

INSTRUCTION MANUAL  
**MODEL 662**  
GUARDED DC  
DIFFERENTIAL VOLTMETER

## **WARRANTY**

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

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

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

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

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\* Yellow Change Notice sheet is included only for instrument modifications affecting the Instruction Manual.

## SECTION 1. GENERAL DESCRIPTION

### 1-1. DESCRIPTION.

a. The Keithley Model 662 Guarded dc Differential Voltmeter is an extremely precise self-contained, guarded potentiometer. It measures from 100 millivolts to 500 volts with 0.01% limit of error, and below 100 millivolts within 10 microvolts. Since the limit of error includes all stability considerations, the unit need not be periodically calibrated or manually restandardized for a full year. The 500-volt reference supply permits infinite impedance at null for measurements from 0 to 500 volts. Six dials assure that every voltage setting has at least 5-dial resolution.

b. Features for convenient use include: six in-line readout dials with automatically lighted decimal points; 10 to 25-millivolt recorder output; input polarity switch; floating operation up to 500 volts off chassis ground; line frequency rejection greater than 45 db. Also, full guarding minimizes leakage problems.

1-2. OPERATING MODES. The Model 662 can be used as a potentiometer or as a conventional vacuum tube voltmeter. As a potentiometer, it measures from 100 millivolts full scale to 500 volts with  $\pm 0.01\%$  limit of error and from 100 microvolts full scale to 100 millivolts within 10 microvolts. As a VTVM, the Model 662 measures from 1 millivolt full scale to 500 volts with an accuracy of  $\pm 3\%$  of full scale. It can also measure resistances from 1 megohm to 100,000 megohms within  $\pm 5\%$ .

### 1-3. APPLICATIONS.

a. The Model 662 meets exacting requirements in research, development and production for accurate voltage measurements. It can be used with a recorder to detect source instabilities down to 25 ppm over weeks of continuous measurements.

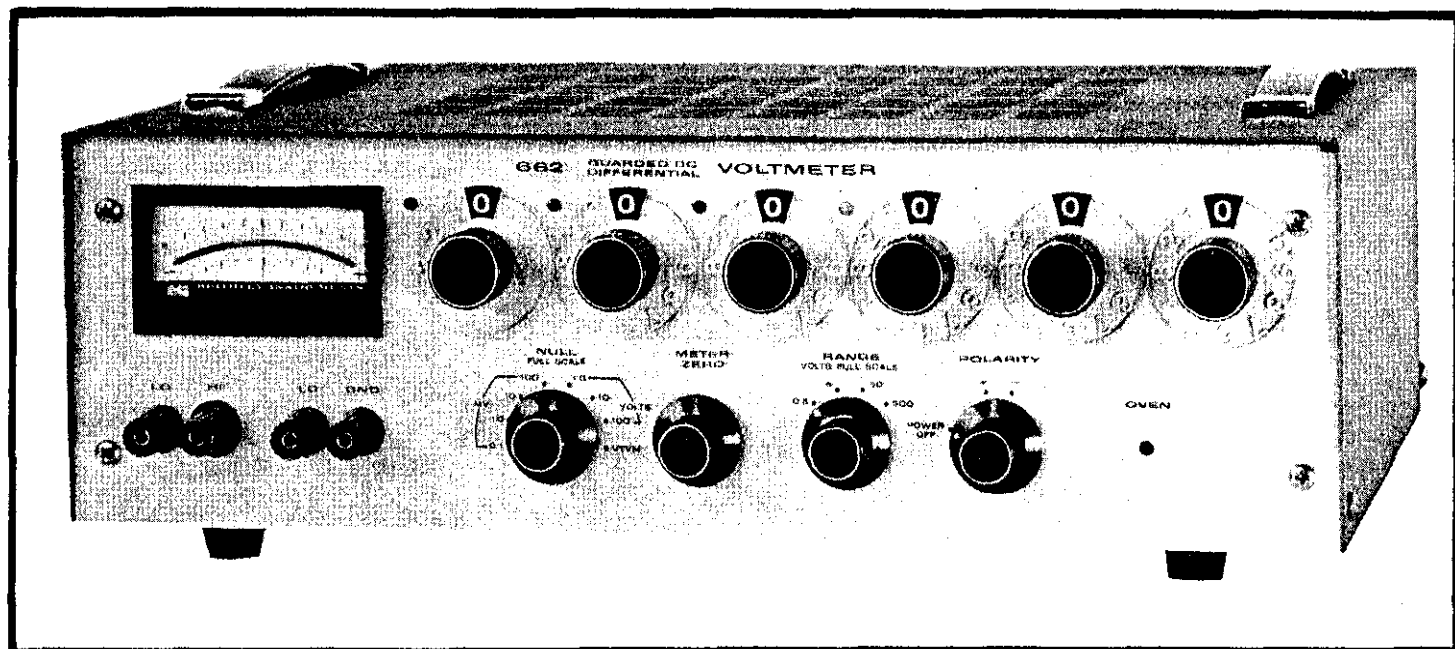


FIGURE 1. Keithley Instruments Model 662 Guarded dc Differential Voltmeter.

b. Typical applications include calibrating power supplies and meters; monitoring noise, transients and drift in precise voltage sources, such as zener diodes and electro-chemical cells.

c. The null-detector output permits use with potentiometric recorders and digital voltmeters equipped with automatic printout. The Model 662 is useful in quality control, product development, inspection and production.

#### 1-4. SPECIFICATIONS.

##### AS A POTENTIOMETER:

LIMIT OF ERROR:  $\pm 0.01\%$  of reading or 10 microvolts, whichever is greater, after 30-minute warm-up.

LONG-TERM STABILITY: Will operate within stated limit of error for one year.

TEMPERATURE COEFFICIENT: Does not exceed 0.001% per °C.

REPEATABILITY: Within 0.0025%.

MAXIMUM NULL SENSITIVITY: 100 microvolts full scale with 3-microvolt resolution.

INPUT RESISTANCE: Infinite at null, from 0 to 500 volts.

FLOATING OPERATION: 500 volts maximum off chassis ground.

INPUT ISOLATION: Circuit ground to chassis ground:  $10^8$  ohms shunted by 0.05 microfarad.

##### RESOLUTION CHART:

Input Voltage Range, volts	Maximum Dial Resolution, millivolts	Maximum Usable Full-Scale Null Sensitivity, millivolts	Meter Resolution, microvolts
50 - 500	1	1	10
5 - 50	0.1	0.1	3
0.5 - 5	0.01	0.1	3
0 - 0.5	0.01	0.1	3

##### AS A VACUUM TUBE VOLTMETER:

VOLTAGE RANGES: 0.5 volt full scale to 500 volts in four decade ranges.

NULL RANGES: 100 microvolts full scale to 100 volts in seven decade ranges.

VTVM ACCURACY:  $\pm 3\%$  of full scale on all ranges, except  $\pm 5\%$  on 100-microvolt range, exclusive of noise and drift.

ZERO DRIFT: Less than 10 microvolts per 24 hours, non-cumulative, after 30-minute warm-up.

INPUT RESISTANCE: 50 megohms, 0.5 to 500-volt ranges;  
10 megohms, 0.1-volt range;  
1 megohm, 0.1 to 10-millivolt ranges.

LINE FREQUENCY REJECTION: Greater than 45 db.

GENERAL:

LINE STABILITY: Better than 5 ppm for 10% change in line voltage.

RECORDER OUTPUT:

Output: Adjustable 10 to 25 millivolts dc for full-scale meter deflection.

Output Resistance: 300 ohms maximum.

Noise: 2 microvolts peak-to-peak referred to input up to 1 cps.

Note: Recorder used must have fully isolated input,  $10^{10}$  ohms minimum to ground.

POLARITY: Positive or negative, selectable by switch.

CONNECTORS: Input: Binding posts. Output: Banana jacks.

POWER: 105-125 or 210-250 volts (switch selected), 50-400 cps, 50 watts.

DIMENSIONS, WEIGHT: 5-1/2" high x 17-1/2" wide x 13-1/2" deep; net weight, 25 pounds.

1-5. ACCESSORIES.

a. Model 6601A High Voltage Divider is a 100:1 divider which extends the range of the Model 662 to 5000 volts. The divider accuracy is  $\pm 0.01\%$  and its input resistance is 10 megohms. The overall limit of error of the Model 662 with the Model 6601A is  $\pm 0.02\%$ . Section 7 gives operating instructions for the Divider.

b. Model 4000 Rack Mounting Kit, containing two brackets and a top cover, converts the Model 662 to fit standard 19-inch racks. Rack mounted, the Model 662 is 5-1/4 inches high x 19 inches wide x 13-1/2 inches deep. Section 7 has assembly instructions.

1-6. EQUIPMENT SHIPPED. The Model 662 Guarded dc Differential Voltmeter is factory-calibrated and is shipped with all components in place. All units are shipped for bench use. Model 4000 Kit may be ordered for rack mounting; refer to Section 7 for assembly instructions. The shipping carton also contains the Instruction Manual.

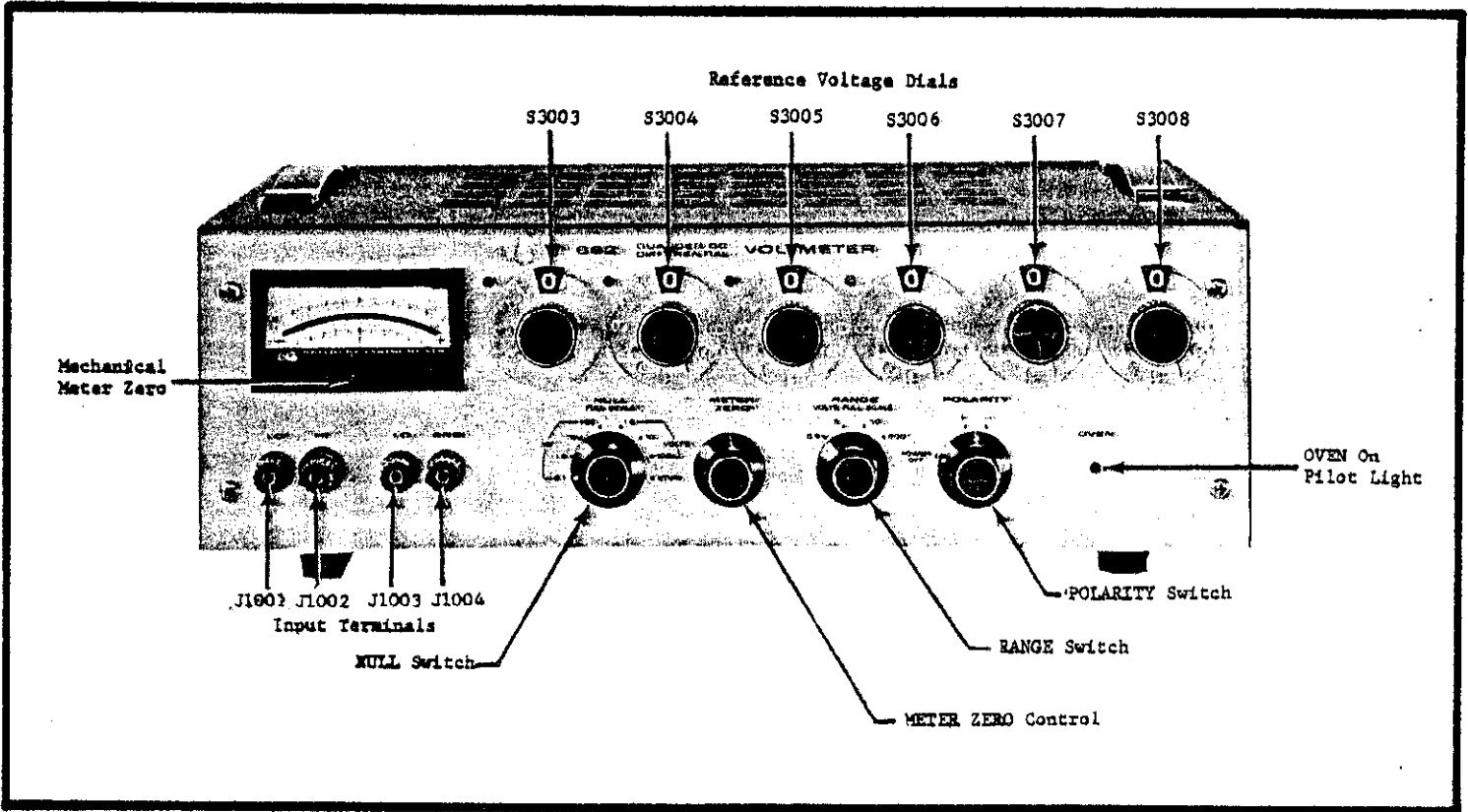


FIGURE 2. Model 662 Front Panel Controls and Terminals. Circuit designations refer to the Replaceable Parts List and the Schematic Diagram. Newer Model 662's have a toggle switch in place of the OVEN Pilot Light to turn on the instrument.

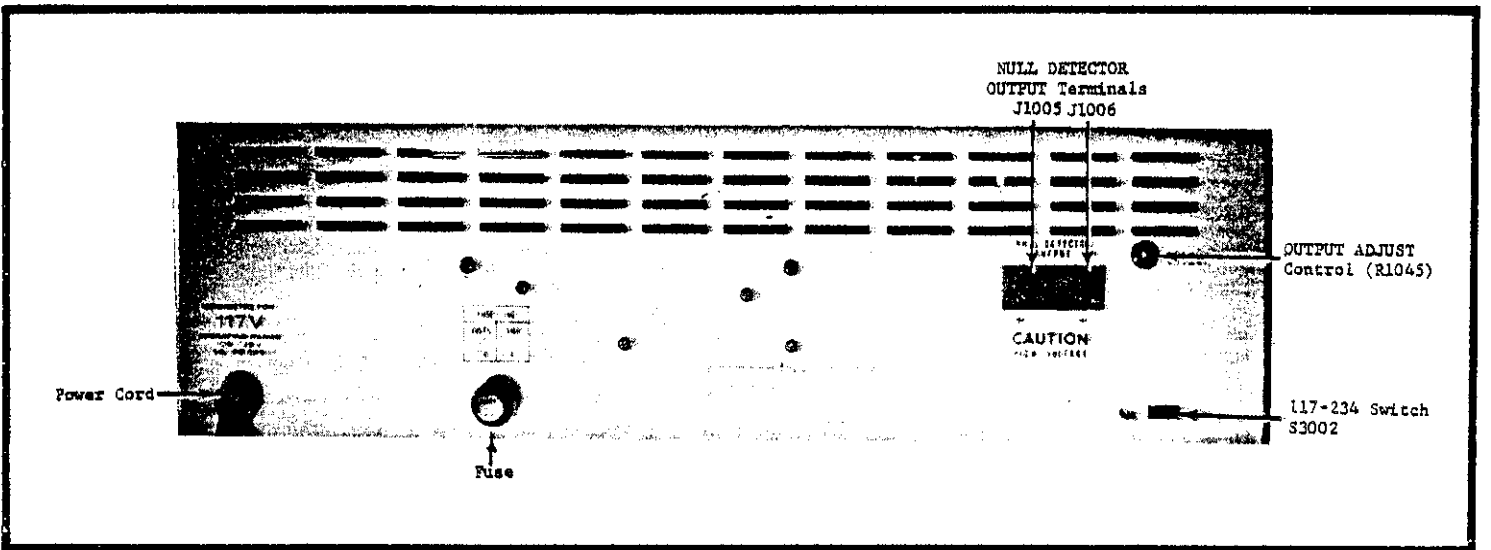


FIGURE 3. Model 662 Rear Controls and Terminals.

## SECTION 2. OPERATION

### 2-1. FRONT PANEL CONTROLS AND TERMINALS. (See Figure 2.)

a. **POLARITY Switch.** The POLARITY Switch selects the input polarity by reversing the polarity of the internal reference voltage supply; thus, both positive and negative voltages may be measured. The Switch does not reverse meter polarity. On older models, the Polarity Switch also turns the instrument on. Newer models have a toggle switch.

b. **NULL Switch.** The NULL Switch sets the null detector sensitivity for seven decade ranges from 0.1 millivolt full scale to 100 volts. When the Switch is in the VTVM position, the Model 662 operates as a conventional vacuum tube voltmeter for the four ranges of the RANGE Switch.

c. **RANGE Switch.** The RANGE Switch adjusts VTVM sensitivity in four steps: 0.5, 5, 50 and 500 volts full scale. It also determines the voltage across the Kelvin-Varley divider and the position of the decimal point light — which also serves as a pilot light — between the six Reference Voltage Dials.

d. **Reference Voltage Dials.** Six in-line dials at the top of the front panel set the reference voltage when the Model 662 is used as a potentiometer.

e. **METER ZERO Control.** The METER ZERO Control adjusts the meter needle to zero. The Control is needed on only the 0.1 and 1.0-millivolt null ranges; on the other ranges, the needle will normally be on zero without adjustment. The Control has a range of approximately  $\pm 30$  microvolts.

f. **Input Terminals.** The red HI Post is for connections to the high impedance terminal and the black LO Post is for connections to the low impedance terminal of the unknown voltage. A second set of binding posts marked LO and GND is provided for grounding the LO input terminal to the chassis when desired. The LO terminals are connected together internally.

#### NOTE

Older models have an OVEN Pilot Light which indicates when the oven controlling the temperature for the zener diode in the reference voltage supply is on. The slight clicking sound is characteristic of the oven cycling.

### 2-2. REAR CONTROLS AND TERMINALS. (See Figure 3.)

a. **Fuse.** For 105-125 volt operation, the Model 662 uses a 1-ampere 3 AG fuse. For 210-250 volt operation, the Model 662 uses a 0.5-ampere 3 AG fuse.

b. **Power Cord.** The 3-wire power cord with the NEMA approved 3-prong plug provides a ground connection for the cabinet. A 3:2 prong adapter is also provided.

c. **NULL DETECTOR OUTPUT.** Two terminals, marked + and -, supply a dc signal from the null detector.

d. **OUTPUT ADJUST.** A screwdriver control next to the OUTPUT terminals adjusts the null detector output between 10 and 25 millivolts full scale.



e. 117-234 Switch. The screwdriver-operated slide switch sets the Model 662 for 117 or 234-volt ac power lines.

### 2-3. PRELIMINARY PROCEDURES.

a. Check the 117-234 Switch and the Fuse for the proper ac line voltage. Connect the power cord.

b. Set the Model 662 as follows:

RANGE Switch	500
NULL Switch	VTVM
POLARITY Switch	+
Reference Voltage Dials	Zero

The decimal light between the third and fourth Dials will light. Allow the instrument to warm up for 30 minutes to meet the specified accuracy on all ranges.

c. With the input terminals open, set the NULL Switch to 0.1 MV and zero the meter with the METER ZERO Control. Then return the NULL Switch to VTVM. The stability of the Model 662 is such that no adjustment should be required after a 30-minute warm-up.

### 2-4. OPERATING PROCEDURES.

a. The Model 662 is used first as a VTVM to determine the approximate value of the unknown voltage. It is then used in the potentiometric mode to determine the voltage to  $\pm 0.01\%$ .

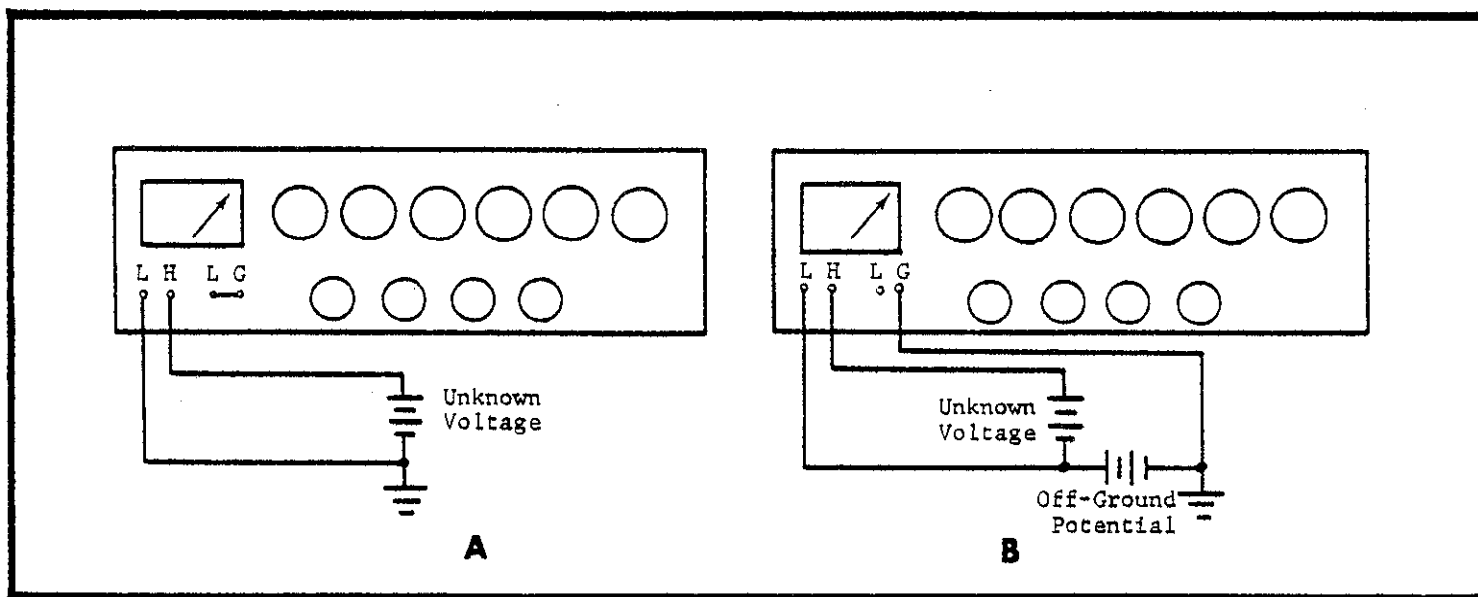


FIGURE 4. Input Connections to Model 662. The two diagrams show the input circuit for measuring at ground and for floating.

In A, the unknown voltage has one terminal at ground. The shorting link is between the LO and GND Posts of the Model 662.

In B, the unknown voltage has both terminals off ground potential. Note this floating or off-ground potential must be less than 500 volts. Also note the shorting link is not used.

## NOTE

The Model 6601A High Voltage Divider extends the Model 662 range to 5000 volts. Refer to Section 7 for operating instructions.

## b. VTVM Operating Procedures.

1. Eleven full-scale ranges are available for VTVM operation. When the NULL Switch is at VTVM, the RANGE Switch determines one of four full-scale ranges. By putting the six Reference Voltage Dials at zero, the Model 662 can then operate as a VTVM on the seven null ranges.
2. Connect the unknown voltage to the input terminals, using the LO Post for the low impedance terminal of the unknown. Refer to Figure 4.
3. Switch the RANGE Switch to the most sensitive range for an on-scale meter deflection.

## c. Potentiometric Operating Procedures.

## NOTE

Avoid large overload voltages on the null detector. No permanent damage will occur even with 500-volt overloads, but some open circuit offset will be caused in the null detector. The offset, due to the polarization of the input filter capacitors, will disappear after about five minutes.

1. Leave the RANGE Switch at the last setting used in the VTVM operation. If the VTVM reading is negative, reverse the POLARITY Switch position.
2. Set the first two Reference Voltage Dials to the first two digits of the unknown voltage found in the VTVM operation.

3. Set the NULL Switch to the initial null setting shown in Table 1. Adjust the Voltage Reference Dials progressively for zero meter deflection while increasing the null detector's sensitivity with the NULL Switch. Deflections to the right indicate the voltage being measured is more positive than the Reference Voltage Dial setting.

RANGE Switch Setting	Initial NULL Switch Setting	Most Sensitive NULL Switch Setting
500 V	100 V	10 MV
50 V	10 V	1.0 MV
5 V	1 V	0.1 MV
0.5 V	100 MV	0.1 MV

TABLE 1. Recommended Null Sensitivities and Settings.

## NOTE

The most accurate resistors in the Kelvin-Varley divider are in the first two Reference Voltage Dials. Therefore, to obtain the most accurate readings, use the first two dials as much as possible.

4. The value of the unknown voltage is read directly from the Reference Voltage Dials.
  - a) The Dial reading will be within the specified limit of error if the NULL Switch

is at the most sensitive setting (Table 1) for the range used and if the meter indicates as close to null as possible. Null does not have to be reached.

b) Readings can be made from only five Reference Voltage Dials to be within specifications ( $\pm 0.01\%$  of reading or 10 microvolts). Using the sixth Dial allows the instrument to approach null closer, further reducing loading effects upon the source.

## 2-5. RECORDER OUTPUT.

a. Recommended recorders for use with the Model 662 are the F. L. Moseley Autograf 680 series recorder and the Minneapolis Honeywell recorder (10mv-0-10mv scale, 50 kilohms input resistance). Any recorder used must be able to float 500 volts off ground and its input must be fully isolated ( $10^{10}$  ohm minimum leakage resistance to ground).

b. Before attaching the recorder, set all Reference Voltage Dials to zero. Disconnect the unknown voltage and short both Model 662 input terminals. Set the NULL Switch to 10 MV. Connect the recorder to the OUTPUT terminals on the Model 662 rear panel.

c. Set the Reference Voltage Dials to 10 millivolts to apply an accurate 10-millivolt potential to the null detector on the 10-millivolt null range. This will provide a full-scale recorder output which can be matched to the recorder's range between 10 and 25 millivolts by adjusting the OUTPUT ADJUST Control.

d. To obtain accurate results and/or to prevent damage to the instruments, the recorder must be able to float off-ground with the Model 662. Leakage and pickup between the two instruments should also be minimized.

1. Make sure neither recorder terminal is grounded. Use a 3-wire grounded power line for the recorder. If a 2-wire line is used, connect the recorder chassis and the Model 662 chassis with a separate lead.

2. Minimize all sources of leakage between the output terminals, the recorder and ground. Use polystyrene or Teflon-insulated wire where possible. If the connecting wires are shielded, connect the shield to the LO Post.

3. Avoid long leads between the Model 662 and the recorder.

4. If difficulty is encountered in off-ground measurements, such as unstable readings, connect a 10-microfarad capacitor between the LO and GND terminals on the Model 662 front panel.

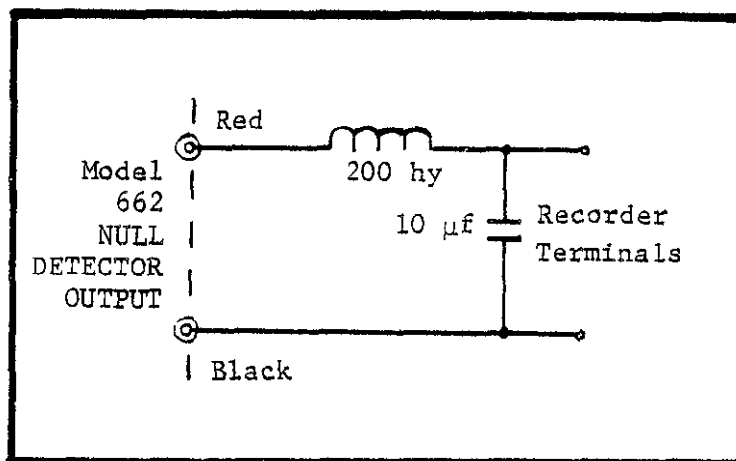


FIGURE 5. Recorder Filter. A filter between the Model 662 and the recorder may be necessary when using the 0.1-millivolt null detector range.

### NOTE

Do not short either Model 662 output terminal to the case; this may damage the Kelvin-Varley divider.

e. If there is substantial recorder jitter on the 0.1-millivolt null range, place a filter between the Model 662 and the recorder. Refer to Figure 5 for this connection. Note the filter must also be insulated from ground.

#### 2-6. EFFECTS DUE TO KELVIN-VARLEY OUTPUT RESISTANCE.

a. When the Model 662 is used for nulling on the 0.1-millivolt range, the last Reference Voltage Dial may appear to be inaccurate. The apparent error is due to a voltage drop across the Kelvin-Varley divider. This effect involves only the null detector sensitivity and not the accuracy of the Dial setting. When the Model 662 is as near to null as possible, the Reference Voltage Dial setting is correct within the instrument's specified limit of error. There is no effect present at null.

b. The effect is most apparent on the 0.1, 1 and 10-millivolt null ranges. For example, on the 0.1-millivolt range a 0.1-millivolt off-null setting of the reference voltage will not produce a full-scale meter deflection. This is because the Kelvin-Varley divider output resistance is significant compared to the shunt resistance across the null detector meter. The IR drop across the divider will cause the meter to be off up to 6%, depending upon the Reference Voltage Dial settings. On the 100-millivolt range the maximum error is 1%. The effect cannot be observed on the other null ranges of the Model 662.

c. The amount of deflection on the meter is equal to the ratio

$$\frac{R_n}{R_n + R_{KV}}$$

where  $R_n$  is the shunt resistance across the meter (50 megohms for the 100 to 1-volt null ranges, 10 megohms for the 100-millivolt range, and 1 megohm for the 10 to 0.1-millivolt ranges);

$R_{KV}$  is the output resistance of the Kelvin-Varley divider, which is a maximum of 62.4 kilohms at Reference Voltage Dial settings of 2 4 5 4 5 5 and 2 5 4 5 5 5 and a minimum of 100 ohms at settings of 4 9 9 9 8 and 0 0 0 0 2.

#### NOTE

For a fuller treatment of the effect source resistance has on measurements, send for the Keithley Instruments Product Note, "The Effective Input Resistance of Potentiometric Voltmeters."

#### 2-7. EFFECTIVE INPUT RESISTANCE.

a. The input resistance of the voltmeter for the seven null ranges varies from 50 to 1 megohm as given in Table 2. This, however, is not the Model 662's effective input resistance. Its input resistance is considerably higher due to the potentiometric principle of operation. When the reference voltage (Reference Voltage Dial setting) is much greater than the meter reading, the value is:

$$R_{in} = \frac{E_d R_n}{V} \quad \text{Equation 1}$$

where  $R_{in}$  is the effective input resistance of the Model 662;  
 $E_d$  is the setting of the Reference Voltage Dials in volts;  
 $R_n$  is the shunt or input resistance of the null detector meter in ohms;  
 $V$  is the null detector meter reading in volts.

b. To find the loading effect the Model 662 will have on a circuit, use equation 1 to compute the effective input resistance. At null, where  $V=0$ , the input resistance is infinite. Off null, the input resistance is usually high compared to the internal resistance of the unknown voltage, and loading will not be enough to affect the measurement accuracy. The graph in Figure 6 shows the Model 662 effective input resistance for the three most sensitive null ranges as a percent of meter reading off null ( $V/E_d$ ).

2-8. THERMAL EMF PRECAUTIONS. Observe standard thermocouple techniques to reduce thermal emf errors for measurements using the most sensitive null ranges. Since the Model 662 can read to 3 microvolts, thermal emf's can introduce considerable errors into the measurements. In general, use pure copper leads throughout the system when measuring in the microvolt range. For extensive measurements in the microvolt region, request the article, DC Microvolt Measurements, from Keithley Instruments, Inc., or its representative.

2-9. AC EFFECTS ON MEASUREMENTS. To minimize errors from ac signals present in the unknown voltage, the Model 662 employs a chopper-stabilized null detector operating at a 42-cps chopping rate with a 3-section R-C filter at the input. Very large ac components on the measuring lines, however, may reduce off-null sensitivity. Also, heavy 60-cps pickup will be observed as needle quiver. If ac components affect measurements by the Model 662, additional filtering is required. For a single-frequency ac signal, a twin-T filter is effective. For a variable frequency signal, use an ordinary low-pass filter.

Voltage Range	Input Resistance
300 volts	50 megohms
50 volts	50 megohms
5 volts	50 megohms
0.5 volts	50 megohms
Null Range	Input Resistance (Slewing)
100 volts	50 megohms
10 volts	50 megohms
1 volt	50 megohms
100 millivolts	10 megohms
10 millivolts	1 megohm
1 millivolt	1 megohm
0.1 millivolt	1 megohm

TABLE 2. Model 662 VTVM Input Resistance by Ranges. Resistance for Null Ranges is when the Reference Voltage Dials are set to zero.

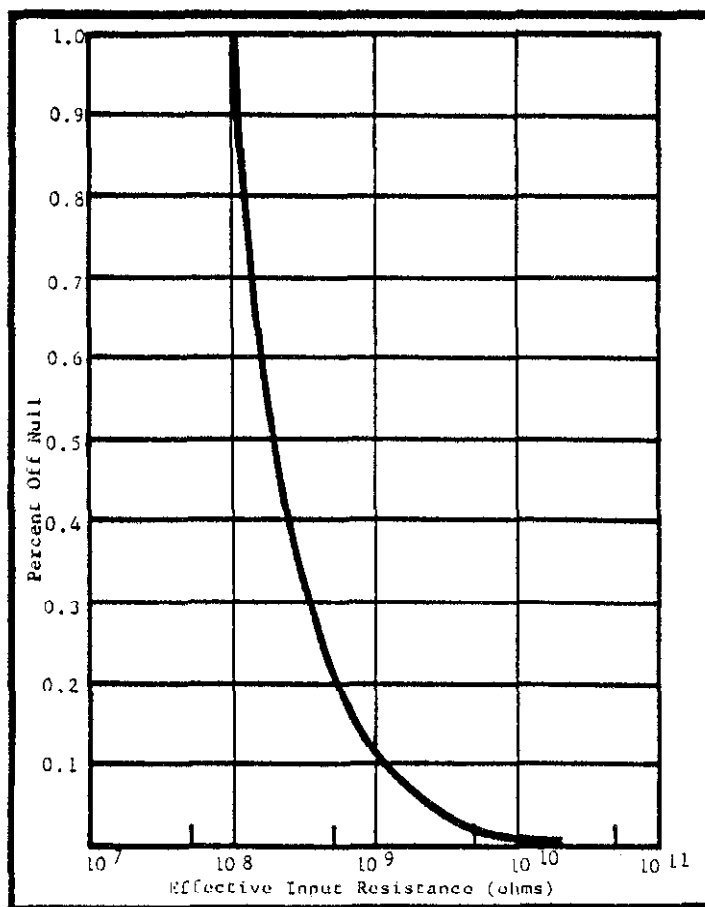


FIGURE 6. Model 662 Off-Null Effective Input Resistance. The graph shows the effective input resistance for the 0.1 to 10-millivolt ranges. Percent off null is  $V/E_d$  as defined in Equation 1.

## SECTION 3. APPLICATIONS

3-1. PROCEDURES FOR MEASURING RESISTANCES. The Model 662 can be used to rapidly measure resistances from 1 megohm to 100,000 megohms with an accuracy of  $\pm 5\%$ . To measure resistance, connect the unknown resistor across the Model 662 HI and LO terminals. Use a short isolated lead to the HI terminal to prevent measuring leakage between the leads. Set the RANGE Switch to 500. Then determine the value of the resistor as follows:

a. For resistances between 1 megohm and 1000 megohms, set the NULL Switch to 10 volts; adjust the Reference Voltage Dials to obtain a full-scale meter deflection. Subtract 10.000 from the Dial setting and multiply the difference by 5 to obtain the value of the resistor in megohms.

b. For resistances between 1000 megohms and 10,000 megohms, set the NULL Switch to 1 volt; adjust the Reference Voltage Dials to obtain a full-scale meter deflection. Subtract 1.0000 from the dial setting and multiply the difference by 50 to obtain the value of the resistor in megohms.

c. For resistances between 10,000 megohms and 100,000 megohms, set the NULL Switch to 1 volt; adjust the Reference Voltage Dials to obtain a convenient deflection on the meter. Calculate the value of the resistor using,

$$R_x = \frac{50 E_d}{V} \text{ megohms} \quad \text{Equation 2}$$

Where  $R_x$  is the unknown resistance;  
 $E_d$  is the Reference Voltage Dial setting in volts;  
 $V$  is the meter reading in volts.

3-2. THEORY OF MEASURING RESISTANCES. The above method for determining the value of an unknown resistor is based upon the equation for the circuit. (See Figure 7.) If an unknown resistance is across the Model 662 input terminals, then

$$E_d = i (R_x + R_n) \quad \text{Equation 3}$$

Where  $E_d$  is the Reference Voltage Dial setting in volts;  
 $i$  is the current in the circuit;  
 $R_x$  is the unknown resistance;  
 $R_n$  is the input resistance of the null detector meter in ohms.

The current can be written  $i = V/R_n$ , where  $V$  is the null detector meter reading in volts. Equation 3 now becomes

$$R_x = R_n \left( \frac{E_d}{V} \right) - R_n \quad \text{Equation 4}$$

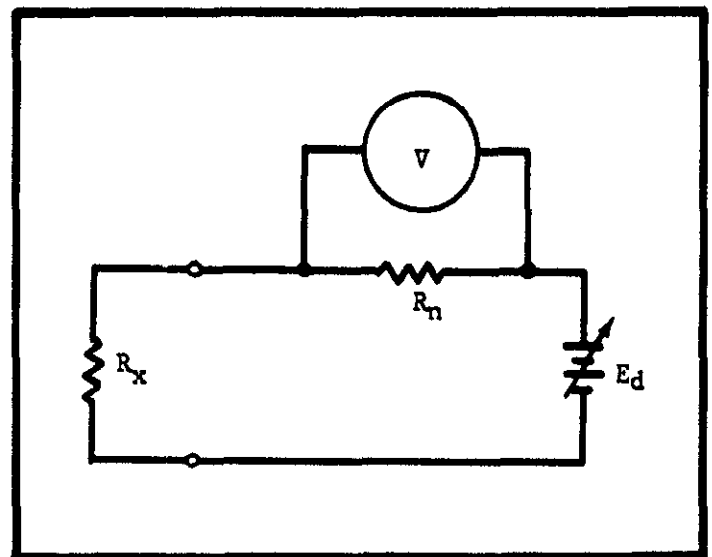


FIGURE 7. Simplified Model 662 Circuit for Measuring Resistances.  $R_x$  is the unknown resistance.  $R_n$  is the input resistance of the null detector;  $V$  is the null detector;  $E_d$  is the buckout voltage.

If measurements are made on the 1 to 100-volt null ranges, the input resistance,  $R_n$ , is 50 megohms. Equation 4 becomes

$$R_{xx} = 5 \times 10^7 \left( \frac{E_d}{V} - 1 \right) \quad \text{Equation 5}$$

This is the basis for the simplified calculations in paragraph 3-1.

## SECTION 4. CIRCUIT DESCRIPTION

4-1. GENERAL. The Model 662 Differential Voltmeter measures voltage by the potentiometric (null) method. The variable known voltage is an ultra-stable 500-volt reference supply used in conjunction with a precision multi-dial Kelvin-Varley divider. Electronic referencing of the 500-volt output to a zener diode standard maintains the reference supply's stability and accuracy. This method eliminates repeated manual standardization. The difference between the divider output and the unknown voltage is indicated by the null detector, a chopper-stabilized vacuum-tube voltmeter. At null the unknown voltage can be read directly from the in-line dials of the Kelvin-Varley divider. The input and null detector are fully guarded to avoid leakage.

### NOTE

Refer to Schematic Diagram 18551E for circuit designations.

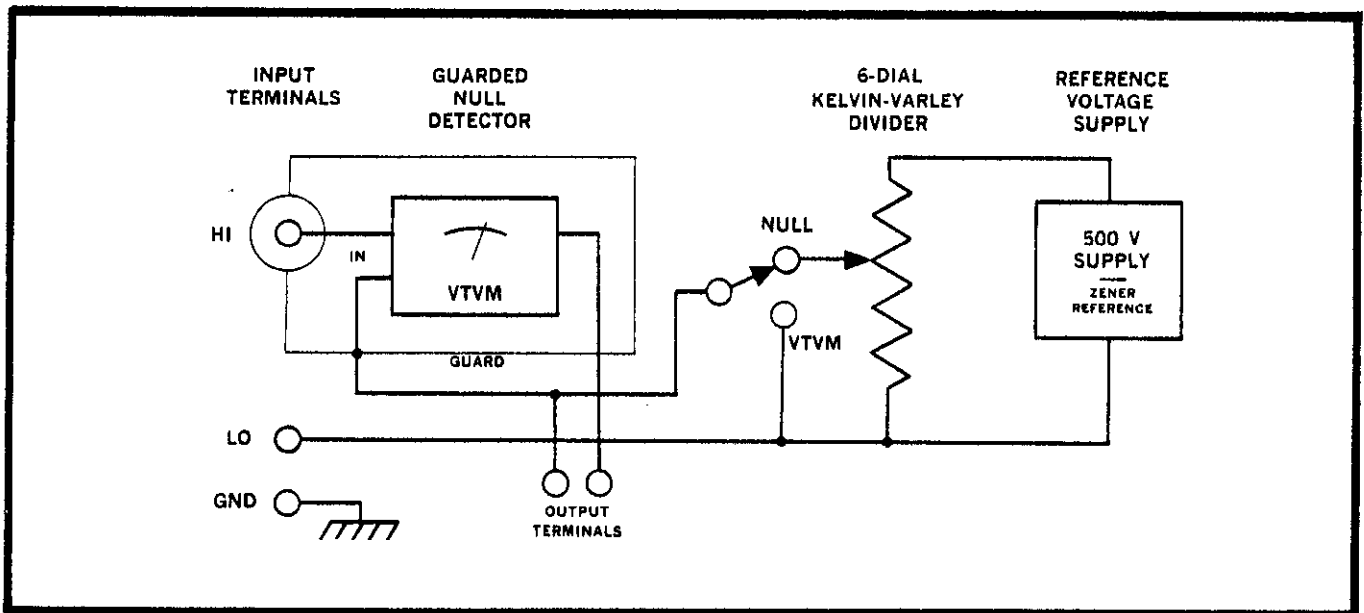


FIGURE 8. Simplified Model 662 Circuit Diagram.

### 4-2. REFERENCE VOLTAGE SUPPLY.

a. Unregulated voltage from transformer T3001 is rectified by a silicon half-wave rectifier, D3001, and is filtered by capacitors C3001 and C3002. The voltage then is applied to the regulator series pass tube, V3004. Regulator tube V3005 is used to keep the screen of V3004 at a constant potential.

b. To obtain a stable, accurate voltage, the 500-volt output of V3004 is sampled by a divider network of wirewound resistors, R3023 to R3028. The divider network ratio is adjusted with potentiometer R3025 to better than 0.01%. Light modulator E3002 compares the sample voltage from the divider network to the voltage across zener diode D3003. Any difference between the two voltages is chopped by E3002 and amplified by a two-stage ac-coupled amplifier, V3001. The amplified output of V3001 is converted to a dc signal by light mod-



ulator E3001 and then is amplified by the two-stage differential dc amplifier, V3002 and V3003. The amplifier output is applied to the grid of the series tube, V3004, to nullify input variations. Capacitor C3004 is used in the ac feedback circuit.

c. An ultra-stable zener diode, D3003, is used as the basic reference; typical variations are limited to less than 10 ppm/°C. Thus, a highly stable reference which eliminates manual standardization is provided with respect to both time and temperature. The zener diode will also withstand shock and vibration.

d. The regulated 500-volt output of V3004 is either applied directly to the Kelvin-Varley divider or it is divided to 50, 5 or 0.5 volts by very stable wirewound resistor networks. The RANGE Switch, S3010, determines which network is used. The 50-volt range divider consists of resistors R3030, R3032 and R3033; the 5-volt, of R3030, R3035 and R3036; and the 0.5-volt of R3030, R3038 and R3039. Using potentiometers R3032, R3035 and R3038 accurately sets the voltage division on each range.

#### 4-3. KELVIN-VARLEY DIVIDER.

a. The Kelvin-Varley divider precisely divides the reference voltage for nulling an unknown voltage. It is, in effect, a constant input impedance decade potentiometer, consisting of resistors R3040 through R3099. The resistors within each decade are matched; the decades are matched for each instrument.

b. Each decade of the Kelvin-Varley divider, except the first, R3040 through R3045, parallels two resistors of the preceding string. Between the two contacts of the first Reference Voltage Switch, S3003, the total resistance is 40 kilohms (80 kilohms in parallel with the 80 kilohms total resistance of the four remaining strings). With the RANGE Switch set at 500, 100 volts dc will appear across the contacts of Reference Voltage Switches S3004, 10 volts across S3005, 1 volt across S3006, 0.1 volt across S3007 and 0.01 volt across S3008.

4-4. NULL DETECTOR. The Model 662 uses a null detector with a chopper stabilized, feedback amplifier. The input signal is attenuated, if necessary, and sent through a three-stage R-C filter. The signal is then amplified and applied to the meter.

a. The null detector has three full-scale sensitivities, 0.1, 1 and 10 millivolts. Above the 10-millivolt range, the input is divided by resistors R1004 through R1009 to the 10 millivolts. The full-scale sensitivities are determined by one of three feedback resistors, R1040 to R1042, in the circuit. A three-stage R-C filter, consisting of R1010, R1011, C1003, R1012, C1004, R1018 and C1005, decreases the ac input components.

b. The light modulators E1001 and E1002 convert the difference between the filtered input voltage and the output of the Kelvin-Varley divider into an ac voltage, which is fed to a four-stage ac coupled amplifier, V1001 and V1002. The amplifier output is then demodulated by light modulator E1003 and filtered by capacitor C1019. The null detector meter, M1001, indicates the value of the filtered signal. A 42-cps oscillator drives the light modulators. Using a drive source harmonically unrelated to the standard line frequency minimizes 60-cps pickup effects.

c. One arm of the feedback network is formed by resistors R1043 to R1046, and one of the feedback range resistors, R1040 to R1042. Resistor R1039 forms the second shunt arm. The feedback is applied to light modulator E1002.

d. A zero-control network is used to buck out thermal emf's at the input on the two

most sensitive ranges. The network consists of a 1.34-volt mercury battery, BT1001, and resistors R1013 through R1016. The zero control on the front panel, R1016, has approximately a 60-microvolt span.

e. The null detector output is obtained across resistors R1045 and R1046, which are in the feedback network. Potentiometer R1045 adjusts the output from 10 to 25 millivolts at full scale. The output voltage is proportional to the full-scale meter reading.

4-5. GUARDING. Guarding is accomplished by floating the null detector and the input circuitry at a voltage equal to the input voltage from a low impedance source. This full guarding eliminates leakage between the input terminal and ground. Such leakage in an unguarded circuit is difficult to avoid, even under laboratory conditions, and can result in sizeable errors. For example, in an unguarded circuit with a 1-megohm source, leakage of  $10^8$  ohms will introduce 1% error. A guarded circuit eliminates this element of error.

### SECTION 5. SERVICING

5-1. GENERAL. Section 5 contains the maintenance and troubleshooting procedures for the Model 662. Follow these procedures as closely as possible to maintain the accuracy and stability of the instrument.

5-2. SERVICING SCHEDULE. The Model 662 needs no periodic maintenance beyond the normal care required of high-quality electronic equipment. No part should need replacement under ordinary use except a pilot lamp, fuse or, occasionally, a vacuum tube.

5-3. PARTS REPLACEMENT.

a. The Replaceable Parts List in Section 8 describes the electrical components in the Model 662. Replace components only as necessary, and use only reliable replacements which meet the specifications.

b. Replace resistors within any one of the first three Kelvin-Varley divider decades only as an assembly. Refer to the Replaceable Parts List for the part number for resistors R3040 to R3099. Resistors R3023, R3024 and R3026 and resistors R3033, R3036 and R3039 are also parts of assemblies. Reorder using the Keithley part number (see Section 8) and replace all resistors in the assembly. Because of its importance in maintaining the power supply stability, order zener diode D3003 only from Keithley Instruments, Inc., or its representative. Refer to paragraph 5-6 for instructions to replace the zener.

5-4. TROUBLESHOOTING.

a. The following procedures are for repairing troubles which might occur in the Model 662. Use these procedures to troubleshoot and use only specified replacement parts. Table 3 lists equipment recommended for troubleshooting. If the trouble cannot be readily located or repaired, contact Keithley Instruments, Inc., or its representative.

b. Paragraph 7-2 describes how to remove the Model 662 cover. Before proceeding with the troubleshooting, check the vacuum tubes. Normally, replacing tubes will clear up the difficulty. All tubes can be readily tested on a grid-modulated tube tester. If replacing a tube does not correct the trouble, continue the procedures. Replacing tubes does not necessitate recalibration of the instrument.

c. Table 4 contains the more common troubles which might occur. If the repairs indicated in the Table do not clear up the trouble, the difficulty will have to be found through

Instrument	Use
Tektronix Type 503 Oscilloscope	Check wave forms
dc voltmeter, 10% accuracy, minimum 100-megohm input resistance, 1 volt to 500 volts	Circuit checking
Grid-modulated tube tester	Test vacuum tubes

TABLE 3. Equipment Recommended for Model 662 Troubleshooting. Use these instruments or their equivalents.

Difficulty	Probable Cause	Solution
Needle quiver	R1048 is out of adjustment	Adjust per paragraph 5-5
Meter rattle, drift or error is observed on all null ranges	Tube V1001, V1002 or V2001 is faulty	Check tubes; replace if faulty
Line voltage variations cause measurements to be out of specifications	Tube V3005 is defective	Check tube; replace if faulty
Reference voltage supply drifts after 30-minute warm-up, requiring frequent adjusting of the range controls, R3025, R3032, R3035, R3038	V3001, V3002, V3003 or V3007 is defective	Check tubes; replace if faulty
	One of the divider resistors, R3023 to R3028, is changing value rapidly during warm-up	Return the instrument for factory check-out
	Zener diode, D3003, is unstable	Return the instrument for factory check-out
	Light modulator E3002, is defective	Check light modulator by replacing
Measurements out of tolerance on all ranges	Out of calibration	Refer to paragraph 6-4 for recalibration
	One of the divider resistors, R3023 to R3028, is faulty	Return the instrument for factory check-out
Measurements are out of specifications on one range other than 500-volt range	Resistor in the range divider network is faulty	Paragraph 4-2 d points out the resistors used for each range. Try to bring the ranges within specifications by calibrating with the potentiometers in the network. See paragraph 6-4. If this does not work, check individual resistors
Measurements are out of specifications on all ranges other than 500-volt range	Resistor R3030 is faulty	Replace the faulty resistor

TABLE 4 (Sheet 1). Model 662 Troubleshooting.

Difficulty	Probable Cause	Solution
Measurements are out of specifications on any range when the Reference Voltage Dials are at any setting other than 4 9 9 9 10	One of the Kelvin-Varley divider resistors is faulty	See paragraph 6-3
Instrument is out of specifications on all null ranges above 10 millivolts	Resistor R1003 is faulty	Check resistor; replace if faulty

TABLE 4 (Sheet 2). Model 662 Troubleshooting.

a point-by-point check of the circuits. Refer to the circuit description in Section 4 to find the more crucial components and to determine their function in the circuit. The complete circuit schematic, 18551E, is found in Section 8.

#### 5-5. ADJUSTING HUM BAL CONTROL.

a. Potentiometer R1048 (Figure 20) minimizes 60-cps pickup in the null detector. Misadjustment will reduce sensitivity and cause needle quiver.

b. To adjust the potentiometer, set the Reference Voltage Dials to zero and short the input terminals. Attach an oscilloscope to the junction of capacitor C1016 and resistor R1035 (from pin 6 of V1002). Figure 9 shows the wave form if potentiometer R1048 is adjusted for minimum output.

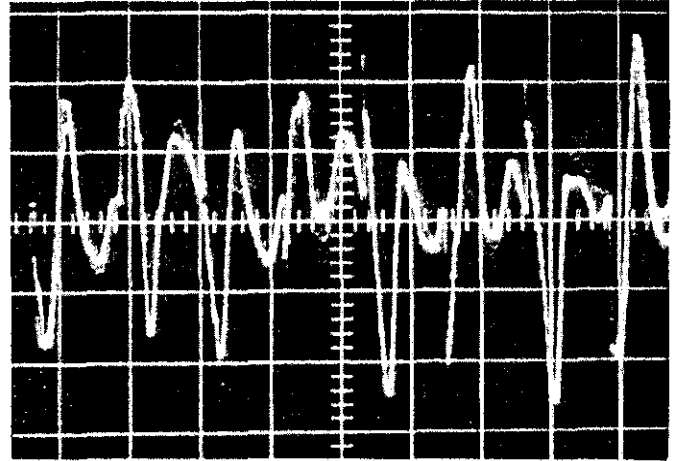


FIGURE 9. Wave Form with R1048 Adjusted. A Type 503 Oscilloscope was used; horizontal sweep was 20 msec/cm; vertical, 10 v/cm.

5-6. ZENER DIODE REPLACEMENT. Zener diode, D3003, is a reference for the voltage divider, resistors R3023 to R3028. The values of resistors R3027 and R3028 (Figure 22) are determined by the reference voltage across diode D3003. When the zener is replaced, the value of these two resistors may have to be changed.

#### 5-7. METER ADJUSTMENT.

a. Potentiometer R1043 (Figure 20) is the internal meter sensitivity adjustment. It sets the current through the meter to indicate a full-scale deflection for a full-scale applied voltage.

b. Warm up the Model 662 for 30 minutes. Set the NULL Switch on the 0.1-millivolt range and set the Reference Voltage Dials to .000100. Adjust potentiometer R1043 until the meter reads full scale.

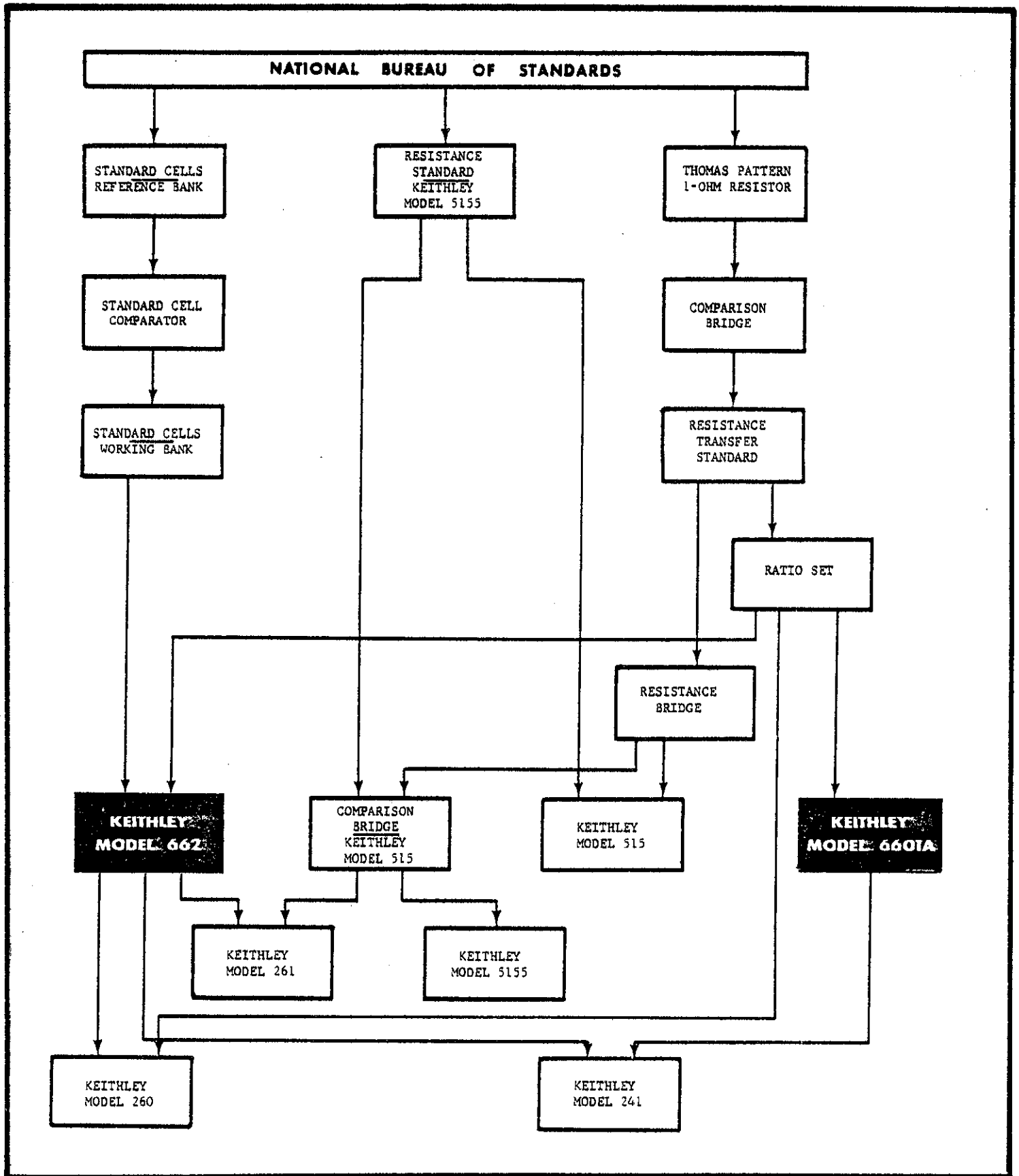


FIGURE 10. Models 662 and 6601A Traceable Chart to National Bureau of Standards. Other Keithley instruments are also shown.

## SECTION 6. CALIBRATION

## 6-1. GENERAL.

a. The following procedures are recommended for calibrating the Model 662. Use the equipment recommended in Table 5. If proper facilities — especially important for calibrating an  $\pm 0.01\%$  instrument — are not available or if difficulty is encountered, contact Keithley Instruments or its representative to arrange for factory calibration.

b. Four procedures are covered: Kelvin-Varley divider verification, voltage range calibration, reference voltage supply stability test and oscillator adjustment.

c. If the Model 662 is not within specifications after the calibration, follow the troubleshooting procedures or contact Keithley Instruments, Inc., or its representative.

Instrument	Use
Electro Scientific Industries Model SV194B Voltage Calibrator, $\pm 0.005\%$ accuracy with corrections on certificate	Range voltage calibration
Electro Scientific Industries Model RV722 Decade Voltage Divider; terminal linearity, $\pm 1$ ppm; certificate corrected to $\pm 0.2$ ppm	Voltage divider for range calibration
Electro Scientific Industries Model LC875B Lead Compensator	Range voltage calibration
Hewlett-Packard Model 200CD Oscillator	Monitor oscillator frequency
Keithley Instruments Model 150A Micro-voltmeter	Null detector for range calibration
Keithley Instruments Model 241 Regulated High Voltage Supply	Voltage supply for range calibration
Keithley Instruments Model 662 Guarded dc Differential Voltmeter	Check voltages in Kelvin-Varley divider
Mosley Instruments Model 680 Direct Reading Recorder	Recorder for reference voltage supply stability
Tektronix Type 503 Oscilloscope	Check wave forms
Weston Instruments Model 3 Type 7 Saturated Standard Cell	Range calibration and reference voltage supply stability
Weston Instruments Model 66 Oil Bath	Range calibration and reference voltage supply stability

TABLE 5. Equipment Recommended for Model 662 Calibration. Use these instruments or their equivalents.

Control	Circuit Desig.	Fig. Ref.	Refer to Paragraph
Meter Calibrate	R1043	20	5-7
Hum Balance	R1048	20	5-5
Oscillator	R2007	22	6-6
500-volt Calibrate	R3025	22	6-4
50-volt Calibrate	R3032	22	6-4
5-volt Calibrate	R3035	22	6-4
0.5-volt Calibrate	R3038	22	6-4

TABLE 6. Model 662 Internal Controls. The Table lists all internal controls, the figure picturing the location and the paragraph describing the adjustment.

### 6-2. CALIBRATION SCHEDULE.

- a. Recalibrate the Model 662 yearly. This normally means performing the voltage range calibration (paragraph 6-4). The other verifications need not be done.
- b. Verify the Kelvin-Varley divider (paragraph 6-3) only if trouble is suspected in it, or if components in the divider have been replaced. Also make the voltage range calibration after verifying the divider accuracy.
- c. Check the reference voltage supply stability (paragraph 6-5) only if trouble is suspected in the supply or if some of its components have been replaced.

### 6-3. KELVIN-VARLEY DIVIDER VERIFICATION.

a. There is no in-field calibration for the Kelvin-Varley divider; its accuracy can only be verified. The divider accuracy depends upon matching resistors and switches. At manufacture, each resistor within the first two Reference Voltage switches, S3003 and S3004, is matched to  $\pm 0.00125\%$ . The resistors in the switches are checked as a set to an accuracy of better than 0.0025%. Individual resistors cannot be replaced without rematching the string at Keithley Instruments.

#### b. Kelvin-Varley Divider Accuracy Verification Procedures.

1. Use another Model 662 Differential Voltmeter or equipment with better limit of error to match the Model 662 under test. Connect the wiper arm of Switch S3008 of the instrument under test to the HI terminal of the Model 662. Connect both LO terminals.

#### NOTE

Be careful of high voltages when working within the Model 662. Up to 900 volts dc is present at various points..

2. Set the dials to random settings on both instruments. Settings should match to  $\pm 0.01\%$ . This procedure, however, only indicates the Kelvin-Varley divider accuracy. The errors of the two instruments may be additive, causing a false verification. The most accurate way is to use standard procedures for checking a Kelvin-Varley divider or to return the Model 662 to Keithley Instruments, Inc., for checking.



3. If any resistor fails to test out, the entire divider string will have to be re-matched at the factory.

#### 6-4. RANGE CALIBRATION.

a. The reference voltage supply has a 500-volt output which can be attenuated to 50, 5 or 0.5 volts. This voltage is then divided by the Kelvin-Varley divider to provide the accurate buckout voltage. Each of the four voltage ranges is set by internally adjusting potentiometers R3025, R3032, R3035 and R3038 (Figure 22).

b. The ranges are calibrated by applying an accurate voltage to the Model 662 for each setting of the RANGE Switch. The Model 662 is set to furnish the equivalent buckout voltage, and the internal range potentiometer is adjusted until the voltmeter indicates a null.

#### NOTE

The accuracy of the Model 662 calibration will be no greater than the accuracy of the voltage source used for calibrating. Unless the user is familiar with techniques for obtaining accuracy greater than 0.002% (20 ppm), it is better to return the Model 662 to the factory for range calibration.

c. The most critical part in range calibration is establishing a reference source whose accuracy exceeds 0.002%. Use the Model SV194B Voltage Calibrator for the 500, 50 and 0.5-volt outputs. Establish the accuracy of these outputs by determining the cor-

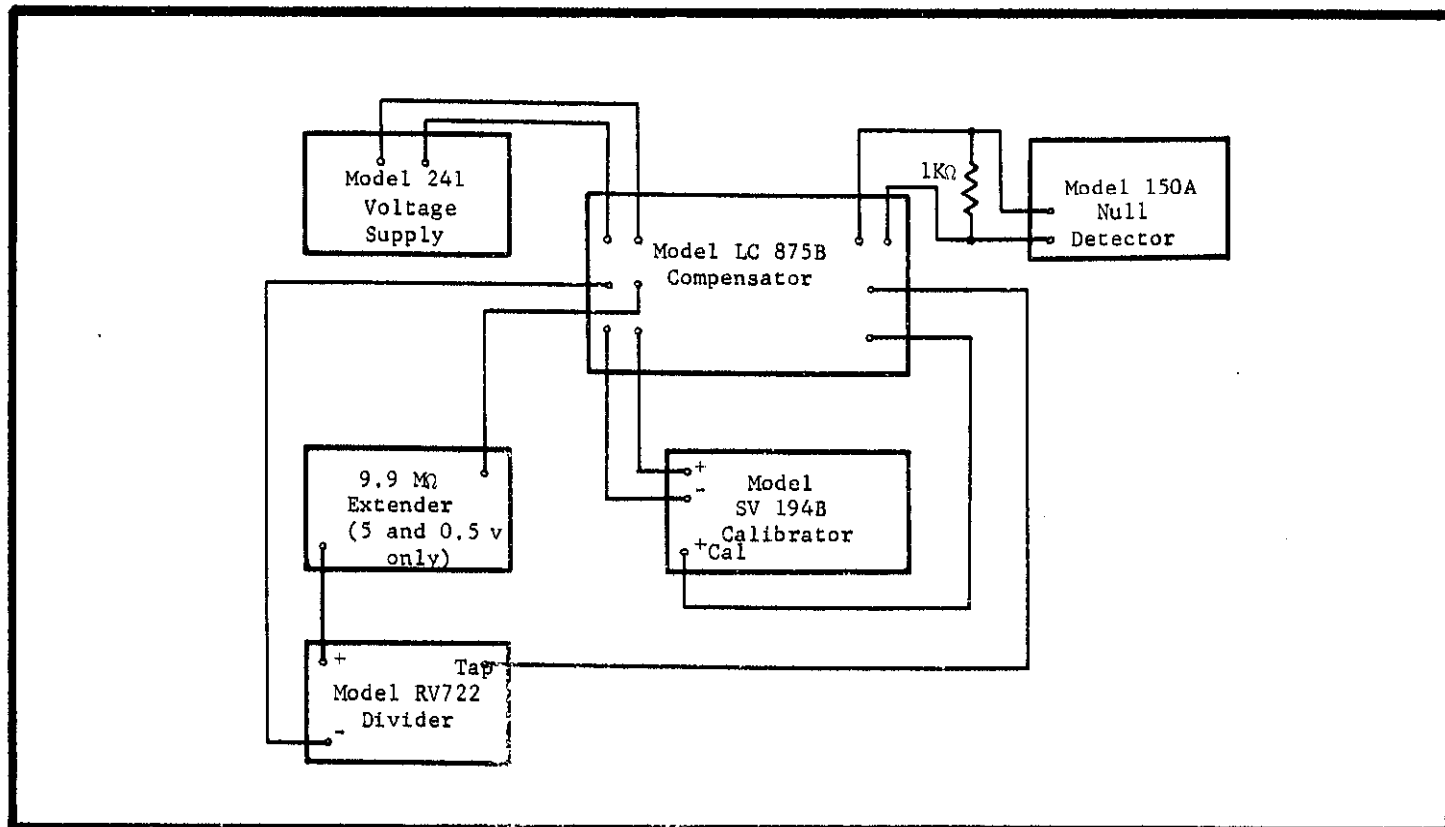


FIGURE 11. Block Diagram to Establish System Accuracy for Model 662 Range Calibration. Fully guard the entire system to prevent leakage errors. Use a 1-kilohm copper resistor to shunt the null detector. See Table 5 for recommended equipment.

rections for the calibrator's CALIBRATION and OUTPUT dials at these outputs. The system's accuracy can be determined to approximately 10 ppm. Added to the accuracy of the standard cell, total accuracy should be approximately 12 ppm. Note that this depends upon properly executed procedures.

d. Procedures to Establish System Accuracy.

1. Set up the system shown in Figure 11. Use the 9.9-megohm extender for only the 0.5 and 5-volt outputs.

2. Establish the corrections for the CALIBRATION dial setting for Model SV194B outputs of 500, 50, 5 and 0.5 volts. Set the Model 241 Voltage Supply to 500 volts. Set the Model RV772 Divider to a voltage equal to that of the standard cell. Adjust the Model SV194B ratio dial until the null detector indicates a null. The difference between the settings of the Model RV772 Divider and the ratio dial is the Model SV194B correction factor at 500 volts. With this correction, the 500 volts may be set to within approximately 12 ppm.

3. Connect the null detector to the 50, 5 and 0.5-volt taps of the Model SV194B Calibrator in that order. Set the Model RV722 Divider to corresponding voltages. Use the 9.9-megohm extender for the 5 and 0.5-volt outputs. (See Figure 11.) The difference read on the null detector is the correction factor for each of the three voltages. These voltages may also be set to within 12 ppm.

4. Use the four correction factors for calibrating the Model 662 range setting.

e. Procedures for Range Calibration.

1. Set up the system shown in Figure 12. The standard cell should be certified to 10 ppm. Use the dial correction factors found for each output. If the system accuracy was properly determined, the input voltage to the Model 662 should be correct to 20 ppm.

2. 500-volt Range Calibration: Set the Model 662 controls as follows:

RANGE Switch	500
Reference Voltage Dials	4 9 9.9 9 10
NULL Switch	VTVM
POLARITY Switch	+

Adjust the Voltage Calibrator to apply 500 volts to the Model 662. Turn the Model 662 NULL Switch to 10 MV and adjust the 500 V CAL potentiometer, R3025 (Figure 22), for null on the Differential Voltmeter.

3. 50-volt Range Calibration: Set the Model 662 controls as follows:

RANGE Switch	50
Reference Voltage Dials	4 9.9 9 9 10
NULL Switch	10 MV
POLARITY	+

Adjust the Voltage Calibrator to apply 50 volts dc to the Model 662. Adjust the 50 V CAL potentiometer, R3032 (Figure 22), for an off-null reading on the Model 662 equal to the correction factor at 50 volts.

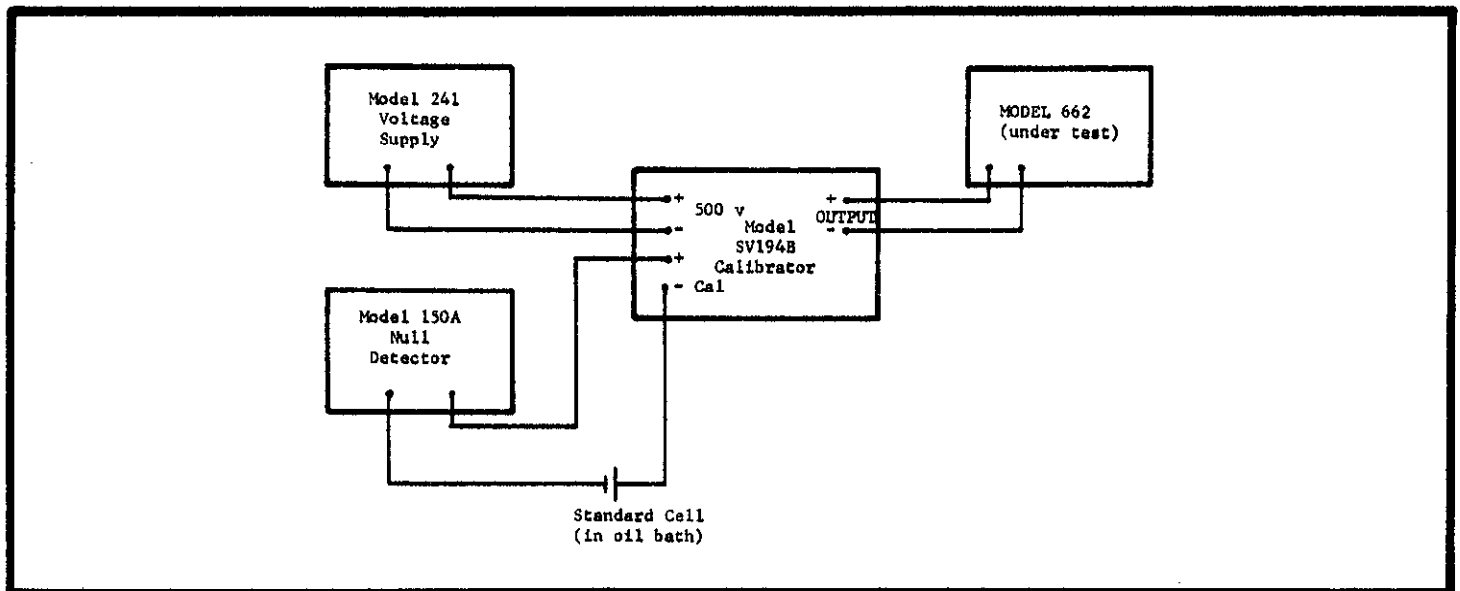


FIGURE 12. Block Diagram for Model 662 Range Calibration. Fully guard the entire system to prevent leakage errors. See Table 5 for recommended equipment.

4. 5-volt Range Calibration: Set the Model 662 controls as follows:

RANGE Switch	5
Reference Voltage Dials	4,9 9 9 9 10
NULL Switch	1 MV
POLARITY Switch	+

Adjust the Voltage Calibrator to apply 5 volts dc to the Model 662. Adjust the 5 V CAL potentiometer, R3035 (Figure 22), for an off-null reading on the Model 662 equal to the correction factor at 5 volts.

5. 0.5-volt Range Calibration: Set the Model 662 controls as follows:

RANGE	0.5
Reference Voltage Dials	.4 9 9 9 9 10
NULL Switch	0.1 MV
POLARITY	+

Adjust the Voltage Calibrator to apply 0.5 volt dc to the Model 662. Adjust the 0.5 V CAL potentiometer, R3038 (Figure 22), for an off-null reading on the Model 662 equal to the correction factor at 0.5 volt.

#### 6-5. REFERENCE VOLTAGE SUPPLY STABILITY TEST.

a. The reference voltage supply, consisting of the power transformer and the main supply (printed circuit PC92), is factory calibrated for an output of 500 volts dc greater than 0.002%. The 500-volt output is adjustable to meet specifications. If the stability of the supply is not within specifications, then troubleshoot for a faulty component.

b. Routine calibration of the Model 662 does not require a stability test of the reference voltage supply. However, a stability test is recommended if one of the components

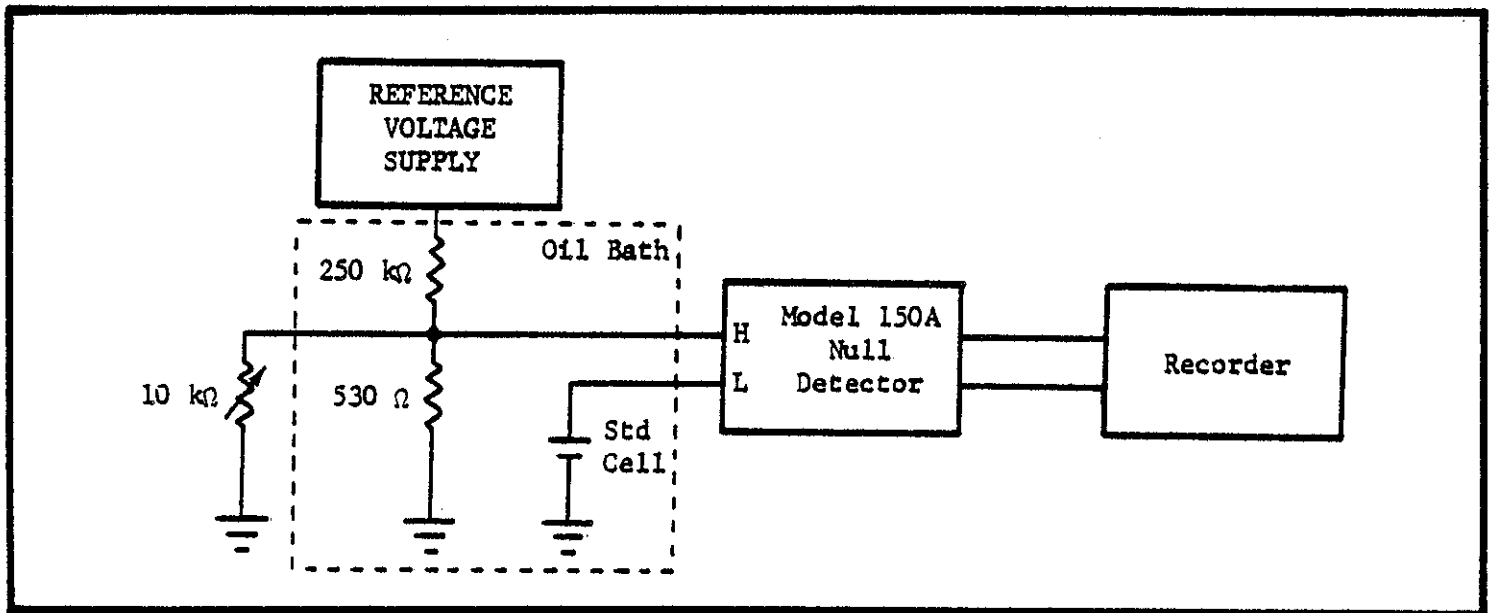


FIGURE 13. Circuit Diagram for Model 662 Reference Voltage Supply Stability Test. The voltage across the 530-ohm resistor is slightly higher than the standard cell. Use the 10-kilohm potentiometer to shunt the divider voltage down. All resistors are wirewound. See Table 5 for recommended equipment.

in the supply is replaced.

c. For the 24-hour test, the 500-volt output of the reference voltage supply is divided and compared to a 1.02-volt saturated standard cell using a sensitive null detector. Variations between the reference voltage supply and the standard cell are detected by the Model 150A and are recorded on a recorder. Refer to Figure 13 for the block diagram of the test circuit.

d. In using the test circuit, the following points are important.

1. Saturated standard cells, though extremely stable with time, have a high temperature coefficient and require a controlled environment during use. Therefore, the Weston Oil Bath, which is maintained at  $+35^{\circ}\text{C} \pm 0.01^{\circ}\text{C}$ , is used for the test. Unsaturated standard cells have a lower temperature coefficient, but they do not have the long term stability required for this test.

2. The resistor divider network is constructed from wire of the same spool for an extremely close temperature coefficient match (4 ppm, typically). Additional stability results when the resistors are immersed in an oil bath to hold the ambient temperature variations to  $\pm 0.01\%$ .

e. Procedures for the Reference Voltage Supply Stability Test.

1. After the saturated standard cell and the resistor divider network are placed in the oil bath, allow sufficient time for the cell to stabilize at  $+35^{\circ}\text{C}$ . (Consult Keithley Instruments, Inc., or its representative for details.) Connect the standard cell to the circuit after turning on the 500-volt supply. Set the Model 662 controls as follows:

RANGE Switch	500
Reference Voltage Dials	4 9 9. 9 9 10
NULL Switch	10 MV
POLARITY Switch	OFF

Connect the resistor divider network across the Model 662's reference voltage supply, the positive side of the divider input to the wiper arm of the last Reference Voltage Switch, S3008, and the negative side of the divider to the LO terminal on the Model 662 front panel.

2. Connect the Model 150A and the recorder as shown in Figure 13. Set the Model 150A to the 3-volt range. Advance the Model 662 POLARITY Switch to + to put 500 volts across the divider. If the Model 150A reads two volts, the standard cell and the divider voltages are improperly connected in series. If the circuit is correct, the Model 150A will read zero. Increase the Model 150A's sensitivity to the 0.1-millivolt range. If it reads more than 20 microvolts, adjust the 500 V CAL potentiometer, R3025 (Figure 22), shunting the divider.

## NOTE

Any adjustment of potentiometer R3025 requires all other ranges to be calibrated.

3. After a 1-hour warm-up, the drift of the entire system should not exceed  $\pm 25$  microvolts in 24 hours (Figure 14).

## 6-6. OSCILLATOR ADJUSTMENT.

a. The oscillator circuit drives the light modulators. Before adjusting the oscillator, make sure the reference voltage supply is operating correctly.

b. Connect the Type 503 Oscilloscope Vertical Input to the plate and low side of tube V2001 (Figure 21) and the Horizontal Input to the Model 200CD Oscillator. Adjust the oscillator frequency to approximately 42 cps with potentiometer R2007 (Figure 22). The Model 662 oscillator is then adjusted for minimum meter noise — normally within a cycle of 42 cps. Disconnect the Oscilloscope before adjusting potentiometer R2007. The Oscilloscope will cause a small loading error.

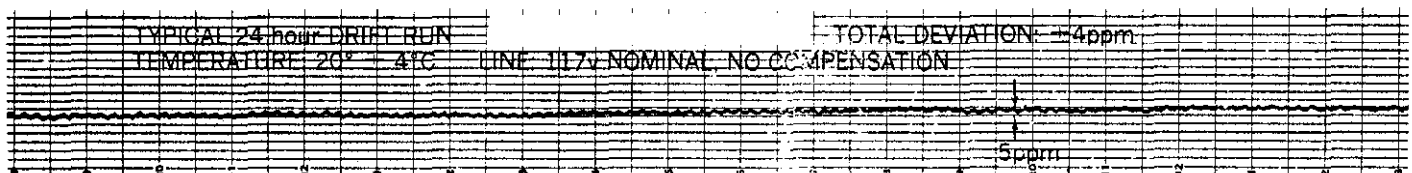


FIGURE 14. Stability Strip Chart for Model 662 reference Voltage Supply. Fluctuations are within  $\pm 0.0025\%$ . Note drift is non-cumulative. No compensation for variations of line voltage or other conditions was made.

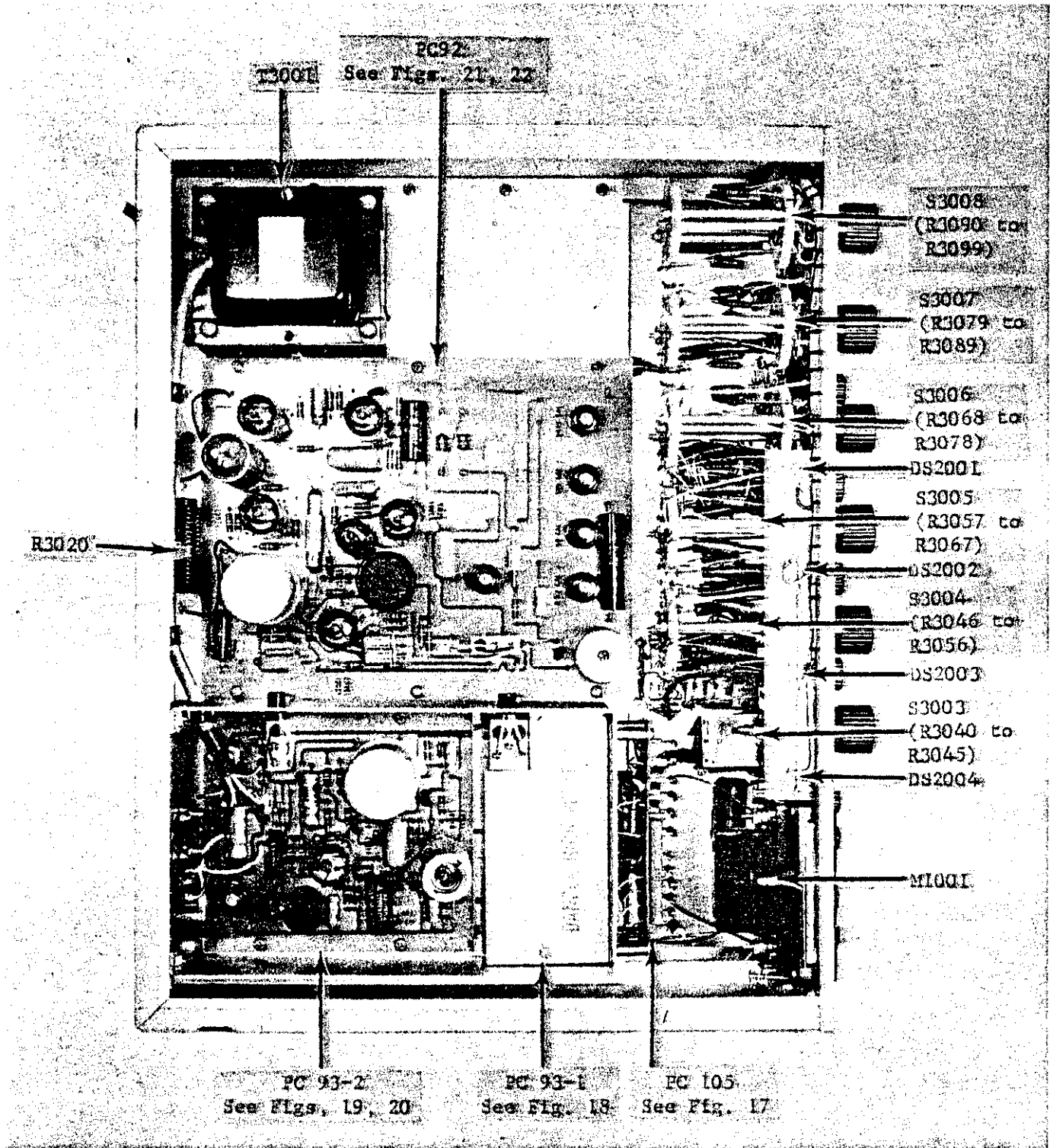


FIGURE 15. Top View of Model 662 Chassis. Front panel faces to the right. Location of components, printed circuits and switches is shown. Refer to the Replaceable Parts List for circuit designations. Figure 16 shows the bottom view.

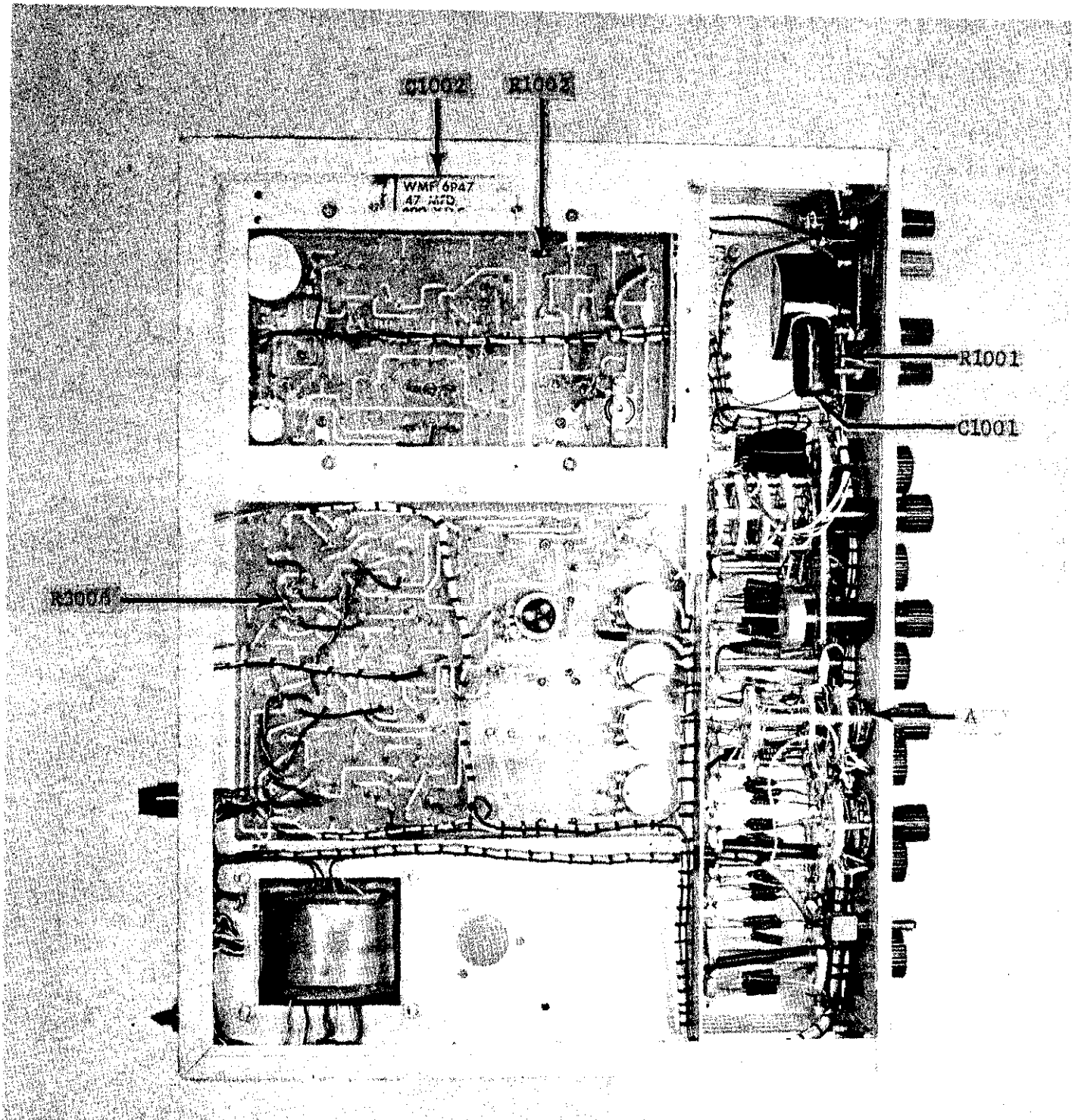


FIGURE 16. Bottom View of Model 662 Chassis. Front panel faces to the right. Reference A in the photograph designates the location of resistors R3031, R3033, R3034, R3036, R3037 and R3039. Figure 15 shows the top view.

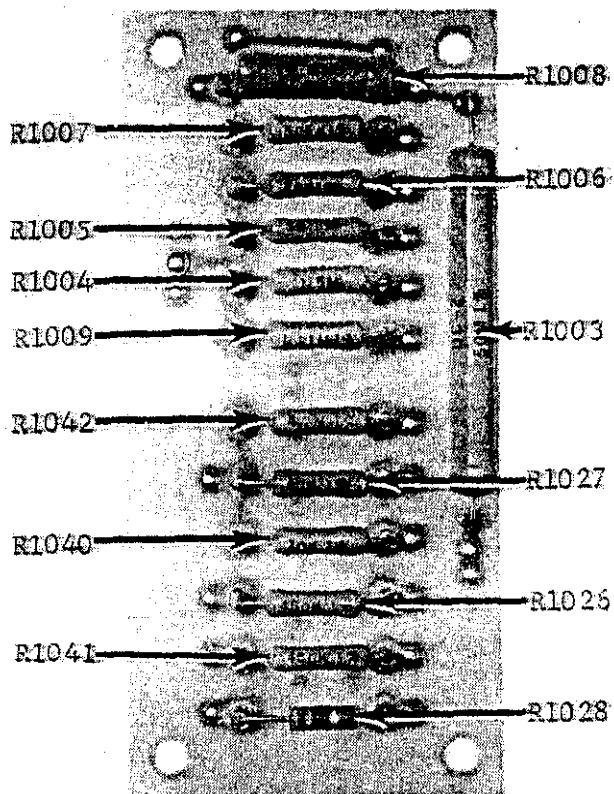


FIGURE 17. Component Locations on Printed Circuit Board PC93-1.

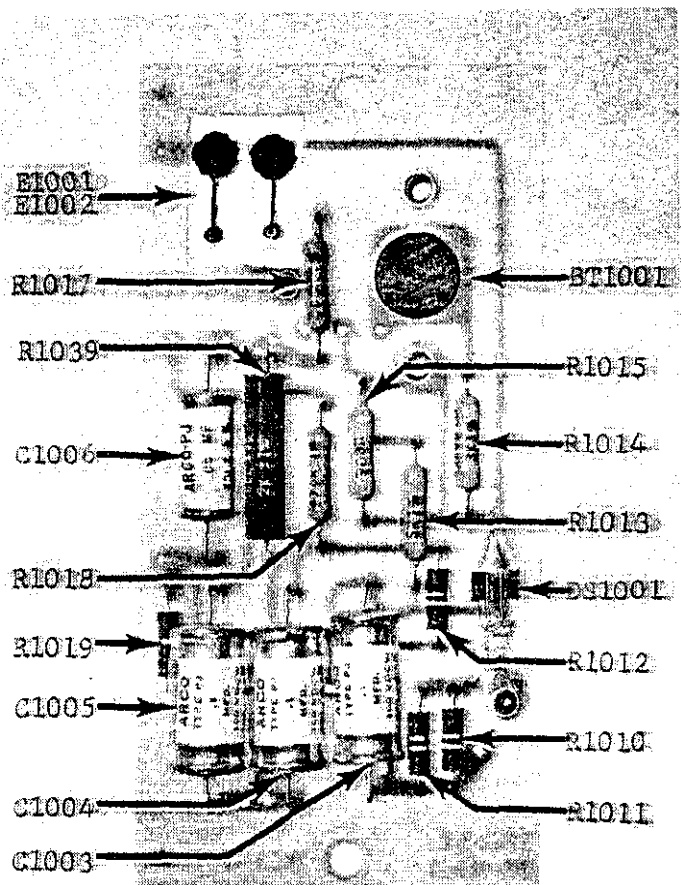


FIGURE 18. Component Locations on Printed Circuit Board PC105.



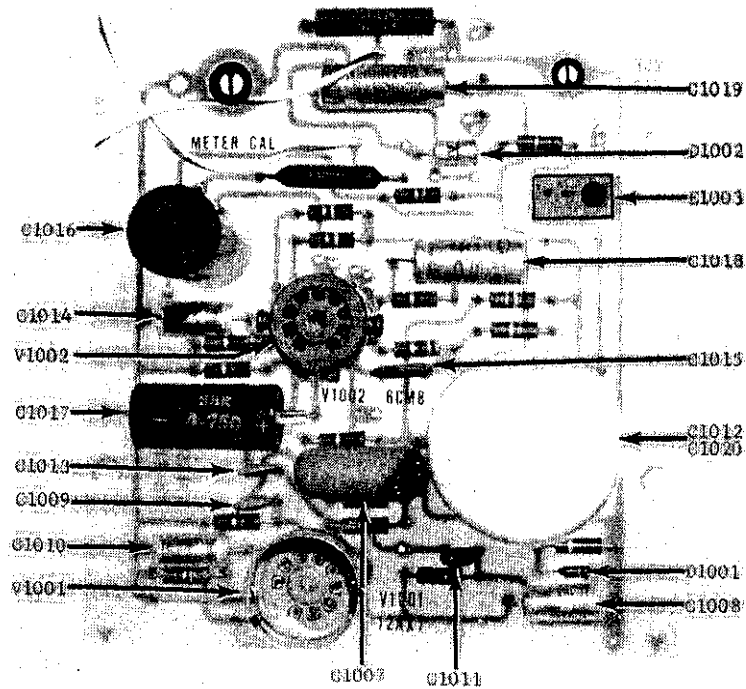


FIGURE 19. Capacitor, Modulator, Diode and Tube Locations on Printed Circuit Board PC93-2. Refer to Figure 20 for resistor locations.

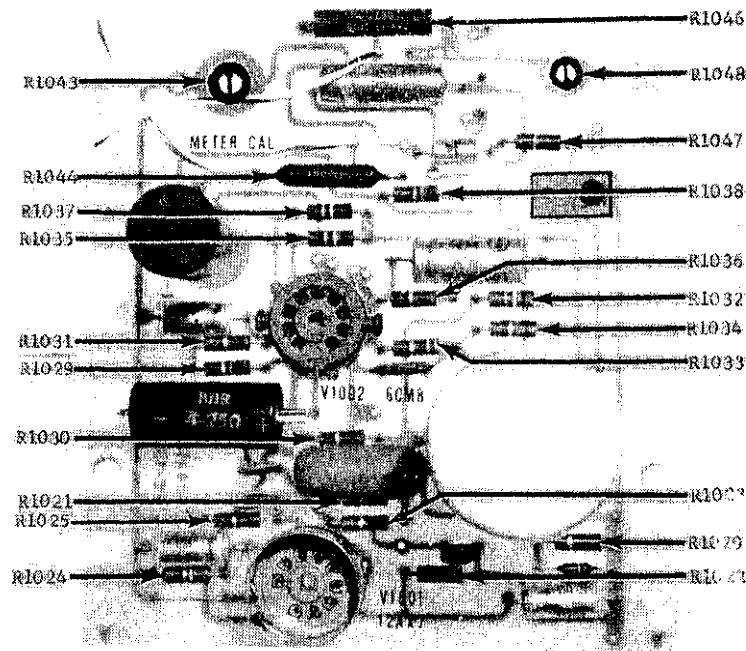


FIGURE 20. Resistor Locations on Printed Circuit Board PC93-2. Refer to Figure 19 for the location of other components.

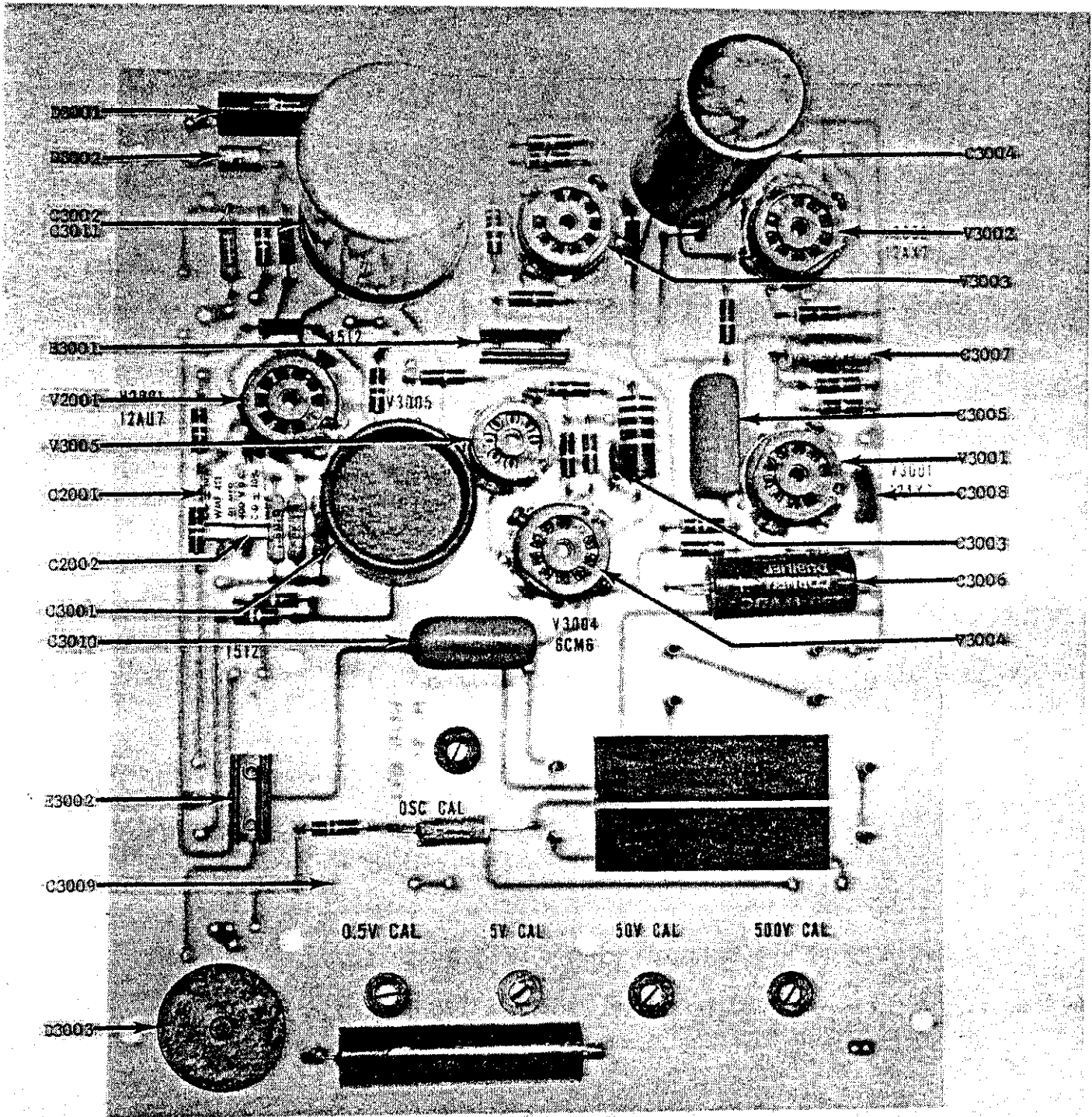


FIGURE 21. Capacitor, Modulator, Diode and Tube Locations on Printed Circuit Board PC92. Refer to Figure 22 for the resistor locations.

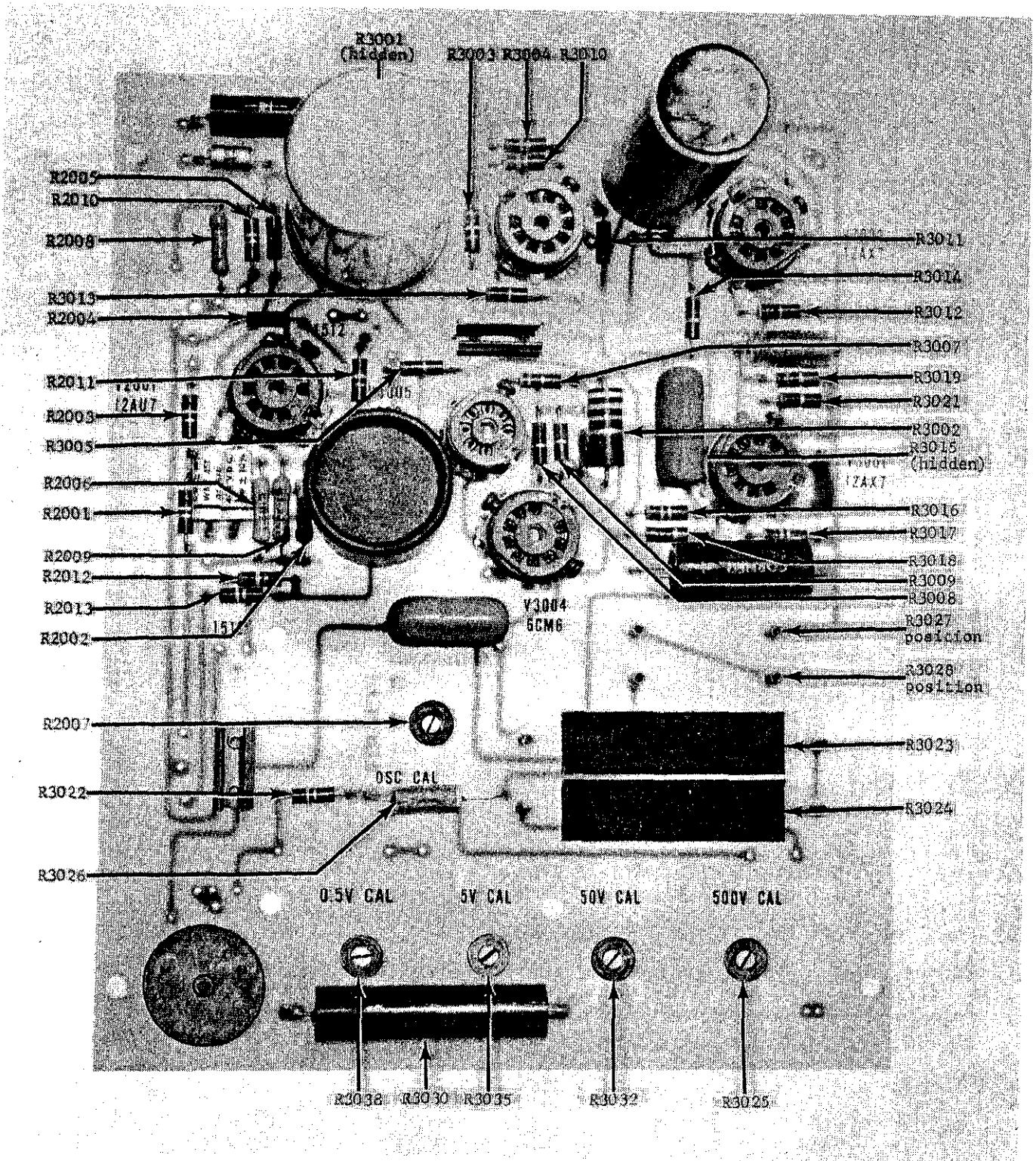


FIGURE 22. Resistor Locations on Printed Circuit Board PC92. Refer to Figure 21 for the location of other components.

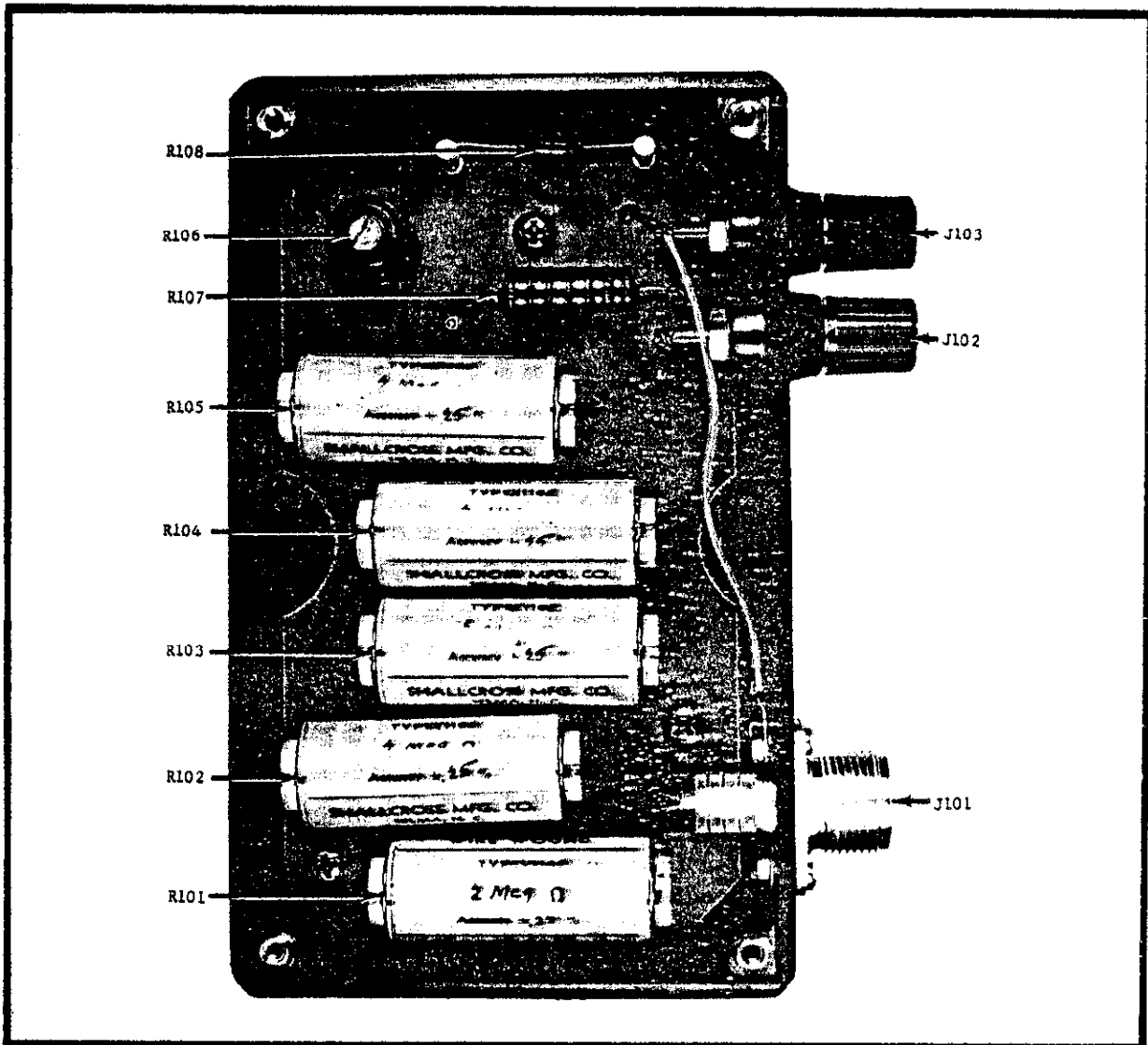


FIGURE 23. Component Locations of Model 6601A. Circuit designations refer to Schematic Diagram 16321B.

## SECTION 7. ACCESSORIES

### 7-1. MODEL 6601A HIGH VOLTAGE DIVIDER.

a. The Model 6601A extends the range of the Model 662 to 5000 volts full scale. The ratio of the Divider is 100:1,  $\pm 0.01\%$ ; the input resistance is 10 megohms. The limit of error using the Models 662 and 6601A is  $\pm 0.02\%$ .

#### NOTE

Maximum input into the Model 6601A is 5000 volts.

b. Set the Model 662 RANGE Switch to 50 volts. The meter will read to 5000 volts full scale. Connect the HI and LO Divider terminals to the HI and LO Voltmeter terminals, respectively. Connect the unknown voltage to the Divider INPUT, and use the Model 662 as outlined in paragraph 2-4.

### 7-2. RACK MOUNTING. (See Figure 25.)

a. The Model 662 is shipped for bench use with four feet and a tilt-bail. The Model 4000 Rack Mounting Kit converts the instrument to rack mounting to the standard EIA (RETMA) 19-inch width.

b. To convert the Model 662, remove the four screws at the bottom of each side of the instrument case. Lift off the top cover assembly with the handles; save the four screws. To remove the feet and tilt bail from the bottom cover assembly, turn the two screws near the back. The two pawl-type fasteners will release the cover and allow it to drop off. Remove the feet and the tilt bail and replace the cover (2).

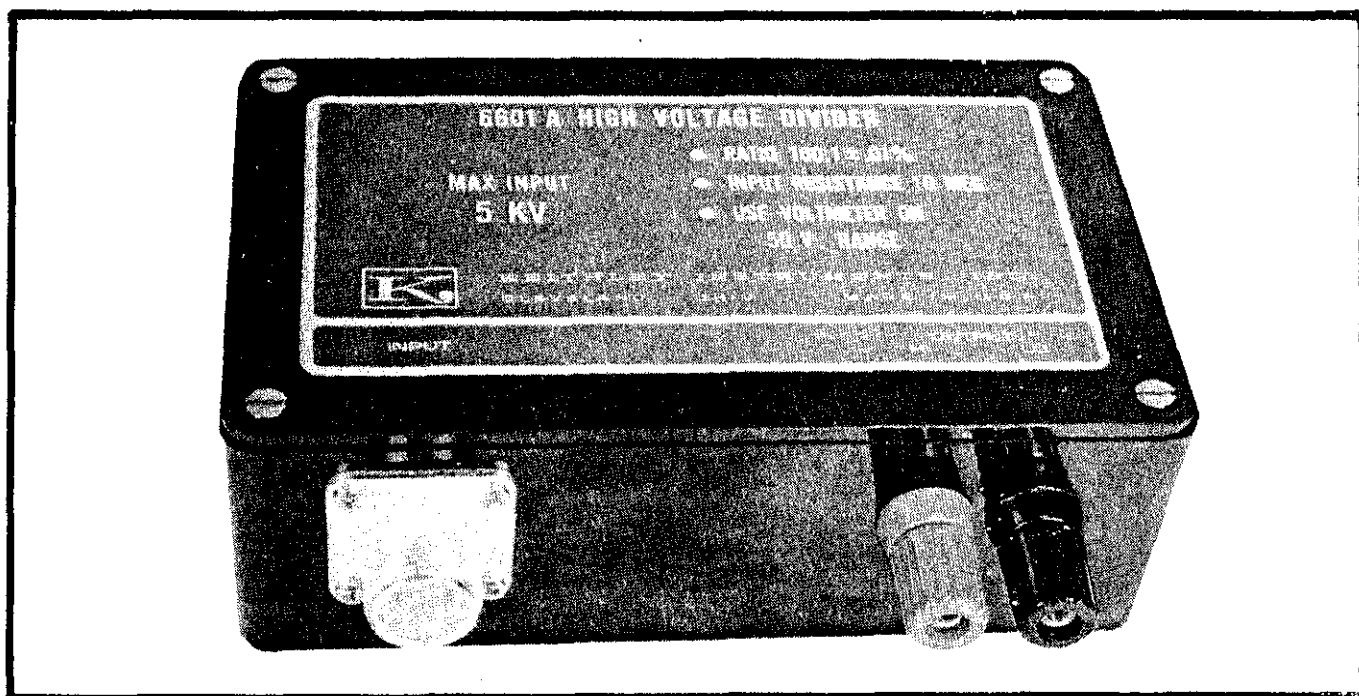


FIGURE 24. Keithley Instruments Model 6601A High Voltage Divider.

c. Attach the pair of rack angles (3) to the cabinet with the four screws (4) previously removed. Insert the top cover assembly (1) in place and fasten to the chassis with the two pawl-type fasteners at the rear. Store the top cover with handles, feet and tilt-bail for future use.

7-3. PLACING IN RACK. The Model 662, once converted for rack mounting, easily fits into the rack. It is recommended, however, that a blower be used in the rack enclosure in which the Model 662 is mounted. The instrument specifications state a 0.001% per °C temperature coefficient. A temperature rise of 5°C (9°F) will cause a 0.005% error.

Item (See Fig. 25)	Description	Keithley Part No.	Quantity
1	Cover Assembly	14623B	1
2	Cover Assembly, Bottom (Supplied with Model 662)	14590B	1
3	Angle, Rack	14624B	2
4	Screw, Slot Head, 10-32 UNC-2 x 1/4 (Supplied with Model 662)	---	4
5	Front Panel (Supplied with Model 662)	---	1

TABLE 7. Parts List for Model 4000 Rack Mounting Kit.

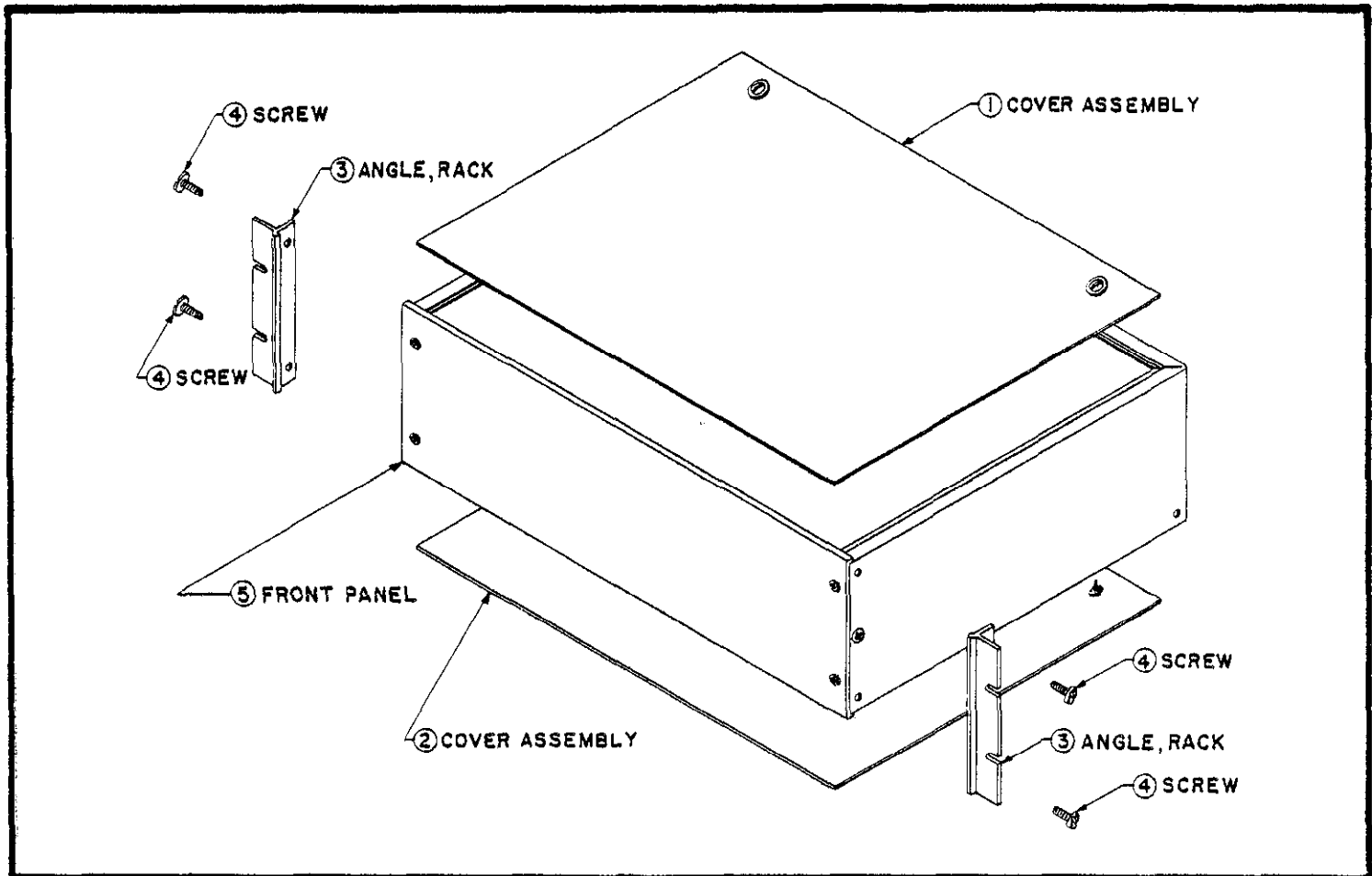


FIGURE 25. Exploded View for Rack Mounting with Model 4000 Kit. Refer to Table 7 for parts list.

### SECTION 8. REPLACEABLE PARTS

8-1. REPLACEABLE PARTS LIST. The Replaceable Parts List describes the components of the Models 662 and 6601A. The List gives the circuit designation, the part description, a suggested manufacturer, the manufacturer's part number and the Keithley Part Number. The last column indicates the figure picturing the part. The name and address of the manufacturers listed in the "Mfg. Code" column are in Table 9.

8-2. HOW TO ORDER PARTS.

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

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

amp	ampere	MtF	Metal Film
CbVar	Carbon Variable	Mil. No.	Military Type Number
CerD	Ceramic, Disc	My	Mylar
Comp	Composition		
CompV	Composition Variable	$\Omega$	ohm
DCb	Deposited Carbon	Poly	Polystyrene
EMC	Electrolytic, metal cased	p	pico ( $10^{-12}$ )
ETB	Electrolytic, tubular	$\mu$	micro ( $10^{-6}$ )
ETT	Electrolytic, tantalum		
f	farad	v	volt
		Var	Variable
k	kilo ( $10^3$ )	w	watt
		WW	Wirewound
M or meg	mega ( $10^6$ ) or megohms	WWVar	Wirewound Variable
m	milli ( $10^{-3}$ )		
Mfg.	Manufacturer		

TABLE 8. Abbreviations and Symbols.

MODEL 662 REPLACEABLE PARTS LIST

(Refer to Schematic Diagram 18551E for circuit designations.)

## CAPACITORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
C1001	.05 $\mu$ f	1600 v	My	14655	DFMS16S5	C87-.05M	16
C1002	.47 $\mu$ f	600 v	My	14655	WMF6P47	C101-.47M	16
C1003	0.1 $\mu$ f	100 v	Poly	00656	1PJ-104J	C129-.1M	18
C1004	0.1 $\mu$ f	100 v	Poly	00656	1PJ-104J	C129-.1M	18
C1005	0.1 $\mu$ f	100 v	Poly	00656	1PJ-104J	C129-.1M	18
C1006	0.05 $\mu$ f	100 v	Poly	00656	1PJ-503J	C129-.05M	18
C1007	.05 $\mu$ f	600 v	My	56289	CPS-S50	C62-.05M	19
C1008	10 $\mu$ f	15 v	ETB	56289	TE1155	C3-10M	19
C1009	.0022 $\mu$ f	1000 v	CerD	72982	851Z5V222P	C22-.0022M	19
C1010	10 $\mu$ f	15 v	ETB	56289	TE1155	C3-10M	19
C1011	680 pf	1000 v	CerD	72982	801X5R681K	C22-680P	19
C1012	40 $\mu$ f	450 v	EMC	56289	TVL2762	C36-40/20M	19
C1013	0.0022 $\mu$ f	1000 v	CerD	72982	851Z5V222P	C22-.0022M	19
C1014	10 $\mu$ f	15 v	ETB	56289	TE1155	C3-10M	19
C1015	.0047 $\mu$ f	1000 v	CerD	72982	811Z5V472P	C22-.0047M	19
C1016	1.0 $\mu$ f	600 v	ETB	13050	Z4009	C12-1M	19
C1017	4 $\mu$ f	250 v	ETB	14655	BBR4-250	C27-4M	19
C1018	100 $\mu$ f	15 v	ETB	56289	TE1162	C3-100M	19
C1019	600 $\mu$ f	6 v	ETT	05079	TEZ600-6C2	C133-600M	19
C1020	20 $\mu$ f	450 v	EMC	56289	TVL2762	C36-40/20M	19
C2001	.01 $\mu$ f	400 v	Poly	14655	WMF4S1	C114-.01M	21
C2002	.01 $\mu$ f	400 v	Poly	14655	WMF4S1	C114-.01M	21
C3001	20 $\mu$ f	450 v	EMC	37942	FP144	C36-20M	21
C3002	20 $\mu$ f	450 v	EMC	56289	TVL2762	C36-20/40M	21
C3003	.001 $\mu$ f	1000 v	CerD	72982	801Z5V102P	C22-.001M	21
C3004	1.0 $\mu$ f	1000 v	ETB	13050	Z4009B	C14-1M	21
C3005	0.05 $\mu$ f	600 v	My	56289	6PS-S50	C62-.05M	21
C3006	4 $\mu$ f	250 v	ETB	14655	BBR4-250	C27-4M	21
C3007	50 $\mu$ f	6 v	ETB	56289	TE1100	C17-50M	21
C3008	.0047 $\mu$ f	1000 v	CerD	72982	811Z5V472P	C22-.0047M	21
C3009	.022 $\mu$ f	200 v	ETB	13050	MW1A	C6-.022M	21
C3010	.05 $\mu$ f	600 v	My	56289	6PS-S50	C62-.05M	21
C3011	40 $\mu$ f	450 v	EMC	56289	TVL2762	C36-20/40M	21



## DIODES

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
D1001	Silicon	1N645	01295	RF-14	19
D1002	Silicon	1N3256	02735	RF-22	19
D3001	Silicon	1N2378	08520	RF-25	21
D3002	Silicon	1N3256	02735	RF-22	21
D3003	Zener	—	80164	DZ-8 (1)	21

## MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Fig. Ref.
BT1001	Battery, 1.34-v mercury (Mfg. No. PX13T2)	37942	BA-16	18
DS1001	Neon Lamp (Mfg. No. NE-81)	08804	PL-7	18
DS2001	Neon Lamp (Mfg. No. NE-2P)	08804	PL-2	15
DS2002	Neon Lamp (Mfg. No. NE-2P)	08804	PL-2	15
DS2003	Neon Lamp (Mfg. No. NE-2P)	08804	PL-2	15
DS2004	Neon Lamp (Mfg. No. NE-2P)	08804	PL-2	15
DS3001	Neon Lamp (Mfg. No. NE-2P) (on older models)	08804	PL-2	
E1001	Light Modulator Assembly	80164	Model 1513	18
E1002	Light Modulator Assembly	80164	Model 1513	18
E1003	Light Modulator Assembly	80164	Model 1514	19
E3001	Light Modulator Assembly	80164	Model 1512	21
E3002	Light Modulator Assembly	80164	Model 1512	21
F1001 (117 v)	Fuse, slow blow, 1 amp (Mfg. Type MDL)	71400	FU-10	3
F1001 (234 v)	Fuse, slow blow, 0.5 amp (Mfg. No. 312.500)	75915	FU-6	3
—	Fuse Holder (Mfg. No. 342012)	75915	FH-3	
J1001	Binding Post, HI (Mfg. No. DF31RC)	58474	BP-8R	2
J1002	Binding Post, LO (Mfg. No. DF31BC)	58474	BP-8B	2
J1003	Binding Post, LO (Mfg. No. DF31BC)	58474	BP-8B	2
J1004	Binding Post, GND (Mfg. No. DF31BC)	58474	BP-8B	2
—	Shorting Link (Mfg. No. 938-L)	24655	BP-6	
J1005	Banana Jack, + (Mfg. No. 108-745-1)	74970	BJ-3	3
J1006	Banana Jack, - (Mfg. No. 108-745-2)	74970	BJ-4	3
M1001	Meter	80164	ME-38	15
P1001	Power Cord, 6 feet (Mfg. No. 4638-13)	82879	CO-2	3
S1001	Rotary Switch less components, NULL	80164	SW-115	2
—	Knob Assembly, Null Switch	80164	14838A	

(1) Refer to paragraph 5-6.

## MISCELLANEOUS PARTS (Cont'd)

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Fig. Ref.
—	Knob Assembly, Meter Zero Potentiometer	80164	15110A	
S3001	Topple Switch, Power (Mfg. No. 20994LH) (on newer models)	04009	SW-4	2
S3002	Slide Switch, 117-234	80164	SW-151	3
S3003	Switch Assembly with components, Readout Dial Assembly, 0-4 Readout	80164 80164	18479B 14827A	2
S3004	Switch Assembly with components, Readout Dial Assembly, 0-9 Readout	80164 80164	17046B 14828A	2
S3005	Switch Assembly with components, Readout Dial Assembly 0-9 Readout	80164 80164	17073B 14828A	2 2
S3006	Rotary Switch less components, Readout Dial Assembly, 0-9 Readout	80164 80164	SW-118 14828A	2
S3007	Rotary Switch less components, Readout Dial Assembly, 0-9 Readout	80164 80164	SW-118 14828A	2
S3008	Rotary Switch less components, Readout Dial Assembly, 0-10 Readout	80164 80164	SW-127 14829A	2
S3009	Rotary Switch less components, POLARITY Knob Assembly, Polarity Switch	80164 80164	SW-119 14838A	2
S3010	Rotary Switch less components, RANGE Knob Assembly, Range Switch	80164 80164	SW-116 14838A	2
T3001	Transformer	80164	TR-67	15
TC3001	Oven (on older model)	80164	OV-1	

## RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
R1001	100 M $\Omega$	20%, 1/2 w	Comp	75042	GBT	R37-100M	16
R1002	1 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1K	16
R1003	50 M $\Omega$	1%, 2 w	DCb	91637	DC-2	R14-50M	17
R1004	1.5 M $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-1.5M	17
R1005	5 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-5K	17
R1006	50 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-50K	17
R1007	505 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-505K	17
R1008	12.5 M $\Omega$	1%, 1 w	DCb	91637	DC-1	R13-12.5M	17
R1009	1.14 M $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-1.14M	17
R1010	220 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-220K	18

## RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
R1011	220 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-220K	18
R1012	220 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-220K	18
R1013	3 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-3K	18
R1014	3 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-3K	18
R1015	900 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-900K	18
R1016	15 k $\Omega$	10%, 5 w	WWVar	71450	AW	RP3-15K	2
R1017	200 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-200K	18
R1018	470 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-470K	18
R1019	1 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1M	18
R1020	22 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-22M	20
R1021	1.5 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1.5M	20
R1022	10 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-10K	20
R1023	1.5 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1.5M	20
R1024	15 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-15K	20
R1025	10 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-10M	20
R1026	70 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-70K	17
R1027	450 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-450K	17
R1028	4 M $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-4M	17
R1029	10 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-10M	20
R1030	1.5 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1.5M	20
R1031	8.2 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-8.2K	20
R1032	100 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-100K	20
R1033	3.3 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-3.3M	20
R1034	10 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-10M	20
R1035	100 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-100K	20
R1036	1.2 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1.2K	20
R1037	220 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-220K	20
R1038	10 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-10K	20
R1039	2 k $\Omega$	1%, 1/2 w	WW	01686	E-30	R58-2K	18
R1040	*40 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-40K	17
R1041	*400 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-400K	17
R1042	*4.7 M $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-4.7M	17
R1043	500 $\Omega$	10%, 5 w	WWVar	71450	AW	RP3-500	20
R1044	1.5 k $\Omega$	1%, 1/2 w	WW	01686	E-30	R58-1.5K	20
R1045	200 $\Omega$	10%, 2 w	WWVar	71450	P252	RP22-200	3
R1046	80 $\Omega$	1%, 1/2 w	WW	01686	E-30	R58-80	20
R1047	1 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1K	20
R1048	1 k $\Omega$	20%, .2 w	CompV	71450	70	RP31-1K	20
R2001	220 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-220K	22
R2002	1.8 M $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-1.8M	22
R2003	100 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-100K	22

\* Nominal value, factory set.

## RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
R2004	150 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-150K	22
R2005	150 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-150K	22
R2006	1.8 M $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-1.8M	22
R2007	50 k $\Omega$	30%, 1/2 w	CompV	71450	VA-45	RP16B-50K	22
R2008	40 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-40K	22
R2009	150 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-150K	22
R2010	180 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-180K	22
R2011	100 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-100K	22
R2012	100 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-100K	22
R2013	220 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-220K	22
R3001	220 $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-220	22
R3002	50 k $\Omega$	1%, 5 w	WW	91637	RS-5	R4A-50K	22
R3003	820 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-820K	22
R3004	150 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-150K	22
R3005	1 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1M	22
R3006	1 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1M	16
R3007	3.3 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-3.3K	22
R3008	1 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1M	22
R3009	470 $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-470	22
R3010	470 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-470K	22
R3011	1 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1M	22
R3012	4.7 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-4.7K	22
R3013	1 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1M	22
R3014	10 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-10M	22
R3015	330 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-330K	22
R3016	680 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-680K	22
R3017	270 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-270K	22
R3018	2.2 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-2.2M	22
R3019	5.6 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-5.6K	22
R3020	65.4 k $\Omega$	0.1%, 50 w	WW	91637	RH-50	R73-65.4K	15
R3021	1 M $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-1M	22
R3022	220 k $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-220K	22
R3023	125 k $\Omega$	0.1%, 2 w	WW	80164		(1)	22
R3024	125 k $\Omega$	0.1%, 2 w	WW	80164		(1)	22
R3025	200 $\Omega$	10%, 5 w	WWVar	71450	AW	RP34-200	22
R3026	4.4 k $\Omega$	0.1%, 1/4 w	WW	80164		(1)	22
R3027	*	0.1%, 1/4 w	WW	01686	7009	R95-*	22
R3028	*	0.1%, 1/4 w	WW	01686	7009	R95-*	22
R3029	1 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-1K	22
R3030	250 k $\Omega$	.1%, 2 w	WW	01686	7070	R93-250K	22

\* Nominal value, factory set. Refer to paragraph 5-6.

(1) R3023, R3024 and R3026 comprise a matched set, Keithley Part No. 18370A.

## RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
R3031	9 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-9K	16
R3032	1 k $\Omega$	10%, 5 w	WWVar	71450	AW	RP34-1K	22
R3033	32.33 k $\Omega$	0.1%, 1/2 w	WW	80164		(2)	16
R3034	91 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-91K	16
R3035	1 k $\Omega$	10%, 5 w	WWVar	71450	AW	RP34-1K	22
R3036	2.563 k $\Omega$	0.1%, 1/2 w	WW	80164		(2)	16
R3037	930 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-930K	16
R3038	1 k $\Omega$	10%, 5 w	WWVar	71450	AW	RP34-1K	22
R3039	250.9 $\Omega$	0.1%, 1/2 w	WW	80164		(2)	16
R3040 to R3045	40 k $\Omega$	0.02%, 1 w	WW	80164		(3)	15
R3046 to R3056	8 k $\Omega$	0.02%, 1 w	WW	80164		(4)	15
R3057 to R3067	1.6 k $\Omega$	0.05%, 1/2 w	WW	80164		(5)	15
R3068 to R3078	320 $\Omega$	0.1%, 1/2 w	WW	01686	7044	R67-320	15
R3079 to R3089	64 $\Omega$	0.1%, 1/2 w	WW	01686	7044	R67-64	15
R3090 to R3099	12.8 $\Omega$	0.1%, 1/2 w	WW	01686	7044	R67-12.8	15
R3100	*100 $\Omega$	10%, 1/2 w	Comp	01121	EB	R1-100	

## VACUUM TUBES

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
V1001	12AX7	73445	EV-12AX7	19
V1002	6CM8	00011	EV-6CM8	19
V2001	12AU7	73445	EV-12AU7	21

\*Nominal value, factory set.

(2) R3033, R3036, and R3039 comprise a matched set, Keithley Part No. 15432A.

(3) Part of assembly with S3003, Keithley Part No. 18479B

(4) Part of assembly with S3004, Keithley Part No. 17046B

(5) Part of assembly with S3005, Keithley Part No. 17073B

## VACUUM TUBES (Cont'd)

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Fig. Ref.
V3001	12AX7	73445	EV-12AX7	21
V3002	12AX7	73445	EV-12AX7	21
V3003	12AX7	73445	EV-12AX7	21
V3004	6CM6	00011	EV-6CM6	21
V3005	OG3	73445	EV-OG3	21

MODEL 6601A REPLACEABLE PARTS LIST

(Refer to schematic Diagram 16321B for circuit designations)

## TERMINALS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Fig. Ref.
J101	Receptacle, hn modified	80164	CS-79	23
—	Plug, hn, Mate of J101, Mil. No. UG-59A/U (Mfg. No. 7908)	91737	CS-80	23
J102	Binding Post, HI OUTPUT (mfg. No. DF31RC)	58474	BP-8R	23
J103	Binding Post, LO OUTPUT (Mfg. No. DF31BC)	58474	BP-8B	23

## RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Mfg. Part No.	Keithley Part No.	Fig. Ref.
R101	2 M $\Omega$	0.1%, 1 w	WW	54294	P116	R91-2M	23
R102	2 M $\Omega$	0.1%, 1 w	WW	54294	P116	R91-2M	23
R103	2 M $\Omega$	0.1%, 1 w	WW	54294	P116	R91-2M	23
R104	2 M $\Omega$	0.1%, 1 w	WW	54294	P116	R91-2M	23
R105	2 M $\Omega$	0.1%, 1 w	WW	54294	P116	R91-2M	23
R106	200 $\Omega$	10%, 2 w	WWVar	71450	AW	RP3-200	23
R107	100 k $\Omega$	0.1%, 1 w	WW	54294	P-36	R90-100K	23
R108	*1 k $\Omega$	1%, 1/2 w	DCb	79727	CFE-15	R12-1K	23

\*Nominal value, factory set.

00011	Sylvania Electric Products, Inc. Buffalo Operations of Sylvania Electronic Systems Buffalo, N. Y.	01121	Allen-Bradley Corp. Milwaukee, Wis.
00656	Aerovox Corp. New Bedford, Mass.	01295	Texas Instruments, Inc. Semi-Conductor-Components Division Dallas, Texas

TABLE 9 (Sheet 1). Code list of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)

01686	RCL Electronics, Inc. Riverside, N. J.	71400	Bussmann Mfg. Div. of McGraw-Edison Co. St. Louis, Mo.
02735	RCA Semiconductor and Materials Division of Radio Corp. of America Somerville, N. J.	71450	CTS Corp. Elkhart, Indiana
04009	Arrow-Hart and Hegeman Electric Co. Hartford, Connecticut	71590	Centralab Division of Globe-Union, Inc. Milwaukee, Wis.
04713	Motorola, Inc. Semiconductor Products Division Phoenix, Arizona	72982	Gudeman Co. Chicago, Illinois
05079	Tansitor Electronics, Inc. Bennington, Vt.	73445	Amperex Electronic Co. Division of North American Philips Co., Inc. Hicksville, N. Y.
08520	Electronic Devices, Inc. North Ridgeville, Ohio	74970	Johnson, E. F., Co. Waseca, Minn.
08804	Lamp Metals and Components Department G. E. Co. Cleveland, Ohio	75042	International Resistance Co. Philadelphia, Pa.
13050	Potter Co. Wesson, Miss.	75915	Littelfuse, Inc. Des Plaines, Ill.
14655	Cornell-Dubilier Electric Corp. Newark, N. J.	79727	Continental-Wirt Electronics Corp. Philadelphia, Pa.
15909	Daven Co. Livingston, N. J.	80164	Keithley Instruments, Inc. Cleveland, Ohio
24655	General Radio Co. West Concord, Mass.	81483	International Rectifier Co. El Segundo, Calif.
37942	Mallory, P. R., and Co., Inc. Indianapolis, Ind.	82879	Royal Electric Corp. Pawtucket, R. I.
53021	Sangamo Electric Co. Springfield, Ill.	85599	Tube Department G. E. Co. Schenectady, N. Y.
54294	Shallcross Mfg. Co. Selma, N. C.	91637	Dale Electronics, Inc. Columbus, Nebr.
56289	Sprague Electric Co. North Adams, Mass.	91737	Gremar Mfg. Co., Inc. Wakefield, Mass.
58474	Superior Electric Co., The Bristol, Conn.		

TABLE 9 (Sheet 2). Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)





