OPERATING INSTRUCTIONS

# TYPE 1650-A

# IMPEDANCE BRIDGE

1650

GENERAL RADIO COMPANY

3005-C

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# TYPE 1650-A

# IMPEDANCE BRIDGE

Form 3005-C
April, 1960

GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS, USA

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## SPECIFICATIONS

Ranges:

Resistance: 1 mΩ - 10 MΩ, 8 ranges ac or dc.

Capacitance: 1 μμf - 1000 μf, 7 ranges series on parallel.

Inductance: 1 μh - 1000 h, 7 ranges series on parallel.

D (of series C): 0.001 - 1 at 1 kc.

D (of parallel C): 0.1 - 50 at 1 kc. ($C_s = C_p$ within 1% if $D < 0.1$.)

Q (of series L): 0.02 - 10 at 1 kc.

Q (of parallel L): 1 - 1000 at 1 kc. ($L_s = L_p$ within 1% if $Q > 10$.)

Accuracy:

Resistance: ±1% ±1 mΩ (residual R ≈ 1 mΩ). (external dc supply required for 1% accuracy above 100 kΩ.)

Capacitance: ±1% ±1 μμf (residual C ≈ 0.5 μμf).

Inductance: ±1% ±1 μh (residual L < 0.2 μh).

D: ±5%; ±0.001 at 1 kc or lower.

1/Q: ±5%; ±0.001 at 1 kc or lower.

Frequency Range (1 kc supplied internally): for 1% accuracy for L and C, 20 cps to 20 kc; for R, 20 cps to 5 kc. (D and Q ranges are functions of frequency.)

Internal Oscillator Frequency (external ac and dc sources can also be used): 1 kc ±2%.

Internal Detector: Response, flat or selective at 1 kc; sensitivity control provided.

Internal DC Supply: 6 v, 60 ma max.

Power Supply: 4 D cells, supplied. Current drain for ac measurements, 10 ma.

DC Polarization: 600 v may be applied (from external source) to series capacitance measurements.

Accessories Supplied: One Type 274-MB Double Plug.

Other Accessories Available: Type 1650-P1 Test Jig.

Other Accessories Required: None. Earphones may be used for high precision at extremes of bridge ranges.

Mounting: Aluminum cabinet, with captive cover.

Dimensions: Height 12-3/4 in., width 12-1/2 in., depth 7-3/4 in., including handle.

Weight: 17 lb.

U.S. Patent No. 2,872,639.

*General Radio Experimenter* reference: Volume 33, No. 3, March 1959; "Orthonull", Volume 33, No. 4, April 1959.

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SPECIAL REQUEST TO THE USER OF THIS INSTRUMENT

We believe that the most effective way to make our products more useful is to learn from the experience and opinions of those who use them. For this reason we have included a questionnaire at the rear of this manual. Your answers to the questions contained, based on your experience in using this instrument, will be of great value to General Radio engineers and other personnel concerned with new products. Such comments will have a strong influence on the direction of future development work. The resulting better products will benefit our customers as well as ourselves.

The questionnaire sheet is its own postage-paid envelope. Simply cut it out, fold as directed, staple, and mail.

Any information you supply will not go outside our company without your specific advance authorization. May we have your opinions?


Figure 1.
Type 1650-A Impedance Bridge.

# TYPE 1650-A
# IMPEDANCE BRIDGE

## Section 1

## INTRODUCTION

1.1 DESCRIPTION.

1.1.1 GENERAL. The Type 1650-A Impedance Bridge (Figure 1) is a self-contained impedance-measuring system, which includes five bridges for the measurement of capacitance, resistance, and inductance, as well as the generators and detectors necessary for dc and 1-kc ac measurements. Features of this bridge include one-percent C, R, and L accuracy over all ranges, high D and Q accuracy, a mechanism to facilitate low Q measurement, visual ac and dc null indications, complete portability, and a convenient tilting mechanism and carrying case.

1.1.2 CONTROLS. The Table of Controls given below lists the controls located on the front panel of the Type 1650-A Impedance Bridge.

1.1.3 CONNECTORS. The Table of Connectors given below lists the connectors located on the front panel of the Type 1650-A Impedance Bridge.

TABLE OF CONTROLS

| Name | No. | Type | Function |
|---|---|---|---|
| CRL MULTIPLIER | S1 | 8-position selector switch | Selects impedance range. |
| CRL SELECTOR | S2 | 5-position selector switch | Selects bridge circuit. |
| FUNCTION Switch | S3 | 5-position selector switch | Turns bridge on to type of operation required. |
| CRL Dial | R1 | Continuous rotary control | Adjusts for bridge balance. |
| DQ Dial | R2 | Continuous rotary control | Adjusts for bridge balance. |
| ORTHONULL Lever | | Mechanical lever | Engages Orthonull mechanism. |
| DETECTOR Switch | S4 | Toggle switch | Controls detector response. |
| OSC LEVEL | R18 | Thumbset rotary control | Controls ac oscillator level. |
| SENSITIVITY | R15 R16 | Continuous rotary control | Controls ac and dc detector sensitivity. |

TABLE OF CONNECTORS

| Name | No. | Type | Function |
|---|---|---|---|
| UNKNOWN | J7, J8 | Jack-top binding-post pair | Connects unknown impedance |
| EXT GEN | J1, J2 | Jack-top binding-post pair | Connects ac or dc external source |
| BIAS | J3, J4 | Jack-top binding-post pair | Connects dc bias |
| DET OUTPUT | J5, J6 | Jack-top binding-post pair | Connects external amplifier or phones |

**1.2 SYMBOLS, ABBREVIATIONS, AND DEFINITIONS.** The following symbols, abbreviations, and definitions are used on the panel of the Type 1650-A and this instruction manual:

| | |
|---|---|
| C | capacitance (—‖—) |
| $C_s$ | series capacitance |
| $C_p$ | parallel capacitance |
| L | inductance (-ooo-) |
| $L_s$ | series inductance |
| $L_p$ | parallel inductance |
| R | resistance (-ww-), the real part of an impedance |
| $R_s$ | series resistance |
| $R_p$ | parallel resistance |
| X | reactance, the imaginary part of an impedance |
| Z | impedance |
| Q | quality factor $= \frac{X}{R} = \frac{1}{D}$ |
| | for inductors $\frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p}$ |
| D | dissipation factor $= \frac{R}{X} = \frac{1}{Q}$ |
| | for capacitors $\omega C_s R_s = \frac{1}{\omega C_p R_p}$ |
| PF | power factor $= \frac{R}{\lvert Z \rvert} = \frac{R}{\sqrt{R^2 + X^2}}$ |
| f | frequency |
| $\omega$ | angular frequency $2\pi f$ |
| $\Omega$ | ohm, a unit of resistance, reactance, or impedance |
| k$\Omega$ | kilohm 1 k$\Omega$ = 1000 ohms |
| M | multiplying factor applied to D and Q at frequencies other than 1 kc |
| M$\Omega$ | megohm 1 M$\Omega$ = $1 \times 10^6$ ohms |
| m$\Omega$ | milliohm 1 m$\Omega$ = 0.001 ohm |
| μf | microfarad, a unit of capacitance |
| mμf | millimicrofarad 1 mμf = 0.001 μf |
| μμf | micromicrofarad 1 μμf = $1 \times 10^{-6}$ μf |
| h | henry, a unit of inductance |
| mh | millihenry 1 mh = 0.001 h |
| μh | microhenry 1 μh = $1 \times 10^{-6}$ h |

**1.3 SERIES AND PARALLEL COMPONENTS.** An impedance that is neither a pure reactance or a pure resistance may be represented at any specific frequency by either a series or a parallel combination of resistance and reactance. The values of resistance and reactance used in the equivalent circuit depend on whether a series or a parallel combination is used. The equivalent circuits are shown in Figure 2.

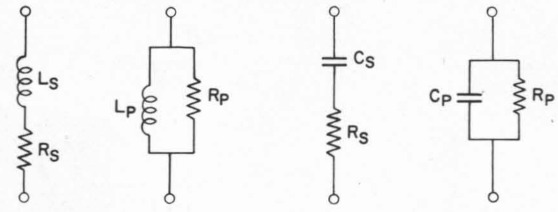



Figure 2. Equivalent Circuits for Complex Impedance.

The relationships between the circuit elements are:

<u>Resistance and Inductance</u>

$$Z = R_s + j\omega L_s = \frac{j\omega L_p R_p}{R_p + j\omega L_p} = \frac{R_p + jQ^2 \omega L_p}{1 + Q^2}$$

$$Q = \frac{1}{D} = \frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p}$$

$$L_s = \frac{Q^2}{1 + Q^2} L_p = \frac{1}{1 + D^2} L_p$$

$$L_p = \frac{1 + Q^2}{Q^2} L_s = (1 + D^2) L_s$$

$$R_s = \frac{1}{1 + Q^2} R_p; \quad R_p = (1 + Q^2) R_s$$

$$R_s = \frac{\omega L_s}{Q}; \quad R_p = Q\omega L_p$$

<u>Resistance and Capacitance</u>

$$Z = R_s + \frac{1}{j\omega C_s} = \frac{\frac{R_p}{j\omega C_p}}{R_p + \frac{1}{j\omega C_p}} = \frac{D^2 R_p + \frac{1}{j\omega C_p}}{1 + D^2}$$

$$D = \frac{1}{Q} = \omega R_s C_s = \frac{1}{\omega R_p C_p}$$

$$C_s = (1 + D^2) C_p; \quad C_p = \frac{1}{1 + D^2} C_s$$

$$R_s = \frac{D^2}{1 + D^2} R_p; \quad R_p = \frac{1 + D^2}{D^2} R_s$$

$$R_s = \frac{D}{\omega C_s}; \quad R_p = \frac{1}{\omega C_p D}$$

# Section 2

# PRINCIPLES OF OPERATION

2.1 GENERAL. Figure 3 shows the five bridge circuits used in the Type 1650-A Impedance Bridge, as well as the balance equations. Hays and Maxwell inductance bridges and series and parallel capacitance comparison bridges are used to provide wide coverage over the D and Q ranges, as shown in Figure 4. Full use of these wide ranges at low Q and high D values is achieved by means of an Orthonull balancing mechanism (refer to paragraph 2.5). Both ac and dc measurements may be made with the bridge, which has no internal phase balance.

The variable bridge components are General Radio precision wire-wound rheostats. The CRL rheostat uses a mechanical justifying mechanism for high accuracy, and the DQ rheostat has a 54-db logarithmic range. The standard capacitor is a General Radio Type 505 silvered-mica capacitor,

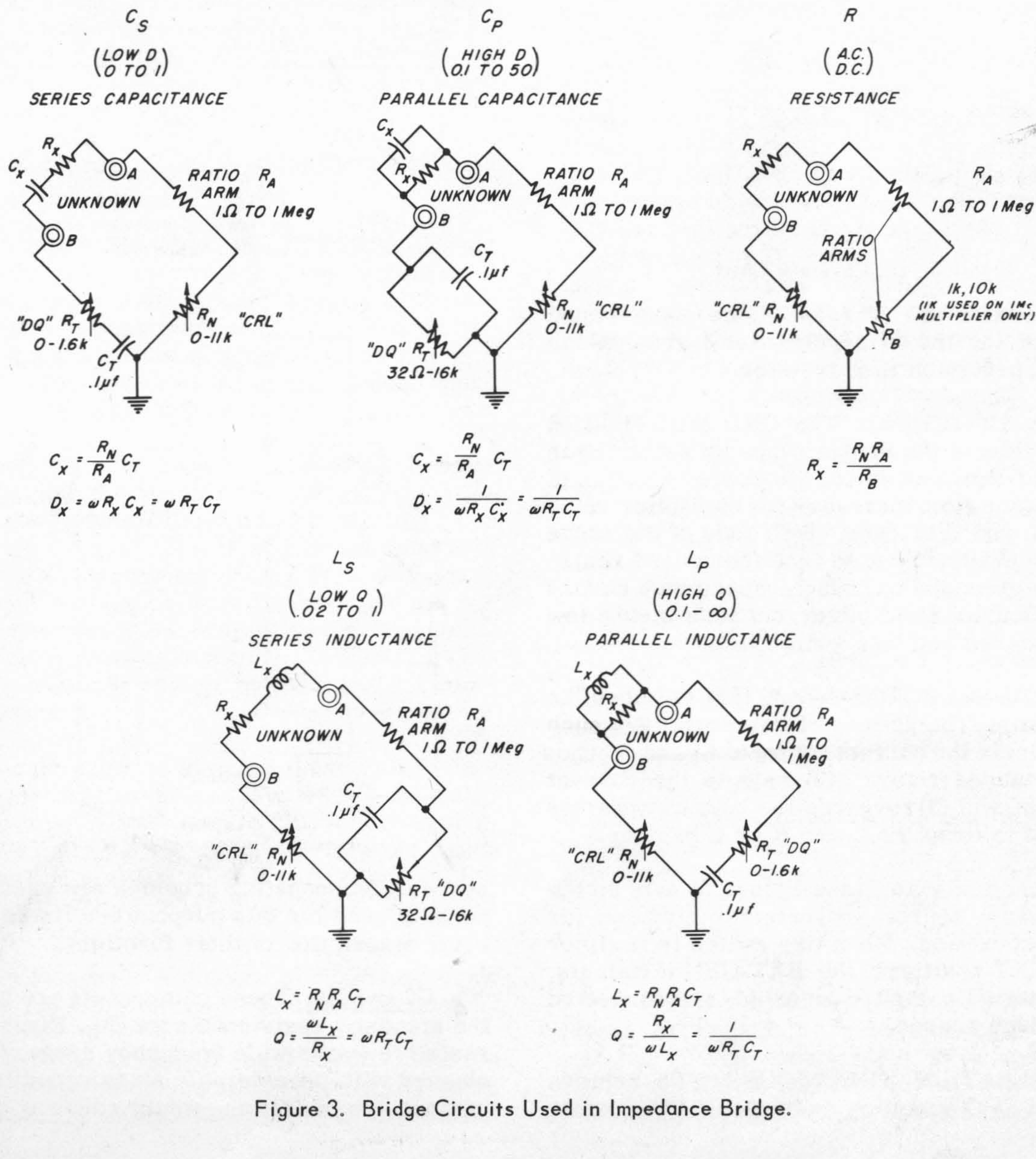



Figure 3. Bridge Circuits Used in Impedance Bridge.

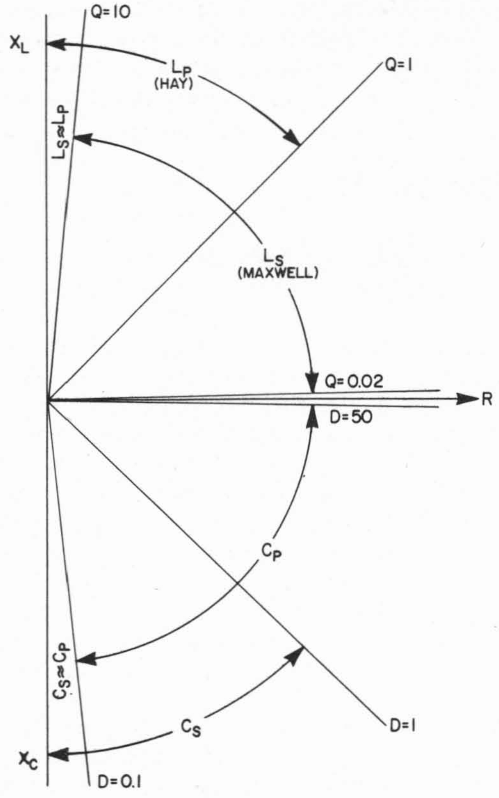



Figure 4. DQ Coverage Chart.

and the resistors are General Radio wire-wound cards except for the 1-megohm ratio arm, which uses a 1/4% precision film resistor.

2.2 BRIDGE SWITCHING. The CRL MULTIPLIER switch (S1) selects the bridge range by switching in various ratio-arm resistors. Clockwise rotation of this two-rotor switch increases the multiplier value for the R, L, and C bridges. Both ends of the range resistor are switched out so that the unused resistors may be grounded to reduce capacitance across this arm. Double, solid silver contacts insure low switch resistance and long switch life.

The CRL SELECTOR switch (S2) switches the bridge circuits. The actions of this switch are such that it (1) selects the correct rotors of S1 and grounds one of the unused rotors, (2) selects the correct standard arm, and (3) reverses the bottom two arms of the bridge to form the L and R or C bridges.

The function switch (see Figure 5) sets up the correct internal source and detector circuits for the desired operation. When this switch is in either of the two EXT positions, the EXT GEN terminals, used for externally applied ac or dc, are connected in as the bridge source.

2.3 COMPENSATION TECHNIQUES. To achieve the required D-Q accuracy over such wide ranges,

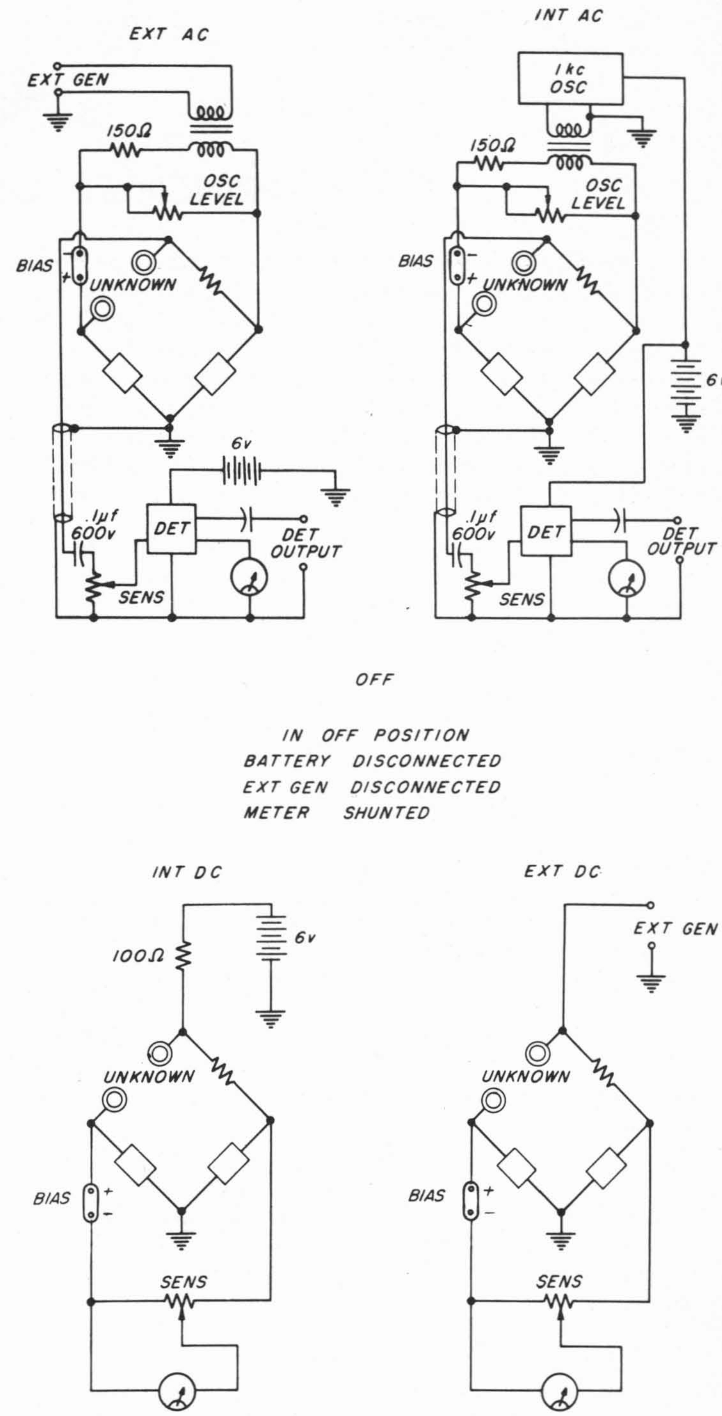



Figure 5. Source and Detector Diagrams.

several compensating schemes are used. The components used for this purpose are listed below, with brief description of their functions.

<u>C2 and L1:</u> These components are used to make the standard resistance arm ($R_b$, Figure 3) appear resistive over a wide frequency range. This arm is shunted with considerable stray capacitance, which, without compensation, would cause a poor ac null

and an error. The resistances of L1 and R4 add up to the required 10 kilohms.

C3: This capacitor corrects the phase angle of the first section of the DQ potentiometer ($R_t$) to compensate for the inductance of the winding. Without compensation, this inductance would cause an error in $C_s$ and $L_p$ at high frequencies, and in $C_p$ and $L_s$ when the unknown has a very low Q or high D.

C4: This capacitor corrects for the phase shift caused by stray capacitance across the CRL rheostat ($R_N$). This capacitor forms a three-terminal T network with the two parts of the rheostat to produce an effective inductance to balance out the stray capacitance.

C5: This capacitor compensates for the stray capacitance across the 1-megohm ratio arm (R12 and R13). The three-terminal T network formed by these components produces an effective inductance to balance out the stray capacitance.

C6: This capacitor compensates for the inductance of the 1-ohm ratio arm (R5).

2.4 BRIDGE SOURCES AND DETECTORS. The dc bridge supply is taken from the four internal D cells, which supply about 6 volts limited by a 100-ohm resistor to a maximum of 60 ma. The dc indicator on the panel has a sensitivity of 2μa/mm near zero, a resistance of 75 ohms, and a shaped characteristic (Marion Type C null indicator).

The ac source is a 1-kc transistor LC oscillator, which uses the primary of the bridge transformer as the inductor in the tuned circuit. The output voltage is about 1 volt at the secondary of the 4-to-1 step-down transformer. This secondary is wound with resistance wire to increase the resistance to about 150 ohms, preventing external loads from affecting the bridge frequency. The OSC LEVEL control adjusts output voltage by loading the transformer secondary.

The ac detector is a three-transistor, variable-gain amplifier, which uses a twin-T RC filter to obtain selectivity with the DETECTOR switch in the 1 kc position. This amplifier drives the panel meter to provide a visual ac null indication, and the output from the amplifier is supplied to the panel DET OUTPUT terminals.

The ac oscillator and detector combined draw less than 10 ma from the internal 6-volt battery.

2.5 ORTHONULL. Orthonull is a mechanical device that improves the bridge balance convergence when low Q inductors or high D capacitors are measured. Ordinarily, balances with such components are tedious and often impossible due to the "sliding null" resulting from the interdependence of the two adjustments. Rapid balances are possible with Orthonull, which does not affect electrical balance but which does help avoid false nulls, improving bridge accuracy for low Q measurements.

The bridge output voltage for the $L_s$ (Maxwell) bridge can be expressed:

$$\frac{E_o}{E_{in}} = \frac{R_x + j\omega L_x - \left(\frac{R_n R_a}{R_t} + j\omega R_n C_t R_a\right)}{\text{Denominator}} \qquad (1)$$

We will assume that the denominator is more or less constant in the region of the null. The numerator is the difference between the unknown impedance $R_x + j\omega L_x$ and what can be called the "bridge impedance". The bridge output is proportional to this difference, which is the distance between them on the complex plane. To balance the bridge, the "bridge impedance" is varied by adjustment of $R_n$ (the CRL dial) and $R_t$ (the DQ dial) until it equals the unknown impedance. An adjustment of $R_t$ varies only the real part of the bridge impedance, whereas an adjustment of $R_n$ varies both parts, and is therefore a multiplier of the bridge impedance. Thus, adjustment of $R_t$ moves the bridge impedance horizontally on the complex plane, while adjustment of $R_n$ moves it radially (see Figure 6). Each control is adjusted for a minimum voltage.

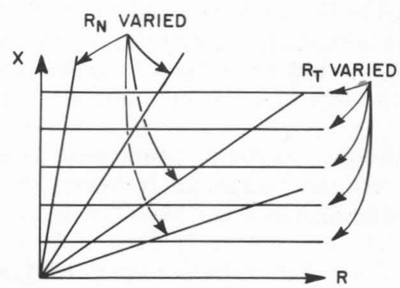



Figure 6. Loci of $R_n$ and $R_t$ Adjustments on Z Plane.

When X»R (i.e. when Q is high) these two adjustments are almost orthogonal, and rapid convergence is possible. When Q is low, however, the adjustment becomes more parallel and convergence is slow, causing a "sliding null", as shown in Figure 7, where Q = 1/2. With smaller Q's, convergence is even slower.

The Orthonull device makes the two adjustments orthogonal by nonreciprocally ganging $R_n$ and $R_t$. From equation (1) it is apparent that if $R_n/R_t$ remained constant as $R_n$ was varied, only the imaginary part of the bridge impedance would

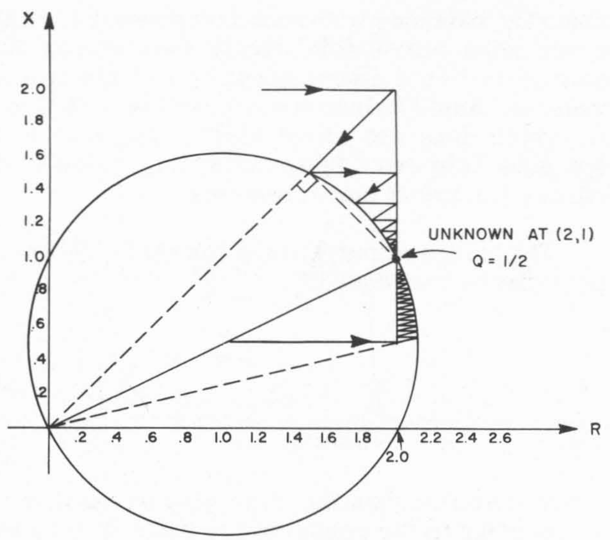



Figure 7. Loci of "Sliding Null" Balance.

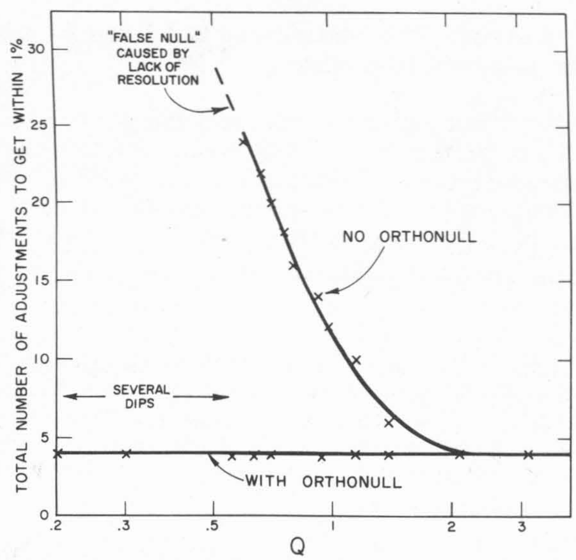



Figure 8. Number of Balances vs Q.

change. But when $R_t$ is adjusted, $R_n$ must not move to vary only the real part. The solution is a simple friction clutch to permit nonreciprocal action. Both the inherent difference in friction of the two rheostats and the pulley ratio favor torque transmission in the desired direction.

The ratio $R_n/R_t$ must be constant for variation in $R_n$ for any initial settings of $R_n$ and $R_t$, since $R_t$ may be moved independently of $R_n$. This requires rheostats with exponential characteristics (and logarithmic dials). The DQ rheostat is a 54-db exponential potentiometer with the correct initial resistance (R3) added when the $L_s$ and $C_p$ bridges are used. The CRL rheostat is exponential in the dial range from 1 to 11, and linear below 1. Thus, for correct Orthonull action, the CRL dial must be in the range above 1.

The Orthonull mechanism is shown in Figure 21. The clutch material is between the pulley attached to the DQ shaft and the free pulley driven by the wire belt. The clutch is disengaged by the lever on the panel so that normal operation is possible for high Q (low D) components.

The advantage of Orthonull is illustrated in Figure 8, which is a plot of the numbers of adjustments necessary for a balance. Not only does the Orthonull reduce the number of balances, but it permits 1% measurements that would otherwise be impossible below a Q of 1/3, due to the finite resolution of the DQ rheostat. This finite resolution causes the meter indication to vary in jumps when Orthonull is used at Q's below 1/3. However, by choosing the best null, 1% accuracy is possible with Q's of less than 0.2. As Q is further reduced, it is eventually impossible to achieve 1% balances. The accuracy that can be expected with careful adjustment is plotted against Q in Figure 9. In the face of the fact that for low Q values

$$\frac{d|Z|}{|Z|} = Q^2 \frac{dL}{L}$$

the eventual lack of accuracy is justified. For example, if Q = 0.03, a 5% change in inductance is a change of only 45 parts per million in impedance.

As far as the user is concerned, the balancing procedure with Orthonull is essentially the same as without it. However, several suggestions for its use are given in paragraph 5.5.

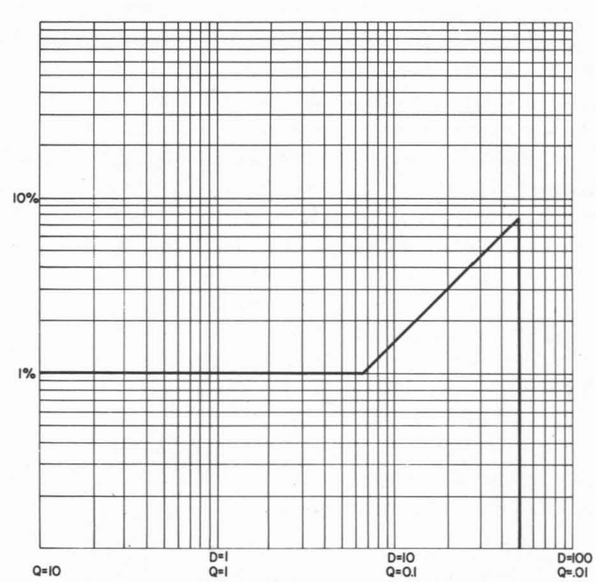



Figure 9. Accuracy vs D or Q.

# Section 3

# INSTALLATION

3.1 OPENING AND TILTING THE CABINET. The directions for opening the Type 1650-A Impedance Bridge are given on the handle support of the instrument. Once open, the instrument may be tilted to any convenient angle as shown in Figure 1. The angle should be chosen to give the most comfortable access to the knobs and the best view of the meter and dials.

The instrument may be locked fully open by the same slide pins that are used to lock the instrument closed. Thus, the instrument can be carried in the open position with the cover firmly in place.

When the instrument is open, the cover forms a convenient storage place for the instruction manual and for any other test data that should be kept with the instrument.

3.2 POWER SUPPLY. The instrument is powered by four D cells, which slide into the instrument through the cap at the top. These batteries, supplied with the instrument, should be installed with the positive terminals (center buttons) facing down.

The instrument is ready to operate as soon as it is in position and turned on.

# Section 4

# OPERATING PROCEDURE DC MEASUREMENTS

4.1 RESISTANCE MEASUREMENTS USING 6-VOLT SUPPLY.

4.1.1 PROCEDURE.

a. Check the NULL meter mechanical zero with the function switch in the OFF position, and, if necessary, center the pointer with the mechanical zero adjustment on the meter.

b. Turn the SENSITIVITY control almost fully counterclockwise.

c. Set the CRL SELECTOR to R.

d. Connect the resistor to be measured to the UNKNOWN terminals.

e. Turn the function switch to INT 6 V.

NOTE

As the function switch is rotated from OFF to INT 6 V, it passes through an undetented position where the circuit is operative but the meter is shunted to reduce sensitivity. A preliminary balance may be made with the switch in this position instead of with the SENSITIVITY control turned down.

f. Set the CRL MULTIPLIER switch and the CRL dial for a zero (center) meter reading, while adjusting the SENSITIVITY control to increase sensitivity. A meter deflection to the right indicates that the unknown is larger than the multiplier and dial setting. For greatest accuracy the final balance should be between 1 and 11 on the CRL dial (possible above 100 milliohms).

g. The value of the unknown resistance is the product of the CRL dial indication and the factor indicated on the CRL MULTIPLIER switch.

4.1.2 SENSITIVITY. With the internal 6-volt supply, one-percent balances may be easily made up to 10 kilohms and with care up to 100 kilohms. Above 100 kilohms a higher external voltage should be used (refer to paragraph 4.2).

A 100-ohm resistor in series with the internal 6-volt supply limits the current in the unknown to 60 ma. The unknown is in series with the CRL rheostat, so that the unknown current is greatest when the CRL dial is at zero.

The maximum power that can be applied to the bridge by the internal supply is 0.09 watt; thus there is no danger of injuring components rated at 1/10 watt or more.

At range extremes it is often desirable to make 1-kc ac measurements to increase sensitivity. For most resistors, the difference between the measured 1-kc and dc values is negligible.

4.1.3 ACCURACY OF DC RESISTANCE MEASUREMENTS. The accuracy of dc resistance measurements is ±1% if the CRL dial reading is between 1 and 11 as long as there is enough sensitivity. Below 100 milliohms, balance must be made with the CRL dial set below 1, and the bridge accuracy is ±1 milliohm if the 1-milliohm zero resistance of the bridge is subtracted from the reading.

For low-resistance measurements, short, heavy leads should be used as connections to the unknown. The zero resistance of the leads should be measured with the free ends connected together, and subtracted from the bridge reading with the unknown in place. The user should be particularly careful when using banana-pin connections. For best connection to the bridge, screw the binding post hard enough to notch the wire inserted in the hole.

4.2 RESISTANCE MEASUREMENTS USING EXTERNAL DC SUPPLIES.

4.2.1 PROCEDURE. The procedure for dc resistance measurements using an external supply is the same as that described in paragraph 4.1.1 except that:

a. The external supply should be connected across the EXT GEN terminals.

b. Set the function switch to the DC EXT position.

WARNING

When using external dc supplies be careful that there is no danger to the operator. It is advisable to limit high-voltage supplies to a current of 5 ma or less by placing resistance in series. Care should also be taken to avoid damage to the bridge and to the unknown component.

4.2.2 VOLTAGE AND CURRENT LIMITS. Bridge voltages must be limited to protect the bridge and the unknown component from damage. It is also advisable to limit the current to 5 ma or less to protect the operator from injury. The maximum voltage limit and standard EIA test voltages are described below.

Unless the utmost in sensitivity or a standard test voltage is desired, a supply of about 100 volts (e.g. a 90-volt battery), with about 25 kilohms in series, is recommended. The available power from such a supply is 0.1 watt, which is low enough dissipation for almost all resistors, and the maximum current is 4 ma. Such a supply permits measurements up to 1 megohm with 1% accuracy. For resistances over 1 megohm a higher voltage is desirable for good sensitivity, but it should be noted that the maximum EIA test voltage is 100 volts, and that various types of resistors have different voltage ratings.

The maximum voltage and current that may be applied to the bridge for each range are given in Table 1. Careful observation of both of these limits will prevent damage to the bridge.

Because the full voltage may be applied to the unknown, it is advisable to limit the available power to a value less than the power rating of the unknown component.

Various EIA standards for testing different types of resistors are summarized in Tables 2 and

TABLE I
MAXIMUM DC BRIDGE VOLTAGE AND CURRENT

| Range Full Scale | Range Multiplier | E Max | I* Max |
|---|---|---|---|
| 1 Ω | 100 mΩ | 71 v | 100 ma |
| 10 Ω | 1 Ω | 71 v | 100 ma |
| 100 Ω | 10 Ω | 71 v | 71 ma |
| 1 kΩ | 100 Ω | 71 v | 22 ma |
| 10 kΩ | 1 kΩ | 71 v | 14.1 ma |
| 100 kΩ | 10 kΩ | 223 v | 14.1 ma |
| 1 MΩ | 100 kΩ | 500 v | 14.1 ma |
| 10 MΩ | 1 MΩ | 500 v | 14.1 ma |

* It is preferable to limit current to avoid shock hazard or to reduce voltage to 10 v.

TABLE 2
EIA STANDARD TEST VOLTAGES
(RS 172 - FIXED COMPOSITION RESISTORS)

| Resistance Range | Bridge Mult Range | EIA Test Voltage Range | Bridge* Voltage |
|---|---|---|---|
| 2.7 - 99 Ω | 1 Ω | 0.5 - 1 v | ** |
| | 10 Ω | 0.5 - 1 v | 50 - 71 v*** |
| 100 - 999 Ω | 100 Ω | 2.5 - 3 v | 27.5 - 33 v |
| 1000 - 9999 Ω | 1 kΩ | 8 - 10 v | 16 - 20 v |
| 10 - 99 kΩ | 10 kΩ | 24 - 30 v | 26.4 - 33 v |
| 100 kΩ up | 100 kΩ | 80 - 100 v | 80 - 100 v |
| | 1 MΩ | 80 - 100 v | 80 - 100 v |

* at EXT GEN terminals
** cannot get required bridge voltage
*** limited to 71 v by bridge

3. A suggested setup for tests at these voltages is shown in Figure 10. The voltmeter here indicates the bridge voltage, and should be set as listed in Tables 2 and 3. An alternate scheme is to put the voltmeter directly across the unknown resistor, assuming that the input resistance of the voltmeter is large enough to cause no error.

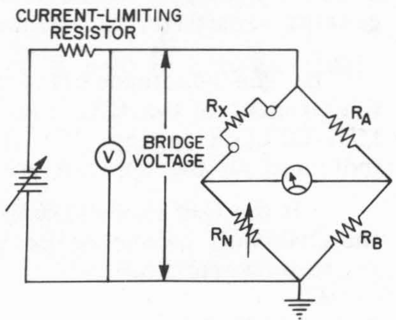



Figure 10.
Circuit for Tests at EIA Voltages.

TABLE 3
EIA STANDARD TEST VOLTAGES
(RS 196 FIXED FILM RESISTORS
REC 117 LOW-POWER WIRE-WOUND RESISTORS)

| Resistance Range | Bridge Mult Range | EIA Max Test Voltage | Max Bridg Voltage* |
|---|---|---|---|
| less than 10 Ω | 1 Ω | 0.3 v | ** |
| 10 - 99 Ω | 10 Ω | 1 v | ** |
| 100 - 999 Ω | 100 Ω | 3 v | 33 v |
| 1000 - 9999 Ω | 1 kΩ | 10 v | 20 v |
| 10 - 99 kΩ | 10 kΩ | 30 v | 33 v |
| 100 kΩ up | 100 kΩ | 100 v | 101 v |
| | 1 MΩ | 100 v | 100 v |

REC 117 applies only up to 9999 Ω.
* At EXT GEN terminals.
** Maximum allowable bridge voltage will not give maximum test voltage.

# Section 5

# OPERATING PROCEDURE — 1-KC MEASUREMENTS

5.1 CAPACITANCE MEASUREMENT.

5.1.1 PROCEDURE.

a. Set OSC LEVEL control fully on (clockwise).

b. Set DETECTOR switch to 1 kc.

c. Set CRL Selector to

$C_s$ - if series capacitance is desired and D is less than 1.

$C_p$ - if parallel capacitance is desired and D is between 0.1 and 50.

(Note: $C_s = C_p$ within 1% if $D < 0.1$.)

d. Set the function switch to INT 1 KC.

e. Connect the unknown capacitor to the UNKNOWN terminals.

f. If the proper range setting of the CRL MULTIPLIER is not known, set the CRL dial at about midscale, adjust the SENSITIVITY control adjusted to give an upscale meter reading, and set the CRL MULTIPLIER switch for a minimum deflection.

g. Adjust the CRL and DQ controls for the best minimum meter reading. The SENSITIVITY control may have to be adjusted to give greater sensitivity as balance is approached.

h. The capacitance of the unknown equals the product of the CRL dial reading and the CRL MULTIPLIER switch setting. The D of the known is that indicated on the appropriate scale on the DQ dial.

If the D of the unknown is near or greater than 1, the Orthonull balancing mechanism is useful. Refer to paragraph 5.5.

Refer to paragraphs 7.4 and 7.6 for measurements on shielded and grounded capacitors.

5.1.2 ACCURACY. The accuracy of the C reading is ±1% if the balance is made between 1 and 11 on the CRL dial. Below 1 on the dial the accuracy is ±1/2 division. Thus the over-all accuracy possible is ±1% or ±1 μμf, whichever is greater, since 1 μμf is 1/2 a dial division on the lowest range. The D accuracy is ±5% or ±0.001, whichever is greater.

The residual ("zero") capacitance of the bridge terminals is approximately 1/2 μμf, which is less than the accuracy of the bridge, and therefore, negligible. If external leads are used to connect the unknown, this zero capacitance is increased and should be subtracted from the bridge reading.

The residual resistance of the bridge is 1 milliohm, which theoretically causes a D error of 0.006 when $C_x$ = 1000 µf. In practice, capacitors of this size have such large D values that such an error is negligible. However, if leads are used to connect large capacitors this D error may become important and a correction should be made. The D error is $+ \omega R_o C_x$ (where $R_o$ is the lead resistance), and this amount should be subtracted from the D reading.

The residual inductance causes negligible error at 1 kc even if $C_x$ = 1000 µf. However, connecting leads could have enough inductance to cause a C error when large capacitors are measured. The error is $+ \omega L_o C_x$ (when $L_o$ is the lead inductance) and this amount should be subtracted from the C reading.

The capacitance accuracy is reduced on the $C_p$ bridge when D becomes larger than 10. However, even with the Orthonull balancing mechanism, balance to 1% precision is impossible, so that this error is negligible. Refer to paragraph 2.1, and Figure 9.

Errors for capacitance measurements at other frequencies are discussed in paragraphs 6.5 and 6.6. Table 5 (page 15) lists the corrections for residual and lead impedances.

5.2 INDUCTANCE MEASUREMENTS.

5.2.1 PROCEDURE.

a. Set the OSC LEVEL fully on (clockwise). Note: for some iron-cored inductors the inductance measured will depend upon the excitation level (refer to paragraph 5.4.4).

b. Set the DETECTOR switch to 1 Kc.

c. Set the CRL SELECTOR to

$L_s$ - if series inductance is desired and Q is between 0.02 and 10.

$L_p$ - if parallel inductance is desired and Q is greater than 1.

If Q is not known, use $L_p$. If unable to balance, switch to $L_s$.

(Note: $L_s = L_p$ within 1% if Q>10)

d. Set the function switch to INT 1 KC.

e. Connect the inductor to be measured to the UNKNOWN terminals.

f. If the proper range setting of the CRL MULTIPLIER is not known, set the CRL dial set at about midscale, set the SENSITIVITY control to give an upscale meter reading, and adjust the CRL MULTIPLIER switch for a minimum deflection.

g. Adjust the CRL control and the DQ control for the best minimum meter reading. The SENSITIVITY control may have to be adjusted to give greater sensitivity as balance is approached.

h. The inductance of the unknown inductor equals the product of the CRL dial reading and the CRL MULTIPLIER setting. The Q of the unknown is that indicated on the appropriate scale on the DQ dial.

If the Q of the unknown is near or less than 1, the Orthonull balancing mechanism is useful. Refer to paragraph 5.5.

5.2.2 ACCURACY. The accuracy of the L reading is ±1% if the balance is made between 1 and 11 on the CRL dial. Below 1 on the dial the accuracy is ±1/2 division. Thus the over-all accuracy is ±1% or ±1 µh, whichever is greater, since 1 µh is 1/2 dial division on the lowest range. The Q accuracy is given in terms of D = 1/Q and is ±5% or ±0.001, whichever is greater.

The residual (zero) inductance is less than 0.2 µh, which is less than the accuracy of the bridge and therefore negligible. If external leads are used to connect to the unknown, this zero inductance is increased and should be subtracted from the bridge reading.

The residual resistance of the bridge is 1 milliohm, which causes a small D (1/Q) error. This error is less than 0.001 if $L_x$ is more than 160 µh. If long leads are used to connect to the unknown, this error may become appreciable and require a correction. The D error is $+ \frac{R_o}{\omega L_x}$ (the Q error is $Q^2 \frac{R_o}{\omega L_x}$) where $R_o$ is the total lead resistance.

The residual zero capacitance of 0.5 µµf theoretically causes an error for inductors above 250 henries. However, this small capacitance is almost always negligible compared with the capacitance of the winding of such a large inductor. If the inductor is shielded, a three-terminal measurement will reduce the effect of stray capacitance to the shield (refer to paragraph 7.6). In order to reduce the effect of the winding capacitance it is necessary to reduce the measurement frequency. The inductance error due to a shunt capacitance $C_o$ is $\omega^2 C_o L_x^2$, and this amount should be subtracted from the bridge reading. (Refer to Table 5.)

The inductance accuracy is reduced slightly if Q is less than 0.1. However, even with Orthonull balance to 1%, precision is impossible, so that this error is negligible. Refer to paragraph 2.5 and Figure 9.

Errors for inductance measurements at other frequencies are discussed in paragraphs 6.5 and 6.6.

5.3 AC RESISTANCE MEASUREMENT.

5.3.1 PROCEDURE.

a. Set the OSC LEVEL control fully on (clockwise).

b. Set the DETECTOR switch to 1 kc.

c. Set the CRL SELECTOR to R.

d. Set the function switch to INT 1 KC.

e. Connect the unknown resistor.

f. If the proper range setting of the CRL MULTIPLIER is not known, set the CRL dial at about midscale, set the SENSITIVITY control to give an upscale meter reading, and set the CRL MULTIPLIER switch for a minimum deflection.

g. Adjust the CRL control for the best minimum meter reading. The SENSITIVITY control may require adjustment to give greater sensitivity as balance is approached.

h. The resistance of the unknown equals the produce of the CRL dial reading and CRL MULTIPLIER switch setting.

5.3.2 ACCURACY OF AC RESISTANCE MEASUREMENTS. The accuracy of the R reading is ±1% if the balance is made between 1 and 11 on the CRL dial. Below 1 on the dial the accuracy is ±1/2 a division. Thus the over-all accuracy is ±1% or ±1 milliohm, whichever is greater, as long as the 1-milliohm residual resistance is subtracted from the R reading.

The residual resistance of 1 milliohm is that of the binding posts themselves. For low-resistance measurements, short, heavy leads should be used as connections to the unknown. The zero resistance of the leads should be measured with the free ends connected together, and subtracted from the bridge reading with the unknown in place. The user should be particularly careful when using banana-pin connections. For best connection to the bridge, screw the binding post hard enough to notch the wire inserted in the hole.

Since there is no internal Q adjustment on the R bridge, reactance affects only the ability to get a good sharp null. If the reactance is large enough to prevent a satisfactory balance, an external capacitor may be used to make a reactance balance (refer to paragraph 7.4).

5.4 NOTES ON AC MEASUREMENTS.

5.4.1 CAPACITANCE TO GROUND. The Type 1650-A Bridge generally measures "ungrounded" components, since neither UNKNOWN terminal is connected directly to the panel. The panel should be connected to a good ground, especially if high-impedance components are to be measured. If the panel is not grounded, stray capacitances from the UNKNOWN terminals and panel to ground can produce an effective capacitance across the UNKNOWN terminals. With the panel grounded, capacitances from the UNKNOWN terminals to ground have a much less serious effect. (For measurements of grounded components refer to paragraph 7.6.)

The effects of stray capacitances to the panel (ground) are usually negligible in the capacitance bridges (see Figure 11). Capacitance from the LOW terminal to ground ($C_a$) shunts the detector and causes no error. Capacitance from the other terminal to ground ($C_b$) shunts the standard capacitor ($C_t$) and produces an error of

$$-\frac{C_b}{C_t} \times 100\% = -\frac{C_b}{0.1\ \mu f} \times 100\%$$

Since $C_t$ is large it takes 1000 μμf to produce a 1% error (when D is small).

In the inductance bridge (see Figure 12) $C_a$ is across the detector and has no effect, but $C_b$ shunts the CRL rheostat. Capacitance across this rheostat

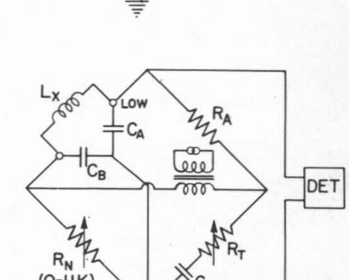



Figure 11.
Capacitance to Ground
for Capacitance Measurement.

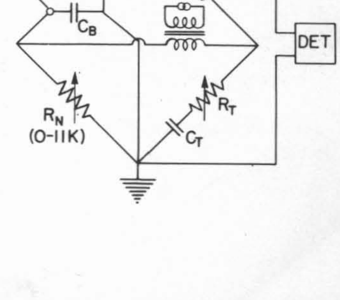



Figure 12.
Capacitance to Ground
for Inductance Measurement.

causes a D (1/Q) error of $-\omega R_n C_b$. The L error is usually negligible except when $Q_x$ is very low

$$\left[L \text{ meas} = L_x\left(1 + \frac{\omega R_n C_b}{Q_x}\right)\right]$$

Thus, for inductance measurements, it is desirable to connect the terminal with the most capacitance to ground to the UNKNOWN terminal marked LOW.

5.4.2 VOLTAGE ON THE UNKNOWN. The voltage applied to the bridge is approximately 1 volt, with a source impedance of about 150 ohms. The actual voltage on the unknown may be calculated with the aid of the circuit diagram of Figure 3 and Table 4, or may be measured with a high-impedance voltmeter.

TABLE 4
RATIO ARM VALUES AND VOLTAGE RATINGS

| CRL MULTIPLIER Setting | $R_a$ Value | $R_a$ Max Voltage | $R_b$ Value | $R_b$ Max Voltage |
|---|---|---|---|---|
| 100 μμf - mΩ - μh | 1 Ω | 0.71 v | 10 kΩ | 71 v |
| 1 mμf - Ω - mh | 10 Ω | 2.2 v | 10 kΩ | 71 v |
| 10 mμf - Ω - mh | 100 Ω | 7.1 v | 10 kΩ | 71 v |
| 100 mμf - Ω - mh | 1 kΩ | 22 v | 10 kΩ | 71 v |
| 1 μf - kΩ - h | 10 kΩ | 71 v | 10 kΩ | 71 v |
| 10 μf - kΩ - h | 100 kΩ | 71 v | 10 kΩ | 71 v |
| 100 μf - kΩ - h | 1 MΩ | 500 v | 10 kΩ | 71 v |
| 1 MΩ | 1 MΩ | 500 v | 1 kΩ | 22 v |

5.4.3 SENSITIVITY. The generator-bridge-detector system is sensitive enough to permit 1% balances with the meter used as a detector. If higher sensitivity is required for precise measurements of D or Q at the range extremes, headphones or an external amplifier may be connected to the DET OUTPUT terminals.

5.4.4 EFFECT OF LEVEL ON IRON-CORED INDUCTOR MEASUREMENTS. Iron-cored inductors are nonlinear devices and the value of inductance depends on the level of the applied voltage. In order to make measurements repeatable, the signal level should be specified. The "initial permeability" inductance, or inductance at zero level, is often used as a reference (as is done on GR Type 1481 Standard Inductors). To obtain this value, plot L vs voltage applied and extrapolate to zero voltage. The OSC LEVEL control permits such measurements, and it is often useful to make a level change in order to see if the unknown inductance depends on the signal level.

5.5 OPERATING PROCEDURE WITH ORTHONULL. In the measurement of inductors whose Q is less than 1 or capacitors whose D is greater than 1, balancing procedure can be simplified and false nulls avoided by the use of Orthonull (refer to paragraph 2.5). The balancing procedure (essentially the same as without Orthonull once the Orthonull mechanism is engaged) is as follows:

a. Set the bridge switches as described in paragraph 5.1.1, 5.2.1, or 6.1, depending on what is being measured. Connect the unknown to the UNKNOWN terminals, and connect the external generator (if one is used) as described in paragraph 6.2.

b. Set the Orthonull lever to ORTHONULL.

c. Set the CRL dial upscale (10 or 11).

d. Make the first balance with the DQ dial.

e. Adjust the CRL dial for further balance (the DQ dial, ganged to the CRL dial by the Orthonull mechanism, will follow). If the CRL setting is less than 1 at balance, turn the CRL MULTIPLIER switch to a lower range and rebalance.

f. Make further balances using first the DQ dial, then the CRL dial, then the DQ dial, etc. until the meter reading cannot be reduced further.

When the Q is very low, the meter deflection will give several sharp dips as the CRL dial is rotated. To find the best dip, rotate the CRL dial slowly over a wide range without making another DQ adjustment.

Often the Q is higher at some other frequency, and it is desirable to change the frequency of measurement. This is necessary if the inductor is above resonance and appears capacitive.

# Section 6

# OPERATING PROCEDURE WITH EXTERNAL AC GENERATOR

6.1 PROCEDURE. The procedure for making measurements with an external oscillator is the same as that with the internal 1-kc oscillator except for the following:

a. Connect the external oscillator to the instrument as described in paragraph 6.2. (Note that the OSC LEVEL adjustment controls the level of external ac applied to the EXT GEN terminals.)

b. Set the DETECTOR switch to FLAT (if frequency is not 1 kc).

c. Set the function switch to AC EXT.

d. Multiply the D and Q readings by the factor M, which is given on each scale of the DQ dial.

for low D and low Q  $M = f/1$ kc

for high D and high Q  $M = 1$ kc$/f$

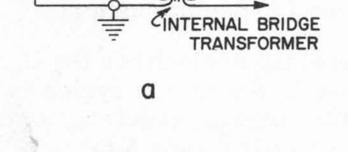
e. The accuracy of the bridge is within 1% if the value of D or Q lies within the limits of paragraph 6.4, and if the effects of the bridge residual impedance and of lead impedances are taken into account (refer to paragraph 6.6). The accuracy is 1% up to 20 kc for the C and L bridges and up to 5 kc for the resistance bridge.

If the presence of a nonlinear unknown causes appreciable distortion in the detector, the best null may not give the correct value. Earphones are helpful in distinguishing a null at the fundamental frequency, or an external selective amplifier, such as the Type 1231-B Amplifier and Null Detector with appropriate filter, can be used.

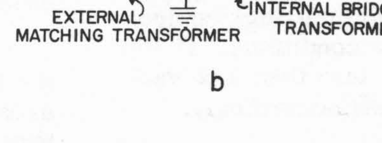
6.2 CONNECTION OF EXTERNAL GENERATOR. The external generator may be connected to the bridge by any one of several methods. The choice depends on frequency and on the amount of overvoltage to be supplied.

The simplest method is to connect the generator to the EXT GEN terminals, which are connected to the primary of the bridge transformer when the function switch is set at AC EXT. Because the internal bridge transformer is used in this method, one terminal of the oscillator is tied to ground, and capacitance across the oscillator has no effect. However, the inductance of the bridge transformer primary is low (23 mh) because it is used in the internal LC oscillator, and becomes quite a load on the external oscillator at low frequencies. A resistor may be put in series with the oscillator to avoid overloading and consequent distortion. (See Figure 13a and paragraph 6.3.)

A matching transformer (see Figure 13b) will provide more power in the bridge at low frequencies. This need not be a shielded bridge transformer; a filament transformer (110 to 6.3 v) is useful at low frequencies.

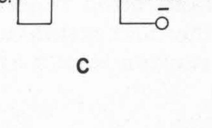



a

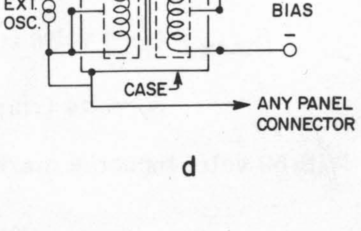



b

Figure 13. Methods of Applying External AC.




c




d

The external generator can also be connected directly into the bridge circuit through the BIAS terminals (be sure to open the jumper strap). See Figure 13c. In this connection capacitance from either terminal of the generator to ground should be considered. Capacitance from the + BIAS terminal to the bridge chassis causes little difficulty in the capacitance bridge if it is less than 1000 μμf, but causes a Q error in the inductance bridges (refer to paragraph 5.4.1). Capacitance from the negative BIAS terminal to chassis can cause a more severe error especially at high frequencies on the low impedance ranges, and should be kept to a minimum. Use of a shielded lead (Figure 13c) keeps this capacitance low.

At times, to reduce the effects of hum between oscillator and power line, it is best to ground the oscillator and to leave the bridge chassis floating.

A shielded bridge transformer, such as the GR Type 578-A Shielded Transformer, may be used to make connections to the BIAS terminals to reduce capacitance difficulties. Connections are shown in Figure 13d.

6.3 MAXIMUM AC VOLTAGE. The maximum ac voltage that may be applied to the Type 1650-A Bridge depends on:

a. the voltage and power ratings of each component (including the unknown),

b. the bridge circuit used,

c. the range used,

d. the position of the variable components,

e. the method of applying the voltage.

Exact limits for any specific measurement may be calculated from the data in Table 4 using the circuit diagrams of Figure 3. If such a maximum voltage is applied, care must be taken to avoid any adjustments of the panel controls that would result in an overload.

A much simpler approach is to limit the power into the bridge to 1/2 watt so that no bridge component can be damaged under any conditions. If the power rating of the unknown is less than 1/2 watt, the input power should be reduced accordingly.

If the external signal is applied to the EXT GEN terminals, the maximum voltage is limited to

$$E_{max} = \left(\frac{f}{6}\right) \text{ volts (rms) f in cps, or}$$

60 volts (rms) whichever is smaller

With 60 volts input the maximum power to the bridge is 1/2 watt and the open-circuit secondary voltage is 15 volts.

If the external signal is connected to the BIAS terminals, the maximum voltage is 280 volts (rms), and a series resistor of $\left(\frac{E^2}{2} - 120\right)$ ohms (where E is in volts) should be placed in series to limit the power to 1/2 watt. Note that if E is 15 volts or less no resistor is required, since the resistance of the transformer secondary limits the power to the bridge.

6.4 ALLOWABLE D AND Q RANGES VS FREQUENCY. The D and Q readings and ranges are functions of frequency. Also, in order to avoid errors in the C and L readings, the D or Q of the unknown is further limited. The resulting allowable D and Q ranges are given in terms of frequency and D or Q of the unknown at the measurement frequency in Figure 14.

The numbers on the various limits refer to the explanations below:

1. End of DQ rheostat range.

2. First division on Low D (0.001) and High Q (1000) scales (no C or L Error).

3. Limited by D of standard capacitor (no C or L Error).

4. 20-cps limit because of meter response.

5. 20 kc, a nominal limit (range narrow above 20 kc).

6. C or L error due to capacitance across standard $C_t$ and $R_t$.

7. C or L error due to inductance in DQ potentiometer.

8. End of the low D and high Q scales. Use the low Q scale to extend the low D range, and the high D scale to extend the high Q range.

9. Limit of 1% C and L accuracy, even with Orthonull (refer to paragraph 2.5).

10. C and L error may be 2% above this line owing to inductance in the DQ potentiometer.

Note that in the overlap area either the $C_s$ or the $C_p$ bridge may be used. Below 100 cycles is an area not covered by either bridge, requiring an external adjustment (refer to paragraph 6.6).

6.5 CORRECTIONS FOR RESIDUAL AND LEAD IMPEDANCES. At high frequencies, the errors resulting from the residual bridge impedances and from the connecting lead impedances become more important, often requiring corrections. The formulas for the correction terms are given in Table 5. These correction terms are first-order terms only.

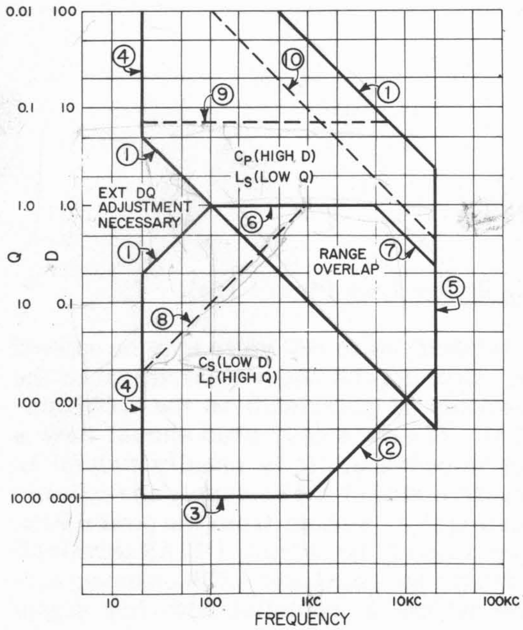



Figure 14. DQ Ranges vs Frequency.
(Refer to paragraph 6.4.)

TABLE 5
ERRORS DUE TO RESIDUAL AND LEAD IMPEDANCES
CORRECTION TERMS; ADD OR SUBTRACT
FROM MEASURED VALUE AS INDICATED

| Measured Quantity | Series Resistance $R_o$ (1 mΩ + leads) | Series Inductance $L_o$ (0.2 μh + leads) | Parallel Capacitance $C_o$ (0.5 μμf + leads) |
|---|---|---|---|
| $C_s$ | No Error | $-\omega^2 L_o C_x^2$ | $-C_o(1 - D_x^2)$ |
| D | $-\omega C_x R_o$ | $-\omega^2 L_o C_x D_x$ | $+D\frac{C_o}{C_x}(1 + D^2)$ |
| $C_p$ | $+2 R_o \omega D_x C_x^2$ | $-\omega^2 L_o C_x^2 (1 - D_x^2)$ | $-C_o$ |
| D | $-\omega C_x R_o (1 + D_x^2)$ | $-\omega^2 L_o C_x D_x (1 + D_x^2)$ | $+\frac{C_o}{C_x} D_x$ |
| R | $-R_o$ | | |
| $L_s$ | No Error | $-L_o$ | $-\omega^2 C_o L_x^2 (1 - \frac{1}{Q_x^2})$ |
| Q | $+Q_x^2 \frac{R_o}{\omega L_x}$ | $-\frac{L_o}{L_x} Q_x$ | $+\omega^2 C_o L_x (Q_x + \frac{1}{Q_x^2})$ |
| $L_p$ | $+\frac{2R_o}{Q\omega}$ | $-L_o (1 - \frac{1}{Q^2})$ | $-\omega^2 C_o L_x^2$ |
| Q | $+\frac{R_o}{\omega L_x}(1 + Q^2)$ | $-\frac{L_o}{L_x}(Q + \frac{1}{Q})$ | $+\omega^2 C_o L_x Q$ |

6.6 EXTENDING THE D AND Q RANGES AT LOW FREQUENCIES. The wide overlap of ranges (see Figure 14) permits D and Q coverage down to 100 cycles without external adjustment. Below 1 kc, more of the low D and high Q range may be used than is calibrated. In this region, the low Q scale may be used to indicate D directly and the high D scale used to indicate Q directly with a maximum additional error of 2%.

Below 100 cycles there is a D and Q range not covered by the internal DQ adjustment. An external rheostat or decade box may be used to extend the range of any of the D or Q scales. (However, to avoid error, the low D and high Q ranges should not be extended beyond a value of 1 at frequency of measurement (see Figure 14).

To connect the external resistance, remove the bridge from its cabinet and connect the two wires from the external resistance to the terminals marked 16 and 17, which are on the bracket directly behind the BIAS terminals (see Figure 21). Remove the jumper between terminals 16 and 17, and bring the leads out through the panel hole directly below the BIAS terminals after removing the snap button.

The low D and low Q scales are directly proportional to frequency. Therefore, the total D or Q value is the sum of the dial reading plus the $\omega RC$ product due to the external resistor. That is:

low D = (low D dial reading + 0.628R) x f (kΩ, kc)

low Q = (low Q dial reading + 0.628R) x f (kΩ, kc)

The low Q circuit has a fixed 32-ohm resistor in series with the potentiometer, but that is included in the dial calibration.

The high D and high Q scales are inversely proportional to frequency, and the effects of the internal and external resistors are therefore not additive. The DQ rheostat should be set to a minimum (high Q = 0 or high D = 50), and the whole adjustment will be on the external resistance and will be:

$$\text{high Q} = \frac{1.592}{fR} \quad (k\Omega, kc)$$

$$\text{high D} = \frac{1.592}{f(R + 0.032)} \quad (k\Omega, kc)$$

# Section 7
# SPECIAL MEASUREMENTS

7.1 APPLICATION OF DC BIAS TO CAPACITORS. Up to 600 volts of dc bias may be applied to the unknown capacitor by any of several different methods. The simplest method can be used for measuring only series capacitance; fortunately, this is how most capacitors are specified.

WARNING

> Charged capacitors form a shock hazard, and care should be taken to ensure personal safety during measurement and to be sure that the capacitors are discharged after measurement. The external dc supply should also be handled carefully.

It is advisable to limit the power that may be drawn from the external dc supply to 1/2 watt (by a resistor, fuse, or circuit breaker) in order to protect the bridge components in case the unknown is short-circuited.

The various methods of applying dc bias to capacitors are described below, along with suggestions for their use:

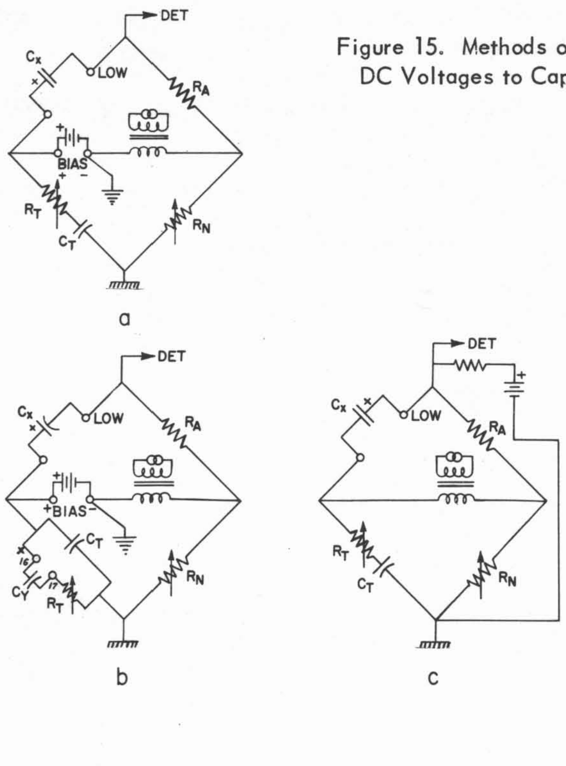



Figure 15. Methods of Applying DC Voltages to Capacitors.

Method 1. $C_s$ Bridge (see Figure 15a).

In this method, up to 600 volts may be applied on any range. Connect the negative terminal of the unknown capacitor (if polarized) to the LOW unknown terminal. The dc supply used should have a low ac output impedance. It is usually helpful to ground the negative side of the dc supply and to leave the bridge floating to avoid hum from the power line. If the negative side of the supply (-BIAS terminal) is grounded, the bridge panel and LOW unknown terminal will be at low dc potential with low signal voltage on them.

Method 2. $C_p$ Bridge (see Figure 15b).

The same precautions mentioned in Method 1 apply here, and a blocking capacitor should be added between the internal terminals 16 and 17, which are directly behind the BIAS terminals. The positive side of the blocking capacitor should be tied to terminal 16 as shown in Figure 15b. The voltage rating of this capacitor should be sufficient for the full dc applied. The capacitance required depends on the D of the unknown and on the accuracy required. The errors caused by this capacitor are:

$$C \text{ measured} = C_x\left(1 - \frac{C_t}{C_y} D_x^2\right) \qquad C_t = 0.1\ \mu f$$

$$D \text{ measured} = D_x\left(1 + \frac{C_t}{C_y} D_x^2\right)$$

Method 3. $C_s$ or $C_p$ Bridge (see Figure 15c).

This method is recommended for small capacitors. The maximum voltages that may be applied to the $C_s$ bridge are given in Table 6. For the $C_p$ bridge, the maximum voltages on the unknown given in Table 6 apply, but the maximum voltages on the bridge are a function of the DQ dial setting.

The ac impedance of the dc source should be high (>10 k) to avoid shunting the detector, and the dc source should have low hum. The advantages of this circuit are that the bridge and supply are both grounded and the dc current can be easily limited by a resistor, since the impedance of the source should be high.

WARNING

Note that the LOW UNKNOWN terminal has the high voltage on it in this method.

TABLE 6
MAXIMUM DC VOLTAGES APPLIED TO CAPACITORS BY METHOD 3

| Range Multiplier | Max Volts On Bridge | Max Volts On Unknown |
|---|---|---|
| 100 μμf | 505 v | 500 v |
| 1 mμf | 242 v | 220 v |
| 10 mμf | 142 v | 71 v |
| 100 mμf | 78 v | 7 v |
| 1 μf | 72 v | 0.7 v |
| 10 μf | 71 v | 0.07 v |
| 100 μf | 71 v | 0.007 v |

7.2 APPLICATION OF DIRECT CURRENT IN INDUCTORS. Direct current may be supplied to inductors during measurement by any of several different methods so that incremental inductance measurements may be made. The various methods are described below along with suggestions for their use. The block capacitor $C_b$ (Figure 16) is needed only for the $L_s$ bridge shown, and is connected between terminals 16 and 17, on a bracket behind the BIAS terminals (see Figure 21). The errors caused by this capacitor are:

$$L_s \text{ measured} = L_x\left(1 - \frac{C_t}{C_b}\,\frac{1}{Q_x^2}\right) \qquad C_t = 0.1\ \mu f$$

$$Q \text{ measured} = Q_x\left(1 - \frac{C_t}{C_b}\,\frac{1}{Q_x^2}\right)$$

WARNING

Large inductors carrying high currents are shock hazards. Reduce the dc to zero before disconnecting the dc supply or unknown inductor.

Method 1. (See Figure 16a.)

The maximum current is limited to that given in Table 7. The dc supply may be tied to ground and the instrument left floating as shown, where the capacitance of the bridge to ground shunts $R_n$ and causes a D (1/Q) error of $-\omega R_n C$. If the dc supply has low capacitance to ground and low internal capacitive coupling to the power line, the bridge may be grounded and the dc supply left floating.

The blocking capacitor $C_b$ must be of high enough rating to take a voltage equal to the maximum direct current in amperes times 120 ohms.

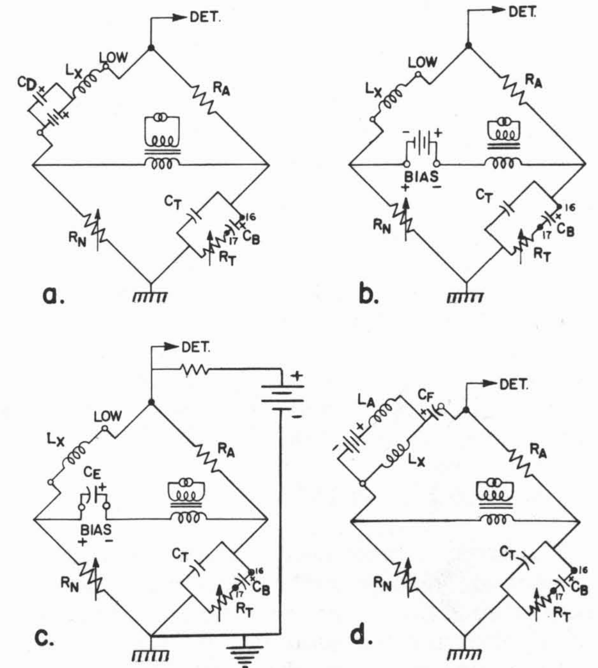



Figure 16. Methods of Applying DC to Inductors.

The source impedance of the dc supply must be low compared with that of the unknown, since the bridge measures both of these impedances in series. A large capacitor ($C_d$) shunting the dc supply is sometimes useful.

Method 2. (See Figure 16b.)

The maximum current in this method is limited to that given in Table 7. The dc supply is connected to the BIAS terminals with the signs reversed in order to keep the bridge case and dc supply both at zero volts dc from ground. The blocking capacitor $C_b$ must be able to take the full dc voltage. The ground connection may be made to either the panel or the dc supply.

TABLE 7
MAXIMUM DC THROUGH INDUCTORS OR RESISTORS (METHODS 1 AND 2)

| Range Multiplier | | Maximum Current | $R_a$ (Ratio Arm) |
|---|---|---|---|
| L | R | | |
| 100 μh | 100 mΩ | 100 ma | 1 Ω |
| 1 mh | 1 Ω | 100 ma | 10 Ω |
| 10 mh | 10 Ω | 71 ma | 100 Ω |
| 100 mh | 100 Ω | 22 ma | 1 kΩ |
| 1 h | 1 kΩ | 7.1 ma | 10 kΩ |
| 10 h | 10 kΩ | 2.2 ma | 100 kΩ |
| 100 h | 100 kΩ | 0.5 ma | 1 MΩ |
| | 1 MΩ | 0.5 ma | 1 MΩ |

Method 3. (See Figure 16c.)

This method is recommended for large inductors, since the maximum current is the same for any range. In this method both the bridge and the dc supply are grounded.

The maximum allowable current for any range is 40 ma. The output impedance of the dc supply should be high enough to avoid loading the detector (a series resistor is often useful) and should have low hum.

The blocking capacitor $C_e$ must be able to take the dc IR drop across the unknown inductor, and $C_b$ must be able to take the whole dc voltage.

Method 4. (See Figure 16d.)

The method must be used with very large dc. The maximum voltage on the unknown is limited only by the rating of $C_f$. The ac source impedance of the dc supply must be much higher than the impedance of the unknown since the bridge measures the parallel combination of these two impedances. A large inductor, $L_a$, may be connected as shown to provide a high source impedance. Often it is possible to resonate the feed inductor to increase the source impedance further. Also, the impedance of the blocking capacitor, $C_f$, should be low compared with the impedance of the unknown since it is directly in series with the unknown.

7.3 DC BIAS FOR AC RESISTANCE MEASUREMENTS. A dc bias voltage and current may be applied to various types of nonlinear resistive elements such as diodes, varistors, and thermistors in order to measure small ac signal resistance. For voltage sensitive devices, diodes, and varistors, the ac resistance is the slope of the dc voltage-current curve. For thermally sensitive devices, the ac resistance is equal to the dc resistance as long as the time constant is much longer than the period of the ac signal. Several methods of applying dc are shown in Figure 17.

Method 1. (See Figure 17a.)

In this method all of the current supplied flows through the unknown. The current is limited to the amount given in Table 7. The dc source impedance should be low compared with that of the unknown, or the source should be shunted by a large capacitor as shown. If the dc supply is grounded, the bridge chassis may be at a potential of up to 6 volts.

Method 2. (See Figure 17b.)

This method removes the dc supply from the bridge arm so that its impedance is not so important. The current in the unknown is equal to the current supplied multiplied by $\frac{R_b}{R_a + R_b}$, and should be limited to that given in Table 7. The voltage applied should be limited to 71 volts*. If the dc supply is grounded, the bridge chassis may be at a potential of up to 37 volts.

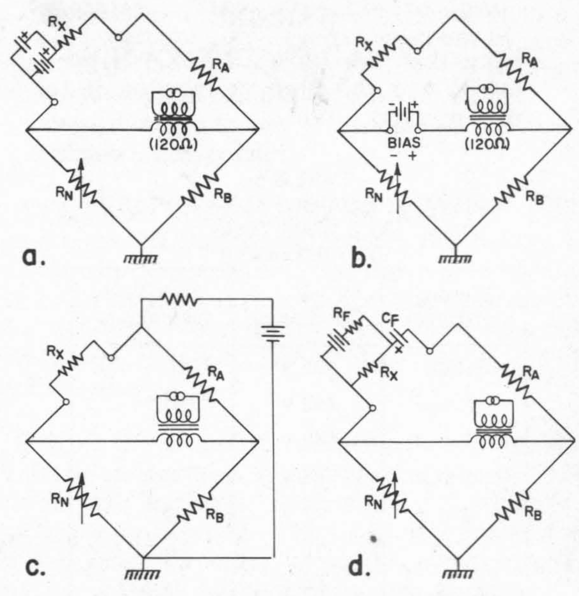



Figure 17. Methods of Applying DC for AC Resistance Measurements.

Method 3. (See Figure 17c.)

This method permits grounding of both the bridge chassis and the dc supply. The current through the unknown is equal to the current supplied multiplied by $\frac{R_a}{R_a + R_x}$. The dc current and voltage limits are given in Table 1, page 8.

Method 4. (See Figure 17d.)

This method permits large currents through low resistors, since no current flows in the bridge. The resistor $R_f$ should be large compared with the unknown, and the blocking capacitor $C_f$ should be able to take the dc voltage $I_{dc}R_x$. The impedance of the blocking capacitor should be low compared with that of the unknown.

7.4 MEASUREMENT OF AC RESISTANCE WITH REACTANCE. If the unknown resistor has a large reactance a good ac balance is difficult to obtain. Use of an external capacitor to balance the reactance will permit a sharp balance.

If the unknown is capacitive, the external capacitor should be connected from either BIAS terminal to ground, as in Figure 18a. At balance, the CRL dial will read the effective parallel resistance

*22 volts at 1MΩ range.

of the unknown, and the external capacitance $C_n$ is a measure of the capacitance of the unknown. The formula is

$$C_x = C_n \frac{R_n}{R_x}$$

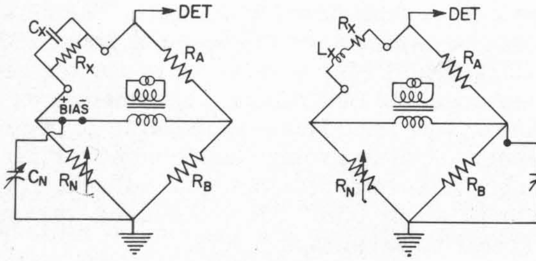



Figure 18. Measurement of Resistance with Reactance.

If the unknown is inductive the external capacitor should be connected across the standard resistance as in Figure 18b. The connection must be made internally to terminal 16 (located on a bracket behind the BIAS terminals), and the lead brought out through the panel hole. With this connection the CRL dial indicates series resistance and the external capacitor C is a measure of the Q of the resistor. The formula is

$$Q = \omega R_b C_b$$

where $R_b$ = 10 kΩ, except on the 10 MΩ range where it is 1 kΩ.

Note that R series = R parallel within 1% as long as Q is less than 0.1. The formulas are

$$R_s = R_p \frac{1}{1 + Q^2}$$

$$R_p = R_s (1 + Q^2)$$

$$Q = \frac{\omega L_s}{R_s}$$

$$Q = \omega R_p C_p$$

The reactive balances are limited to a Q accuracy of about ±0.01.

7.5 RESONANT FREQUENCY OF TUNED CIRCUITS. The resonant frequency of a series or parallel tuned circuit may be found by means of an external variable-frequency oscillator and the ac resistance bridge. The external oscillator is connected as described in paragraph 6.2, and the tuned circuit is connected to the UNKNOWN terminal.

The frequency and the CRL dial are then varied for the best null attainable. The bridge indicates, at balance, the effective series resistance of a series tuned circuit or the effective parallel resistance of a parallel tuned circuit, while the oscillator indicates the resonant frequency.

7.6 MEASUREMENTS ON SHIELDED THREE-TERMINAL COMPONENTS. When the unknown is shielded and the shield is not tied to either unknown terminal a three-terminal component is formed (see Figure 19). The impedance Z of the component itself is the direct impedance of the three-terminal system. To measure the direct capacitance of a three-terminal system, connect the third terminal to the panel of the instrument, using any grounded panel terminal or a ground lug with screw just below the UNKNOWN terminals. The capacitances to the shield have negligible effect as long as one of them is reasonably small (refer to paragraph 5.4.1).

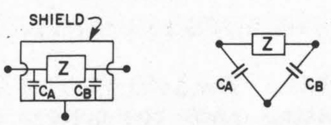



Figure 19. Shielded Three-Terminal Impedance.

Often the shield of an inductor is not connected to either terminal. When the inductance and frequency are low so that stray capacitance across the inductor causes negligible error, the shield should be connected to the unknown terminal marked LOW. When the inductance (or frequency) is high, the effective inductance is increased because of the shunting capacitance. The error is +100 $(\omega^2 L_x C_x)$% (refer to paragraph 5.2.2). To avoid an inductance error, the shield may be tied to the panel of the bridge. The inductor terminal that has the larger capacitance to the shield should be tied to the LOW bridge terminal. A Q error results from the capacitance from the other unknown terminal to the shield ($C_b$ in Figure 12) but a better measurement of $L_x$ is possible. (This connection does not affect the winding capacitance itself.)

7.7 REMOTE MEASUREMENTS. Due to the small effect of stray capacitance to ground, particularly for capacitance measurements (refer to paragraph 5.4.1), the unknown may be placed some distance away from the bridge. If at least one of the connecting leads is shielded, the capacitance between the leads is avoided. The shielded lead should be connected to the LOW unknown terminal, and the bridge should be grounded. The other lead may also be shielded, at the cost of increased capacitance to ground. When low impedance measurements are made, the effect of the lead resistance and inductand should be considered (see Table 5).

7.8 MEASUREMENT OF GROUNDED COMPONENTS. If the component to be measured is connected direct ly to ground, the component may be measured with the case of the Type 1650-A floating off ground.

Either unknown terminal of an unknown capacitor may be grounded. Grounding the low terminal tolerates large capacitance from the case to ground, but increases sensitivity to hum. However, most of the hum can be removed by the internal 1-kc filter in the amplifier. Grounding the other unknown terminal decreases sensitivity to hum, but a capacitance of 1000 μf from the case to ground causes a 1% capacitance error (refer to paragraph 5.4.1).

If the unknown is an inductor, the LOW terminal should be grounded.

Even when the bridge is floating, the bridge panel can be used as a guard terminal for three-terminal or remote measurements.

7.9 USE OF THE TYPE 1650-P1 TEST JIG.

7.9.1 GENERAL. The 1650-P1 Test Jig provides a means of making quick connections to the bridge with a pair of conveniently located clip terminals. When the Type 1650-A is set up for limit measurements (refer to paragraph 7.10), the combination facilitates the rapid sorting of electrical components.

The jig is also useful for measurements on small capacitors because of its small zero capacitance and because the unknown component is positioned and shielded to make repeatable measurements possible.

7.9.2 INSTALLATION. The test jig is connected to the bridge UNKNOWN terminals by means of the shielded Type 274 Connector attached to the jig. A three-terminal connection is necessary. The third connection is made by means of the screw, located directly below the UNKNOWN terminals, and the lug on the shield of the connector. This screw makes the ground connection to the jig and also holds the connector in place.

The leads of the test jig may be brought around in back of and underneath the bridge so that the jig may be located directly in front of the bridge without interference from the leads.

7.9.3 RESIDUAL IMPEDANCES OF THE TEST JIG. The residual resistance of the leads is about 80 milliohms (total) and the inductance is about 2 μh. The zero capacitance, when the leads are connected to the bridge, is negligible (≈ 0.2 μμf). The shielded leads cause a capacitance to ground of about 100 μμf each. Corrections may be necessary for the residual resistance and inductance when measurements are made on low impedances (see Table 5, page 15). The capacitances to ground cause no error for capacitance measurements, but can cause a D (1/Q) error up to about 0.007 for inductance measurements (refer to paragraph 5.4.1).

7.10 LIMIT TESTING.

The Type 1650-A may be set up to provide a go-no-go indication useful for component setting. The panel meter is used as the indicator. The set-up procedure is as follows:

a. Balance the bridge with one of the components to be measured (preferably one within tolerance).

b. Offset the CRL dial by the desired tolerance, if the tolerance is symmetrical, or by one half of the total allowable spread if unsymmetrical.

c. Adjust the SENSITIVITY control for a five-division meter deflection.

d. Set the CRL dial to the center value (the nominal value if the tolerance is symmetrical).

e. Connect each component to the bridge (or Type 1650-P1 Test Jig). If the meter deflection is less than five divisions, the component is within limits.

When the unknown has a tolerance greater than ±10%, the limits may be in error by more than 1% if the above method is used. A sure method is to set the CRL dial so that unknown components at both limits give the same deflection.

# Section 8

# SERVICE AND MAINTENANCE

8.1 GENERAL. The two-year warranty given with every General Radio instrument attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible.

In case of difficulties that cannot be eliminated by the use of these service instructions, please write or phone our Service Department, giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial and type numbers of the instrument.

Before returning an instrument to General Radio for service, please write to our Service Department or nearest district office (see back cover), requesting a Returned Material Tag. Use of this tag will insure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

8.2 BATTERY REPLACEMENT. The Type 1650-A Impedance Bridge is powered by four D cells, which will last for over 500 hours operation with normal use. The instrument can operate with greatly reduced battery voltage, but will become less sensitive; also, the oscillator frequency may change slightly.

For a simple check of the battery, connect an ammeter from the LOW unknown terminal to any panel (ground) terminal and measure the current flowing when the function switch is in the DC INT 6 V position. If this current is less than 40 ma, the cells should be replaced.

8.3 ADJUSTMENTS. The few internal adjustments are factory set and should not require attention. Procedures for setting these components are included here, but should be used only when the operator is positive that the component in question requires readjustment.

C5 This capacitor is set to give a zero D reading when a 1000-μμf 3-terminal air capacitor is measured on the 100 μμf CRL MULTIPLIER position. (Refer to paragraph 7.4 describing 3-terminal measurements).

R1 The light-colored screws on the rear of this rheostat control the characteristic of this circuit element. They should be set so that the resistance of R1 is equal to the CRL dial reading multiplied by 1000 ohms.

8.4 TROUBLE-SHOOTING SUGGESTIONS.

8.4.1 BRIDGE PROPER.

a. Noisy or Erratic Balances. If the Type 1650-A bridge is idle for an extended period, surface contamination of the wire-wound CRL and DQ adjustments may cause an erratic behavior of the null indicator. To remedy this situation, rotate the controls back and forth several times.

b. Bridge Error. The bad component causing a bridge error can usually be determined from a knowledge of which ranges and bridges are affected. The CRL rheostat, R1, is the only component used on all ranges of all circuits.

c. Inability to Obtain Balance. If the bridge does not seem to balance at all, several things should be considered before the bridge is assumed to need repair.

(1) Is the unknown component connected correctly?
(2) Is the unknown what it is thought to be? (Large inductors can look like capacitors at 1 kc.)
(3) Are all the panel switches set properly?
(4) Is the jumper between the BIAS terminals in place?
(5) Is the Q so low (D so high) that Orthonull should be used?

d. Low or No Meter Deflection When Bridge Unbalanced.

(1) Is OSC LEVEL control on?
(2) Is SENSITIVITY control on?
(3) Are the cells correctly in place? (For battery check refer to paragraph 8.2.)

8.4.2 CHECKING ORTHONULL OPERATION. The Orthonull mechanism is working correctly if any motion of the CRL dial causes a motion of the DQ dial, but not vice versa, when the Orthonull mechanism is engaged. When the Orthonull is disengaged, the two controls should be independent of each other. If the CRL dial does not drive the DQ dial, turn the nut on the spring spade lug clockwise. Also be sure that nothing is impeding the full rotation of the DQ potentiometer. If the DQ dial drives the CRL dial, turn this nut counterclockwise.

8.4.3 OSCILLATOR AND DETECTOR CHECKS. The oscillator and detector circuits are shown in Figure 19, and test point voltages are listed in Table 8. This information should enable one skilled in the art to locate any faulty components in these circuits.

For access to the printed circuit shown in Figure 20, unfasten the DETECTOR switch and the SENSITIVITY controls from the panel, remove the three screws holding the board in place, disconnect the PHONE connector and slide the board out. If this is done, the board is still connected and operative.

TABLE 8
TRANSISTOR VOLTAGES

| | Collector | Base | Emitter |
|---|---|---|---|
| TR1 | 0 | + 5.65 | + 5.7 |
| TR2 | + 1.60 | + 1.05 | + 0.95 |
| TR3 | + 1.70 | 1.06 | + 0.96 |
| TR4 | + 6.0 | + 1.60 | + 1.40 |

Set: SENSITIVITY counterclockwise
OSCILLATOR LEVEL clockwise
INT 1 KC

A General Radio Type 1803-B Vacuum-Tube Voltmeter was used to obtain the above voltages.

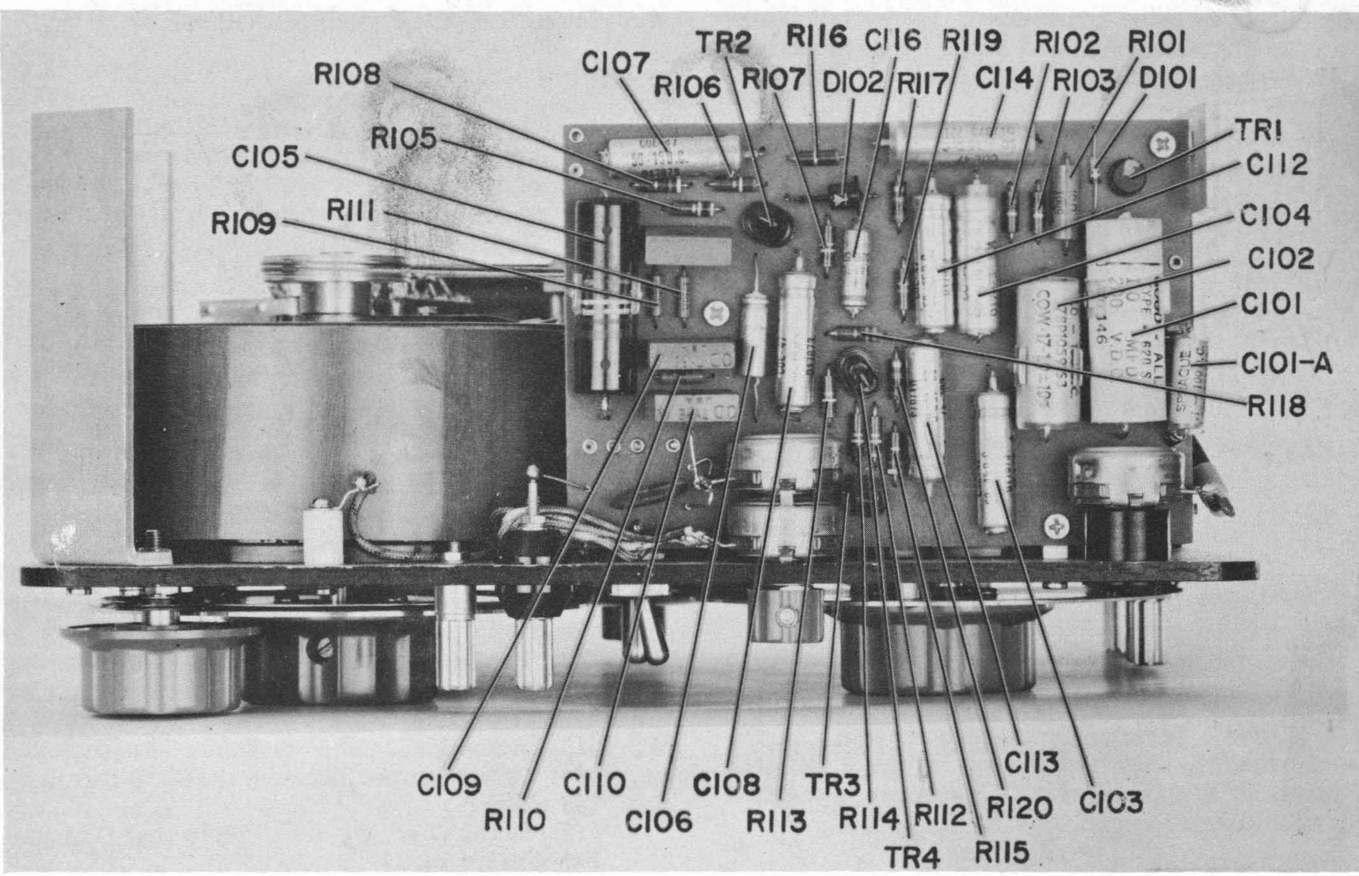
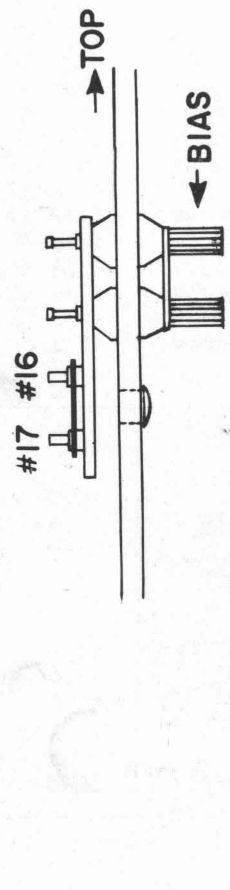



Figure 20. Bottom Interior View.



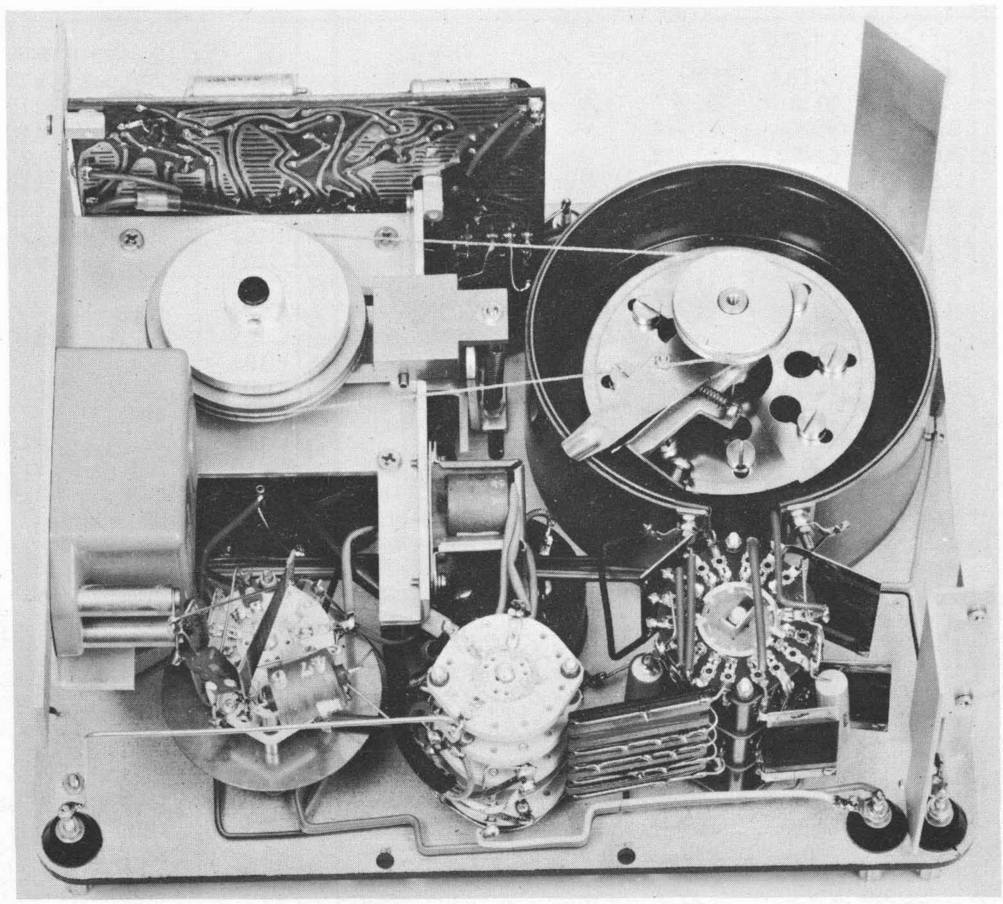



Figure 21. Rear Interior View.

# PARTS LIST

RESISTORS (NOTE B)

| | | | | PART NO. (NOTE A) |
|---|---|---|---|---|
| R1 | 0-11.7 k | | | 433-408 |
| R2 | 0-16 k | | | 977-402 |
| R3 | 31.6 | ±1% | 1/4 w | REF-65 |
| R4 | 9930 | ±1/4% | | 510-390-2 |
| R5 | 0.982 | ±1/4% | | 510-437 |
| R6 | 9.0 | ±1/4% | | 510-437 |
| R7 | 90 | ±1/4% | | 510-437 |
| R8 | 900 | ±1/4% | | 510-437 |
| R9 | 1 k | ±1/4% | | 602-304 |
| R10 | 10 k | ±1/4% | | 602-305-2 |
| R11 | 100 k | ±1/4% | | 602-306 |
| R12 | 30 k | ±5% | 1/2 w | REC-20BF |
| R13 | 970 k | ±1/4% | 1 w | 1650-41 |
| R14 | 1.111 k | ±1/4% | | 510-390-2 |
| R15 | 500 } | | | 1650-400 |
| R16 | 50 k } | | | |
| R17 | 100 | ±5% | 1/2 w | REC-20BF |
| R18 | 2.5 k | ±10% | | POSC-18 |
| R19 | 4.7 | ±10% | 1/2 w | REW-3C |
| R101 | 10 | ±1% | 1/2 w | REF-70 |
| R102 | 22 | ±5% | 1/2 w | REC-20BF |
| R103 | 2 k | ±5% | 1/2 w | REC-20BF |
| R104 | 150 | ±5% | 1/2 w | REC-20BF |
| R105 | 30 k | ±5% | 1/2 w | REC-20BF |
| R106 | 120 k | ±5% | 1/2 w | REC-20BF |
| R107 | 20 k | ±5% | 1/2 w | REC-20BF |
| R108 | 4.7 k | ±5% | 1/2 w | REC-20BF |
| R109 | 18 k | ±1% | 1/8 w | REF-60 |
| R110 | 18 k | ±1% | 1/8 w | REF-60 |
| R111 | 5.75 k | ±1% | 1/8 w | REF-60 |
| R112 | 30 k | ±5% | 1/2 w | REC-20BF |
| R113 | 120 k | ±5% | 1/2 w | REC-20BF |
| R114 | 20 k | ±5% | 1/2 w | REC-20BF |
| R115 | 4.7 k | ±5% | 1/2 w | REC-20BF |
| R116 | 1.5 k | ±5% | 1/2 w | REC-20BF |
| R117 | 1 k | ±5% | 1/2 w | REC-20BF |
| R118 | 1.5 k | ±5% | 1/2 w | REC-20BF |
| R119 | 220 | ±5% | 1/2 w | REC-20BF |
| R120 | 1 k | ±5% | 1/2 w | REC-20BF |
| R121 | 12 | ±5% | 1/2 w | REC-20BF |

CAPACITORS (NOTE C)

| | | | | PART NO. (NOTE A) |
|---|---|---|---|---|
| C1 | 0.0995-0.0999 | | | 505-499 |
| C2 | 220 μμf | ±2% | 500 dcwv | COM-20E |
| C3 | 0.0047 | ±10% | 500 dcwv | COM-30B |
| C4 | 180 μμf | ±5% | 500 dcwv | COM-20D |
| C5 | 0.5-8 μμf | | | COT-27 |
| C6 | 0.33 | ±10% | 100 dcwv | COW-17 |
| C7 | 47 μμf | ±10% | 500 dcwv | COM-15B |
| C101 | 1.0 | ±2% | 200 dcwv | COP-19 |
| C102 | 1.0 | ±10% | 100 dcwv | COW-17 |
| C103 | 50 | | 15 dcwv | COE-47 |
| C104 | 50 | | 15 dcwv | COE-47 |
| C105 | 0.1 | ±10% | 600 dcwv | COL-71 |
| C106 | 5 | | 50 dcwv | COE-57 |
| C107 | 50 | | 15 dcwv | COE-47 |
| C108 | 50 | | 15 dcwv | COE-47 |
| C109 | 0.01 | ±1% | 500 dcwv | COM-1F |
| C110 | 0.01 | ±1% | 500 dcwv | COM-1F |
| C111 | 0.02 | ±1% | 300 dcwv | COM-1F |
| C112 | 50 | | 15 dcwv | COE-47 |
| C113 | 50 | | 15 dcwv | COE-47 |
| C114 | 50 | | 15 dcwv | COE-47 |
| C115 | 0.022 | | 1000 dcwv | COC-63 |
| C116 | 5 | | 50 dcwv | COE-57 |

| | | |
|---|---|---|
| D102 | DIODE | 1N91 |
| L1 | INDUCTOR, 45 mh ±5% | ZCHA-57 |
| M1 | METER | MEDS-86 |
| S1 | SWITCH | SWRW-172 |
| S2 | SWITCH | SWRW-173 |
| S3 | SWITCH | SWRW-174 |
| S4 | SWITCH | SWT-333NP |
| T1 | TRANSFORMER | 746-432 |
| TR1 | TRANSISTOR | 2N321 |
| TR2 | TRANSISTOR | 2N445A |
| TR3 | TRANSISTOR | 2N445A |
| TR4 | TRANSISTOR | 2N445A |

NOTES

(A) GR Type designations for resistors and capacitors are as follows:

- COC - Capacitor, ceramic
- COE - Capacitor, electrolytic
- COL - Capacitor, oil
- COM - Capacitor, mica
- COP - Capacitor, plastic
- COW - Capacitor, wax
- POSC - Potentiometer, composition
- REC - Resistor, composition
- REF - Resistor, film

(B) All resistances are in ohms except as otherwise indicated by k (kilohms).

(C) All capacitances are in microfarads, except as otherwise indicated by μμf (micromicrofarads).

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When ordering replacement components, be sure to include complete description as well as Part Number. (Example: R85, 51k ±10%, 1/2w, REC-20BF).

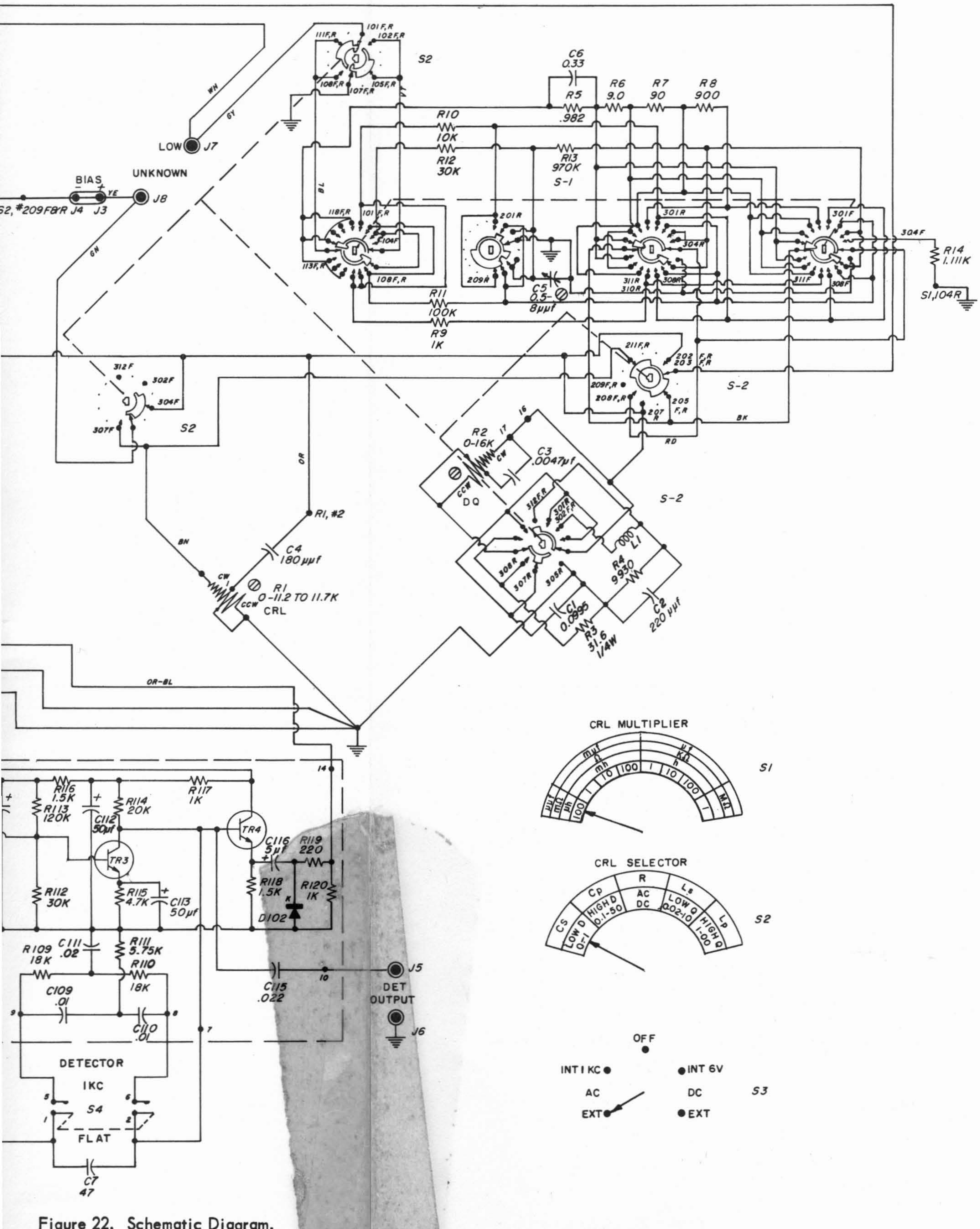

Figure 22. Schematic Diagram.

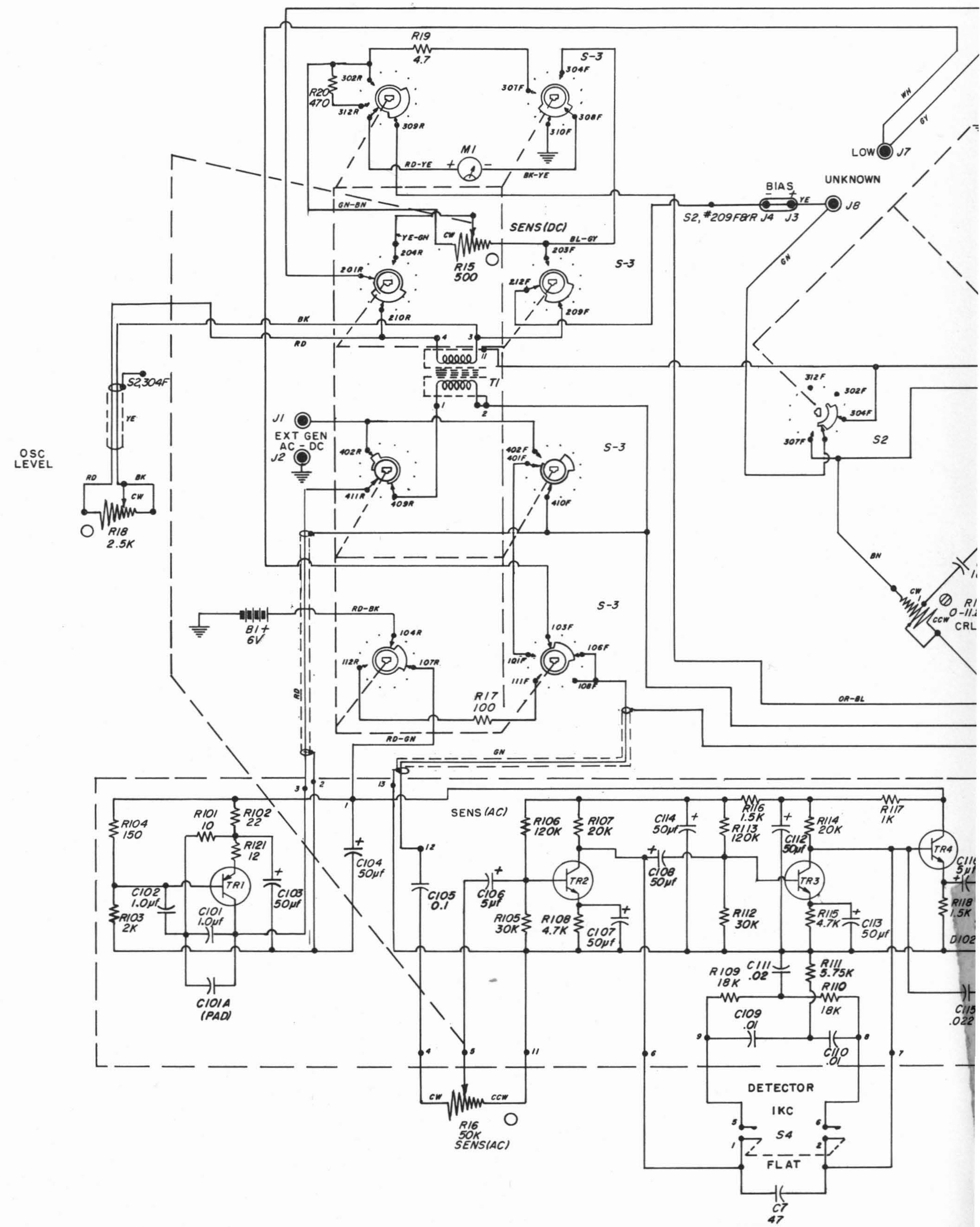


Figure 22. Schematic Diagram.

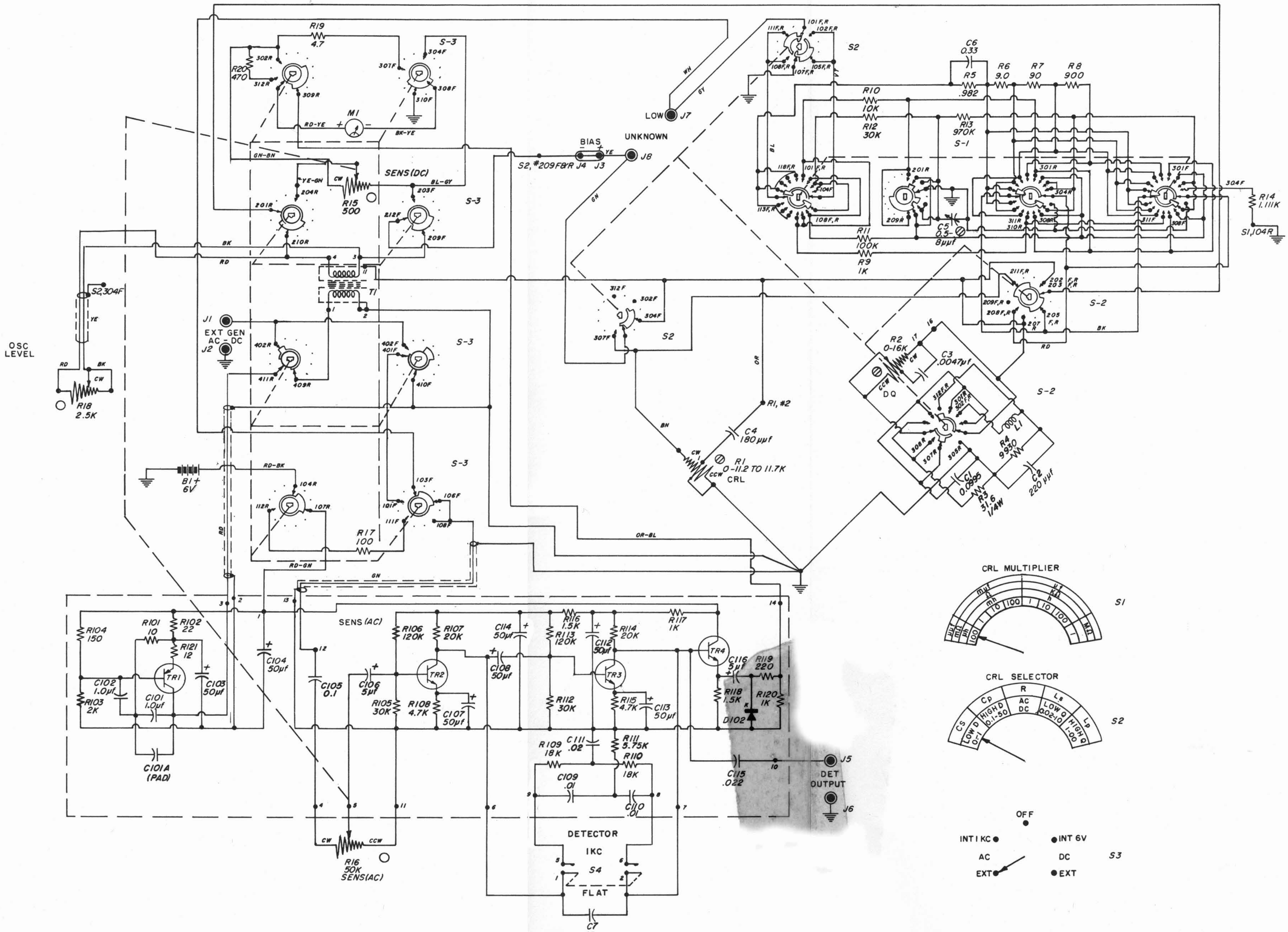

Figure 22. Schematic Diagram.

# GENERAL RADIO COMPANY

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