate with the 616 in this configuration only. Remove the "side dress" panels (Item 11) on the sides which are adjacent. Loosen the socket head screws (Item 24) and slide the panels to the rear of the instruments. After both panels are removed install the "mounting clamp" (Item 23)

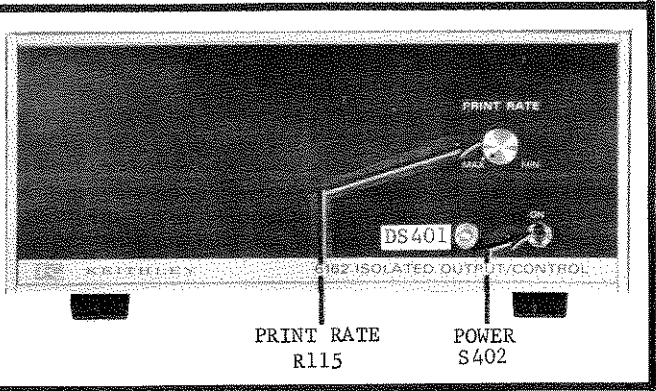


FIGURE 16. Front Panel of Model 6162.

using the original hardware. Remove two screws on one of the instruments and insert the mounting clamp behind the corner bracket as shown in Figure 17. Replace and tighten the two screws to hold the clamp in place. Next, insert the open part of the clamp behind the corner bracket on the second instrument. Attach a 1-1/8" long Phillips head screw (Item 25) and kepnut (Item 26) to secure the two instruments together.

2. Rack Mounting. Proceed as described in the above paragraph for bench mounting. Then attach an "angle bracket" (Item 21) on each instrument using hardware (Item 22) in place of original hardware. The bottom corner feet and tilt bail assemblies may be removed if necessary. The original hardware, side dress panels, feet and tilt bail assemblies should be retained for future conversion back to bench mounting.

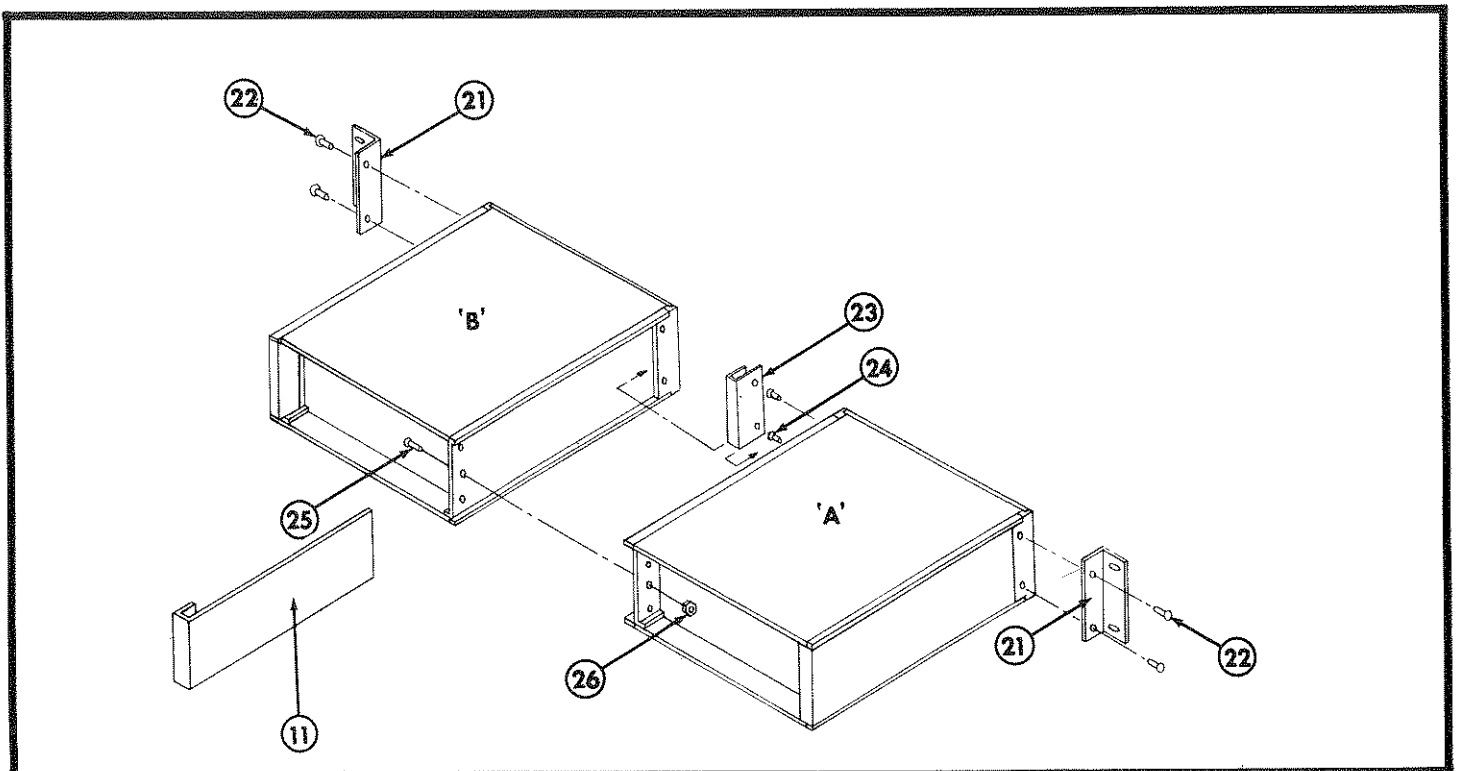


FIGURE 17. Dual Rack Mounting Using Model 1007 Hardware.

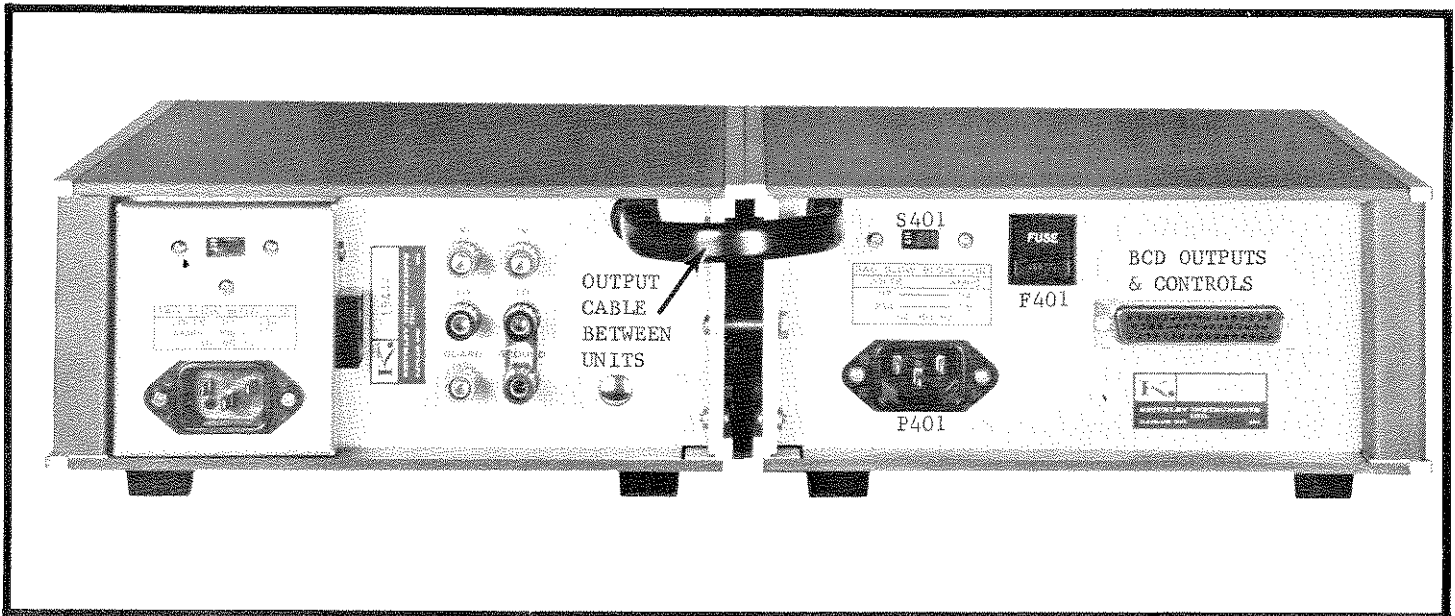


FIGURE 18. Rear Panel of Model 616 and 6162.

c. Connections. A single prewired cable plugs into the 616's chassis to provide all necessary communication between units. To install the cable, remove the 616's top cover, place rubber grommet within the rear panel slot, insert cable, and plug the three mini-connectors into their respective pc-board locations as shown in Figure 19. A separate 50-pin AMP type 205211-1 connector provides isolated outputs and control lines. A mating 50-pin connector is furnished with the 6162 (Keithley Part No. CS-271).

d. Power Requirements. The 6162 is powered from 50-60Hz line voltage and has a separate power switch and fuse. Line voltage is selected using the rear panel switch. Fuse type is 3AG SLO-BLO, 1/4A(117V) or 1/8A(234V).

e. Summary of Digital Information. Table 3-7 identifies the data lines available at the 6162 output connector. The data is grouped in 4-bit bytes with a corresponding Strobe line. The strobe (or enable) line permits serial data transfer from a single 6162 or multiplexing of the data output of a number of 6162's onto a common data bus. Conventional parallel data transfer is obtained when all strobe lines are at Logic "0" (closure to output LO within 0.5 volt).

f. Print Rate. The basic 616 has a reading rate of 5 readings per second. The front panel RATE control on the 6162 varies the print rate in 1/5 second increments.

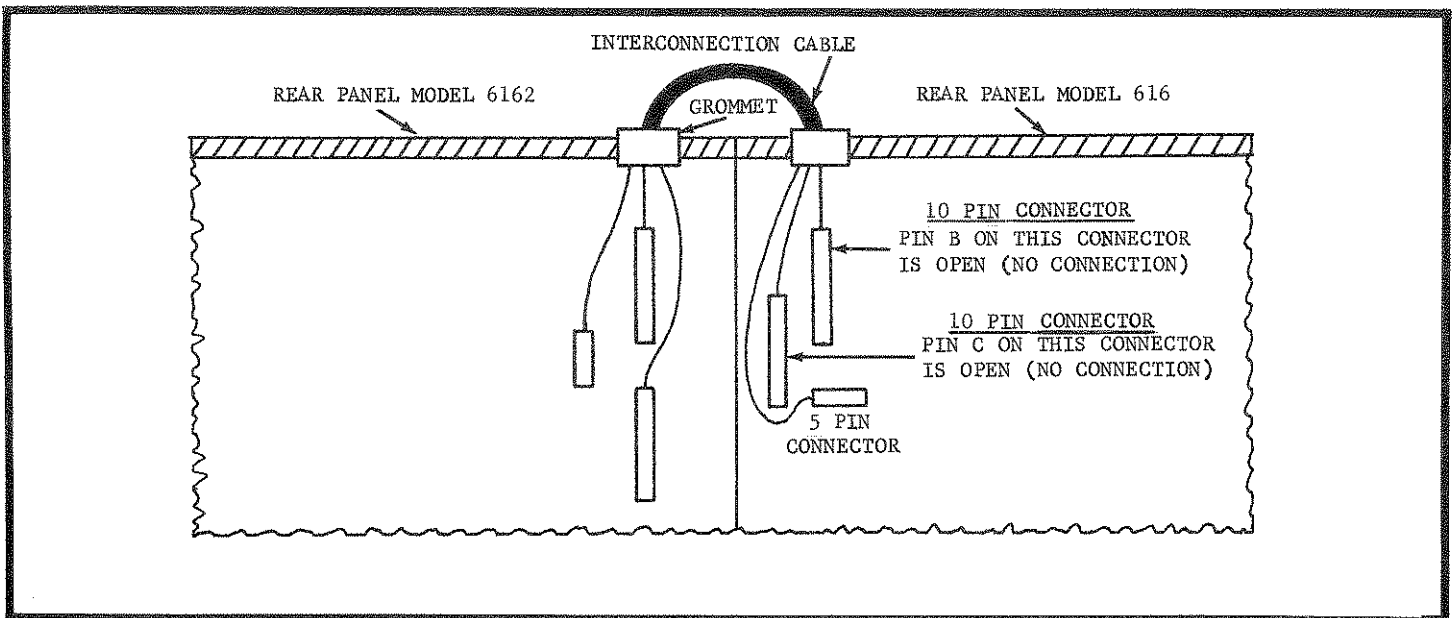


FIGURE 19. Diagram of Interconnection Cable Between 616 and 6162.

TABLE 3-7.
Pin-Out for 50-Pin Connector

Pin No.	Name	Function	Pin No.	Name	Function
1	Strobe #4	Buffer Control	26	4×10^2	Data #3
2	Output Hold	Control	27	FLAG	Timing Output
3	Strobe #7	Buffer Control	28	4×10^1	Data #2
4	Output Lo	GND	29	2×10^1	Data #2
5	DP3 (1.000)	Decimal Point	30	1×10^2	Data #3
6	DP4 (10.00)	Decimal Point	31	MANUAL RANGE	Range Control
7	DPI (.01000)	Decimal Point	32	R ₁	Range Control
8	DR	Down-range	33	R ₄	Range Control
9	UR	Up-range	34	EXP 8×10^0	Output
10	FLAG	Timing Output	35	EXP 4×10^0	Output
11	4×10^0	Data #1	36	Strobe #3	Buffer Control
12	2×10^0	Data #1	37	EXP 1×10^0	Output
13	ZERO CHECK	Output	38	EXP 2×10^0	Output
14	R ₂	Range Control	39	Strobe #9	Buffer Control
15	ZERO CHECK	Remote Control	40	"0" (10 mV range)	Output
16	8×10^0	Data #1	41	EXP POL	Output
17	1×10^0	Data #1	42	EXP 1×10^1	Output
18	Strobe #5	Buffer Control	43	POLARITY	Output
19	Strobe #6	Buffer Control	44	F ₁	Function
20	Strobe #8	Buffer Control	45	F ₂	Function
21	1×10^3	Data #4	46	8×10^1	Data #2
22	DP 2 (.1000)	Decimal Point	47	1×10^1	Data #2
23	DP5 (100.0)	Decimal Point	48	Strobe #1	Buffer Control
24	8×10^2	Data #3	49	Strobe #2	Buffer Control
25	2×10^2	Data #3	50	Display Hold	Control

g. Data Transfer. Conventional parallel data transfer is accomplished through parallel connections with one bit of information per conductor. Strobing allows data to be grouped into word lengths (bytes) appropriate to the acquisition device, thus simplifying the interfacing between the 6162 and 8, 12, or 16-bit devices. When all STROBE lines are at Logic "0", the 6162 data outputs are enabled and are available in parallel form. Individual strobe lines may be used to connect to a common data bus in multiples of 4-bit words. The 6162 "open-collector" outputs are "open" unless the respective strobe lines are at Logic "0". The use of "open-collector" configuration allows the parallel connection of 2 or more 6162 units since none of the outputs will conduct unless strobed. The 6162 outputs are TTL and DTL compatible. The "open collector" output switches between a high and low impedance level rather than specific voltage levels. This permits the user to determine the voltage level defined by logic state "1". The output "1" state may be selected from any voltage over the range of +2 and +12 volts. The "0" state is 0.5V at +35 mA (maximum) sink current.

h. Word Sequence. The particular sequence in which the words appear in serial data transfer is determined by the way the "STROBE" lines are grouped and the order of activation, in addition to the wiring of the data blocks.

i. Control Features.

1. Flag (Flag). This output provides a logic level which can be used to indicate the proper time interval for transfer of data. A logic "1" occurs from 50 milliseconds to 7 seconds depending

on the Print Rate control setting. No change in the Digital Output is made during this interval. On some digital devices, it may be necessary to trigger off the leading edge of the Flag or Flag waveform by differentiating or other wave shaping.

2. Display Hold. This control line retains the last reading on the display (except polarity) when closure is made to digital LO (Pin 4). Neither the a/d conversion nor digital output are affected by this control.

3. Output Hold. This control line retains the last reading at the Digital Output when closure is made to digital LO (Pin 4). Neither the a/d conversion nor digital display are affected by this control.

4. Zero Check. This control line actuates the 616's zero check solenoid to permit monitoring of the electrometer amplifier offset. When the line is released (Logic "1") the 616 returns to normal operating configuration. The front panel ZERO CHECK switch must be set to OFF position to permit remote zero check control.

j. Remote Programming. Remote lines are provided at the 50-pin connector to permit remote selection of sensitivity over five decades. When the 616's SENSITIVITY Switch is set to AUTO position, the sensitivity may be remotely programmed or allowed to function automatically. When the MANUAL RANGE line on the 6162 is at Logical "0" the coded range lines are enabled, and the LSI range lines are disabled.

TABLE 3-8.
Cross-Reference for Digital Outputs.

Name	Pin No.	Remarks	Name	Pin No.	Remarks	
Strobe #1	48	Buffer Control	Strobe #7	3	Buffer Control	
F1	44	Coded function lines See Table 3-11 Logic "1" = +	FLAG	27	Timing Output	
F2	45		FLAG	10	Timing Output	
EXP POL	41					
EXP 1 x 10 ¹	42					
Strobe #2	49	Buffer Control	Strobe #8	20	Buffer Control	
EXP 1 x 10 ⁰	37	Used on OHMS, AMPERE, COULOMB ranges	1 x 10 ³	21	Overrange Output	
EXP 2 x 10 ⁰	38		POLARITY	43	Logic "1" = +	
EXP 4 x 10 ⁰	35		DP1	7	.00000 = 10 mV	
EXP 8 x 10 ⁰	34		"0" (10 mV range)	40	Dummy Zero	
Strobe #3	36	Buffer control for Data #1	Strobe #9	39	Buffer Control	
1 x 10 ⁰	17	Data #1 (BCD)	DP2	22	.0000 = 100 mV	
2 x 10 ⁰	12		DP3	5	0.000 = 1 V	
4 x 10 ⁰	11		DP4	6	00.00 = 10 V	
8 x 10 ⁰	16		DP5	23	000.0 = 100 V	
Strobe #4	1	Buffer control for Data #2	The following are not strobed.			
1 x 10 ¹	47	Data #2 (BCD)			Output Hold	2
2 x 10 ¹	29		Display Hold	50	Remote Control	
4 x 10 ¹	28		MANUAL RANGE	R ₁	31	Sensitivity lines See Table 3-12
8 x 10 ¹	46			R ₂	32	
Strobe #5	18	Buffer control for Data #3	R ₄	14		
1 x 10 ²	30	Data #3 (BCD)	R ₄	33		
2 x 10 ²	25		Digital Lo	4	Ground Reference	
4 x 10 ²	26		Zero Check	13	Indication	
8 x 10 ²	24		Strobe #6	19	Buffer Control	
DR	8	Down Range	Zero Check	15	Remote Control	
UR	9	Up Range				

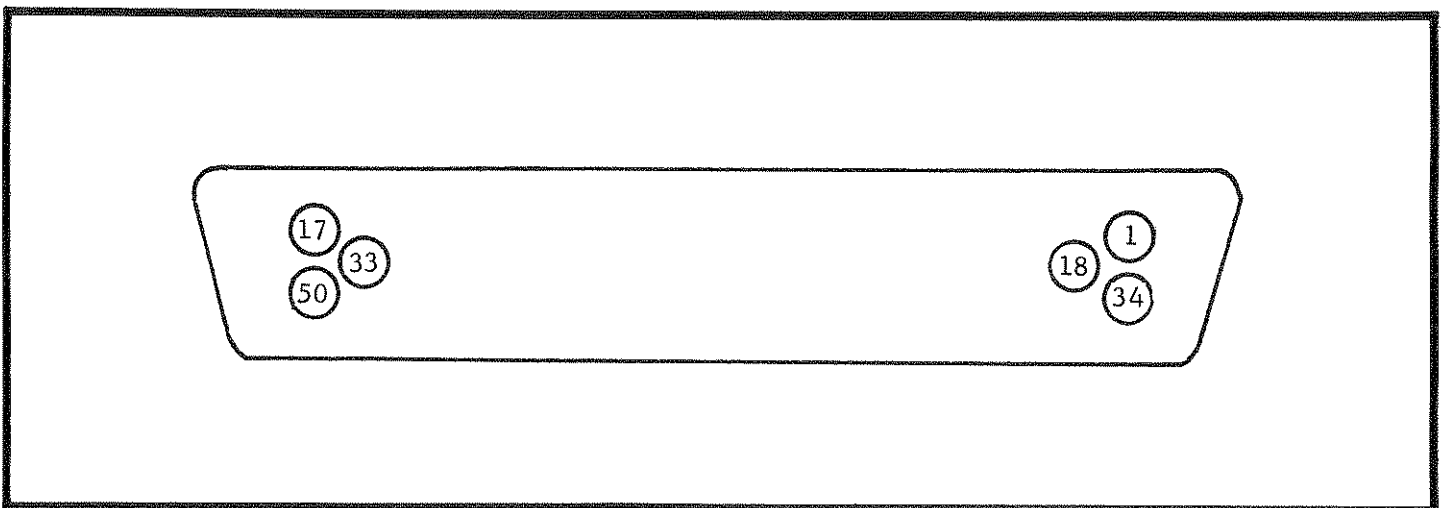


FIGURE 20. Identification of Pins on Digital Output Connector.

TABLE 3-9.
Truth Table for 8-4-2-1 BCD Code

Decimal Number	8×10^n (4th bit)	4×10^n (3rd bit)	2×10^n (2nd bit)	1×10^n (1st bit)
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

n = 0,1,2,3, or 4 depending on digit being decoded.

TABLE 3-10.
Truth Table for Serial Transfer

Strobe Line No.	Condition Of Strobe Lines.									Output A	Output B	Output C	Output D
	1	2	3	4	5	6	7	8	9				
1	0	1	1	1	1	1	1	1	1	F_1	F_2	EXP POL	Exp 1×10^1
2	0									Exp 1×10^0	Exp 2×10^0	Exp 4×10^0	Exp 8×10^0
3	0									1×10^0	2×10^0	4×10^0	8×10^0
4	0									1×10^1	2×10^1	4×10^1	8×10^1
5	0									1×10^2	2×10^2	4×10^2	8×10^2
6	0									DR	UR	--	--
7	0									FLAG	$\overline{\text{FLAG}}$	--	--
8	0								1×10^3	POL	DP1	"0"	
9	0									DP2	DP3	DP4	DP5

TABLE 3-11.
Truth Table for Function

Function	F_1	F_2
OHMS	0	0
COULOMB	0	1
AMPERE	1	0
VOLT	1	1

TABLE 3-12.
Truth Table for Programmed Sensitivity

Sensitivity	Manual Range	R_4	R_2	R_1
.01	0	0	0	0
.01	0	0	0	1
.01	0	0	1	0
.01	0	0	1	1
.1	0	1	0	0
1.	0	1	0	1
10.	0	1	1	0
100.	0	1	1	1

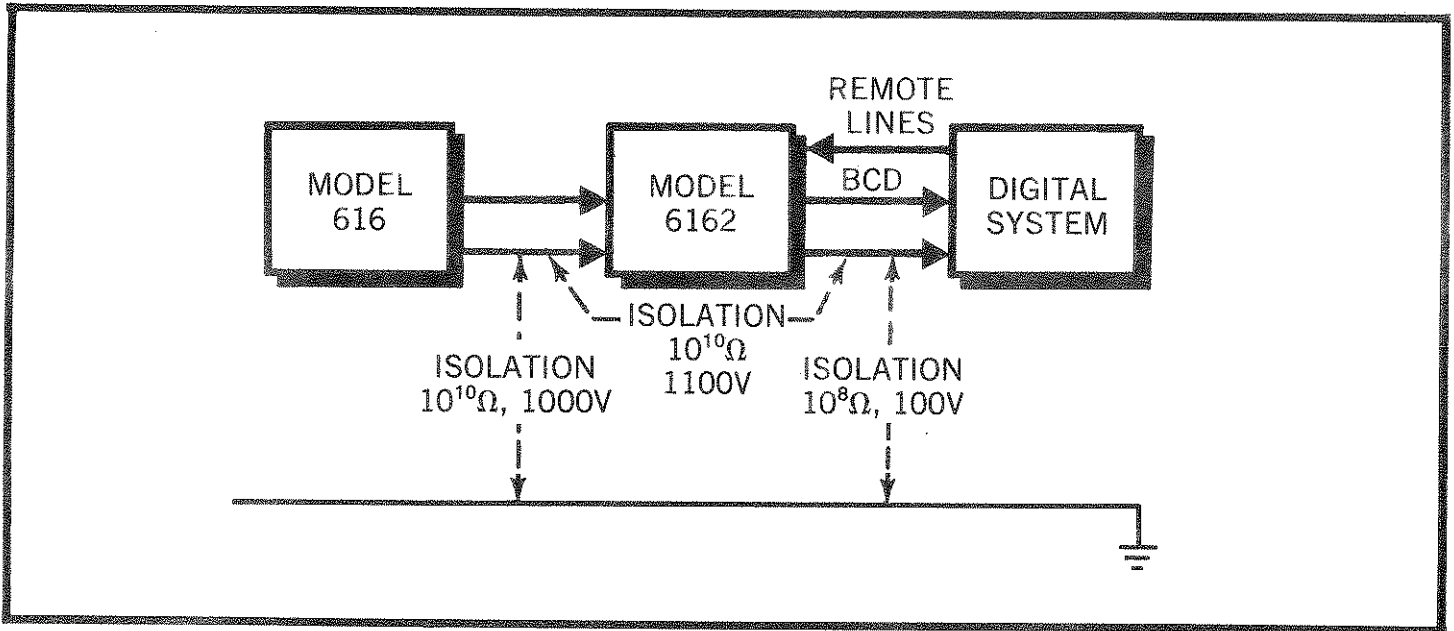


FIGURE 21. Block Diagram of 616/6162 System.

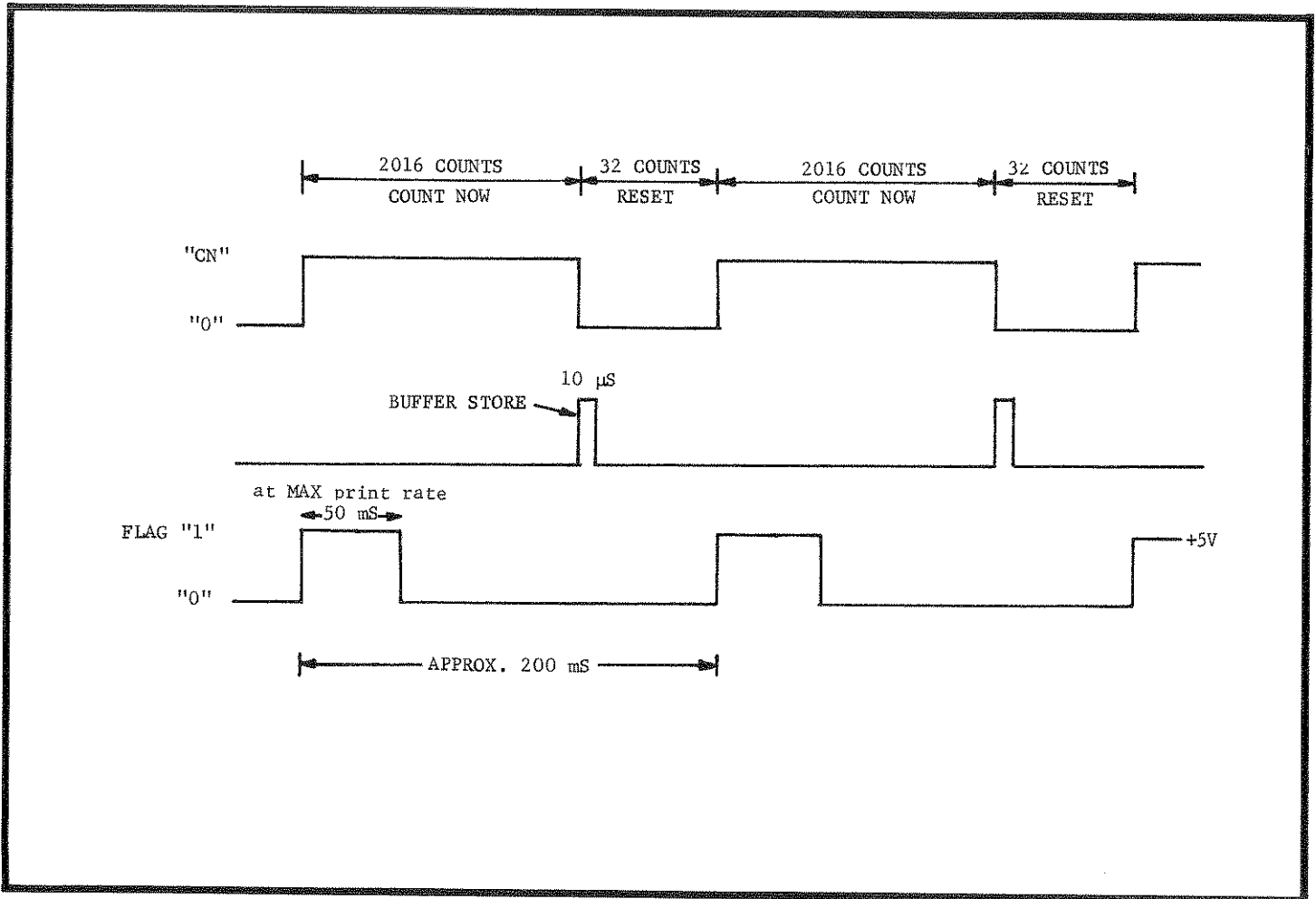


FIGURE 22. Timing Diagram for 6162 Outputs.