DEL. CAL. LAB.

INSTRUCTION MANUAL

Type 1608-A

Impedance Bridge

D

GENERAL RADIO

NOTE

Throughout this manual cycles-per-second (cps) and its decade multiples are used, but each is equivalent to hertz (Hz) and its decade multiples.
Example: 1 cps = 1 Hz, 1 kc/s = 1 kHz, etc.

WARRANTY

Type 1608-A

Impedance Bridge

D

GENERAL RADIO COMPANY
West Concord, Massachusetts U.S.A. 01781
Form 1608-0100-D
January, 1969
ID-2528

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SPECIFICATIONS

RANGES

Capacitance: 0.05 pF to 1100 μF in seven ranges, series or parallel.

Inductance: 0.05 μH to 1100 H in seven ranges, series or parallel.

Resistance: (series) 0.05 milliohm to 1.1 megohms, ac or dc.

Conductance: (parallel) 0.05 nanomho to 1.1 mhos, ac or dc (20,000 megohms to 0.9 ohm).

D: (of series capacitance) — 0.0005 to 1 at 1 kHz.
(of parallel capacitance) — 0.02 to 2 at 1 kHz.

Q: (of series inductance) — 0.5 to 50 at 1 kHz
(of parallel inductance) — 1 to 2000 at 1 kHz.
(of series resistance) — 0.0005 to 1.2 inductive at 1 kHz.
(of parallel conductance) — 0.0005 to 1.2 capacitive at 1 kHz.

Frequency: 1 kHz with internal oscillator module supplied; 20 Hz to 20 kHz with external oscillator.

ACCURACY

C, G, R, L

At 1 kHz: ±0.1% ±0.005% of full scale except on lowest R and L ranges and highest C and G ranges, where it is ±0.2% ±0.005% of full scale.

Additional % error terms for high frequency and large phase angle:

C and L: ($\pm 0.001 f^2_{kHz} \pm 0.1 D f_{kHz} \pm 0.5 D^2$)% of measured value.
R and G: ($\pm 0.002 f^2_{kHz} \pm 0.000001 f^4_{kHz} \pm 0.1 Q$)% of measured value.

Residual Terminal Impedance: $R \simeq 0.001\ \Omega$, $L \simeq 0.15\ \mu H$, $C \simeq 0.25$ pF.

DC Resistance and Conductance: Same as for 1-kHz measurement, except that accuracy is limited by sensitivity at the range extremes. Balances to 0.1% are possible from 1 ohm to 1 megohm with the internal supply and detector.

D $\left(\text{or } \frac{1}{Q}\right)$ of C or L: ±0.0005 ±5% at 1 kHz or lower.
$\pm 0.0005 f_{kHz} \pm 5\%$ above 1 kHz.

Q of R or G: $\pm 0.0005 f_{kHz} \pm 2\%$.

GENERAL

Generator: Internal, 1 kHz ±1% module normally supplied; plug-in modules for other frequencies available on special order. Level control provided. With external generator, frequency range of bridge is 20 Hz to 20 kHz. Type 1310-A or the 1210-C Oscillator recommended if external generator required. Internal dc supply 3.5, 35, and 350 V, adjustable; power limited to 1/3W or less.

Detector: Internal or external; ac; can be used either flat or selective at frequency of plug-in module (normally 1 kHz); other frequencies available; second-harmonic rejection of 25 dB. Sensitivity control provided. Type 1232-A Tuned Amplifier and Null Detector recommended when external generator is used.

Dc Bias: Capacitors can be biased to 500 V from external source; bias current can be applied to inductors up to 40 mA.

Power Required: 105 to 125 or 210 to 250 V, 50 to 60 Hz; 10 W.

Accessories Supplied: Power cord, spare fuses, spare indicator lamps.

Accessories Available: 1650-P1 Test Jig.

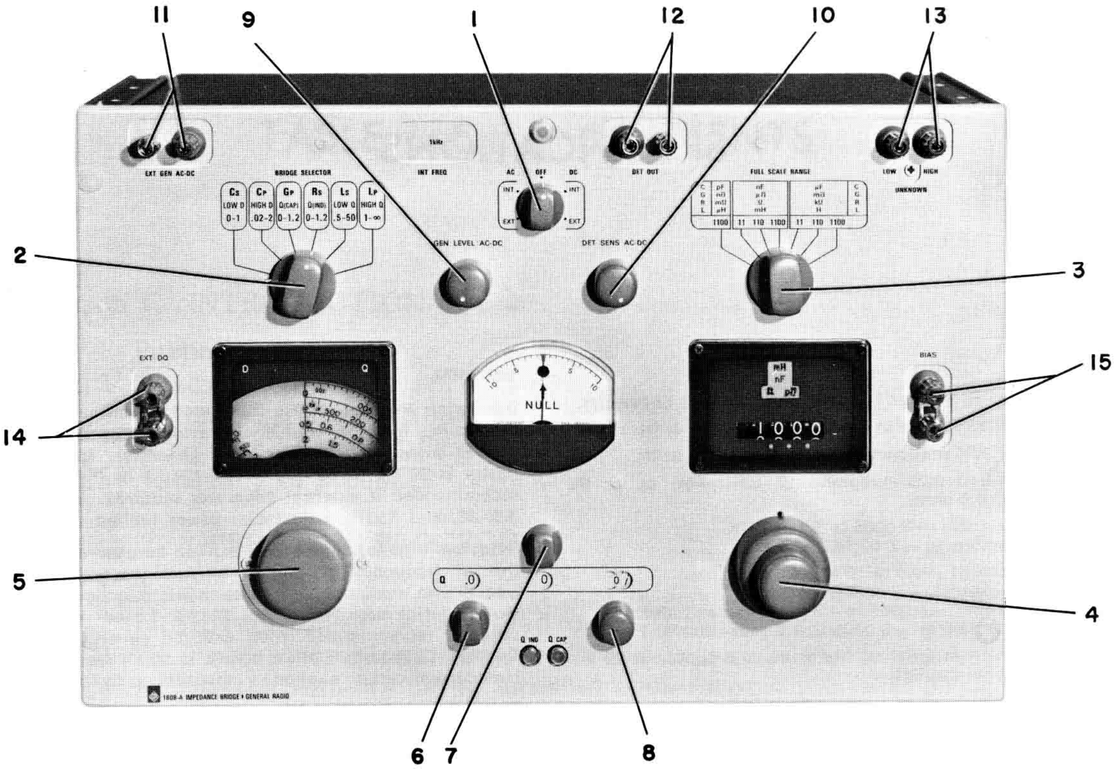
Mounting: Rack-Bench Cabinet.

Dimensions (width x height x depth): Bench model, 19 x 12½ x 11½ in. (485 x 320 x 295 mm); rack model, 19 x 12¼ x 10 in. (485 x 315 x 255 mm).

Weight: Net, 36½ lb (17 kg); shipping, 54 lb (24.5 kg).

Catalog Number	Description
1608-9801	Bench Model
1608-9811	Rack Model

— See **GR Experimenter** for March 1962.



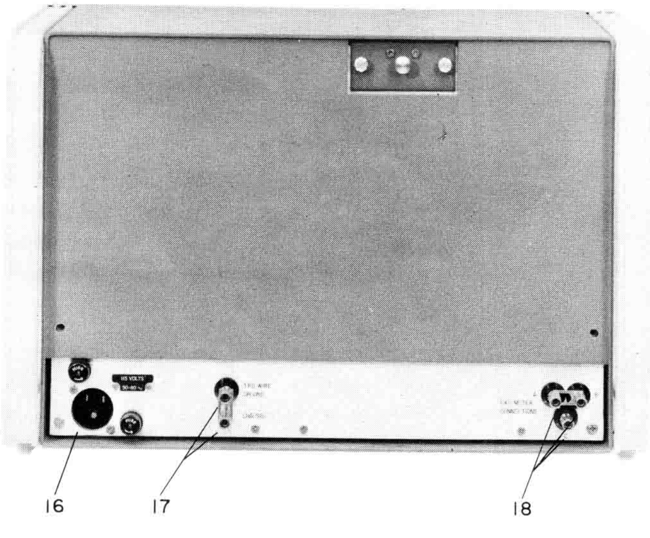


Figure 1-1. The Type 1608-A Impedance Bridge (for legend see page 2).

SECTION **1**

INTRODUCTION

1.1 PURPOSE.

The Type 1608-A Impedance Bridge (Figure 1-1) is a self-contained impedance-measuring system, which includes six bridges for the measurement of capacitance, conductance, resistance, and inductance, as well as the generators and detectors necessary for dc and 1-kc ac measurements.

1.2 DESCRIPTION.

1.2.1 GENERAL. The six bridges contained in the Type 1608-A are shown schematically in Figure 1-2. Provision is made for ac and dc measurements, both with internal and external generator and detector. The generator and detector connections for the four "on" positions of the function switch (INT AC, INT DC, EXT AC, EXT DC) are shown schematically in Figure 1-3.

1.2.2 CONTROLS AND CONNECTORS. Table 1-1 lists the controls and connectors on the front and rear panels of the Type 1608-A Impedance Bridge.

1.3 SYMBOLS, ABBREVIATIONS, AND DEFINITIONS.

Table 1-2 lists symbols and abbreviations used in this manual, together with their definitions.

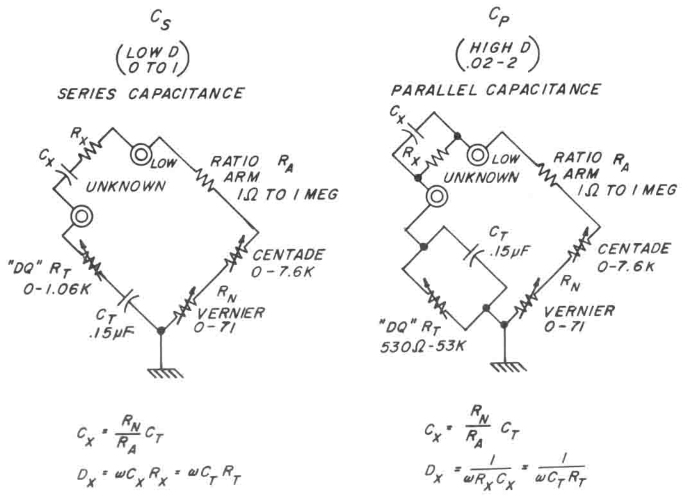


Figure 1-2. The six bridges of the Type 1608-A.

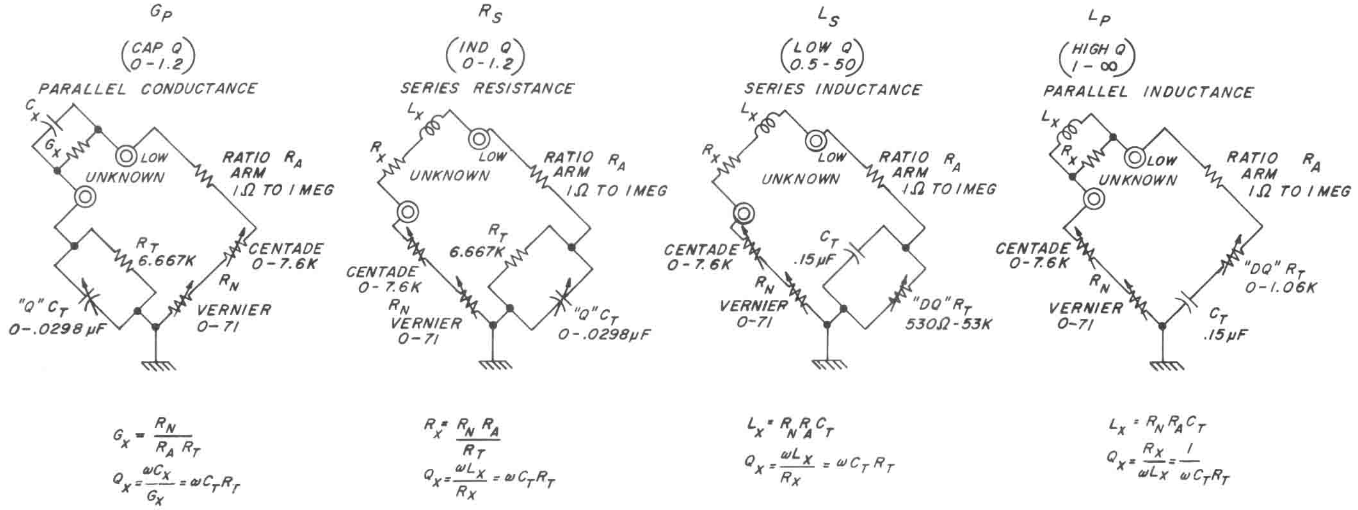


TABLE 1-1
TABLE OF CONTROLS AND CONNECTORS

CONTROLS

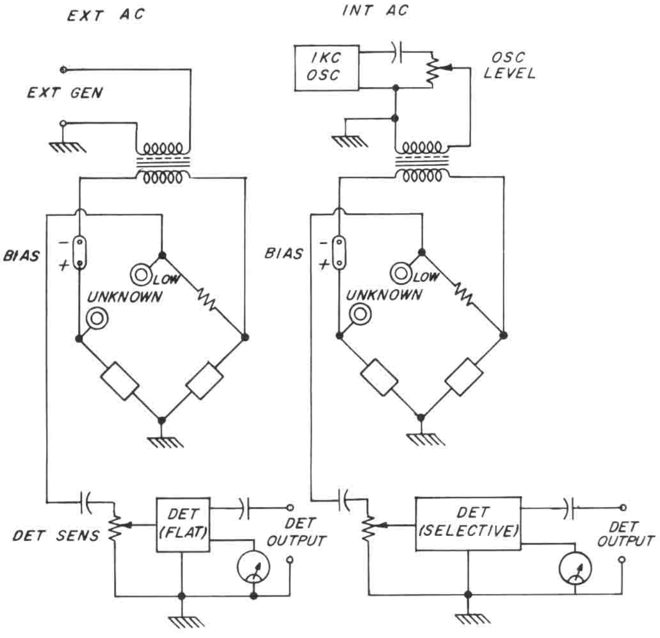
Fig. 1-1 Ref	Name	Type	Function
1	Function	5-pos rotary switch	Turn instrument on or off, selects internal or external ac or dc operation.
2	BRIDGE SELECTOR	6-pos rotary switch	Selects appropriate bridge circuit for measurement of C_s, C_p, G_p, R_s, L_s, and L_p.
3	FULL SCALE RANGE	7-pos rotary switch	Selects measurement range, indicates full-scale value of CGRL indicator.
4	CGRL	coaxial rotary controls	Main balance control. Small knob controls two right-hand digits of indicator, large knob controls three left-hand digits.
5	DQ	Continuous rotary control	DQ balance control, used for C and L measurements
6	Q	12-pos rotary switch	Q balance controls, used in G and R measurements.
7		11-pos rotary switch	
8		Continuous rotary control	
9	GEN LEV	Continuous rotary control	Controls output level of internal generator, ac and dc.
10	DET SENS	Continuous rotary control	Controls sensitivity of internal detector, ac and dc.

CONNECTORS

Fig 1-1 Ref	Name	Type	Function
11	EXT GEN	Jack-top binding-post pair	Connection to external generator, ac and dc.
12	DET OUT	Jack-top binding-post pair	Output connection from internal detector. ac only.
13	UNKNOWN	Jack-top binding-post pair	Connection to unknown component.
14	EXT DQ	Jack-top binding-post pair	Connection to external resistance or capacitance to extend DQ ranges.
15	BIAS	Jack-top binding-post pair	Connection to external bias supply.
16	Power	Three-terminal recessed male connector	Power input connector
17	3RD WIRE GROUND	Jack-top binding-post pair	Connection to ground wire of three-wire power line.
18	EXT METER CONNECTIONS	Three jack-top binding posts	Connection to external dc null indicator.

TABLE 1-2
SYMBOLS AND ABBREVIATIONS

C	capacitance (—|(—)
C_s	series capacitance
C_p	parallel capacitance
L	inductance (⌒⌒⌒)
L_s	series inductance
L_p	parallel inductance
R	resistance (∿∿) $R = \frac{1}{G}$
R_s	series resistance $R_s = \frac{1}{G_s}$
R_p	parallel resistance $R_p = \frac{1}{G_p}$
G	conductance (∿∿) $G = \frac{1}{R}$
G_s	series conductance $G_s = \frac{1}{R_s}$
G_p	parallel conductance $G_p = \frac{1}{R_p}$
Z	impedance, $Z = R + jX$
X	reactance, the imaginary part of an impedance
Y	admittance, $Y = G + jB$
B	the imaginary part of an admittance
Q	quality factor $= \frac{X}{R} = \frac{B}{G} = \frac{1}{D}$
	for inductors or inductive resistors $Q = \frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p}$
	for capacitive resistors $Q = \omega C_p R_p$
D	dissipation factor $= \frac{R}{X} = \frac{G}{B} = \frac{1}{Q}$
	for capacitors $D = \omega R_s C_s = \frac{1}{\omega C_p R_p}$
PF	power factor $= \frac{R}{\sqrt{R^2 + X^2}}$
f	frequency
ω	angular frequency $= 2\pi f$
Ω	ohm, a unit of resistance, reactance or impedance
kΩ	kilohm 1 kΩ = 1000 Ω
MΩ	megohm 1 MΩ = 1,000,000 Ω
mΩ	milliohm 1 mΩ = 0.001 Ω
℧	mho, a unit of conductance, susceptance or admittance
m℧	millimho 1 m℧ = .001℧
μ℧	micromho 1 μ℧ = 1×10^{-6}℧
n℧	nanomho 1 n℧ = 1×10^{-9}℧
μf	microfarad, a unit of capacitance
nf	nanofarad 1 nf = 0.001 μf = 1 mμf
pf	picofarad 1 pf = 1×10^{-6} μf = 1 $\mu\mu$f
h	henry, a unit of inductance
mh	millihenry 1 mh = 0.001 h
μh	microhenry 1 μh = 1×10^{-6} h



OFF

IN OFF POSITION
POWER OFF
EXT GEN DISCONNECTED
METER SHUNTED

IN BETWEEN OFF
AND INT DC POSITIONS
DC BRIDGE OPERATIVE
BUT METER SHUNTED
TO REDUCE SENSITIVITY

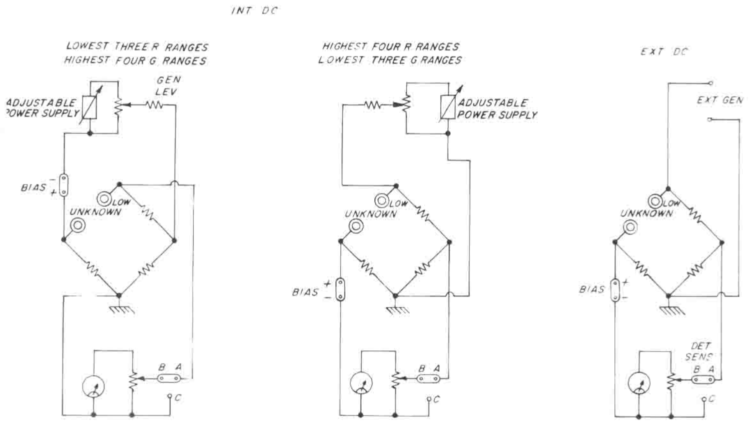


Figure 1-3. Generator and detector connections.

1.4 SERIES AND PARALLEL PARAMETERS.

An impedance that is neither a pure reactance nor a pure resistance can 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 parallel representation is used. The equivalent circuits are shown in Figure 1-4. A nomograph for series-parallel conversion is given in Figure 1-7. The relationships between the various circuit elements are as follows:

Resistance and Inductance

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

$$Y = G_p + \frac{1}{j\omega L_p} = \frac{1}{R_s + j\omega L_s} = \frac{G_s + \frac{Q^2}{j\omega L_s}}{1 + Q^2}$$

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

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

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

Resistance and Capacitance

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

$$Y = G_p + j\omega C_p = \frac{j\omega C_s}{1 + j\omega C_s R_s} = \frac{D^2 G_s + j\omega C_s}{1 + D^2}$$

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

$$Q = \frac{\omega C_p}{G_p} = \omega R_p C_p$$

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

$$R_s = \frac{D^2}{1 + D^2} R_p = \frac{1}{1 + Q^2} R_p = \frac{1}{(1 + Q^2) G_p}$$

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

$$G_p = \frac{1}{(1 + Q^2) R_s} ;\; C_p = \frac{Q G_p}{\omega}$$

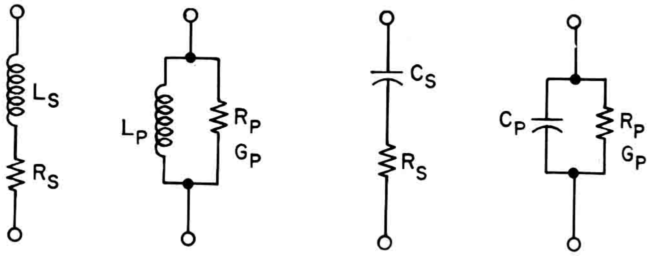


Figure 1-4. Equivalent circuits for complex impedance.

1.5 ACCURACY OF MEASUREMENTS.

1.5.1 CGRL ACCURACY AT 1 KC. The basic bridge accuracy is 0.1%. This is a function of the accuracy of the adjustment and stability of the bridge arms. The instrument is initially calibrated to an accuracy of ±0.05% or better and should hold the 0.1% accuracy for well beyond the two-year warranty period. A simple calibration check procedure is given in Section 5.2.

The lowest-resistance (1-ohm) resistance ratio arm is the most difficult ratio arm to set accurately, is the most affected by switch and lead resistance, and has slightly poorer stability than the other arms. Therefore, the accuracy specification for the lowest impedance range for each bridge is 0.2%.

The fixed error of ±0.005% of full scale or one-half a digit on the counter read-out allows for backlash in the adjustment and for the limitations of linearity and resolution of the vernier rheostat. This fixed error gives an over-all accuracy at 1 kc (on all but the lowest range) of 0.105% at full scale and 0.15% at one-tenth of full scale. Therefore, the final balance should be made with as many digits on the counter as possible.

1.5.2 TEMPERATURE COEFFICIENT. The over-all temperature coefficient of the instrument is less than 30 ppm/°C. This means that there may be a 0.03% change in reading for a temperature change of 10°C (50°F). This change is usually negligible compared with the change in the unknown component for a similar temperature change. For the most accurate measurements, the bridge and components to be measured should be stabilized at a temperature near 23°C (73°F).

1.5.3 ADDITIONAL ERRORS FOR HIGH D CAPACITORS, LOW Q INDUCTORS, AND HIGH Q RESISTORS. The DQ dial adjustments used for phase balance on the C and L bridges are wire-wound rheostats. When lossy (high D or low Q) components are measured, the limited resolution of these adjustments prohibits balance of the C or L adjustment to its full resolution. A term of 0.5%D^2 is added to the specifications to allow for this effect, but somewhat better accuracy is possible with extreme care. Precision components generally have a low enough D or a high enough Q to make this term negligible (see Figure 1-5).

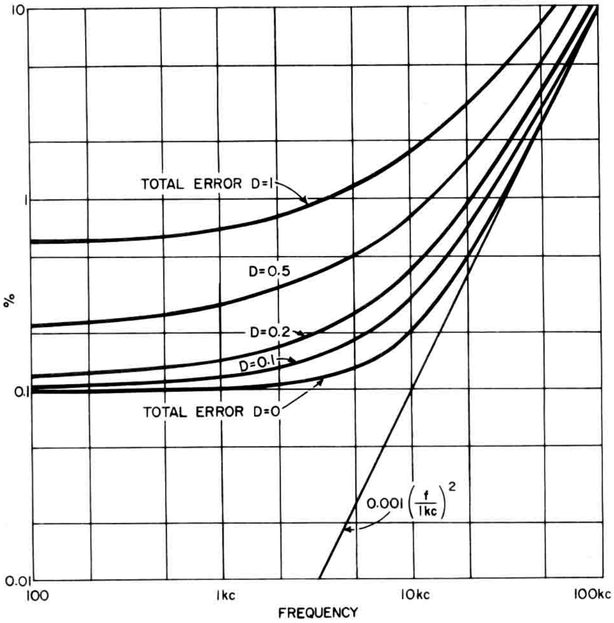


Figure 1-5. Capacitance and inductance errors vs frequency.

The Q adjustment for the R_s and G_p bridges consists of two decades of mica capacitors and a variable capacitor with infinite resolution. Losses in the mica capacitors appear as an R or G error when Q is relatively large, and the added error term of 0.1%Q is therefore necessary (see Figure 1-6).

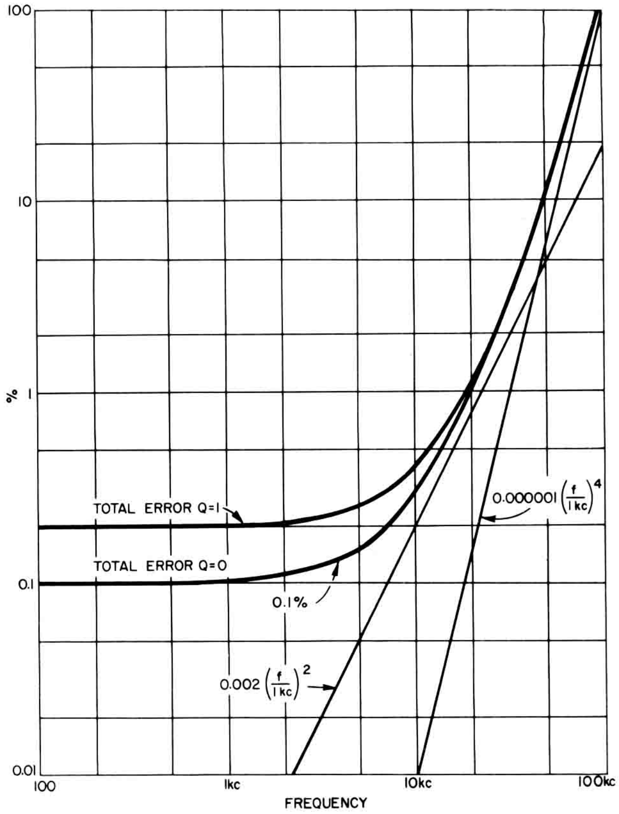


Figure 1-6. Resistance and conductance errors vs frequency.

1.5.4 FREQUENCY ERRORS. The main cause of additional error on the C and L bridges at higher frequencies is the inductance of the bridge wiring in series with the standard capacitor, effectively increasing its value. This error is proportional to f^2, and is accounted for in the added error term 0.001% $(f/1\ kc)^2$. This term, which amounts to a 0.1% error at 10 kc and a 0.4% error at 20 kc, is large enough to account for other smaller sources of error (see Figure 1-5).

For high D (low Q) measurements at high frequencies, there is an added error term due to the inductance of the DQ rheostats. This term is 0.1D (f/1 kc). (See Figure 2-7.) The series rheostat (C_s and L_p bridges) is phase-compensated to a large degree, but nevertheless adds inductance in series with the standard capacitor. The inductance of the parallel rheostat (C_p and L_s bridges) is placed in parallel with the standard capacitor, and at high enough D values effectively reduces the capacitance of this bridge arm. The error on the C_p and L_s bridges is somewhat less, and these bridges have more useful D and Q ranges at high frequencies (see Figure 2-7).

A frequency-dependent error term is necessary for the resistance and conductance bridges because of a network built into the standard resistance arm to compensate for stray capacitance (refer to paragraph 4.5). The effective resistance of this arm has one term proportional to f^2 and one proportional to f^4, requiring the added error terms ±0.002 $(f/1\ \text{kc})^2$ and ±0.000001 $(f/1\ \text{kc})^4$. The first term is more important up to 45 kc, and adds an extra 0.2% error at 10 kc and 0.8% error at 20 kc (see Figure 1-6).

1.5.5 RESIDUAL TERMINAL IMPEDANCE.

The accuracy specifications are valid only if the effect of the residual terminal impedance of the UNKNOWN connection is considered. The residual resistance and capacitance can be easily measured and subtracted from the final measured value. At high frequencies somewhat more complicated corrections are necessary, particularly at the range extremes, and correction formulae are given in Table 2-5 .

1.5.6 D AND Q ACCURACY.

The 5-percent term in the D and Q accuracy specifications for C and L measurements depends upon the tracking accuracy of the DQ rheostats with the dial calibration. The fixed term, ±0.0005, depends upon the phase angle of each arm of the bridge, and many compensating components are required to achieve this accuracy (refer to paragraph 4.5). This specification of ±0.0005 holds for measurements made down to 1/20 of the full-scale CGRL counter reading. Below this reading, the phase angle of the vernier CGRL adjustment (R4), even though compensated for, can add additional DQ error. This could amount to an error of 0.001 at 1/100 of full scale and 0.005 at 1/1000 of full scale. The detector sensitivity is also a limiting factor here. Lower CGRL ranges should be used to achieve better D and Q accuracy.

At high frequencies the DQ error increases because the phase angles of the bridge arms increase with f. Therefore, this fixed error term is 0.0005 $\frac{f}{1\ \text{kc}}$ above 1 kc. At frequencies below 1 kc, the D accuracy cannot be improved because it is limited by the D of the standard capacitor.

The percent term in the Q accuracy for R_s and G_p bridges is ±2%, which is limited by the accuracy of the capacitance decades used for Q adjustment. The fixed term is ±0.0005 at 1 kc, just as in the L and C bridges, since the same phase angle considerations apply. However, for the R_s and G_p bridges, this term is ±0.0005 $\frac{f}{1\ \text{kc}}$ at higher and at lower frequencies. This gives extremely good Q accuracy at low frequencies, but does not help in the measurement of the time constant (Q/ω) of resistors, which is independent of frequency (except at very high frequencies).

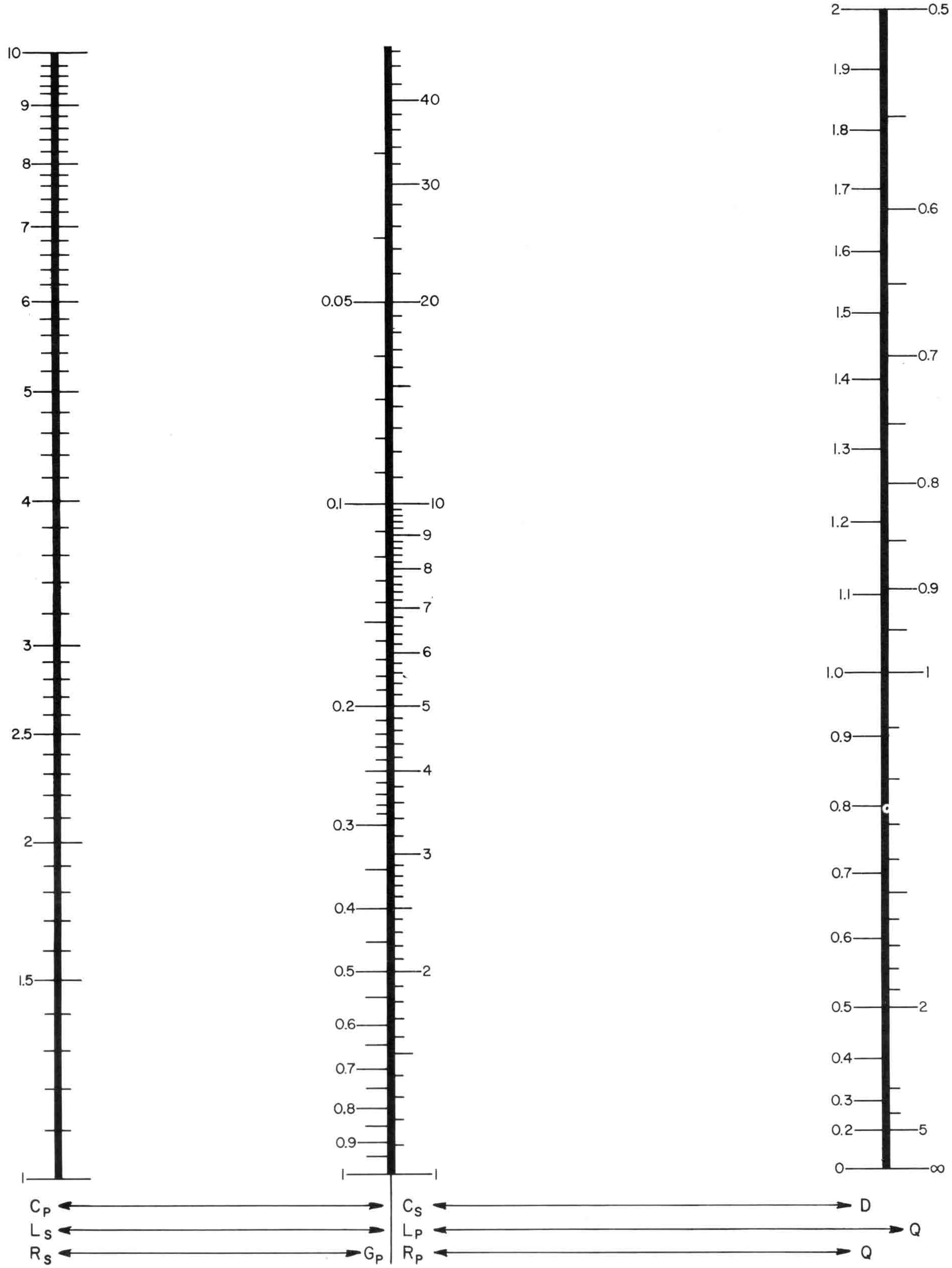


Figure 1-7. Nomograph for conversion of C, L, R, D, and Q at 1 kc.

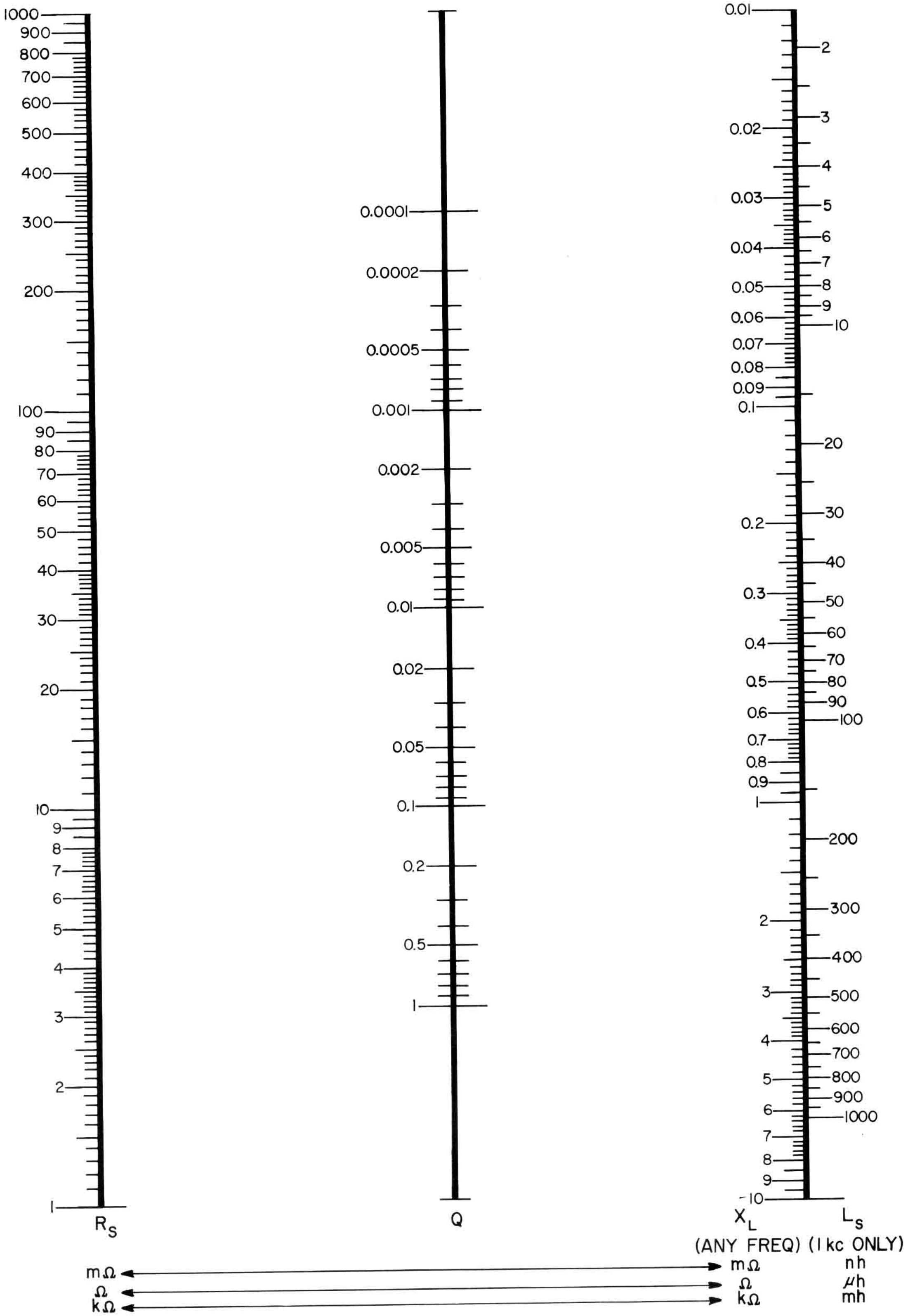


Figure 1-8. Nomograph for conversion of R_S to L_S and vice versa.

SECTION 2

OPERATING PROCEDURE

2.1 INSTALLATION.

2.1.1 POWER CONNECTIONS. Connect the bridge to a suitable power source as indicated on the plate above the power receptacle on the rear of the instrument (115 or 230v, 50-60 cps). A three-wire power cord is supplied.

2.1.2 GROUNDING. The bridge should generally be operated with the bridge chassis grounded except in specific cases where the unknown component or a dc bias supply should be grounded (refer to paragraphs 3.1.5 and 3.5). The ground connection is made through the three-wire power cord to the 3RD WIRE GROUND terminal on the rear of the instrument. This terminal should be connected to the adjacent CHASSIS terminal unless the bridge must be ungrounded. If the three-wire power cord is not used, this connection should be made externally.

2.1.3 MOUNTING. The instrument is available as either the 1608-9801, for bench mounting, or 1608-9811, for relay-rack mounting. The bench-mounting model is equipped with aluminum end frames, while the 1608-9811 includes mounting brackets for relay-rack installation. Instructions for assembly accompany these brackets, which may be ordered separately, to convert from bench to rack use.

The mounting brackets are of a unique General Radio design which permits the instrument to be pulled out on slides for service. Either chassis or cabinet can be removed from the rack independently of the other.

2.2 INTERPRETATION OF "X" IN READ-OUT.

The main CGRL indication consists of up to five digits displayed in an in-line read-out. The three left-hand digits are controlled by the larger of the two concentric CGRL controls; the two right-hand digits are controlled by the smaller (vernier) control. To provide an overlapping transition from full-scale vernier reading (99) to the next higher coarse step, the vernier read-out extends beyond 99, up to 106. To avoid the ambiguity of two digits on the same counter, an X is used in place of the number 10. To interpret a reading containing an X, simply substitute 0 for the X and add 1 to the digit immediately to the left of the X. For example, 102X3 = 10303; 99X2 =10002.

The letter X is also used on two of the three Q dials used with the R_s and G_p bridges. Here again, substitute 0 in place of the X and add 1 to the digit to the left of the X. For example, .1X4 =.204; .2XX =.310.

Users may find it helpful to record measurement data exactly as it appears on the bridge read-out, including any X's that appear. In that way, any possible error in the interpretation of the X can be rechecked.

2.3 DC RESISTANCE MEASUREMENTS.

2.3.1 PROCEDURE.

a. With the function switch (1, Figure 1-1) off, check the NULL meter mechanical zero position, and, if necessary, center the pointer with the screw-driver adjustment on the meter.

b. Turn the DET SENS control almost fully counterclockwise.

c. Set the BRIDGE SELECTOR switch to R_s for resistance measurements from 0 to 1.1 MΩ and G_p for resistance measurements above 1 MΩ and for conductance measurements from 0 to 1.1 mho.

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

e. Turn the function switch to INT DC.

NOTE

> As the function switch is rotated from OFF to INT DC, it passes through an undetented position where the circuit is operative but the meter sensitivity is greatly reduced. A preliminary balance may be made with the switch in this position instead of with the DET SENS control turned down.

f. Adjust the FULL SCALE RANGE switch and the concentric CGRL balancing controls for a zero (center) reading, and adjust the DET SENS and GEN LEV controls for increased sensitivity as necessary. A meter deflection to the right indicates that the unknown is larger than the indicated CGRL dial setting. For greatest accuracy the reading should have at least four digits showing. If not, turn to the next lower range.

g. The value of the UNKNOWN is read directly on the counter with the decimal point correctly located and the unit illuminated above. The meaning of an X indicator is explained in paragraph 2.2.

2.3.2 ACCURACY. The accuracy of dc resistance and conductance measurements is ±0.1%, ±0.005% of full scale (which is ±1/2 of the last digit) on all but the lowest R and highest G ranges as long as there is sufficient sensitivity. On the lowest R and highest G range the accuracy is limited by the sensitivity to ±1/2% ±1 mΩ.

For low-resistance measurements, short, heavy leads should be used as connections to the unknown component. Measure the zero resistance of the leads and terminals by connecting the free ends together, and subtract this amount from the bridge reading with the unknown in place. For best connection to the bridge, screw the binding post hard enough to notch the wire inserted in the hole.

2.3.3 INTERNAL VOLTAGE APPLIED TO THE UNKNOWN. There are three internal dc supplies, each having a limiting resistor to limit the available power to 1/2 watt or less to avoid damage to the bridge components or to the unknown. They are all controlled by the GEN LEV panel control. The lowest voltage supply, approximating 3.5 volts open circuit, is applied "horizontally" to the bridge (see Figure 1-3) and the 35-volt and 350-volt supplies are applied "vertically". The FULL SCALE RANGE switch selects the optimum supply for each range as given in Table 2-1.

Because of the limiting resistor, the maximum voltage applied to the unknown is usually of much less than the open-circuit value. Figure 2-1 shows the actual voltage applied to any unknown resistor when measured on the R bridge (with a 115-volt line voltage).

EIA specifications for testing different types of resistors are summarized in Tables 2-2 and 2-3. Figure 2-1 shows that these standard voltages can be supplied from the internal power supplies over most of the resistance range. For low-resistance measurements the GEN LEV control can be set for the desired test voltage by use of a high-impedance dc voltmeter connected directly to the UNKNOWN terminals. For high-resistance measurements, where the voltage is applied vertically, the ratio between the voltage across the unknown and that across the whole bridge is fixed over each range at null and therefore the voltmeter can be placed across the bridge input (LOW UNKNOWN terminals to chassis) and the GEN LEV control set to give the "bridge voltage" given in Tables 2-2 and 2-3.

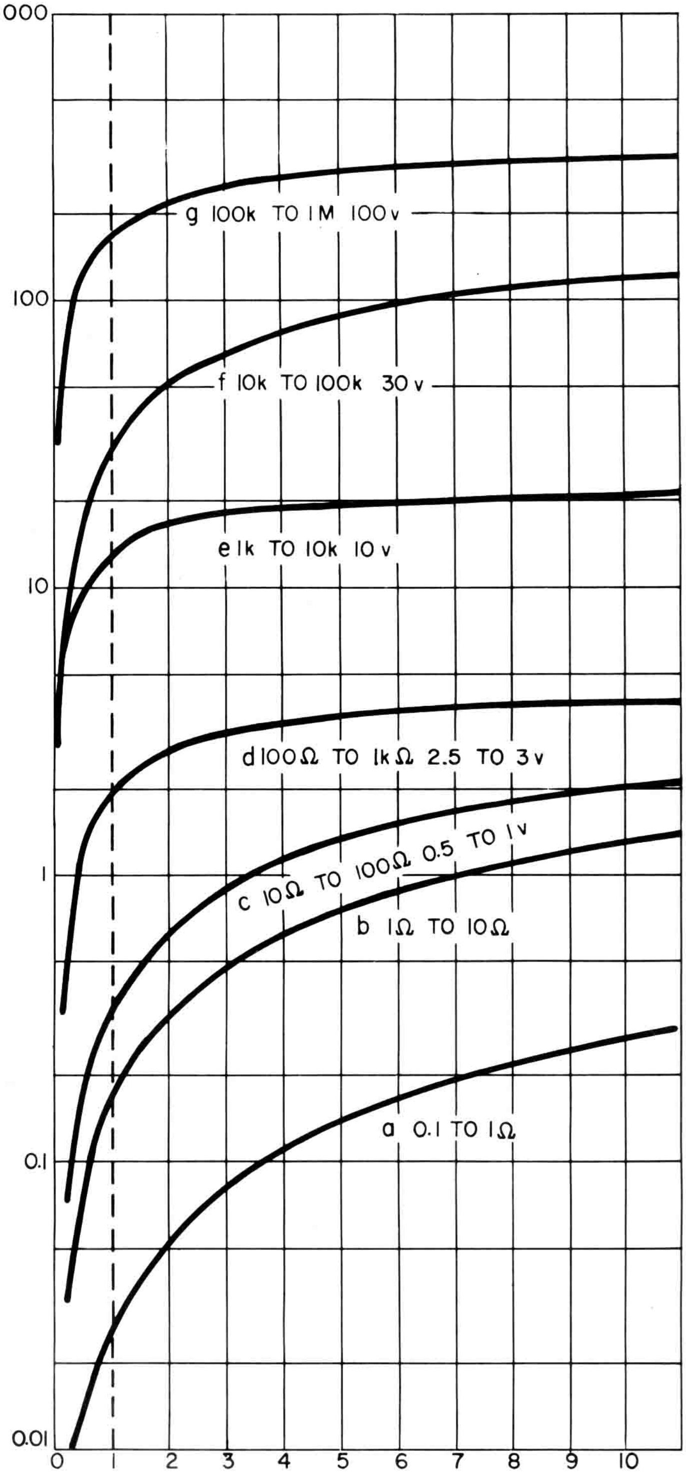


Figure 2-1. Dc voltage applied to unknown resistor (115-v line).

2.3.4 EXTERNAL DC DETECTOR. The internal dc supplies and the internal detector permit measurements from 1 ohm to 1 megohm to 0.1% when the GEN LEV and DET SENS controls are at maximum. If accurate measurements beyond this range are desired or if it is necessary to make measurements at lower voltages, an exter-

TABLE 2-1
DC SOURCE AND DETECTOR CONNECTIONS

R_s Bridge	FULL SCALE RANGE	1100 mΩ	11 Ω	110 Ω	1100 Ω	11 kΩ	110 kΩ	1100 kΩ
	VERTICAL	METER			MVS		HVS	
	HORIZONTAL	LVS			METER			
G_p Bridge	FULL SCALE RANGE	1100 n℧	11 μ℧	110 μ℧	1100 μ℧	11 m℧	110 m℧	1100 m℧
	VERTICAL	HVS			METER			
	HORIZONTAL	METER			MVS		LVS	

HVS HIGH-VOLTAGE SUPPLY = 350 v open-circuit
MVS MEDIUM-VOLTAGE SUPPLY = 35 v open-circuit
LVS LOW-VOLTAGE SUPPLY = 3.5 v open-circuit

TABLE 2-2
EIA STANDARD TEST VOLTAGES
Fixed Composition Resistors (RS172)

RESISTANCE	BRIDGE	RANGE	EIA TEST VOLTAGE	BRIDGE VOLTAGE*
2.7 - 9.9 Ω	R_s	11 Ω	0.5 - 1 v	**
10 - 99 Ω	R_s	110 Ω	0.5 - 1 v	**
100 - 999 Ω	R_s	1100 Ω	2.5 - 3 v	19.2 - 23 v
1000 - 9999 Ω	R_s	11 kΩ	8 - 10 v	13.4 - 16.7 v
10 - 99 k Ω	R_s	110 kΩ	24 - 30 v	25.6 – 32 v
100 kΩ - 1 MΩ	R_s	1100 kΩ	80 - 100 v	81 - 101 v
1 MΩ - up	G_p	1 n℧	80 - 100 v	81 - 101 v

TABLE 2-3
EIA STANDARD TEST VOLTAGES
Fixed Film Resistors (RS-196)
Low-Power Wire-Wound Resistors (REC-117 up to 9999 Ω)

RESISTANCE	BRIDGE	RANGE	EIA MAX VOLTAGE	MAX BRIDGE VOLTS*
less than 10 Ω	R_s	11 Ω	0.3 v	**
10 - 99 Ω	R_s	110 Ω	1 v	**
100 - 999 Ω	R_s	1100 Ω	3 v	23 v
1000 - 9999 Ω	R_s	11 kΩ	10 v	16.7 v
10 - 99 kΩ	R_s	110 k Ω	30 v	32 v
100 kΩ - 1 MΩ	R_s	1100 kΩ	100 v	101 v
1 MΩ - up	G_p	1 n℧	100 v	100 v

* This is the voltage from the LOW UNKNOWN terminal to chassis. In the EXT DC position, this is also the voltage at the EXT GEN terminals.

** This voltage varies with the resistance of the unknown (see paragraph 4.3).

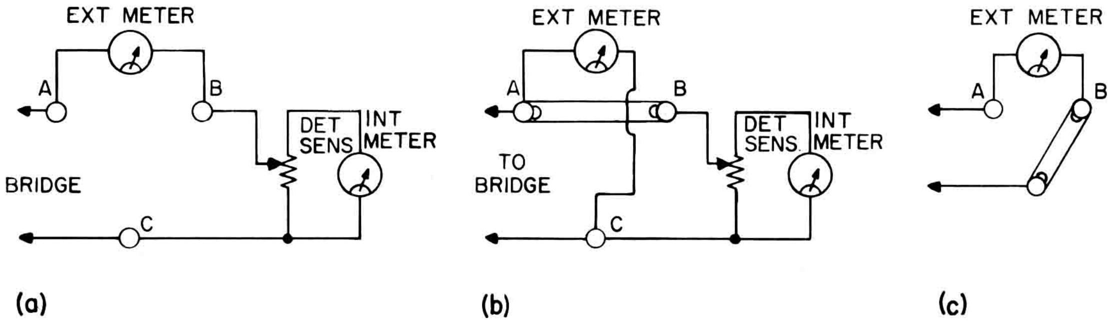


Figure 2-2. External meter connections.

nal detector with increased sensitivity can be used. The external detector can be connected in series with the internal meter, in parallel with the meter, or in place of the meter by appropriate connection to the EXT METER CONNECTIONS on the rear of the instrument as shown in Figure 2-2.

2.3.5 EXTERNAL DC SUPPLY.

If higher voltage is required on the unknown resistor, an external supply may be used. The EXT GEN terminals are connected directly across the vertical bridge diagonal in the EXT DC position of the function switch and the detector is across the horizontal diagonal on the top four ranges. Be careful not to exceed the maximum voltage or current given in Table 2-4 in order to avoid damage to the bridge components.

When an external supply or detector is used, the measurement procedure is the same as that with the internal supply and detector except that the GEN LEV control does not control the level of an external supply and the DET SENS control does not control the sensitivity of an external detector.

If an external dc supply is used when making measurements in the lowest three R ranges, set the function switch to INT DC, open the link on the BIAS terminals, and connect the external dc supply between the + BIAS terminal and the short-circuited EXT DQ terminals.

2.4 AC MEASUREMENTS USING INTERNAL GENERATOR.

2.4.1 1-KC CAPACITANCE MEASUREMENT.

2.4.1.1 Procedure.

a. Set the GEN LEV control fully clockwise.

b. Set the BRIDGE SELECTOR to:

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

C_p - if the parallel capacitance is desired and D is between 0.02 and 2.

(Note: $C_s = C_p$ within 0.1% if $D < 0.03$.)

G_p - if D is greater than 2 (measure as a conductance, $C_p = \frac{QG_p}{\omega}$).

TABLE 2-4

MAXIMUM EXTERNAL DC BRIDGE VOLTAGE AND CURRENT

BRIDGE	RANGE	E MAX	I MAX	TERMINALS
R_s	1100 mΩ	1.4 v	710 ma	BIAS
R_s	11 Ω	4.5 v	223 ma	BIAS
R_s	110 Ω	14.2 v	71 ma	BIAS
R_s	1100 Ω	22 v	17.2 ma	EXT GEN
R_s	11 kΩ	71 v	17.2 ma	EXT GEN
R_s	110 kΩ	223 v	17.2 ma	EXT GEN
R_s	1100 kΩ	400 v	17.2 ma	EXT GEN
G_p	1000 n℧	400 v	17.2 ma	EXT GEN

c. Set the function switch to INT AC.

d. Connect the unknown capacitor to the UNKNOWN terminals.

e. If the proper range setting of the FULL SCALE RANGE is not known, set the concentric CGRL controls for a reading somewhere near 5000, adjust the DET SENS control for an upscale meter reading and set the FULL SCALE RANGE switch for a minimum meter deflection.

f. Adjust the concentric CGRL controls and the DQ control for minimum meter deflection. The DET SENS control may have to be readjusted to give greater sensitivity as balance is approached.

g. The capacitance of the unknown is indicated directly on the counter readout with the correct decimal point and unit illuminated. The D of the unknown is indicated directly on the illuminated scale on the DQ dial. The meaning of an X indicator is explained in paragraph 2.2.

2.4.1.2 Accuracy. The accuracy of the C reading is ±0.1% of the reading ±0.005% of full scale (which is ±1/2 of the last digit) on all but the highest capacitance range, where the accuracy is ±0.2% of the reading ±0.005% of full scale. On the lowest C range it is necessary to subtract the residual ("zero") capacitance of the bridge terminals, approximately 0.25 pf, from the reading to determine the correct value of the unknown capacitor. If external leads are used to connect the unknown, this zero capacitance is increased and should be subtracted from the reading. The error caused by capacitance between the terminals and leads may be removed by means of a three-terminal shielded capacitance measurement (refer to paragraph 3.2).

The residual resistance and inductance of the bridge have negligible effect on the C or D accuracy except for a slight D error on the highest C range (D error = 0.006 when C_x = 1000 pf). However, if long leads are used when measurements are made on large capacitors, a correction for the lead resistance and inductance may be necessary. The correction terms are given in Table 2-5.

When capacitors with high D's are measured, an additional error of ±(0.5%) D^2 is added to the specification (refer to paragraph 1.5.3). This error is negligible when D is less than 0.2.

2.4.2 1-KC INDUCTANCE MEASUREMENT.

2.4.2.1 Procedure.

a. Set the GEN LEV control fully clockwise.

Note: For some iron-cored inductors the inductance measured will depend upon the excitation level (refer to paragraph 2.4.5.4).

b. Set the BRIDGE SELECTOR to:

L_s - if the series inductance is desired and Q is between 0.5 and 50.

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

(Note: $L_s = L_p$ within 1% if $Q > 32$)

R_s - if Q is less than 0.5 (measure R_s and Q;

$L_s = \frac{QR_s}{\omega}$ refer to paragraph 2.4.3).

c. Set the function switch to INT AC.

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

e. If the proper range setting of the FULL SCALE RANGE is not known, set the concentric CGRL controls for a reading somewhere near 5000, adjust the DET SENS control for an upscale reading, and set the FULL SCALE RANGE switch for a minimum meter deflection.

f. Adjust the concentric CGRL controls and the DQ control for minimum meter deflection. The DET SENS control may have to be readjusted to give greater sensitivity as balance is approached.

g. The inductance of the unknown is indicated directly on the counter readout with the correct decimal point and unit illuminated. The Q of the unknown is indicated directly on the illuminated scale of the DQ dial. The meaning of an X indicator is explained in paragraph 2.2.

2.4.2.2 Accuracy. The accuracy of the L reading is ±0.1% of the reading ±0.005% of full scale (which is ±1/2 of the last digit) on all but the lowest ranges, where the accuracy is ±0.2% of the reading ±0.005% of full scale. When Q is low there is an additional error of $0.5\% \frac{1}{Q^2}$, which is negligible when Q is approximately 5 or higher.

On the lowest range, the residual inductance of the binding posts (0.14 μh) must be subtracted from the reading in order to obtain full accuracy. If external leads are used to connect the unknown inductor to the bridge, then the residual inductance should be measured and subtracted from the L reading. To measure this lead inductance, short the leads together, measure the impedance on the R_s bridge, and calculate $L_s = \frac{QR_s}{\omega}$. Be careful to keep the lead configuration the same for the residual inductance measurement and the total inductance measurement, since an increase in the area between the leads would increase the residual inductance.

The residual resistance of the bridge is approximately 0.9mΩ. This can cause a small Q error when L_x is small. If long leads are used, the Q error becomes more important (see Table 2-5). The residual bridge capacitance of 0.25 pf can cause an L error when L_x is very large. However, this capacitance is usually negligible compared with the capacitance of a large inductor. Long leads to the inductor may appreciably change the total capacitance. The corrections for these lead effects are given in Table 2-5.

When inductors with low Q's are measured, an additional error term of $\pm 0.5\% \frac{1}{Q^2}$ is added to the specifications (refer to paragraph 1.5.3). This error is negligible when Q is greater than 5.

TABLE 2-5
CORRECTIONS FOR ERRORS CAUSED BY TERMINAL AND LEAD IMPEDANCES

(Add or subtract from the measured value as indicated.)

Measured	Series Resistance $R_o = 0.9\,m\Omega$ + leads	Series Inductance $L_o = 0.14\ \mu h$ + leads	Parallel Capacitance $C_o = 0.25$ pf + leads
C_s	NO ERROR	$-\omega^2 L_o C_x{}^2$	$-C_o(1 - D_x{}^2)$
D	$-\omega C_x R_o$	$-\omega^2 L_o C_x D_x$	$+ D_x \frac{C_o}{C_x}(1 + D_x{}^2)$
C_p	$+2R_o D_x \omega C_x{}^2$	$-\omega^2 L_o C_x{}^2(1 - D_x{}^2)$	$-C_o$
D	$-\omega C_x R_o(1 + D_x{}^2)$	$-\omega^2 L_o C_x D_x(1 + D_x{}^2)$	$+\frac{C_o}{C_x} D_x$
G_p	$+G_x{}^2 R_o(1 + Q_x{}^2)$	$+\omega^2 L_o{}^2 G_x{}^3(1 - \frac{2Q_x}{\omega G_x L_o})$	NO ERROR
Q	$+Q_x G_x R_o(1 - Q_x{}^2)$	$+\omega L_o G_x(1 + Q_x{}^2)$	$\frac{-\omega C_o}{G_x}$
R_s	$-R_o$	NO ERROR	$+\omega^2 C_o{}^2 R_x{}^3(1 - \frac{2Q_x}{\omega C_o R_x})$
Q	$Q_x \frac{R_o}{R_x}$	$-\frac{\omega L_o}{R_x}$	$+\omega C_o R_x(1 + Q_x{}^2)$
L_s	NO ERROR	$-L_o$	$-\omega^2 C_o L_x{}^2(1 - \frac{1}{Q_x{}^2})$
Q	$+Q_x{}^2 \frac{R_o}{\omega L_x}$	$-\frac{L_o}{L_x} Q_x$	$+\omega^2 C_o L_x(Q_x + \frac{1}{Q_x})$
L_p	$+\frac{2R_o}{Q\omega}$	$-L_o(1 - \frac{1}{Q_x{}^2})$	$-\omega^2 C_o L_x{}^2$
Q	$+\frac{R_o}{\omega L_x}(1 + Q^2)$	$-\frac{L_o}{L_x}(Q_x + \frac{1}{Q_x})$	$+\omega^2 C_o L_x Q_x$

2.4.3 1-KC RESISTANCE AND CONDUCTANCE MEASUREMENTS.

2.4.3.1 Procedure.

a. Set the GEN LEV control fully clockwise.

b. Set the BRIDGE SELECTOR to:

R_s - if series resistance is desired, and the resistance of the unknown is between 0 and 1 MΩ or if the unknown is inductive.

G_p - if parallel conductance is desired, and the conductance of the unknown is between 0 and 1 mho or if the unknown is capacitive. (Refer to Section 3.8 for R_p measurement.)

> (Note: Any resistor small enough to require use of the R_s bridge because of value will be inductive; likewise, any resistor large enough to require use of the G_p bridge will be capacitive. In the range between 1 Ω and 1 MΩ the phase of the resistor will determine which bridge is required unless Q is small enough to permit use of either bridge. R_s may be calculated from G_p, and vice versa, from the formula $R_s = \frac{1}{(1 + Q^2)\, G_p}$.

c. Set the function switch to INT AC.

d. Connect the unknown resistor to the UNKNOWN terminals.

e. If the proper range setting of the FULL SCALE RANGE is not known, set the concentric CGRL controls for a reading somewhere near 5000, adjust the DET SENS control for an upscale meter reading and set the FULL SCALE RANGE switch for a minimum meter deflection.

f. Adjust the concentric CGRL controls and the three Q controls for the best minimum meter deflection. The DET SENS control may have to be readjusted to give greater sensitivity as balance is approached.

g. The resistance or conductance of the unknown is indicated directly on the counter readout with the decimal point and unit illuminated. The Q of the unknown is read directly on the Q readout and is inductive or capacitive as indicated by the lights (unless the Q balance is less than 0, in which case the opposite is true). Note the decimal point in the first (coarsest) adjustment, which makes major divisions on the vernier dial steps of 0.001. The meaning of an X indicator is explained in paragraph 2.2.

2.4.3.2 Accuracy.

The accuracy of the R or G reading is ±0.1% of the reading ±0.005% of full scale (which is ±1/2 of the last digit) on all but the lowest R and highest G ranges where the accuracy is ±0.2% of the reading ±0.005% of full scale.

On the lowest R range the residual resistance of the bridge (approximating 0.9 mΩ) should be subtracted from the measured resistance. Use short, heavy leads to connect the unknown resistor, measure the resistance of these leads by connecting the free ends together, and subtract this value from the measured value.

Residual inductance and capacitance affect only the Q of the resistor. Corrections for these effects are given in Table 2-5. When resistors with high Q's are measured, an additional error term of 0.1%Q is added to the specification (refer to paragraph 1.5.3). This term is practically negligible when Q is less than 0.2.

2.4.4 MEASUREMENTS USING INTERNAL GENERATOR AT FREQUENCIES OTHER THAN 1 KC.

If an oscillator-detector tuning unit other than the 1-kc unit usually supplied is used, the operating procedure is the same as for 1-kc measurements, but the accuracy specifications and D and Q ranges are the same as those for an external generator at the same frequency (refer to Section 2.5). The plug-in unit gives the DQ multiplier required for the various bridges so that it does not have to be calculated (refer to paragraph 2.5.1).

2.4.5 NOTES ON AC MEASUREMENTS.

2.4.5.1 Capacitance to Ground.

The Type 1608-A Impedance Bridge generally measures "ungrounded" components, since neither UNKNOWN terminal is connected directly to the panel, which should be grounded except for measurements on grounded components (refer to paragraph 3.5). Capacitance from the LOW UNKNOWN terminal is placed directly across the detector (see Figure 2-3) and does not cause an error, but can, if large enough, cause a reduction in sensitivity. Capacitance from the other UNKNOWN terminals shunts an arm of the bridge and therefore causes an error which can be significant if the stray capacitance is large enough. Table 2-6 gives the error caused by a stray capacitance for each quantity measured.

Note that for the capacitance bridges stray capacitance causes a small capacitance error. Since C_t is 0.15 μf, it takes a stray capacitance of 150 pf to cause

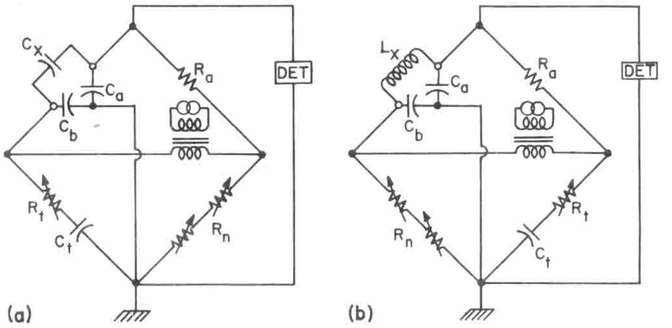


Figure 2-3. Capacitance and inductance bridge diagrams, showing capacitances to ground.

TABLE 2-6
CORRECTION TERMS FOR ERRORS CAUSED BY CAPACITANCE TO GROUND (C_b)

(Add or subtract from measured value as indicated.)

$C_t = 0.15\ \mu f,\ R_t = 6.67\,k\Omega$

$R_n = 0.667 \times$ (centade reading*)

C_s	$+\frac{C_xC_b}{C_t}(1-D_x^2)$	C_p	$+\frac{C_xC_b}{C_t}$
D (low)	$-\frac{C_b}{C_t}D_x(1+D_x^2)$	D (high)	$-\frac{C_b}{C_t}D_x$
G_p	NO ERROR	R_s	$+\omega C_b R_n R_x Q_x$
Q (cap)	$+\omega C_b R_t$	Q (ind)	$-\omega C_b R_n$
L_s	$\frac{+\omega C_b R_n L_x}{Q_x}$	L_p	$\frac{+\omega C_b R_n L_x}{Q_x}$
Q (low)	$-\omega C_b R_n Q_x^2$	Q (high)	$-\omega C_b R_n Q_x^2$

*omitting decimal point; e.g., for a centade reading of 10.000, $R_n = 6670\,\Omega$.

a 0.1% error. Note also that for the other bridges, C_b causes an error in Q only, except when low-Q inductors or high-Q resistors are measured.

Measurements made with the unknown grounded are discussed in paragraph 3.5 and measurements on three-terminal, shielded components are discussed in paragraph 3.2.

2.4.5.2 Voltage on Unknown. The voltage applied to the bridge is approximately 1 volt with a source impedance of 50 ohms when the GEN LEV control is fully on. The actual ac voltage on the unknown can be calculated with the aid of Table 2-7 and the circuit diagram of Figure 1-2, or it can be measured with a high-impedance voltmeter (which should be removed when high-impedance measurements are made in order to avoid shunting the unknown).

2.4.5.3 AC Sensitivity. The generator-bridge-detector system is sensitive enough to balance the bridge to the stated accuracy specifications. However, there are cases where additional sensitivity may be useful, such as measuring accurate D or Q when the main CGRL adjustment is at the low end of its range or when the signal level on the unknown must be set at some low level. In these cases an external detector following the internal detector may be of use. The Type 1232-A Tuned Amplifier and Null Detector is recommended. It should be connected to the DET OUT terminals.

When very low impedances are measured, there may be enough inductive hum pickup to limit the sharpness of the null. This is caused primarily by harmonics of the power-line frequency that are close enough to the tuned frequency to pass through the selective detector. In some cases a small "beating" on the meter may be noticed; this is a beat between harmonics of the oscillator and line. An oscilloscope connected to the DET OUT terminals may be used to advantage in such cases. If the oscilloscope is set to synchronize with the power line, the voltage at the line frequency and its harmonic will be a fixed display pattern and the bridge output signal will be a time-varying display. The final bridge balance adjustments should be made to remove any time-varying component from the oscilloscope display.

TABLE 2-7
BRIDGE COMPONENT RATINGS

FULL-SCALE RANGE setting				Ra	Ra Max	Ra Max
C	G	R	L	Value	Voltage	Current
1100 μf	1100 m℧	1100 mΩ	1100 μh	1 Ω	0.71 v	710 ma
110 μf	110 m℧	11 Ω	11 mh	10 Ω	2.2 v	220 ma
11 μf	11 m℧	110 Ω	110 mh	100 Ω	7.1 v	71 ma
1100 nf	1100 μ℧	1100 Ω	1100 mh	1 kΩ	22 v	22 ma
110 nf	110 μ℧	11 kΩ	11 h	10 kΩ	71 v	7.1 ma
11 nf	11 μ℧	110 kΩ	110 h	100 kΩ	220 v	2.2 ma
1100 pf	1100 n℧	1100 kΩ	1100 h	1 MΩ	500 v	0.7 ma

CENTADE - R_n (R1): 30 ma
STANDARD RESISTOR R_t (R3): 58 v, 86 ma.
STANDARD CAPACITOR, C_t (C1): 600 v peak (425 v rms).
DETECTOR INPUT CAPACITOR (C556): 400 v peak (280 v rms).

2.4.5.4 Effect of Level on Iron-Cored Inductor Measurements. Iron-cored inductors are nonlinear devices whose inductance depends on the level of the applied voltage. If measurements are to be repeatable, the signal level must be specified. The "initial permeability" inductance, or inductance at "zero level", is often used as a reference (as on General Radio Type 1481 Inductors). To obtain this value, plot L vs applied voltage and extrapolate to zero voltage. The GEN LEV 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.

2.4.6 DIFFERENCES BETWEEN AC AND DC RESISTANCE MEASUREMENTS.

2.4.6.1 General. The ac resistance bridge of the Type 1608-A Impedance Bridge provides a means for extending the range and sensitivity of resistance measurements over that possible with dc, without using a higher applied voltage or a sensitive dc amplifier. The ac resistance of a resistor can differ from the dc value for a number of reasons. However, most of those are negligible at 1000 cps, and in some cases the use of ac avoids undesirable effects that can cause errors in dc measurement.

2.4.6.2 Frequency Effects.

a. Series Inductance and Parallel Capacitance. At audio frequencies almost all resistors except those of very high value (see b and c below) can be accurately represented by the equivalent circuit of Figure 2-4. In this circuit the resistor is a pure resistance and equal to the low-level dc value unless some other effect is appreciable. If we let $Q_L = \frac{\omega L}{R}$ and $Q_c = \omega R_c$, then the effective series resistance of this equivalent circuit is

$$R_s = \frac{R}{1 - 2Q_cQ_L + Q_c^2 + Q_c^2Q_L^2} \qquad (1)$$

and the effective parallel conductance is

$$G_p = \frac{1}{R} \times \frac{1}{1 + Q_L^2} \qquad (2)$$

Low-valued resistors have a completely negligible Q_c but Q_L can become appreciable, particularly for wire-wound resistors. Since Q_c is negligible, the value of R_s is equal to the dc value, but the value of G_p is not equal to $\frac{1}{R_{dc}}$. However, on the Type 1608-A, if the resistor is inductive, it can be balanced only on the R_s bridge, where there is no error.

High-valued resistors have a negligible Q_L but Q_c is appreciable even if the parallel capacitance is small. If the unknown resistor is capacitive, it can be measured only on the G_p bridge where there is no error due to lumped parallel capacitance.

It is conceivable that both Q_L and Q_c could be large enough to have an appreciable effect in the middle

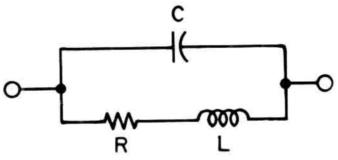


Figure 2-4 Resistor equivalent circuit.

resistance range, so that both R_s and G_p would differ appreciably from the dc values. However, it is highly unlikely that a component designed as a resistor would have the required inductance and capacitance (although a large air-cored inductor could). A 1-kilohm resistor would have to have a 5000-pf shunt capacitance to produce a 0.1% error from the $Q_c{}^2$ term in equation (1) and a 5-mh series inductance to produce a 0.1% error from the $Q_L{}^2$ term in equation (2). The product Q_cQ_L is equal to $\left(\frac{f}{f_o}\right)^2$ where f_o is the resonant frequency $\left(\frac{1}{2\pi\sqrt{LC}}\right)$. To produce a 0.1% error at 1 kc from the $2Q_cQ_L$ term, the resonant frequency would have to be less than 45 kc.

b. Distributed Capacitance along Resistor. For very high-value resistors an equivalent circuit consisting of a resistor and a single parallel lumped capacitor is not good enough. Actually, there is capacitance from every part of the surface of the resistor to every other part. As a result of this distributed capacitance, the real part of the admittance, or parallel conductance, G_p, is frequency-dependent. A rule of thumb for film-type resistors is that the equivalent parallel resistance will be reduced by approximately 10% when the product of the resistance in megohms and the frequency in megacycles is unity. Composition resistors have a somewhat larger change. At 1 kc this would mean a 10% change at 1000 MΩ or, since the error is roughly proportional to R, the error would be approximately 0.1% at 10 MΩ. The Type 1608-A has 0.15% accuracy at 100n ℧ (or 10MΩ) and reduces to 5% at 1n℧ (or 1000MΩ). Therefore, this effect is just barely noticeable at the extreme of the G_p range for most resistors.

c. Distributed Capacitance to Bridge Case. If there is distributed capacitance from the body of the resistor to a third (guarded) terminal, such as the cabinet of the Type 1608-A Bridge, the effective measured parallel conductance, G_p, will decrease with frequency. The expression :

$G_p = \frac{1}{R} \frac{1}{1 + \frac{\omega^2R^2C^2}{50}}$ gives the first error term. At 1 kc,

$G_p \simeq \frac{1}{R} \frac{1}{1 + R^2C^2 x 10^{-6}}$ where R is in MΩ and C is in pf. This gives a 1% error when R = 100 MΩ and C = 1 pf. This effect is just noticeable if a large resistor is spaced very close to the bridge panel, and causes no measurable error if the unknown is spaced away from the panel and other grounded conductors.

d. Magnetic Coupling - Iron Loss. If the resistor is wire-wound and is placed near a conductor, currents may be induced in the inductor, and the resulting eddy current losses (and hysteresis loss if iron) will be equivalent to a resistor shunting the unknown. This effect is completely negligible in resistors, but is the main reason why the ac and dc resistances of transformers differ. The effect is hardly noticeable on high-frequency ferrite-cored chokes measured at 1 kc.

e. Skin Effect. This is completely negligible at 1 kc. The error would be worse for heavy wire and at 1 kc the error would be less than 10 ppm for 50 mil (No. 16) manganin wire

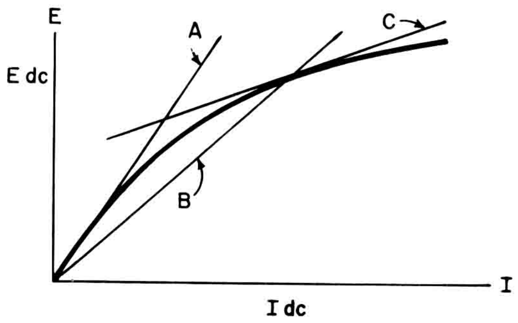


Figure 2-5. Resistance of nonlinear resistor.

2.4.6.3 Level Effects.

a. Power Dissipation. The measured ac and dc resistance of a resistor could differ if the power level for the two measurements were different, resulting in different resistor temperatures. Generally, ac bridges are more sensitive than dc bridges and therefore require less applied power for equal precision. Therefore, the ac measurement would usually give a more accurate measurement of low-level resistance.

If the thermal time constant of the resistor being measured is not very long compared with the period of the ac signal, the resistance could change during the ac cycle, giving an ac value that is frequency-dependent. This effect would rarely be noticeable at 1 kc.

b. Nonlinear Resistors. If a resistor is nonlinear, as is the resistance curve of Figure 2-5, there are several different ways of specifying resistance. Line A is the low-level resistance which could be more easily measured using ac because of the higher sensitivity of ac bridges. Line B is the dc resistance at a given voltage, E_{dc}. Another value, line C, is the incremental value using a low-level ac signal superimposed on a dc bias (refer to paragraph 3.1.3).

c. Thermal Voltages. If the two connections to the unknown are not at the same temperature, a small dc thermocouple voltage is induced that can cause an error in dc measurements. The error varies with the applied dc level.

2.5 AC MEASUREMENTS WITH EXTERNAL GENERATOR.

2.5.1 PROCEDURE. The procedure for making measurements with an external generator 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 2.5.3. (Note that the GEN LEV control does not control the level of an externally applied signal.)

b. Set the function switch to EXT AC (this connects the EXT GEN terminals to the bridge input transformer and switches the detector to a flat frequency characteristic).

c. Multiply the D and Q readings by the following factors to determine the value at the test frequency, f.

Bridge		Multiplying Factor
C_s	LOW D	f/1 kc
C_p	HIGH D	1 kc/f
G_p	Q	f/1 kc
R_s	Q	f/1 kc
L_s	LOW Q	f/1 kc
L_p	HIGH Q	1 kc/f

If the presence of a nonlinear unknown causes distortion in the detector, the best meter null may not give the correct value. Also, excess noise may limit the null obtainable. Earphones (connected to the DET OUT terminal) are helpful in distinguishing a null at the fundamental frequency, or an external selective amplifier, such as the Type 1232-A Tuned Amplifier and Null Detector, can be used. In extreme cases, distortion or noise could have enough amplitude to overdrive the internal detector when the function switch is at EXT AC and could thus give erroneous readings on a selective detector connected to the DET OUT terminals. In such cases, the external detector should be connected from the LOW UNKNOWN terminal to panel ground.

2.5.2 ACCURACY. The accuracy of measurements made with an external generator is the same as that with the internal oscillator except that the following frequency-dependent terms are added to the specifications:

L and C measurements:

$$\pm 0.001\% \left(\frac{f}{1\text{ kc}}\right)^2, \quad \pm 0.1\%\, D \frac{f}{1\text{ kc}}$$

R and G Measurements:

$$\pm 0.002\% \left(\frac{f}{1\text{ kc}}\right)^2, \quad \pm 0.000001 \left(\frac{f}{1\text{ kc}}\right)^4$$

These extra terms and the total error are shown diagrammatically in Figures 1-5 and 1-6. In order to achieve this accuracy, it is necessary to correct for the effect of the residual impedances of the terminals and connecting leads, which become more important at higher frequencies (refer to paragraph 2.5.7). For R_s and G_p measurements there is a slight error if more than 3 volts is applied by the external generator.

The percent D or Q error is 5% for L and C measurements at any frequency, but the fixed error term becomes $0.0005 \frac{f}{1\text{ kc}}$ or 0.0005, whichever is larger. For R_s and G_p measurements the Q accuracy is ±2% ±0.0005 f/1 kc. For large applied voltages, a somewhat larger Q error may be caused by saturation of the phase-compensating inductor. This error may be as large as 0.005 f/1 kc.

2.5.3 CONNECTION OF EXTERNAL GENERATOR. In most cases when an external generator is used it should be connected to the EXT GEN terminals. In this connection, the external generator is connected directly to the internal bridge transformer when the function switch is in the EXT AC position, and the low generator terminal is connected to the bridge chassis (which should be grounded; refer to paragraph 2.1.2). A second ground connection to the generator should be avoided.

If the external generator can be overdriven when connected to a low-impedance load, it is generally desirable to place a resistor in series with the ungrounded generator connection to the bridge. This resistor should be large enough to prevent distortion even when the bridge input is short-circuited. The bridge input impedance at the EXT GEN terminals is a minimum of 30 ohms (resistive) at 1 kc when the bridge is set to measure a short circuit on the UNKNOWN terminals. This is shunted by the inductance of the primary of the bridge transformer, which is approximately 0.25 henry.

In some cases where more input power is required, particularly in measurements of low impedance, a matching transformer between generator and bridge is useful. This transformer need not be shielded.

When the desired bridge voltage is higher than can

SECTION 3

SPECIAL MEASUREMENTS

3.1 APPLICATION OF DC BIAS TO UNKNOWN.

3.1.1 APPLICATION OF DC BIAS TO CAPACITORS (OPERATION WITH INTERNAL OSCILLATOR). Up to 500 volts of dc bias may be applied to the unknown capacitor by any of several methods. The simplest method can be used only for measuring 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 carefully handled and connecting leads insulated wherever possible.

It is advisable to limit the power that can 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:

Method 1. C_s Bridge (see Figure 3-1a).

With this method up to 500 volts can be applied on any range. Connect the negative terminal of the unknown capacitor (if polarized) to the LOW UNKNOWN terminal. The dc supply should have a low ac output impedance. For this method of bias the bridge and the dc supply do not have a common ground and one must be left floating. This problem is discussed in paragraph 3.1.5.

Method 2. C_p Bridge (see Figure 3-1b).

This method is the same as Method 1 above, except that a large blocking capacitor is placed in the standard bridge arm to prevent direct current from flowing through the D adjustment rheostat. Connect this capacitor, C_y of Figure 3-1, between the EXT DQ terminals, with the positive terminal connected to the upper terminal.

Since this capacitance is not infinite, there will be an error in the measured value of C_x and D_x. The true values can be calculated from the following formulas:

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

$$D_x = D_{measured}\left(1 - \frac{C_t}{C_y} D_x{}^2\right)$$

Method 3. C_s or C_p Bridge. Small Capacitors (see Figure 3-1c).

This method is recommended for small capacitors. The maximum voltage that can be applied depends on the bridge range as given in Table 3-1. The "Max DC Current" column is correct only for the C_s bridge unless a blocking capacitor, C_y (see Figure 3-1b), is used with the C_p bridge. If no blocking capacitor is used, the maximum direct current will depend on the DQ rheostat setting, but the full current indicated can be applied on the three lowest capacitance ranges.

The advantage of this method is that both the dc source and the bridge are grounded and that the dc can easily be limited by a series resistor since the imped-

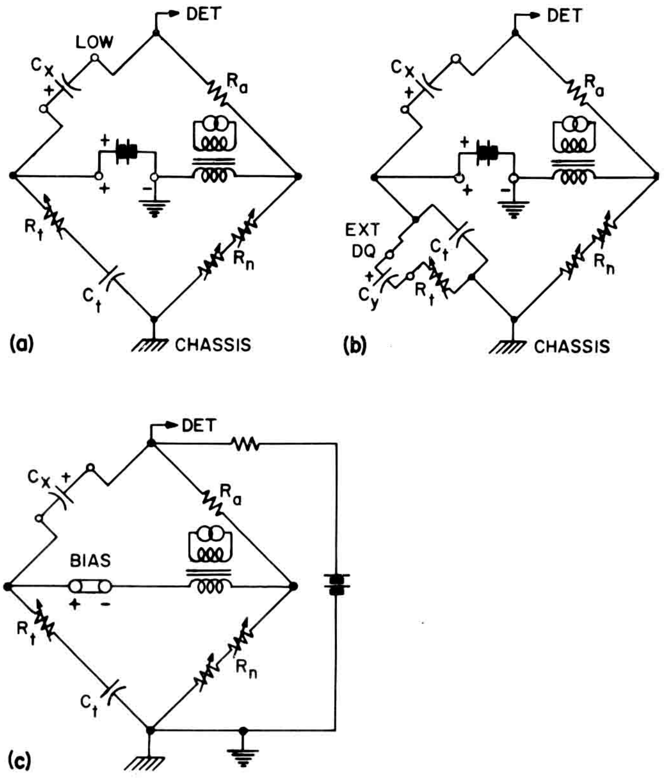


Figure 3-1. Methods of applying dc bias to capacitors.

ance of the dc source should be high (above 10 kΩ) to avoid shunting the detector. The dc source should have low hum on its output because it is tied to the detector input. External filtering on the dc source may be required, but is relatively easy to obtain when the required current is small.

> WARNING
>
> Note that the LOW UNKNOWN terminal has high voltage applied to it in this method of biasing capacitors.

TABLE 3-1

MAXIMUM VOLTAGE APPLIED TO CAPACITORS BY METHOD 3*

RANGE	MAX VOLTS ON UNKNOWN	MAX DC CURRENT
1100 pf	393 v	0.39 ma
11 nf	220 v	2.2 ma
110 nf	71 v	7.1 ma
1100 nf	22 v	22 ma
11 μf	3 v	30 ma
110 μf	0.3 v	30 ma
1100 μf	0.03 v	30 ma

*Methods 1 and 2 allow 500 v to be applied to all capacitors

3.1.2 APPLICATION OF DIRECT CURRENT TO INDUCTORS (OPERATION WITH INTERNAL OSCILLATOR).

Direct current can be applied to inductors during measurement by several different methods to permit incremental inductance measurements. The various methods are described below along with suggestions for their use. An external blocking capacitor, C_y in Figure 3-2a, is needed only for measurements on the L_s bridge. It should be connected between the EXT DQ terminals with its positive terminal connected to the upper of the two bridge terminals. There is a slight error due to the finite size of this capacitor, and the true value of L_x and Q_x can be calculated from the measured values by the following formulas:

$$L_x = L_{measured}\left(1 + \frac{C_t}{C_y}\frac{1}{Q_x^2}\right)$$

$$Q_x = Q_{measured}\left(1 + \frac{C_t}{C_y}\frac{1}{Q_x^2}\right)$$

> WARNING
>
> Large inductors carrying high current are shock hazards because of the high voltage induced if the connections are broken. Reduce the dc to zero before disconnecting the dc supply of the unknown inductor.

Method 1. (see Figure 3-2a) 30 ma max.

This method is preferred because both the dc supply and bridge are grounded and up to 30 ma may be applied to large inductors. At the 30-ma level there is an added 0.03% error in inductance and there may be a D $\left(\frac{1}{Q}\right)$ error as large as 0.001.

The resistor in series with the supply should be large enough to avoid shunting the detector, and to keep the dc constant as the bridge adjustment is made. Connect the capacitor C_e between the BIAS terminals, with its positive terminal connected to the black BIAS terminal. The voltage rating of this capacitor should be greater than the IR drop in the inductor. The voltage rating of the capacitor C_y (L_s bridge only) should be greater than Idc x 7.6 kΩ. (7.6 k is the maximum value of the adjustable bridge arm). If the dc supply has high hum, external filtering may be necessary.

Method 2. (see Figure 3-2b) High Current in Small Inductors.

This method permits higher currents in small inductors because the current is fed through the ratio arm resistor R_a, which is small on the lower inductance range. The maximum current is limited to that given in Table 3-2.

The dc supply is connected between the BIAS terminals with the positive supply terminal connected to the black BIAS terminal in order to keep the bridge case and dc supply at zero volts dc from ground. The blocking capacitor C_y (necessary only on the L_s bridge) must take the full dc voltage applied.

With this method of bias, the bridge and the dc

TABLE 3-2

MAXIMUM CURRENT THROUGH INDUCTORS (METHOD 2) AND RESISTORS (METHODS 2 & 3)

RANGE		MAXIMUM CURRENT	RATIO ARM (R_a)
L BRIDGE	R BRIDGE		
1100 μh	1100 mΩ	100 ma	1 Ω
11 mh	11 Ω	100 ma	10 Ω
110 mh	110 Ω	71 ma	100 Ω
1100 mh	1100 Ω	22 ma	1 kΩ
11 h	11 kΩ	7.1 ma	10 kΩ
110 h	110 kΩ	2.2 ma	100 kΩ
1100 h	1100 kΩ	0.4 ma	1 MΩ

supply do not have a common ground and one must be left floating. This problem is further discussed in paragraph 3.1.5.

Method 3. Large Currents (Figure 3-2c).

This method must be used for very large currents and the bridge does not limit the amount of current applied, since none of the current flows in the bridge. The ac source impedance of the dc supply must be very high, since it is in parallel with the unknown. An inductor, L_a, very large compared with the unknown, may be used. Often it is possible to resonate this shunt inductor to increase the source impedance still further. The impedance of the blocking capacitor, C_f, must be low compared with the unknown since it is in series with it. If the dc supply is grounded there will be a dc voltage between the bridge chassis and ground, equal to I_{dc} (dc resistance of L_x).

The same grounding difficulties are present for this method as are present for Method 2 above.

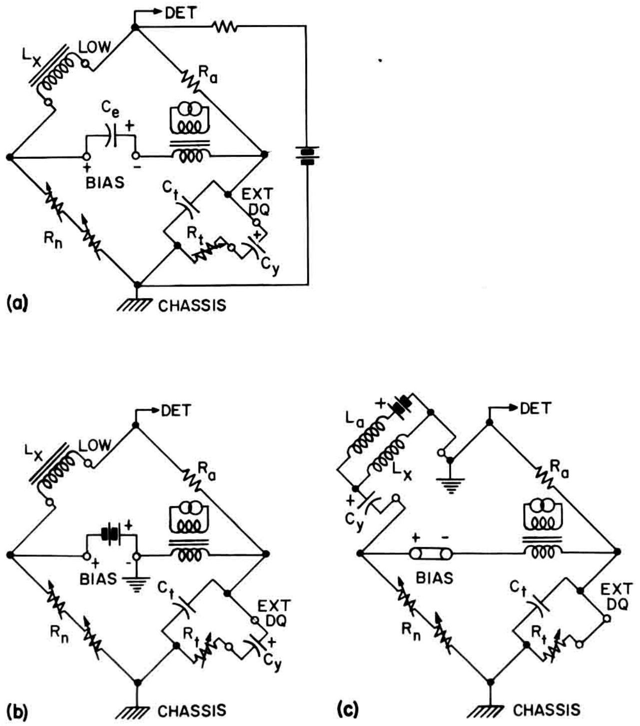


Figure 3-2. Methods of applying dc to inductors.

3.1.3 DC BIAS FOR AC RESISTANCE MEASUREMENTS (OPERATION WITH INTERNAL OSCILLATOR).

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 the incremental resistance. For voltage-sensitive devices, the ac resistance is the slope of the dc voltage-current characteristic. For thermally sensitive devices the ac resistance is equal to the dc value if the same total power is applied in both cases (as long as the thermal time constant is much longer than the period of the signal).

Method 1. (see Figure 3-3a).

This method is preferred because the bridge and dc source are both grounded and all the applied current flows through the unknown. A maximum current of 30 ma may be applied to the unknown resistors. The total voltage applied to the bridge should not exceed 400 volts.

The impedance of the blocking capacitor, C_d, should be small compared with that of the unknown resistor (this may be difficult when R_x is small), and the voltage rating of C_d must be greater than the IR drop of the unknown resistor. The voltage rating of capacitor, C_e, connected to the BIAS terminals should be greater than I_{dc} x 7.6 kΩ and the capacitance should be over 50 μf. A resistor should be placed in series with the dc supply to avoid shunting the detector with a low ac impedance.

A variation in this method is to short-circuit the two blocking capacitors, C_d and C_e. Then the current through the unknown will be $I_{input} \left(\frac{R_a}{R_a + R_x}\right)$, where R_a is given in Table 3-2, and the voltage and current limits of Table 2-7 apply.

Method 2. (see Figure 3-3b).

This method can be used to get higher currents through small unknown resistors, and the current limit for each range is given in Table 3-2. The maximum voltage is limited to 71 volts. Also, this method avoids the use of a capacitor in series with the unknown or ratio arm.

In this method the current through the unknown is the total current multiplied by $\left(\frac{R_t}{R_a + R_t}\right)$, where R_t is 6667 ohms and R_a is given in Table 3-2. On the lower ranges this ratio is near unity.

Also, for this method the bridge and dc supply do not have a common ground and one must be left floating. This problem is discussed in paragraph 3.1.5. There is a dc potential difference between the chassis and the negative terminal of the dc supply that varies with the adjustment of the CGRL control up to a maximum of 37 volts.

Method 3. (see Figure 3-3c).

This method is very similar to Method 2 but here all the current flows through the unknown and a very low-impedance dc supply is required. If the dc supply has high ac output impedance, it should be shunted with a large capacitor since it is in series with the unknown resistor.

With this method the bridge and dc supply do not have a common ground and one must be left floating. This problem is discussed in paragraph 3.1.5. There will be a dc potential between the chassis and negative terminal of the dc supply, equal to approximately $I_{dc} R_a$.

Method 4. (see Figure 3-3d).

With this method any amount of dc may be supplied to the unknown resistor because none of the current flows through the bridge and the applied voltage is limited only by the voltage rating of the blocking capacitor.

Here the dc supply shunts the unknown, and it is necessary to use a series resistor or inductor with an impedance much larger than that of the unknown. Therefore, this method is limited to relatively small resistors. Also, for this method there is a grounding problem since the bridge and the dc supply do not have a common ground. See paragraph 3.1.5. There will be a dc potential between the chassis and negative terminal of the dc supply, equal to approximately $I_{dc} R_x$.

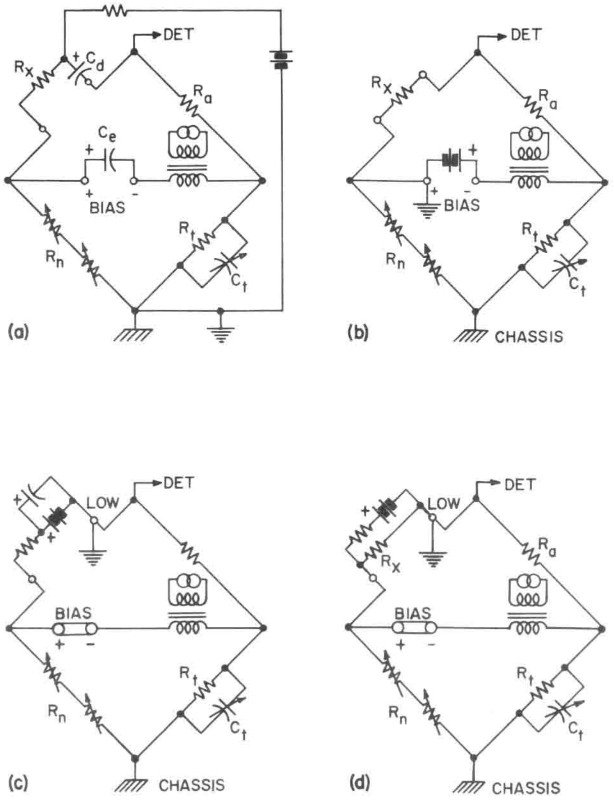
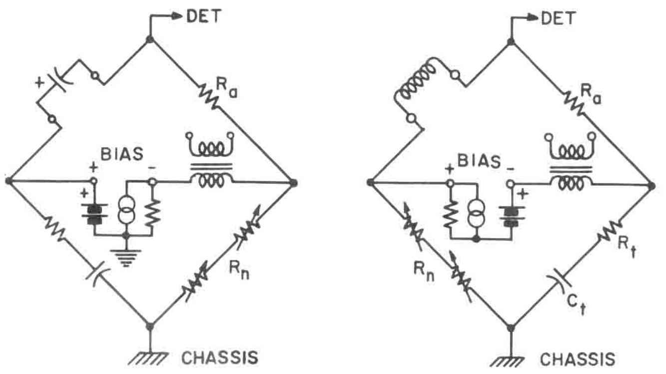


Figure 3-3. Methods of applying dc to resistors for ac resistance measurements.

3.1.4 APPLICATION OF DC BIAS WITH EXTERNAL AC GENERATOR. When an external generator is used, the grounding problem (see paragraph 3.1.5) becomes even more serious since the internal detector is not selective in the EXT AC position and the hum pickup is unattenuated. In many cases it will be necessary to use an external selective detector, such as the Type 1232-A Tuned Amplifier and Null Detector. In some cases the induced hum may overload the internal detector, causing erroneous readings, in which case the external detector should be connected between the LOW UNKNOWN terminal and the bridge panel rather than to the DET OUT terminals. In extreme cases, the bridge may be disconnected from the power line, thus removing all internal source of hum. This has the disadvantage of turning off all the indicator lights.

For those biasing methods where the dc supply and the bridge have a common ground, the external ac supply should be connected to the EXT GEN terminals which have the same common ground. With those methods that do not have a common ground between the bridge and dc supply, it is generally best to ground the external dc and ac supplies at the same point, as shown in Figures 3-4a and 3-4b, and unground the bridge. A resistor should be put in parallel with the ac generator to provide a dc path. When the bridge is floating and an external detector is used, this detector is also floating and should be battery operated (as is the Type 1232-A) to avoid additional hum pickup and capacitance to ground.

3.1.5 GROUNDING PROBLEMS WITH DC BIAS. For those biasing methods described above that do not have a ground in common with the bridge chassis, it is necessary to float (unground) either the dc supply or the bridge. This results in two difficulties. First, there is



CAPACITANCE BRIDGE (METHOD 2)

INDUCTANCE BRIDGE (METHOD 2)

Figure 3-4. Connections of external ac and dc supplies.

capacitance from the floating bridge or power supply to ground, which can cause an error if it is placed across a bridge arm. Second, there is generally capacitive coupling between the floating bridge dc supply and the ac line, which causes hum pickup in the detector, resulting in a residual deflection.

If the dc supply is self-powered, it should be left floating and spaced away from any ground, and the bridge should be grounded. If the dc supply is line-operated, it will probably have more capacitance to ground and to the power line than has the bridge, and therefore the supply should be grounded and the bridge ungrounded. To disconnect the bridge from ground, open the link between the rear terminal labeled 3RD WIRE GROUND and the adjacent CHASSIS terminal. The 3RD WIRE GROUND terminal will be grounded if a three-wire power cord is used and should be grounded externally if a two-wire cord is used.

When the bridge is floating, there is approximately 300 pf between the case and the 3RD WIRE GROUND internally. External capacitance from the case to ground will increase this total value somewhat. If the BIAS terminals or the UNKNOWN terminal not marked LOW is grounded, this capacitance will be placed across the standard capacitor for capacitance measurements, across the fixed standard resistor, R, for conductance measurements, and across the CGRL adjustment for resistance and inductance measurements. The error due to this capacitance can be computed from the equations of Table 2-6. For 300 pf, the main errors are a 0.2% error in capacitance measurements, a Q error of - 0.013 for G_p measurements, a maximum Q error of + 0.013 for R_s measurements (dependent upon the CGRL counter setting) and a maximum D $(\frac{1}{Q})$ error of - 0.013 for inductance measurements (dependent upon the CGRL control setting).

If the bridge is grounded at the LOW UNKNOWN terminal, this capacitance is placed across the detector where it causes no error.

The residual deflection caused by hum pickup can seriously limit the accuracy obtainable, particularly if the detector is not selective as it is when an external generator is used (refer to paragraph 3.1.4). The hum pickup will be about the same when either UNKNOWN terminal or the BIAS terminals are grounded when low impedances are measured, but can be much worse when high impedances are measured and the LOW UNKNOWN terminal is grounded. Earphones may be helpful in detecting the null of the fundamental in the presence of hum. In extreme cases, the bridge can be disconnected from the power line and a battery-operated selective detector, such as the Type 1232-A Tuned Amplifier and Null Detector, can be used to avoid all internal hum pickup.

3.2 MEASUREMENTS ON SHIELDED THREE-TERMINAL COMPONENTS.

When the unknown component is shielded, and the shield is not tied to either unknown terminal, a three-terminal component is formed (see Figure 3-5). The impedance, Z, of the component itself is the direct impedance of the three-terminal system. To measure the direct impedance, connect the shield (third terminal) to the bridge chassis, using any grounded terminal or a ground lug held by the screw directly below the UNKNOWN terminals. Connect the UNKNOWN terminal with the larger capacitance to ground to the LOW UNKNOWN terminal, because capacitance from the other UNKNOWN terminal to ground may cause an error if it is large enough. See Table 2-6 and paragraph 2.4.5.1.

Often the shield of an inductor is not connected to either terminal. When the inductance and frequency are so low that stray capacitance across the inductor causes negligible error, the shield should be connected to the LOW UNKNOWN terminal. 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 2.4.2.2). To avoid an inductance error, the shield may be tied to the panel of the bridge. The inductor terminal that has the large capacitance to the shield should be tied to the LOW UNKNOWN terminal. A Q error results from the capacitance from the other UNKNOWN terminal to the shield (C_b in Figure 2-3) but a better measurement of L_x is possible (this connection does not affect the winding capacitance itself).

3.3 REMOTE MEASUREMENTS.

Because of the small effect of capacitance to ground, particularly for capacitance measurements (refer to paragraph 2.4.5.1), the unknown may be placed some distance from the bridge. At least one of the connecting leads should be shielded to avoid the errors due to capacitance between the leads shunting the unknown. The shielded lead should be connected to the LOW UNKNOWN terminal and its shield tied to the bridge chassis. The other lead may also be shielded, but this will increase the capacitance to ground, causing an error (see Table 2-6 and paragraph 2.4.5.1). When low-impedance meas-

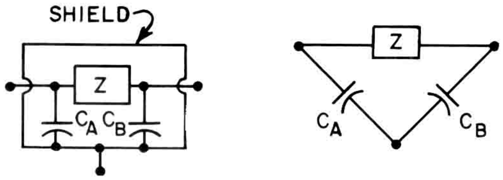


Figure 3-5. Shielded three-terminal impedance.

urements are made, the effects of lead resistance and inductance should be considered (see Table 2-5).

3.4 USE OF TYPE 1650-P1 TEST JIG.

3.4.1 GENERAL. The Type 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 1608 is set up for limit measurements (refer to paragraph 3.6), 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.

3.4.2 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 can be routed through cable clamps secured by the fluted panel screws so that the jig can be located directly in front of the bridge without interference from the leads.

3.4.3 RESIDUAL IMPEDANCES OF 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 approximately 0.2 pf. The shielded leads cause a capacitance to ground of about 100 pf each. Corrections may be necessary for the residual resistance and inductance when measurements are made on low impedances (see Table 2-5). The capacitances to ground cause an error of 0.07% for capacitance measurements, but can cause a D $(\frac{1}{Q})$ error up to about 0.004 for inductance measurements (see Table 2-6).

3.5 MEASUREMENTS ON GROUNDED COMPONENTS.

If the component to be measured is grounded, the cabinet of the Type 1608-A must be disconnected from ground. To do this, open the link between the rear terminal labeled 3RD WIRE GROUND and the adjacent terminal tied to the chassis. The 3RD WIRE GROUND should be grounded externally if an ungrounded, two-wire power cord is used (refer to paragraph 2.1.2).

If the LOW UNKNOWN terminal is grounded there is no error due to the capacitance of the bridge to ground, but there is a residual meter deflection due to internal hum pickup in the bridge as well as external hum pickup to the bridge chassis which can usually be removed by grounding of nearby equipment. This hum pickup can become very large when high-impedance components are measured.

There is less hum pickup in the measurement of high-impedance components if the other (unlabeled) UNKNOWN terminal is grounded. However, the internal capacitance of the bridge chassis to ground (approximately 300 pf), plus any external capacitance from the chassis to ground, will shunt one arm of the bridge, causing an error given in Table 2-6.

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

3.6 LIMIT TESTING.

The Type 1608-A can be set up to provide a go-no-go indication useful for component setting. The panel meter is used as the indicator. The procedure is as follows:

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

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

c. Adjust the DET SENS control for five-division meter deflection.

d. Set the CGRL 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 CGRL dial so that unknown components at both limits give the same deflection.

3.7 MEASURING RESONANT FREQUENCY AND RESONANT IMPEDANCE OF TUNED CIRCUITS.

The resonant frequency of a series or parallel tuned circuit can be found with the use of an external variable-frequency oscillator. Either the G_p or R_s bridge may be used (depending upon the desired quantity). Connect the external generator to the EXT GEN terminals and set the function switch to EXT AC. Set the Q balance adjustment to zero, and null the bridge using the concentric CGRL controls and the frequency adjustment on the oscillator.

At null the bridge reads the effective R_s or G_p of the tuned circuit at that frequency where the tuned circuit is resistive. The resonant frequency is indicated by the variable-frequency oscillator. The accuracy of the R_s or G_p reading depends on the test frequency (refer to paragraph 2.5.5) and the accuracy of the resonant frequency depends on the Q of the tuned circuit, and is limited to the frequency change that would give a measurable change in the bridge Q adjustment ($\pm 0.0005 \frac{f}{1\text{ kc}}$, above 1 kc).

3.8 MEASUREMENT OF R_p.

To measure the parallel resistance of capacitive resistors directly (rather than measuring G_p and inverting) place an external capacitor, C_n, across R_n of the R_s bridge (see Figure 1-2). Set the internal Q adjustment, C_t, for a zero reading and balance the bridge with R_n and the external capacitor. At balance, the main readout indicates R_p and the capacitance across the unknown is

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

To evaluate R_n multiply the indication of the main readout by 2/3 (neglect the decimal point).

SECTION 4

PRINCIPLES OF OPERATION

4.1 BRIDGE CIRCUITS.

Figure 1-2 shows the six bridge circuits used in the Type 1608-A Impedance Bridge as well as the balance equations. These six bridges completely cover the passive half of the complex impedance plane as shown in Figure 4-1. There is considerable overlap between the D and Q ranges of the various bridges, allowing the measurement of series or parallel C or L over a wide range. L_s and C_p can each be measured over a full 90 degrees. The D coverage extends down to 0.02 (Q to 50), and at D's below 0.02 $L_p = L_s$ and $C_s = C_p$ to 0.04%, and at high D's or low Q's, the unknown can be measured as a resistance or conductance and L_s and C_p can be calculated from R or G and Q. Both ac and dc measurements can be made on the R and G bridges.

The coaxial CGRL balancing controls consist of a 114-position detented switch and a continuously adjustable vernier, wire-wound rheostat. The switch introduces in the variable bridge arm fixed steps of resistance proportional to the first three digits of the indicating counter that it drives. This adjustment is called a "centade," because it is similar to a decade-resistance unit but with approximately 100 positions. It uses precision wire-wound resistors (details of its operation are discussed in paragraph 4.4). The vernier sets the last two digits of the counter and adds resistance proportional to this reading in series with the resistance of the centade.

The ratio-arm resistors, which range from 1 ohm to 1 megohm, are all General Radio precision wire-wound resistors. The two ganged DQ adjustments are wire-wound rheostats with a 40-db logarithmic range.

The standard capacitor is specially constructed for low temperature coefficient. Most of its capacitance is that of a General Radio silvered-mica unit, which has

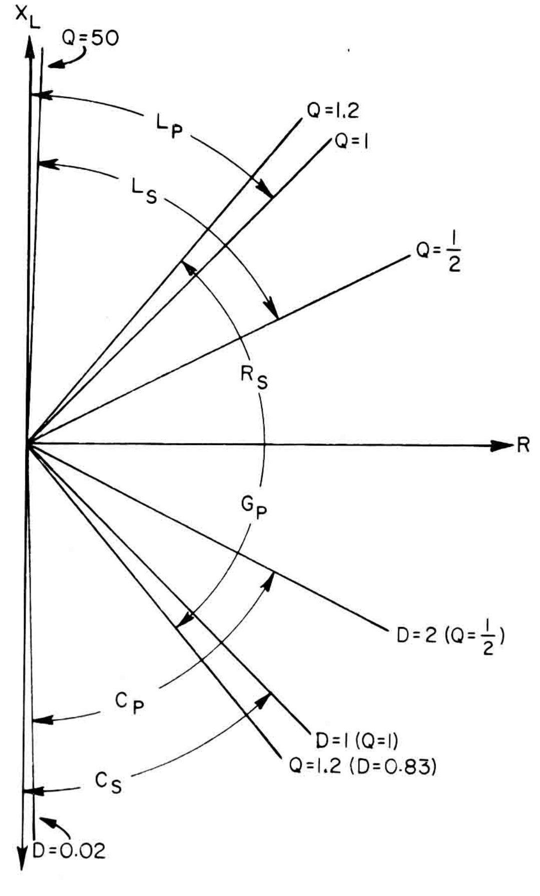


Figure 4-1. DQ coverage chart.

a positive temperature coefficient of approximately 35 ppm. A small, stabilized, polystyrene capacitor is in parallel with the mica unit to reduce the over-all temperature coefficient.

4.2 BRIDGE SOURCES AND DETECTORS.

There are three dc sources of approximately 3.5, 35 and 350 volts open-circuit that are connected to the bridge for dc resistance and conductance measurements according to the schedule of Table 2-1. Resistors in series with these sources limit the power supplied to the bridge to less than 1/2 watt to avoid damaging the internal bridge resistors or the unknown.

The dc detector is a panel meter, with a sensitivity of 1 μa/mm near zero and a shaped characteristic to facilitate balancing. Its resistance is approximately 500 ohms. A more sensitive null indicator can be connected if desired, through connectors on the rear panel (refer to paragraph 2.3.4).

The ac generator is a 1-kc, two-stage, transistor RC oscillator. This drives a 3-to-1-stepdown shielded bridge transformer, with a maximum output of approximately 1 volt behind 50 ohms. The GEN LEV control adjusts the voltage to the primary of the transformer.

The ac detector is a high-gain transistor amplifier with a twin-T in a feedback loop for selectivity at 1 kc. The DET SENS control on the input adjusts the gain. The range switch causes the gain to be increased on the two extreme bridge ranges, and a compression circuit is used to reduce the necessity for constant readjustment of the DET SENS control during balance. This amplifier drives the panel meter and has an auxiliary DET OUT connection.

In the EXT DC position of the function switch, the EXT GEN terminals are connected across the vertical diagonal of the bridge (see Figure 1-3) (with no series resistor), and the internal dc detector is in place. When EXT AC is used, the EXT GEN terminals are connected directly to the bridge transformer (see Figure 1-3) and the twin-T is removed from the detector to give it a flat frequency characteristic.

When other plug-in frequency modules replace the 1-kc module supplied, the selective circuits for the oscillator and detector are changed to produce the desired signal frequency and to provide selective amplification at that frequency (refer to paragraph 2.4.4).

4.3 BRIDGE SWITCHING.

The FULL-SCALE RANGE switch (S1) changes the ratio-arm resistor of the bridge. Two separate rotors are used so that a clockwise rotation will increase the size of the unit for all six bridges. Both ends of the resistors are switched out, and the unused resistors are grounded to reduce stray capacitance. The range switch also positions the decimal point on the main readout, determines which dc supply will be used for dc G or R measurements and where the supply and meter will be connected to the bridge, and increases the ac gain on the extreme bridge ranges.

The BRIDGE SELECTOR switch (S2) switches the internal bridge components to form the six bridges of Figure 1-2. It also connects the appropriate set of rotors for the range switch, determines which type of unit is illuminated above the main readout, indicates the correct D or Q scale or type of resistance Q, and permits dc to be applied to the bridge only when it is in the G or R positions.

The function switch (S3) connects the appropriate generator and detector for internal and external ac and dc measurements. In the EXT DC position the EXT GEN terminals are connected directly to the bridge, and in the EXT AC position they are connected directly to the primary of the bridge transformer.

All switches used in the bridge have solid silver contacts, and double contacts are used on the range switch for low contact resistance.

4.4 CENTADE OPERATION.

The adjustment for the first three digits of the counter used as the CGRL readout places in the bridge circuit 114 precise steps of resistance. These steps increase or decrease continuously with no discontinuity in the switching, other than the increase or decrease from one fixed value to the other, in order to avoid sudden bridge unbalances that would momentarily deflect the panel meter. A binary scheme, using only seven resistors, could be switched to give 128 fixed values, but there would be many places over the range where two switching operations would have to occur at exactly the same moment to avoid a large transient. Or, 114 precision wire-wound resistors could be connected in series on a simple selector switch with a shorting rotor (as in a decade box) to give the desired operation, but would be quite expensive. To effect a 114-position decade-type switch (which we call a "centade") using fewer resistors, a scheme using three rotor contacts is used.

The operation of the centade is best explained by an examination of Figure 4-2. Briefly, fixed values in between the values of the series-resistor chain are obtained first by the shunting of one series resistor with two resistors that will reduce it to 1/3 of its value. In the next step, one shunting resistor is removed, increasing the resistance to 2/3. In the third step, the series resistor is unshunted giving its full value, and the shunting resistors are moved into position to shunt the next series resistor on subsequent steps.

With this scheme, the number of series resistors is reduced to one third of 114 and two resistors are added to the rotor. This idea could be extended to reduce the number of resistors even further, but the number of resistors saved for each additional rotor contact becomes smaller, and the mechanical design becomes more complex.

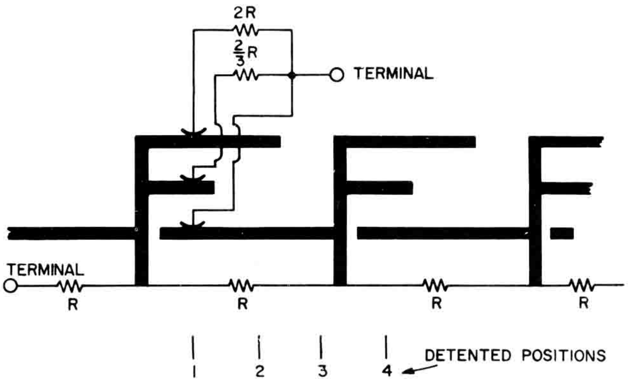


Figure 4-2. Diagram showing centade operation.

4.5 PHASE-COMPENSATION TECHNIQUES.

Several phase-compensating schemes are used to achieve the required D and Q accuracy over such wide ranges. The components used for this purpose are listed below with a brief description of their function.

C13, C14--These capacitors compensate for the inductance of the 1- and 10-ohm ratio-arm resistors.

C3, C3A, and L1--These components are used to make the standard resistor arm (R_3) have a low phase angle and a constant value over the frequency range in spite of the rather large stray capacitance placed across this arm by the bridge transformer and wiring.

C14, C15, and C16--These capacitors are used to compensate for inductance in the winding of the lower-valued DQ rheostat (R_4).

LA, LB, LC, etc, RA, RB, RC, etc on R1--The inductors are used to compensate for the capacitance placed across the whole variable arm by the wiring and switches. The inductors have enough resistance to require resistors in parallel to restore the correct over-all value. See Figure 4-3.

Capacitors are used to compensate for the inductance of the vernier potentiometer R2, and the resistors are used to adjust its value to better than ±1/4% of full scale.

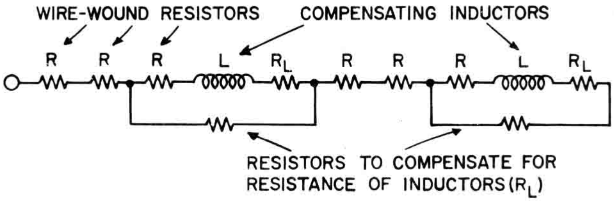


Figure 4-3. Phase compensation of centades.

SECTION **5**

SERVICE AND MAINTENANCE

5.1 FIELD SERVICE AND INSTRUMENT RETURN.

Our two-year warranty attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone our Service Department (see last page), 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, requesting a "Returned Material Tag." Use of this tag will ensure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid necessary delay.

5.2 CALIBRATION CHECKS.

5.2.1 FIXED BRIDGE COMPONENTS.

A calibration check of the fixed-bridge components in the Type 1608-A Impedance Bridge can be made by the series of measurements listed below.

The accuracy of this calibration check depends on the accuracy of the internal standards used. A General Radio Type 1409-T Standard Capacitor is recommended as a capacitance standard. This capacitor is calibrated to ±0.03%. GR Type 1440 Resistors, or equivalent, are recommended as the resistance standards. Their accuracy is 0.01% (except for the 1-ohm unit, whose accuracy is 0.02%).

a. Check of R_t (Standard Resistor). Measure a 1. 10-kΩ resistor on both the R_s bridge (11-kΩ range and 2. the G_p bridge (110-μ℧ range). The average of these two readings, neglecting decimal points, should be 10000, and the difference from this value indicates the error in R_t. (Actually, it is the difference between the

TABLE 5-1

RATIO ARM CHECKING PROCEDURE

(Refer to paragraph 5.2.1.)

Type 1440 GR.
STD. RES.

	EXT STD	BRIDGE	RANGE	R_a RESISTOR	+ERROR MEANS R_a
4	1 Ω	R_s	1100 MΩ mΩ	R7	too small
5	10 Ω	R_s	11 Ω	R8*	too small
6	100 Ω	R_s	110 Ω	R9*	too small
7	1 k	R_s	1100 Ω	R10*	too small
8	1 k	G_p	1100 μ℧	R14	too large
9	10 k	G_p	110 μ℧	R15	too large
10	100 k	G_p	11 μ℧	R11	too large
11	1 MΩ	G_p	1100 n℧	R13	too large

* Actually, the ratio arms for these ranges are the sum of several resistors, but if the previous measurement is correct, the indicated resistor is the component in error.

3. centade, R_n, and R_t.) If this error is greater than 0.05% (that is, if the average of the two readings is less than 9995 or more than 10005), adjust R_t with the potentiometer, R16 (see Figure 5-4).

4-11 b. Ratio Arms (R_a). If R_t is of the correct value, the ratio-arm resistors can be checked by the series of measurements given in Table 5-1. Note that the same set of ratio arms is used on all bridges except that there are two 1-k resistors (see Table 2-7). The C and G bridges use R14 as a 1-k ratio arm and the L and R bridges use the series sum of R7 + R8 + R9 + R10. The ratio arms may be double-checked by measurement of each external standard (when possible) on both the R_s and G_p bridges.

12 c. Check of C_t (Standard Capacitor). To check the standard capacitor, C_t, measure any capacitor of known value. For best resolution, choose the value of the capacitor and range of the bridge for a full-scale indication (A GR Type 1409 .01-μF Standard Capacitor is recommended). Before measuring the capacitor, check the ratio-arm resistor for the range used (refer to Table 2-7 for ratio-arm values). If the bridge indication is in error by more than 0.05%, adjust C_t with the variable capacitor, C17 (see Figure 5-4), or, if necessary, change the values of the padding capacitors.

Note that if a General Radio Type 1401 Air Capacitor is used for accuracy checks on the lowest capacitance range, the bridge indication will be about 0.3 pf high, even after the residual zero capacitance is subtracted from the measured value. This discrepancy occurs because the Type 1401 is calibrated with a grounded measurement, whereas the Type 1608 Bridge measures the capacitor with neither terminal grounded.

5.2.2 CHECK OF CENTADE ACCURACY.

It is not necessary to check the total value of the centade, since if it is slightly in error, a correction of R_t and C_t will give the correct bridge readings (see above). However, the centade must have good linearity. It can be checked over its range by measurement of a decade resistor on the bridge as it is adjusted over the range. A General Radio Type 1433-K is recommended, and this should be adjusted in 10-ohm steps to check each step of the centade. Actually, it is necessary to check only those centade positions that are divisible by three once the first two steps have been checked (refer to paragraph 4.4).

5.2.3 CHECK OF CGRL VERNIER ADJUSTMENT (R2).

The vernier rheostat adjustment can be checked by measurement of a 1-k decade resistor (Type 1433-K) on the 110-kΩ R_s bridge range. The shaft position of this potentiometer should be set to give a correct reading at 1 (10 ohms on the Type 1433-K), and the padding resistors should be adjusted for best accuracy over the rest of the range.

5.2.4 DQ CHECKS.

D and Q scale checks can be made by calculation of D and Q of series or parallel RC combinations of precision components. Checking the two capacitance bridges is much easier than checking the inductance bridges, and checks on both are not necessary since the DQ scales depend upon the same components for both bridges (see Figure 1-2). Likewise, it is easier to check the G_p bridge than the R_s bridge.

The fixed phase-shift error (±0.0005) can be checked on the C bridge by measurement of capacitors with low, known D values. The D error on the lowest C range depends somewhat on the position of the 1-M ratio arm (R13). The fixed Q error on the R_s and G_p bridges can be set by adjustment of C3 (just below the standard capacitor) to give a zero Q reading when a 1-k composition or film resistor is measured.

5.3 ADJUSTMENTS.

5.3.1 OSCILLATOR OUTPUT CONTROL (R529).

This control, on the rear of the printed wiring board at the top of the instrument, controls the maximum output level of the internal RC oscillator. It should be set to give an unclipped output at anchor terminals 32 and 31 when the GEN LEV control is fully off (counterclockwise).

5.3.2 CENTADE ADJUSTMENTS.

The mechanical adjustments of the centade should not be necessary unless the centade assembly has been taken apart. If adjustment is necessary, it should be done carefully and in the correct sequence.

First, adjust the position of the detent block so that the digits of the counter readout are centered in the window. To do this, slightly loosen the hex-head nuts on the rear of the subpanel and rotate the detent block.

Next, connect a component of known value to the bridge and set the FULL SCALE RANGE switch and CGRL control to the correct value. Then balance the bridge by positioning the rotor of the centade. This setting should be accurately made since the centade should change value halfway between the detented steps. Tighten the rotor set screws. It is best to check the centade adjustments at several points of its range.

Finally, loosen the centade knob (the larger knob) and set it so that a zero reading appears when the knob hits the stop, which is on the dress panel under the knob.

The pressure for the centade detent is adjusted by the screw on the detent block directly behind the front panel. The setting of this pressure is a matter of personal preference. Too tight an adjustment will make the control difficult to rotate, and too loose an adjustment will not give the necessary detent action to ensure that the centade rests on a detented position.

5.3.3 ADJUSTMENT OF CGRL VERNIER CONTROL.

The procedure for setting the vernier CGRL control with respect to the counter reading is given in paragraph 5.2.3 above. The stop for this control, mounted on the front of the plate holding the vernier rheostat (see Figure 5), should be set to give a zero reading when the potentiometer is fully counterclockwise. To do this, slightly loosen the hex-head screws and push the detent block in or out as necessary.

5.3.4 DQ RHEOSTAT ADJUSTMENT.

The ganged DQ rheostats (R4 and R5) should be set to give the best over-all tracking with the DQ dial, as determined by measurement of RC networks with known D values (see paragraph 5.2.4). The dial should be positioned to give the best tracking with the inner rheostat (R4, LOW D). Then the rotor of the rear rheostat (R5, HIGH D) should be set on the shaft to give the best tracking with the dial.

5.4 REPLACING INDICATOR LAMPS.

The indicator lamps are operated well below their rated voltage and should last for many years. If they do require replacement, the pilot light and the two lamps labeled INDUCTIVE and CAPACITIVE can easily be replaced after their lenses are unscrewed. To replace the other lamps, it is necessary to remove the dress panel. To do this, remove the eight panel screws at the edges, the two screws directly below the meter, and all knobs except the DQ knob.

In order to replace the lamps under the DQ dial, the dial must be removed. Before removing the dial, make a note of its setting so that it can be replaced accurately. The unit dial must be removed to replace the unit indicating lamps and should be replaced in the same position. To replace the lamps held in place by insulating washers, it is easier to unsolder the connection on the pin coming through the washer. Be careful not to let solder or rosin run down this pin and prevent its free movement in the washer.

All lamps are GE Type 327 miniature lamps and are available in most hardware or hobby stores. If unavailable locally, they are available from General Radio Company.

A schematic diagram of the lamp circuits is shown in Figure 5-12.

5.5 TROUBLE-SHOOTING SUGGESTIONS.

5.5.1 BRIDGE PROPER.

a. Bridge Error. Refer to paragraph 5.2 for a calibration procedure that will locate any bridge component that is in error.

TABLE 5-2

DC VOLTAGES ON OSCILLATOR-DETECTOR-AMPLIFIER CIRCUIT BOARD

CONTROL SETTINGS:
DET SENS: fully clockwise
GEN LEVEL: fully clockwise
Power: AC INT
BRIDGE SELECTOR: R_s
RANGE: 1100 mΩ
CGRL: maximum
UNKNOWN terminals open

TRANSISTOR (TYPE)	PIN	DC VOLTS
Q525 (2N520A)	E	11.4
	B	11.2
	C	6.4
Q526 (2N1415)	E	10.6
	B	11.0
	C	4.7
Q550 (TR1)	E	0.57
	B	0.61
	C	1.62
Q551 (2N445A)	E	1.95
	B	1.62
	C	3.77
Q552 (2N445A)	E	1.82
	B	1.67
	C	4.95
Q553 (2N520A)	E	2.88
	B	3.77
	C	1.68
Q554 (2N445A)	E	7.0
	B	6.3
	C	7.9
Q555 (2N520)	E	8.1
	B	7.9
	C	6.6
OSC OUTPUT	32	2.5 vac
DC INPUT	42	14.0 vdc

b. Noisy or Erratic Balance. If the instrument is idle for an extended period, surface contamination of the wire-wound DQ or CGRL vernier adjustments may cause an erratic behavior of the null indicator. To remedy this situation, rotate these controls back and forth several times to clean the brush track.

Misalignment of the centade (CGRL adjustment) may cause a change in its value as it is rocked in a detented position. The rotor of this adjustment should be set so that the centade changes value halfway between the detented steps (see paragraph 5.3.2).

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 defective.

(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.) Try another unknown.

(3) Are all the panel switches set properly?

(4) Are the jumpers between the BIAS terminals and between the EXT DQ terminals in place?

(5) Is the correct bridge being used? (Low Q inductors and high D capacitors should be measured on the R_s and G_p bridges, respectively (refer to paragraphs 2.4.1.1 and 2.4.2.1).

d. Low or No Meter Deflection when Bridge Unbalanced.

(1) Is the GEN LEVEL control on (clockwise)?

(2) Is the DET SENS control on (clockwise)?

(3) Is the function switch set properly (and in a detented position)?

(4) Check the oscillator and detector (see below).

5.5.2 OSCILLATOR AND DETECTOR CHECKS.

The oscillator output can be measured from either BIAS terminal to either EXT DQ terminal when the bridge is set to R_s, L_s, or L_p. If there is no output when the function switch is in the INT AC position and the GEN LEV control is on (clockwise), the oscillator is not operating properly. (Note: the output will be very low with a low-impedance unknown.) The test point voltages given in Table 5-2 and the diagram (Figure 5-16) should enable anyone skilled in the art to locate the difficulty. One of the first things is to try to remove the plug-in frequency board and bend up (slightly) all the terminals to ensure contact.

To check the detector, insert a signal between the LOW UNKNOWN terminal and ground. Be sure the function switch is set properly and the DET SENS control is clockwise.

TABLE 5-3
DC VOLTAGES ON UNKNOWN, R AND G BRIDGES

Centade at maximum
GEN LEVEL fully clockwise
For location of S3, 401FR, see Figure 5-1.

RANGE	MEASURE		VOLTS DC
	FROM	TO	
1100 mΩ	S3,401FR	J2	3.5
11 Ω	S3,401FR	J2	3.5
110 Ω	S3,401FR	J2	3.5
1100 Ω	J1	Chassis	30
11 kΩ	J1	Chassis	35
110 kΩ	J1	Chassis	180
1100 kΩ	J1	Chassis	340
1100 n℧	J1	Chassis	340
11 µ℧	J1	Chassis	180
110 µ℧	J1	Chassis	40
1100 µ℧	S3,401FR	J2	35
11 m℧	S3,401FR	J2	30
110 m℧	S3,401FR	J2	3.5
1100 m℧	S3,401FR	J2	3.5

5.6 TABLES OF TEST VOLTAGES.

The following tables give voltages as an aid in trouble-shooting. Table 5-2 lists dc voltages at transistor terminals on the oscillator-detector-amplifier etched board. Table 5-3 gives voltages from the UNKNOWN terminals to chassis for the R and G bridges. J1 in this table is the left-hand binding post, J2 the right.

All voltages are as measured with a vacuum-tube voltmeter, and are dc voltages from the terminal designated to chassis, except as otherwise indicated. Line voltage for measurements should be 115 volts.

5.7 REMOVAL - REPLACEMENT PROCEDURES.

5.7.1 FRONT - PANEL REMOVAL.

The front panel can be removed for access to controls behind the panel. Perform the following steps:

a. Remove all the knobs except the DQ control knob. Refer to paragraph 5.7.2 for instructions.

b. Remove the bushings from the BRIDGE SELECTOR, FULL SCALE RANGE and CGRL control shafts according to the procedure in paragraph 5.7.2.

c. Remove the screws above the BRIDGE SELECTOR and FULL SCALE RANGE legends on the front panel and the two screws below the NULL meter on the front panel.

d. Lift the dress panel off; the DQ knob should remove with the dress panel. Replace the panel by reversing the removal procedure.

5.7.2 CONTROL REMOVAL-REPLACEMENT.

5.7.2.1 Removal. Perform the following steps to remove the front-panel knobs:

a. Set the control(s) full ccw.

b. Pull the control knob straight off with the fingers.

CAUTION

Do not lose the retention spring in the knob when the knob is removed.

NOTE

If the knob and bushing are combined when the knob is removed, turn a machine tap a turn or two into the bushing on the knob for sufficient grip for easy separation.

c. If for any reason the bushing must be removed (this is necessary if the large CGRL knob is to be removed), remove the setscrew from the bushing; use a hex-socket key wrench. Remove the bushing.

d. If the large CGRL knob is to be removed, pull the knob off with the fingers and remove (if desired) the exposed bushing according to step c.

5.7.2.2 Replacement. To replace a knob control:

a. Make sure the control shaft is turned full ccw.

b. Install the bushing on the shaft and tighten the setscrew on the bushing.

NOTE

Make sure that the end of the shaft does not protrude through the bushing, or the knob won't set properly.

c. Install the knob on the bushing, ***making sure the retention spring is opposite the setscrew*** and that the marking on the knob points to the correct position (if applicable).

NOTE

If the retention spring in the knob comes loose, reinstall it in the interior notch with the thin flange set into the small slit in the wall of the knob.

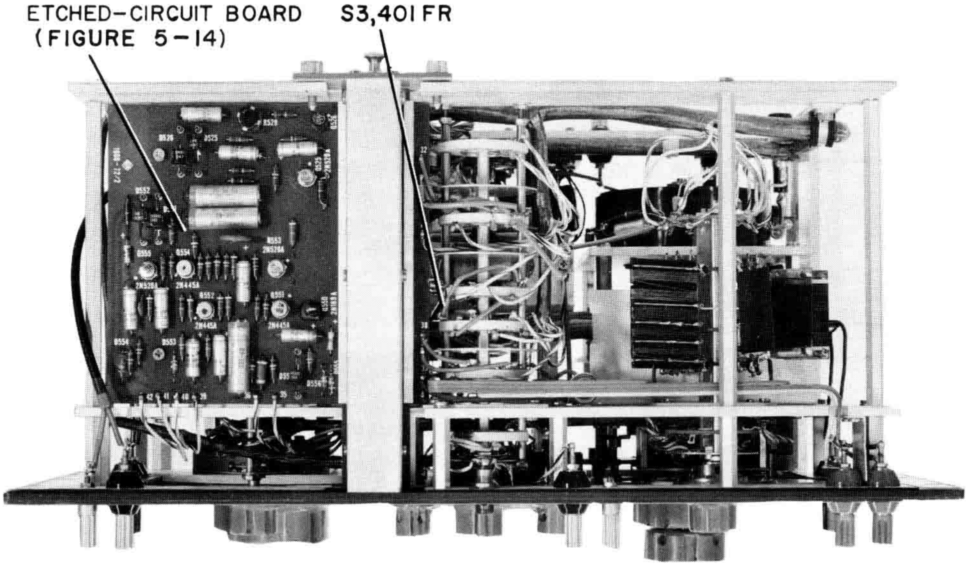


Figure 5-1. Top interior view.

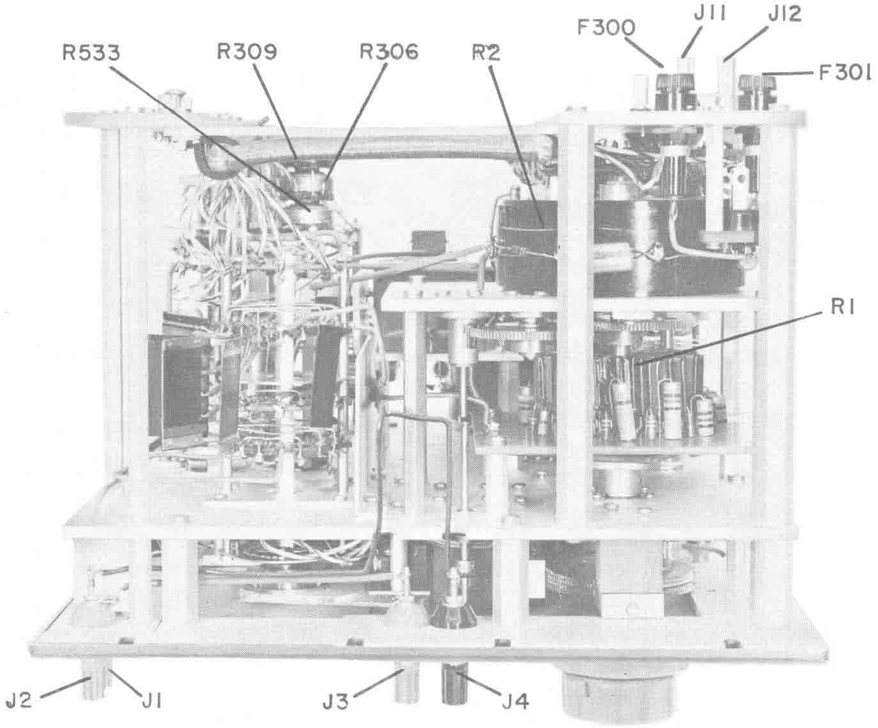


Figure 5-2. Right side interior view.

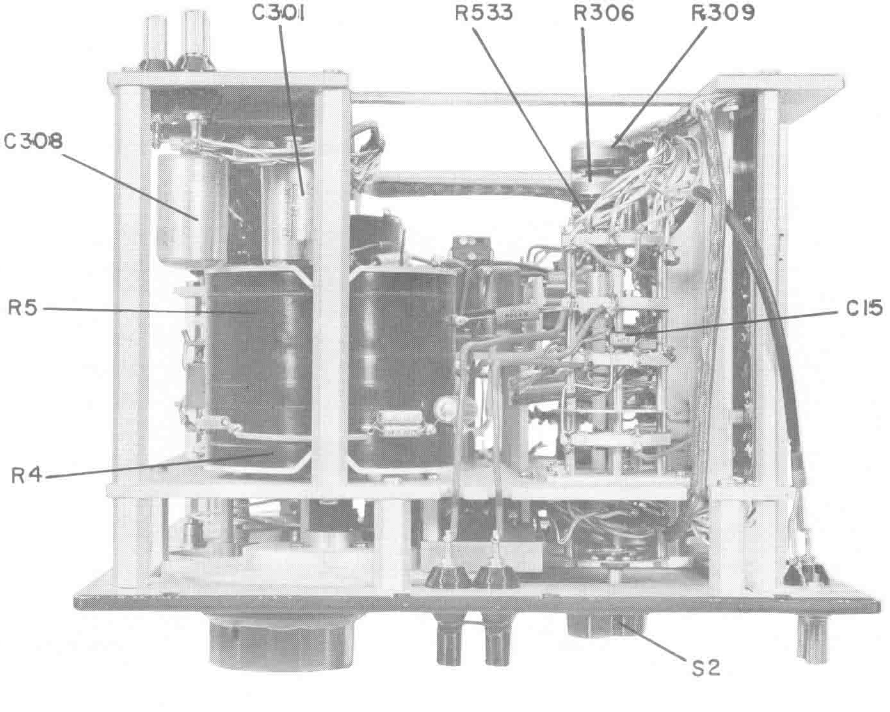


Figure 5-3. Left side interior view.

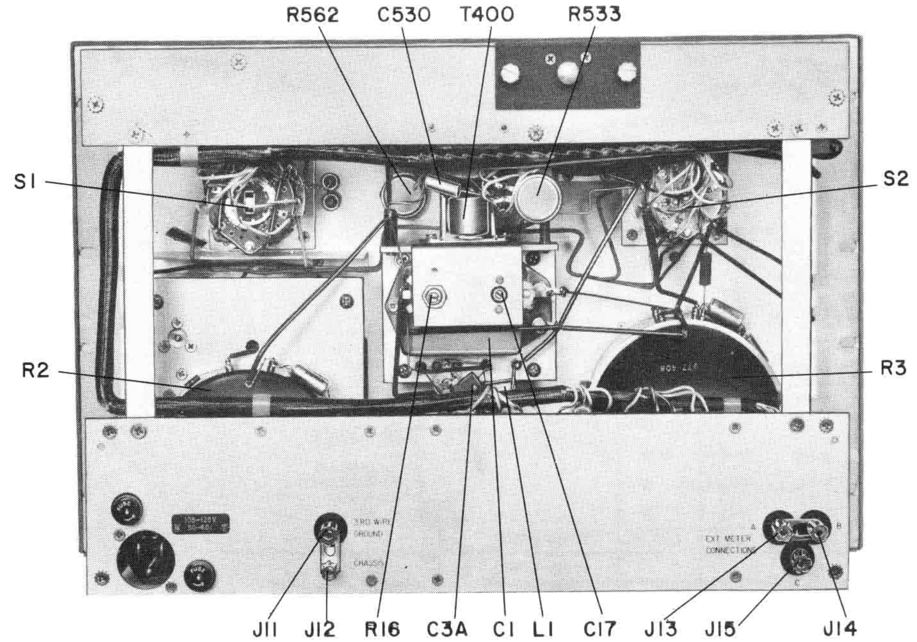
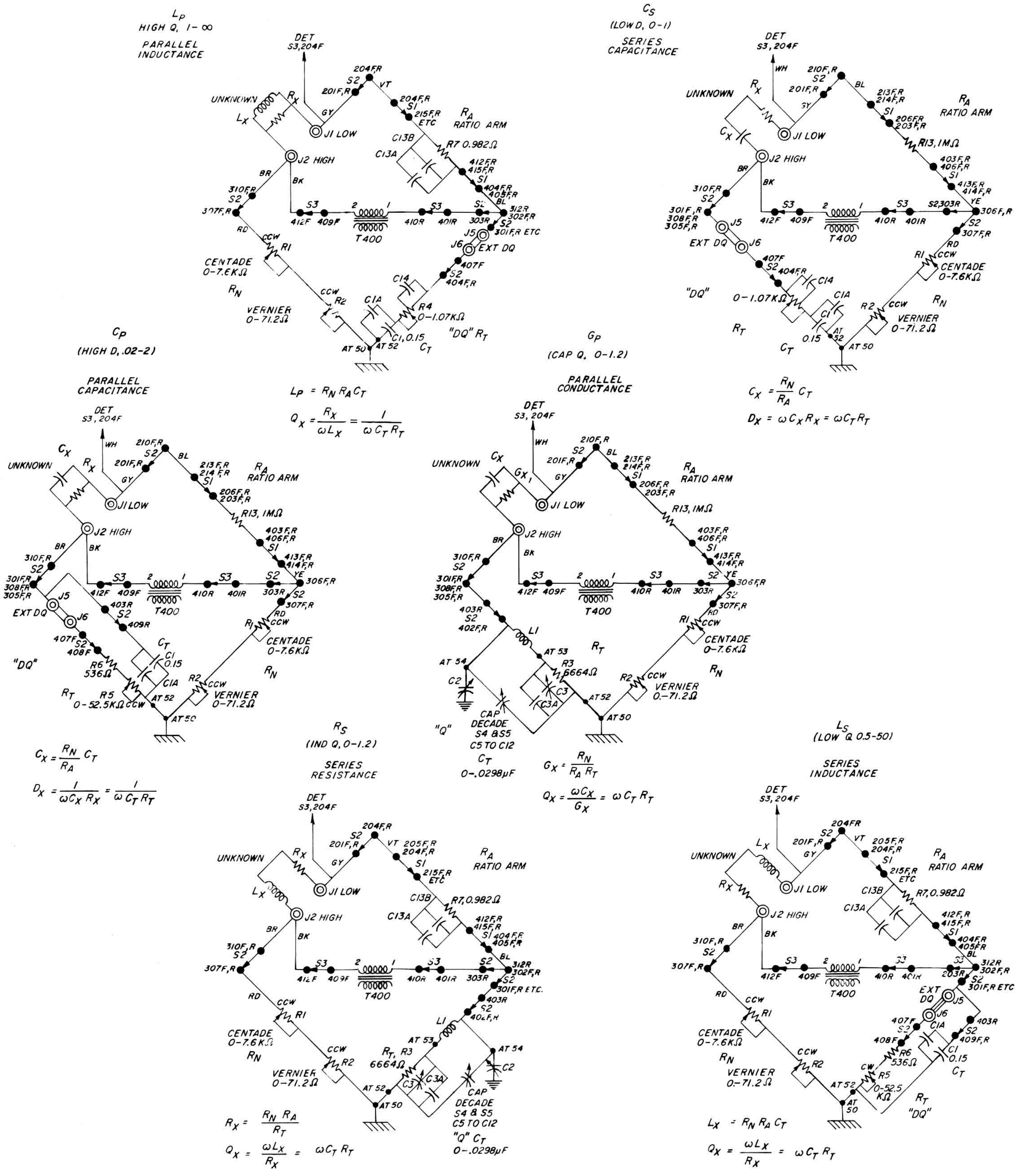


Figure 5-4. Rear interior view.

MECHANICAL REPLACEABLE PARTS

Fig. 1-1 Ref. No.	*Name*	*Description*	*GR Part No.*	*Fed. Mfg. Code*	*Mfg. Part No.*	*Fed. Stock No.*
1	Knob Asm.	Knob, OFF/AC/DC, incl. retainer 4143-3123	5500-5321	24655	5500-5321	
2	Knob Asm.	Knob, BRIDGE SELECTOR, incl. retainer 4143-3161	5500-5421	24655	5500-5421	
3	Knob Asm.	Knob, FULL SCALE RANGE, incl. retainer 4143-3161	5500-5421	24655	5500-5421	
4	Knob Asm.	Knob, CGRL Fine (small knob), incl. retainer 4143-3161	5520-5420	24655	5520-5420	
4	Knob Asm.	Knob, CGRL Coarse (large knob), incl. retainer 4143-5161	5520-5531	24655	5520-5531	
5	Knob Asm.	Knob, DQ, incl. retainer 5220-5401	5520-5520	24655	5520-5520	
6	Knob Asm.	Knob, Q, tenths, incl. retainer 4143-3161	5500-5220	24655	5500-5220	
7	Knob Asm.	Knob, Q, Hundredths, incl. retainer 4143-3123	5500-5220	24655	5500-5220	
8	Knob Asm.	Knob, Q, Variable, incl. retainer 4143-3123	5520-5220	24655	5520-5220	
9	Knob Asm.	Knob, GEN LEVEL, incl. retainer 4143-3123	5520-5321	24655	5520-5321	
10	Knob Asm.	Knob, DET SENS, incl. retainer 4143-3123	5520-5321	24655	5520-5321	
-	Window Asm.	DQ Window	1608-7140	24655	1608-7140	
-	Window Asm.	CGRL Window	1608-7142	24655	1608-7142	
-	Fuseholder	Fuse Mounting	5650-0100	71400	HKP-H	5920-284-7144
-	Foot (Cabinet)	Black Neoprene	5260-0710	24655	5260-0710	



= BRIDGE GROUND

= CHASSIS GROUND

S1, FULL SCALE RANGE SWITCH = COUNTERCLOCKWISE (LOWEST RANGE)
S3, GENERATOR SELECTOR SWITCH = COUNTERCLOCKWISE (AC INTERNAL)

Figure 5-5. Simplified schematic of the bridge circuits.

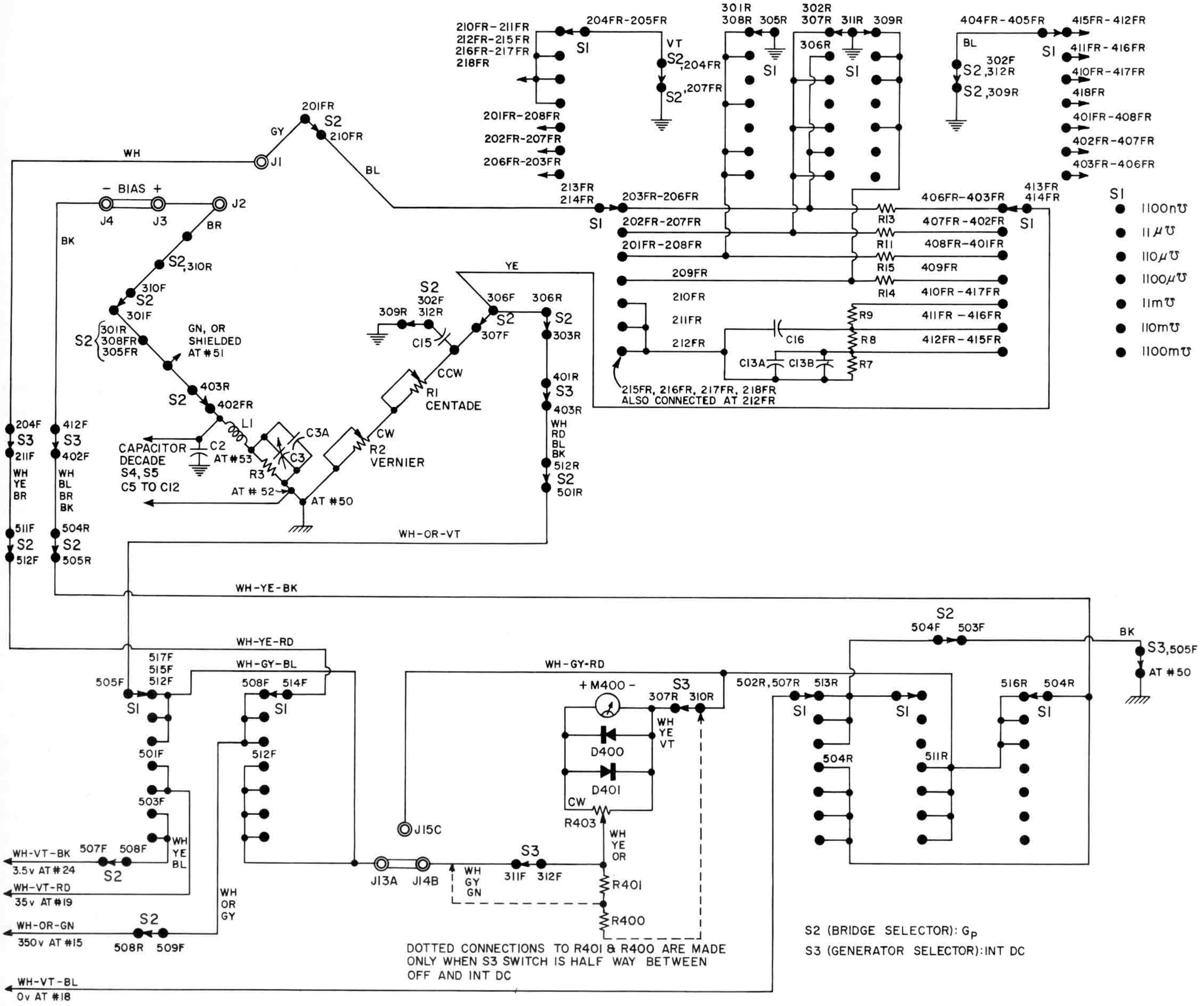


Figure 5-6. Simplified schematic showing the bridge in relation to various positions of the FULL SCALE RANGE switch (Gp bridge).

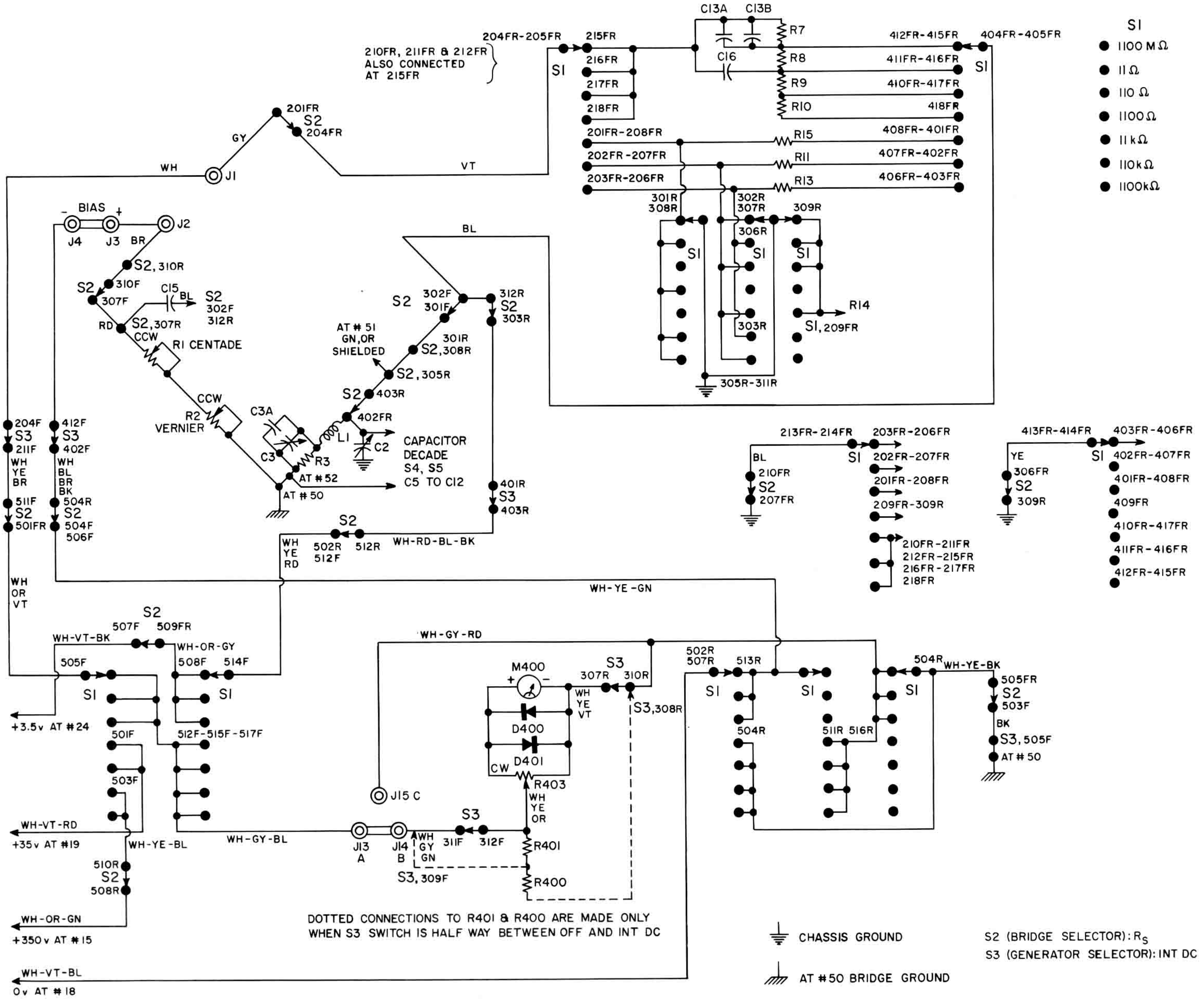
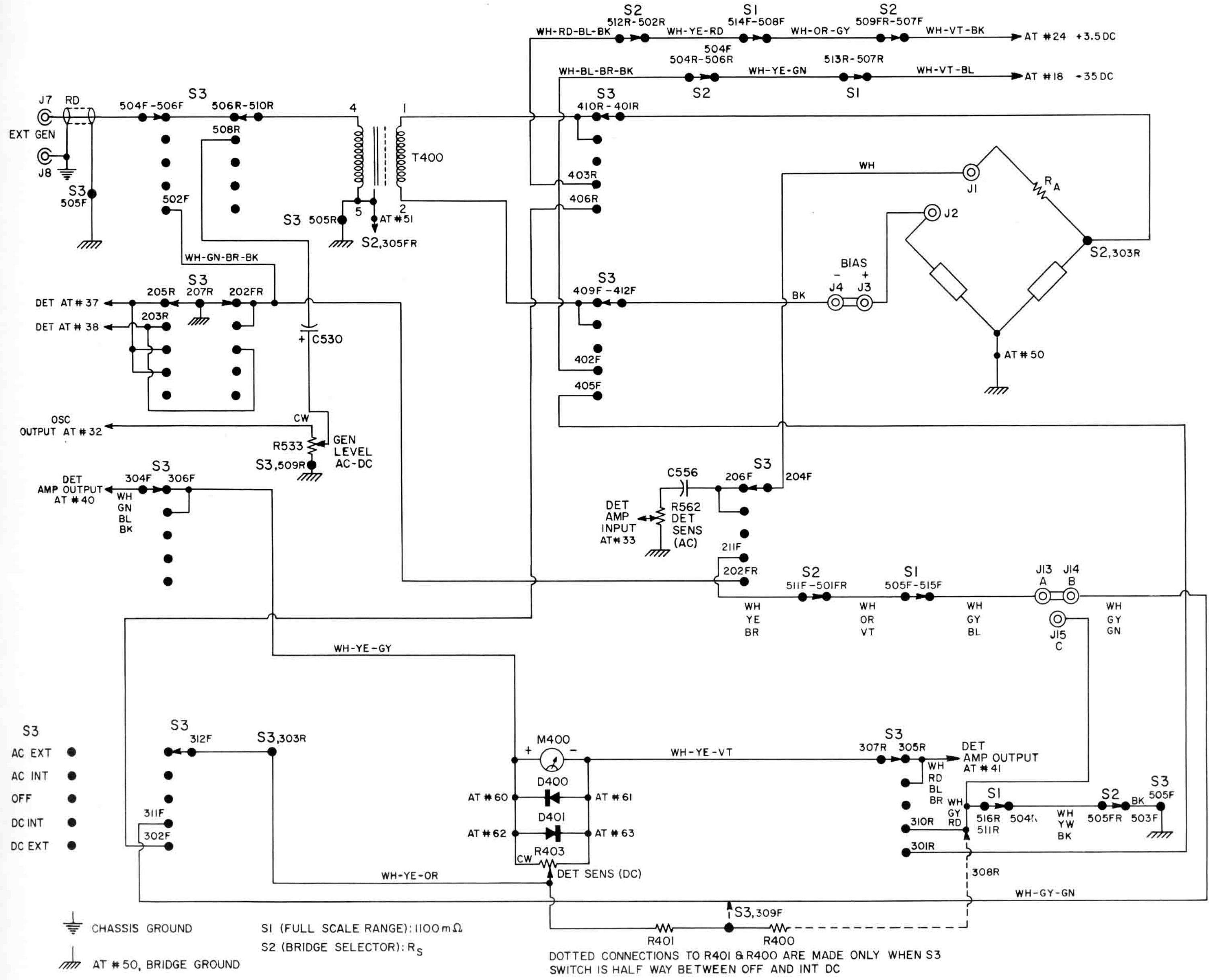


Figure 5-7. Simplified schematic showing the bridge in relation to various positions of FULL SCALE RANGE switch (Rs bridge).



CHASSIS GROUND

AT #50, BRIDGE GROUND

S1 (FULL SCALE RANGE): 1100 mΩ

S2 (BRIDGE SELECTOR): R_S

DOTTED CONNECTIONS TO R401 & R400 ARE MADE ONLY WHEN S3 SWITCH IS HALF WAY BETWEEN OFF AND INT DC

Figure 5-8. Simplified schematic showing the bridge in relation to various positions of S3 (function switch).

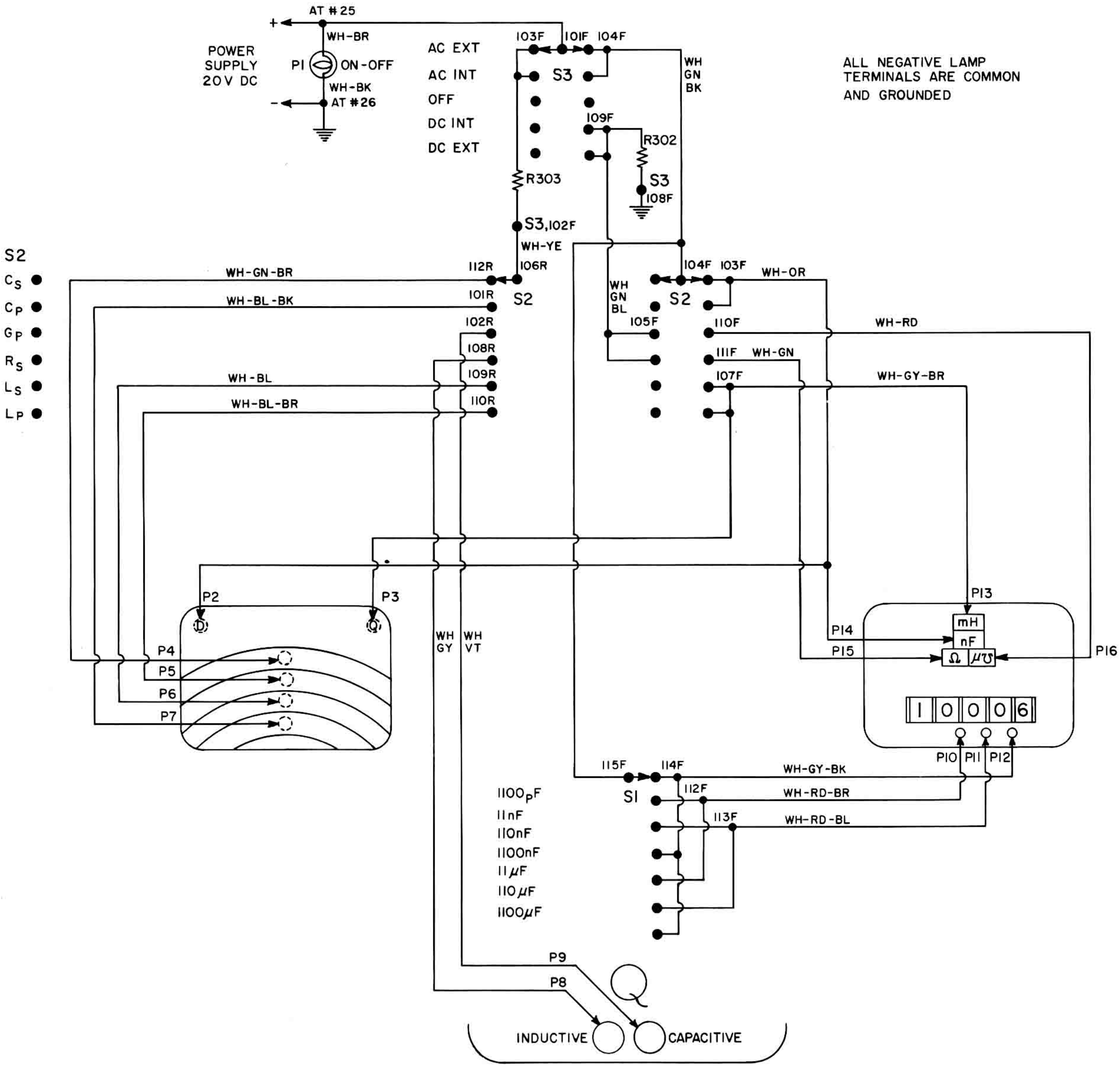
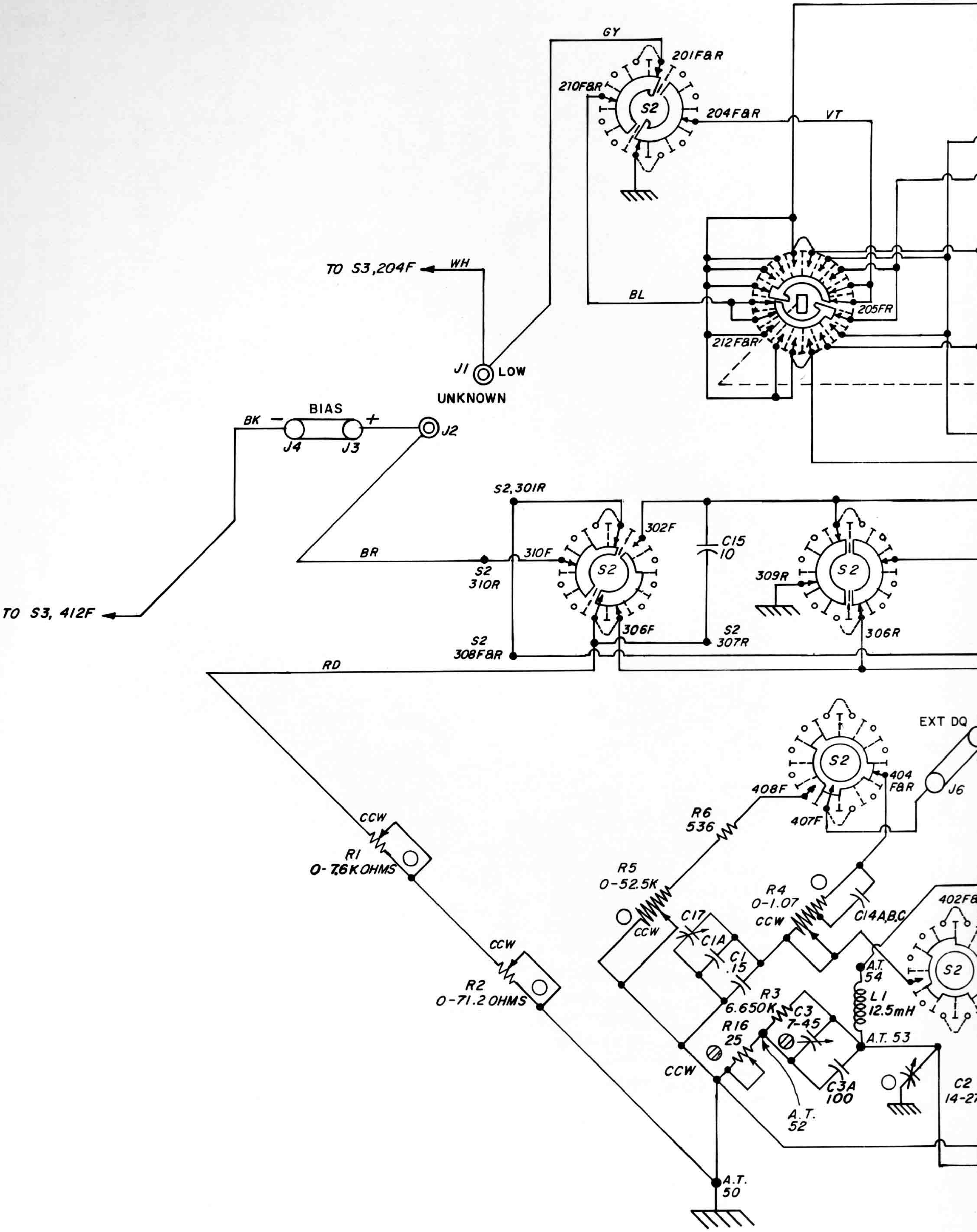


Figure 5-9. Simplified schematic showing light circuits.

BRIDGE CIRCUITS ELECTRICAL REPLACEABLE PARTS

Ref. Desig.	*Description*	*GR Part No.*	*Fed. Mfg. Code*	*Mfg. Part No.*	*Fed. Stock No.*
CAPACITORS					
C1	Mica, 0.1488 - 0-1497 µF	0505-4022	24655	0505-4022	
C1A	Mica, value determined by laboratory				
C2	Air, 14 - 270 pF	4380-5000	73035	20101-21	
C3	Air, 7 - 45 pF	4910-0100	72982	TS2AN300, 7-45 pF	5910-799-9275
C3A	Mica, 100 pF ±5%	4680-1500	81349	CM20D, 100 pF ±5%	
C5	Mica, 0.00240 µF ±1/2% 300 V	4600-1247	72136	DM20 (4CR), 0.00240 µF ±.5%	
C6	Mica, 0.00481 µF ±1/2% 100 V	4600-1411	72136	DM20-4CR, 0.00481 µF ±.5%	
C7	Mica, 0.00965 µF ±1/2% 500 V	4560-0197	72136	DM30-4CR, 0.00965 µF ±.5%	
C8	Mica, 0.00965 µF ±1/2% 500 V	4560-0197	72136	DM30-4CR, 0.00965 µF ±.5%	
C9	Mica, 240 pF ±1/2% 500 V	4710-0423	72136	DM-15 (4CR), 240 pF ±.5%	
C10	Mica, 481 pF ±1/2% 300 V	4710-0553	14655	22A, 481 pF ±.5%	
C11	Mica, 965 pF ±1/2% 300 V	4710-1965	14655	22A, 965 pF ±.5% 300 V	
C12	Mica, 965 pF ±1/2% 300 V	4710-1965	14655	22A, 965 pF ±.5% 300 V	
C13	Plastic, 0.75 µF ±5% 100 V	4860-8006	84411	663UW, .75 µF ±.5% 100 V	
C14A	Plastic, 0.20 µF ±5% 100 V	Part of 0977-4080	24655	0977-4080	
C14B	Plastic, 0.033 µF ±10% 100 V	Part of 0977-4080	24655	0977-4080	
C14C	Wax, 0.001 µF ±10% 100 V	Part of 0977-4080	24655	0977-4080	
C15	Ceramic, 10 pF ±10% N750 500 V	4400-3101	00656	CI-1-N750	
C16	Ceramic, 0.0047 µF +80-20% 500 V	4406-2479	72982	811, .0047 µF +80-20%	5910-846-2777
C17	Trimmer, 10 - 100 pF	4910-0700	71590	823-BN, 10 to 110 pF	
RESISTORS					
R1	Assembly, 0 - 7.6 kΩ ±0.05%	1608-2700	24655	1608-2700	
R2	Assembly, 0 - 71.2 Ω ±2%	1608-2070	24655	1608-2070	
R3	Wire-wound, 6.65 kΩ ±0.05%	0510-3940	24655	0510-3940	
R4	POTENTIOMETER, 0 - 1.062 kΩ ±2%	part of 0977-4080	24655	0977-4080	
R5	POTENTIOMETER, 0 - 52.5 kΩ ±2%	part of 0977-4080	24655	0977-4080	
R6	Film, 536 Ω ±1%	6450-0536	75042	CEC, 536 Ω ±1%	
R7	Wire-wound, 0.982 Ω ±0.05%	part of 1608-2060	24655	1608-2060	
R8	Wire-wound, 9.0 Ω ±0.02%	part of 1608-2060	24655	1608-2060	
R9	Wire-wound, 90 Ω ±0.02%	1608-2060	24655	1608-2060	
R10	Wire-wound, 900 Ω ±0.02%	part of 1608-2060	24655	1608-2060	
R11	Wire-wound, 100 kΩ ±0.02%	0510-3600	24655	0510-3600	5905-963-7759
R13	Wire-wound, 1 MΩ ±0.025%	0510-3040	24655	0510-3040	
R14	Wire-wound, 1 kΩ ±0.025%	0602-3040	24655	0602-3040	
R15	Wire-wound, 10 kΩ ±0.025%	0602-3052	24655	0602-3052	
R16	POTENTIOMETER, 25 Ω ±10%	6050-0650	12697	43WX, 25 Ω	
INDUCTOR					
L1	Choke, 12.5 mH ±10%	1608-4060	24655	1608-4060	


GY
201F&R
210F&R
S2
204F&R
VT
TO S3,204F
WH
BL
205FR
212F&R
J1
LOW
UNKNOWN
BIAS
BK
-
+
J4
J3
J2
S2,301R
302F
C15
10
BR
310F
S2
310R
S2
309R
S2
S2
308F&R
306F
S2
307R
306R
TO S3, 412F
RD
S2
EXT DQ
404
F&R
J6
408F
407F
R6
536
CCW
R1
0-7.6K OHMS
R5
0-52.5K
R4
0-1.07
CCW
C14A,B,C
402F
CCW
C17
C1A
C1
.15
A.T.
54
S2
L1
12.5mH
CCW
R2
0-71.2 OHMS
R3
6.650K
C3
7-45
R16
25
A.T. 53
C2
14-27
CCW
C3A
100
A.T.
52
A.T.
50

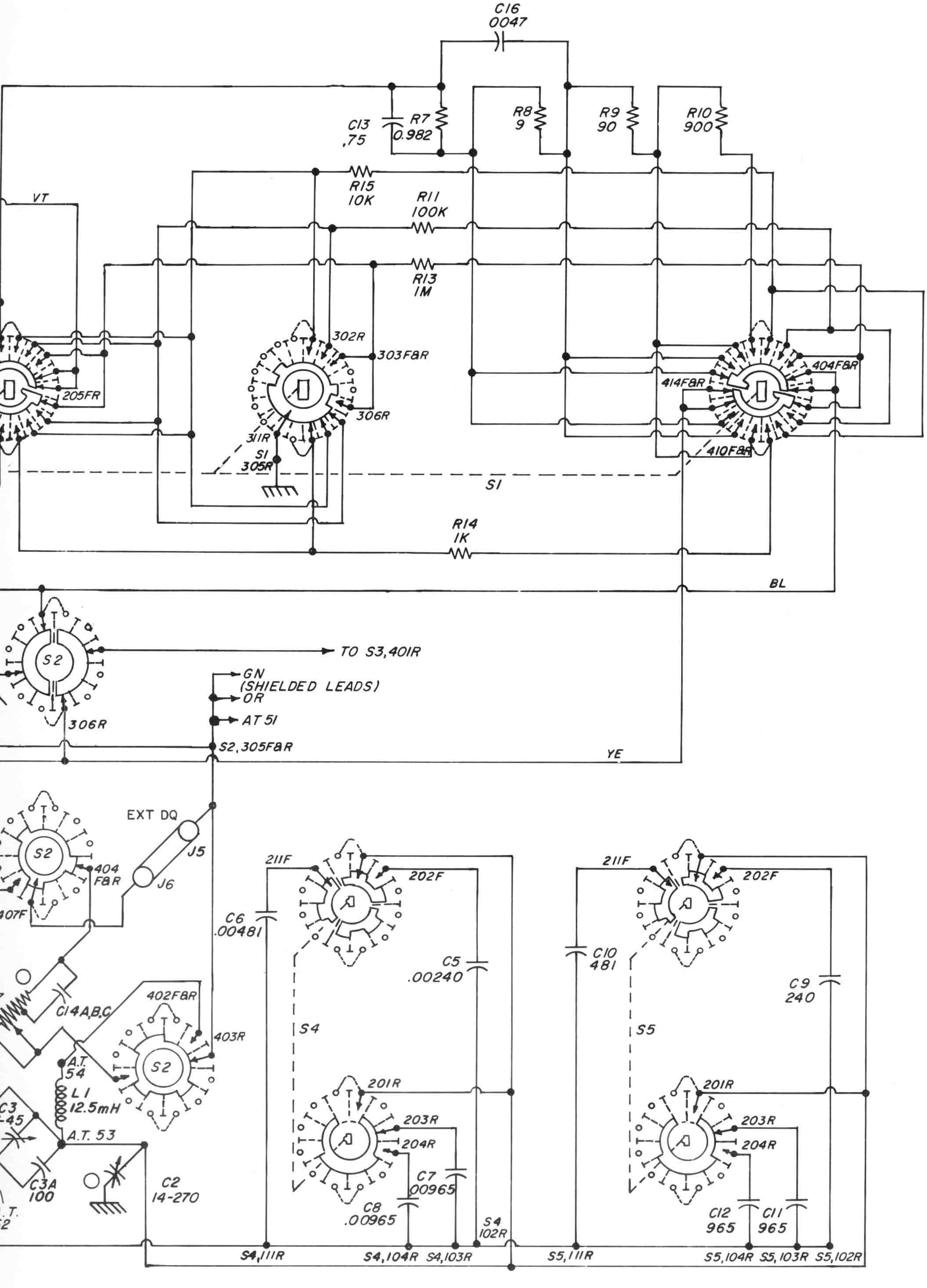


Figure 5-10. Schematic diagram of bridge circuits.

POWER SUPPLY AND LIGHT CIRCUIT ELECTRICAL REPLACEABLE PARTS

Ref. Desig.	*Description*	*GR Part No.*	*Fed. Mfg. Code*	*Mfg. Part No.*	*Fed. Stock No.*
CAPACITORS					
C300A C300B	Electrolytic, 100 µF 100 µF 50 V	4450-1000	74861	1B601-RT	5910-783-5739
C301A C301B	Electrolytic, 100 µF 100 µF 50 V	4450-1000	74861	1B601-RT	5910-783-5739
C302A C302B	Electrolytic, 10 µF 10 µF 450 V	4450-0300	37942	20-10945	5910-792-3165
C303A C303B	Electrolytic, 100 µF 100 µF 50 V	4450-1000	74861	1B601-RT	5910-783-5739
C304A C304B	Electrolytic, 300 µF 300 µF 15 V	4450-2400	37942	2021149S4C10X1	5910-822-2691
C305	Electrolytic, 15 µF 15 V	4450-3700	37942	TT, 15µF 15 V	
DIODES					
D300 through D304	Type IN3253	6081-1001	79089	IN3253	5961-814-4251
D305	Type IN3254	6081-1002	09213	IN3254	5961-082-3988
D306	Type IN3254	6081-1002	09213	IN3254	5961-082-3988
D307 through D311	Type IN3253	6081-1001	79089	IN3253	5961-814-4251
TRANSISTORS					
Q300	Type 2N176	8210-1760	04713	2N176	
Q301	Type 2N445A-BR	8210-4451	93916	2N445A-BR	5960-828-0776
RESISTORS					
R300	Composition, 10 Ω ±10% 1 W	6110-0109	01121	GB, 10 Ω ±10% 1W	
R301	Composition, 51 Ω ±5% 2 W	6120-0515	01121	RC42GF510J	5905-252-5425
R302	Composition, 270 Ω ±5% 1 W	6110-1275	01121	RC32GF271J	5905-279-2628
R303	Composition, 100 Ω ±5% 1/2 W	6100-1105	01121	RC20GF101J	5905-190-8889
R304	Composition, 390 Ω ±5% 1/2 W	6100-1395	01121	RC20GF391J	5905-279-1890
R306	Composition, 250 kΩ ±10%	Part of 1608-4040	24655	1608-4040	-
R307	Composition, 100 kΩ ±5% 2 W	6120-4105	01121	RC42GF104J	5905-254-7101
R309	Composition, 2.5 kΩ ±10%	Part of 1608-4040	24655	1608-4040	-
R310	Composition, 20 kΩ ±5% 1/2 W	6100-3205	01121	RC20GF203J	5905-192-0649
R311	Composition, 2.4 kΩ ±5% 1/2 W	6100-2245	01121	RC20GF242J	5905-279-1877
R312	Composition, 1 kΩ ±5% 2W	6120-2105	01121	RC42GF102J	5905-256-3361
R314	Composition, 22 kΩ ±5% 1/2 W	6100-3225	01121	RC20GF223J	5905-171-2004
R315	Composition, 100 Ω ±5% 1/2 W	6100-1105	01121	RC20GF101J	5905-190-8889
R316	Composition, 10 Ω ±5% 2 W	6120-0105	01121	RC42GF100J	5905-252-1953
FUSES					
F300	115-volt, 0.2-ampere	5330-0600	71400	MDL, .2 Amp	-
	230-volt, 0.1-ampere	5330-0400	71400	MDL, .1 Amp	5920-356-2185
F301	115-volt, 0.2-ampere	5330-0600	71400	MDL, .2 Amp	-
	230-volt, 0.1-ampere	5330-0400	71400	MDL, .1 Amp	5920-356-2185
PILOT LIGHTS					
P1 through P16	Type 2LAP-7	5600-0307	71744	#327	
PLUG					
PL300	Power Connector	4240-0600	24655	4240-0600	5935-816-0254
TRANSFORMER					
T300		0345-4790	24655	0345-4790	

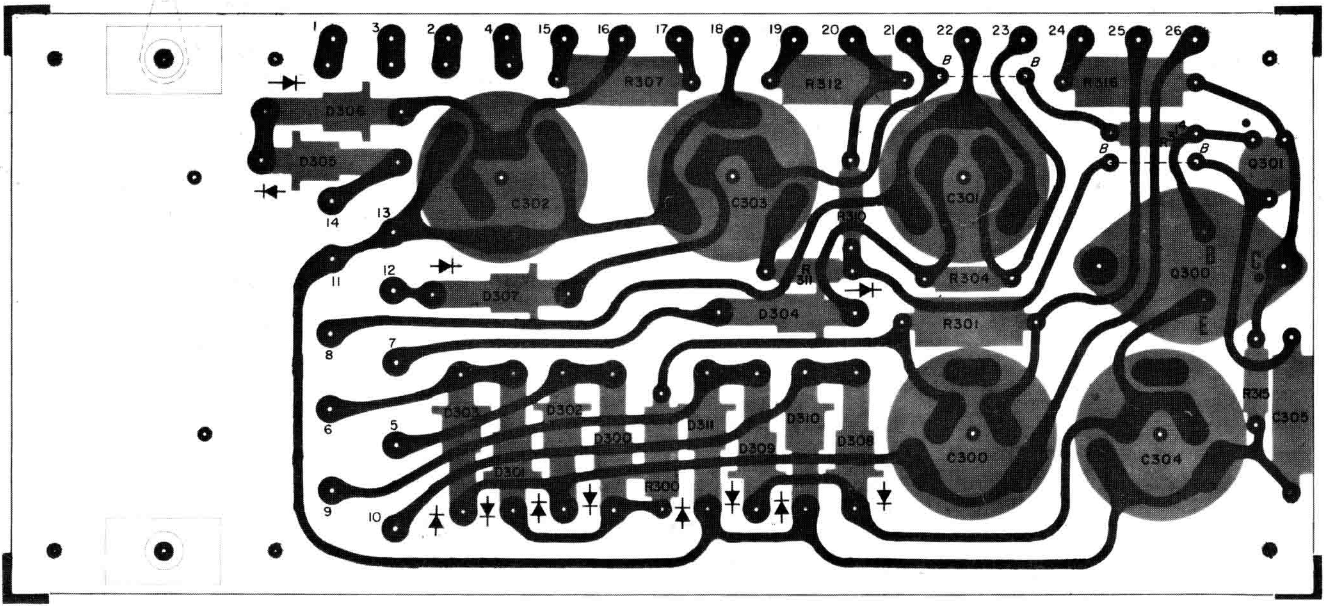


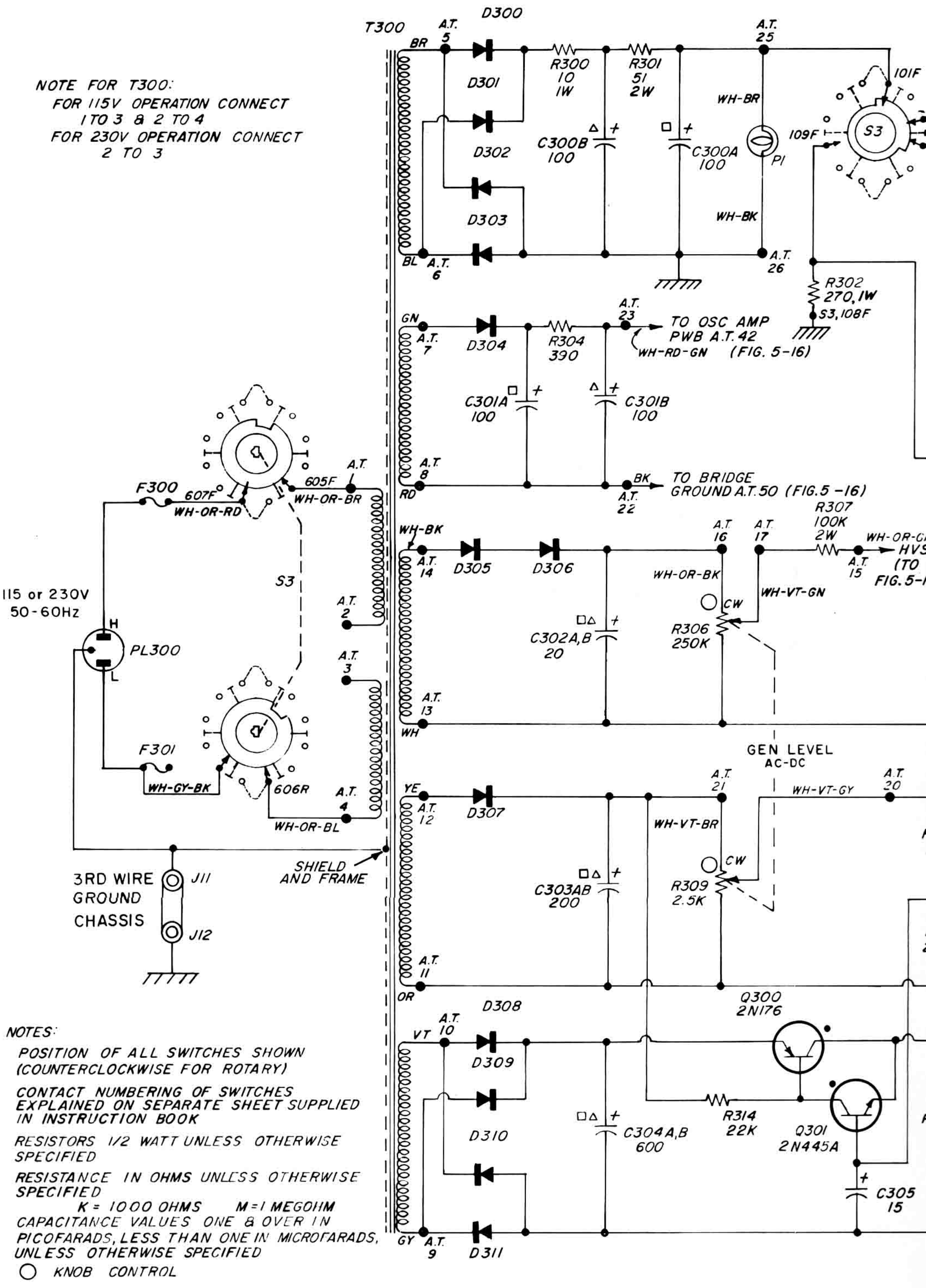
Figure 5-11. Etched-circuit board assembly, power supply (P/N 1608-2740).

NOTE

The number shown on the foil side of the board is not the part number for the complete assembly. This assembly number is given in the caption.

The dot on the foil at the transistor socket indicated the collector lead.

NOTE FOR T300:
FOR 115V OPERATION CONNECT
1 TO 3 & 2 TO 4
FOR 230V OPERATION CONNECT
2 TO 3



NOTES:

POSITION OF ALL SWITCHES SHOWN (COUNTERCLOCKWISE FOR ROTARY)

CONTACT NUMBERING OF SWITCHES EXPLAINED ON SEPARATE SHEET SUPPLIED IN INSTRUCTION BOOK

RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED

RESISTANCE IN OHMS UNLESS OTHERWISE SPECIFIED
K = 1000 OHMS M = 1 MEGOHM
CAPACITANCE VALUES ONE & OVER IN PICOFARADS, LESS THAN ONE IN MICROFARADS, UNLESS OTHERWISE SPECIFIED

○ KNOB CONTROL

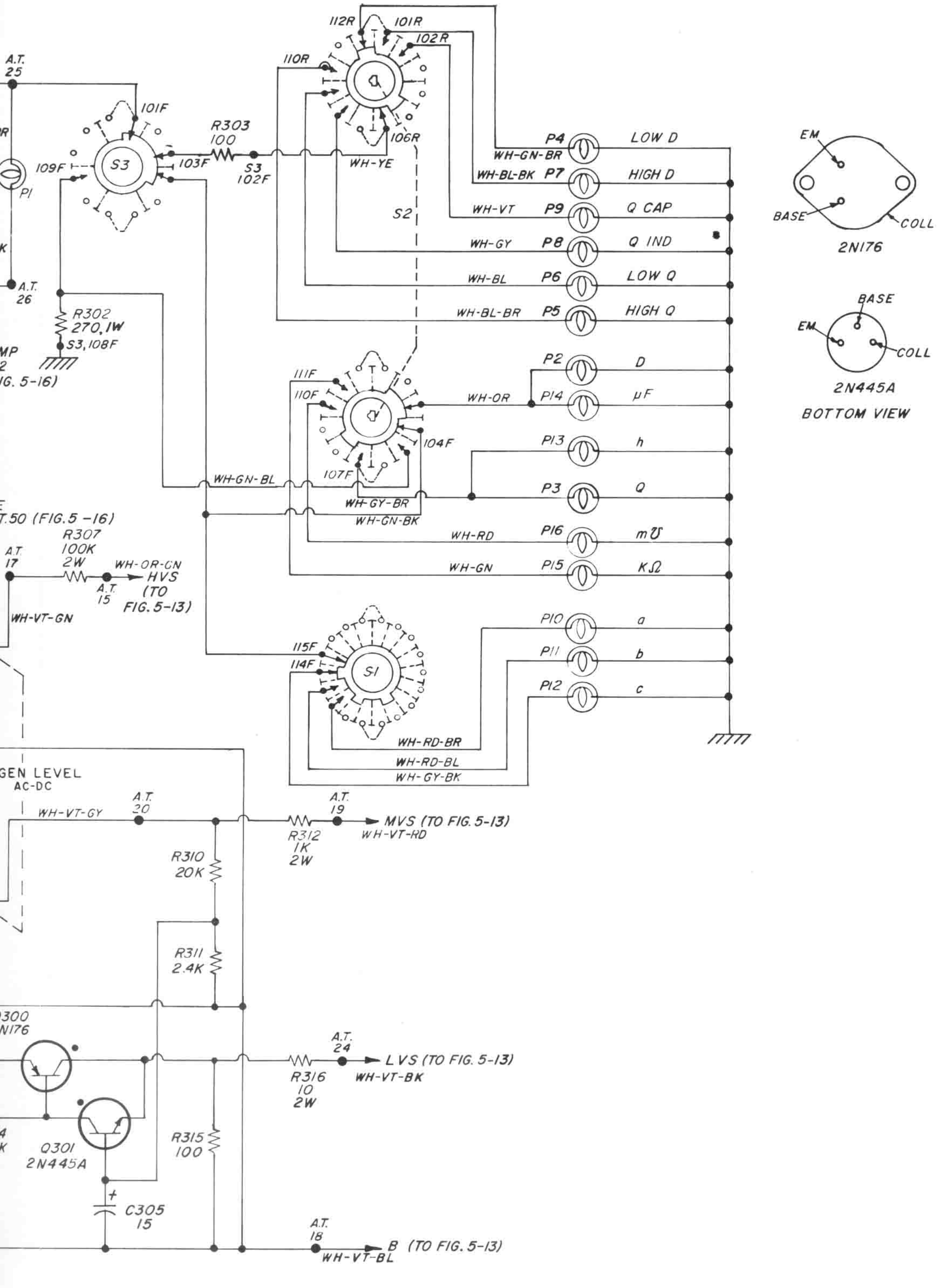


Figure 5-12. Schematic diagram of power supplies and light circuits.

FEDERAL MANUFACTURER'S CODE

From Federal Supply Code for Manufacturers Cataloging Handbooks H4-1 (Name to Code) and H4-2 (Code to Name) as supplemented through August, 1968.

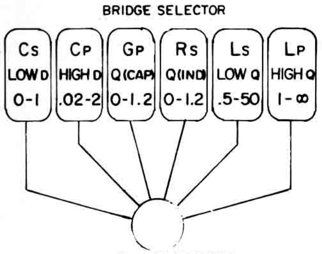
Code	Manufacturer
00192	Jones Mfg. Co, Chicago, Illinois
00194	Walsco Electronics Corp, L.A., Calif.
00434	Schweber Electronics, Westburg, L.I., N.Y.
00656	Aerovox Corp, New Bedford, Mass.
01009	Alden Products Co, Brockton, Mass.
01121	Allen-Bradley, Co, Milwaukee, Wisc.
01295	Texas Instruments, Inc, Dallas, Texas
02114	Ferroxcube Corp, Saugerties, N.Y. 12477
02606	Fenwal Lab Inc, Morton Grove, Ill.
02660	Amphenol Electron Corp, Broadview, Ill.
02768	Fastex, Des Plaines, Ill. 60016
03508	G.E. Semicon Prod, Syracuse, N.Y. 13201
03636	Grayburne, Yonkers, N.Y. 10701
03888	Pyrofilm Resistor Co, Cedar Knolls, N.J.
03911	Clairex Corp, New York, N.Y. 10001
04009	Arrow-Hart & Hegeman, Hartford, Conn. 06106
04713	Motorola, Phoenix, Ariz. 85008
05170	Engr'd Electronics, Santa Ana, Calif. 92702
05624	Barber-Colman Co, Rockford, Ill. 61101
05820	Wakefield Eng, Inc, Wakefield, Mass. 01880
07126	Digitron Co, Pasadena, Calif.
07127	Eagle Signal (E.W. Bliss Co), Baraboo, Wisc.
07261	Avnet Corp, Culver City, Calif. 90230
07263	Fairchild Camera, Mountain View, Calif.
07387	Birtcher Corp, No. Los Angeles, Calif.
07595	Amer Semicond, Arlington Hts, Ill. 60004
07828	Bodine Corp, Bridgeport, Conn. 06605
07829	Bodine Electric Co, Chicago, Ill. 60618
07910	Cont Device Corp, Hawthorne, Calif.
07983	State Labs Inc, N.Y., N.Y. 10003
07999	Borg Inst., Delavan, Wisc. 53115
08730	Vemaline Prod Co, Franklin Lakes, N.J.
09213	G.E. Semiconductor, Buffalo, N.Y.
09408	Star-Tronics Inc, Georgetown, Mass. 01830
09823	Burgess Battery Co, Freeport, Ill.
09922	Burndy Corp, Norwalk, Conn. 06852
11236	C.T.S. of Berne, Inc, Berne, Ind. 46711
11599	Chandler Evans Corp, W. Hartford, Conn.
12040	National Semiconductor, Danbury, Conn.
12498	Crystalonics, Cambridge, Mass. 02140
12672	RCA, Woodbridge, N.J.
12697	Clarostat Mfg Co, Inc, Dover, N.H. 03820
12954	Dickson Electronics, Scottsdale, Ariz.
13327	Solitron Devices, Tappan, N.Y. 10983
14433	ITT Semicondictors, W.Palm Beach, Fla.
14655	Cornell-Dubilier Electric Co, Newark, N.J.
14674	Corning Glass Works, Corning, N.Y.
14936	General Instrument Corp, Hicksville, N.Y.
15238	ITT, Semiconductor Div, Lawrence, Mass.
15605	Cutlet-Hammer Inc, Milwaukee, Wisc. 53233
16037	Spruce Pine Mica Co, Spruce Pine, N.C.
17771	Singer Co, Diehl Div, Somerville, N.J.
19396	Illinois Tool Works, Pakton Div, Chicago, Ill.
19644	LRC Electronics, Horseheads, N.Y.
19701	Electra Mfg Co, Independence, Kansas 67301
21335	Fafnir Bearing Co, New Briton, Conn.
22753	UID Electronics Corp, Hollywood, Fla.
23342	Avnet Electronics Corp, Franklin Park, Ill.
24446	G.E., Schenectady, N.Y. 12305
24454	G.E., Electronics Comp, Syracuse, N.Y.
24455	G.E. (Lamp Div), Nela Park, Cleveland, Ohio
24655	General Radio Co, W. Concord, Mass. 01781
26806	American Zettlet Inc, Costa Mesa, Calif.
28520	Hayman Mfg Co, Kenilworth, N.J.
28959	Hoffman Electronics Corp, El Monte, Calif.
30874	I.B.M, Armonk, New York
32001	Jensen Mfg. Co, Chicago, Ill. 60638
33173	G.E. Comp, Owensboro, Ky. 42301
35929	Constanta Co, Mont. 19, Que.
37942	P.R. Mallory & Co Inc, Indianapolis, Ind.
38443	Marlin-Rockwell Corp, Jamestown, N.Y.
40931	Honeywell Inc, Minneapolis, Minn. 55408
42190	Muter Co, Chicago, Ill. 60638
42498	National Co, Inc, Melrose, Mass. 02176
43991	Norma-Hoffman, Stanford, Conn. 06904
49671	RCA, New York, N.Y. 10020
49956	Raytheon Mfg Co, Waltham, Mass. 02154
53021	Sangamo Electric Co, Springfield, Ill. 62705
54294	Shallcross Mfg Co, Selma, N.C.
54715	Shure Brothers, Inc, Evanston, Ill.
56289	Sprague Electric Co, N. Adams, Mass.
59730	Thomas and Betts Co, Elizabeth, N.J. 07207
59875	TRW Inc, (Accessories Div), Cleveland, Ohio
60399	Torrington Mfg Co, Torrington, Conn.
61637	Union Carbide Corp, New York, N.Y. 10017
61864	United-Carr Fastener Corp, Boston, Mass.
63060	Victoreen Instrument Co, Inc, Cleveland, O.
63743	Ward Leonard Electric Co, Mt. Vernon, N.Y.
65083	Westinghouse (Lamp Div), Bloomfield, N.J.
65092	Weston Instruments, Newark, N.J.
70485	Atlantic-India Rubber, Chicago, Ill. 60607
70563	Amperite Co, Union City, N.J. 07087
70903	Belden Mfg Co, Chicago, Ill. 60644
71126	Bronson, Homer D, Co, Beacon Falls, Conn.
71294	Canfield, H.O. Co, Clifton Forge, Va. 24422
71400	Bussman (McGraw Edison), St. Louis, Mo.
71468	ITT Cannon Elec, L.A., Calif. 90031
71590	Centralab, Inc, Milwaukee, Wisc, 53212
71666	Continental Carbon Co, Inc, New York, N.Y.
71707	Coto Coil Co Inc, Providence, R.I.
71744	Chicago Miniature Lamp Works, Chicago, Ill.
71785	Cinch Mfg Co, Chicago, Ill. 60624
71823	Darnell Corp, Ltd, Downey, Calif. 90241
72136	Electro Motive Mfg Co, Wilmington, Conn.
72259	Nytronics Inc, Berkeley Heights, N.J. 07922
72619	Dialight Co, Brooklyn, N.Y. 11237
72699	General Instr Corp, Newark, N.J. 07104
72765	Drake Mfg Co, Chicago, Ill. 60656
72825	Hugh H. Eby Inc, Philadelphia, Penn. 19144
72962	Elastic Stop Nut Corp, Union, N.J. 07083
72982	Erie Technological Products Inc, Erie, Penn.
73138	Beckman Inc, Fullerton, Calif. 92634
73445	Amperex Electronics Co, Hicksville, N.Y.
73559	Carling Electric Co, W.Hartford, Conn.
73690	Elco Resistor Co, New York, N.Y.
73899	JFD Electronics Corp, Brooklyn, N.Y.
74193	Heinemann Electric Co, Trenton, N.J.
74861	Industrial Condenser Corp, Chicago, Iii.
74970	E.F. Johnson Co, Waseca, Minn. 56093
75042	IRC Inc, Philadelphia, Penn. 19108
75382	Kulka Electric Corp, Mt. Vernon, N.Y.
75491	Lafayette Industrial Electronics, Jamica, N.Y.
75608	Linden and Co, Providence, R.I.
75915	Littelfuse, Inc, Des Plaines, Ill. 60016
76005	Lord Mfg Co, Erie, Penn. 16512
76149	Mallory Electric Corp, Detroit, Mich. 48204
76487	James Millen Mfg Co, Malden, Mass. 02148
76545	Mueller Electric Co, Cleveland, Ohio 44114
76684	National Tube Co, Pittsburg, Penn.
76854	Oak Mfg Co, Crystal Lake, Ill.
77147	Patton MacGuyer Co, Providence, R.I.
77166	Pass-Seymour, Syracuse, N.Y.
77263	Pierce Roberts Rubber Co, Trenton, N.J.
77339	Positive Lockwasher Co, Newark, N.J.
77542	Ray-O-Vac Co, Madison, Wisc.
77630	TRW, Electronic Comp, Camden, N.J. 08103
77638	General Instruments Corp, Brooklyn, N.Y.
78189	Shakeproof (Ill. Tool Works), Elgin, Ill. 60120
78277	Sigma Instruments Inc, S.Braintree, Mass.
78488	Stackpole Carbon Co, St. Marys, Penn.
78553	Tinnerman Products, Inc, Cleveland, Ohio
79089	RCA, Rec Tube & Semicond, Harrison, N.J.
79725	Wiremold Co, Hartford, Conn. 06110
79963	Zierick Mfg Co, New Rochelle, N.Y.
80030	Prestole Fastener, Toledo, Ohio
80048	Vickers Inc, St. Louis, Mo.
80131	Electronic Industries Assoc, Washington, D.C.
80183	Sprague Products Co, No. Adams, Mass.
80211	Motorola Inc, Franklin Park, Ill. 60131
80258	Standard Oil Co, Lafeyette, Ind.
80294	Bourns Inc, Riverside, Calif. 92506
80431	Air Filter Corp, Milwaukee, Wisc. 53218
80583	Hammarlund Co, Inc, New York, N.Y.
80740	Beckman Instruments, Inc, Fullerton, Calif.
81030	International Insturment, Orange, Conn.
81073	Grayhill Inc, LaGrange, Ill. 60525
81143	Isolantite Mfg Corp, Stirling, N.J. 07980
81349	Military Specifications
81350	Joint Army-Navy Specifications
81751	Columbus Electronics Corp, Yonkers, N.Y.
81831	Filtron Co, Flushing, L.I., N.Y. 11354
81840	Ledex Inc, Dayton, Ohio 45402
81860	Barry-Wright Corp, Watertown, Mass.
82219	Sylvania Elec Prod, Emporium, Penn.
82273	Indiana Pattern & Model Works, LaPort, Ind.
82389	Switchcraft Inc, Chicago, Ill. 60630
82647	Metals & Controls Inc, Attleboro, Mass.
82807	Milwaukee Resistor Co, Milwaukee, Wisc.
83033	Meissner Mfg, (Maguire Ind) Mt. Carmel, Ill.
83058	Carr Fastener Co, Cambridge, Mass.
83186	Victory Engineering, Springfield, N.J. 07081
83361	Bearing Specialty Co, San Francisco, Calif.
83587	Solar Electric Corp, Warren, Penn.
83740	Union Carbide Corp, New York, N.Y. 10017
83781	National Electronics Inc, Geneva, Ill.
84411	TRW Capacitor Div, Ogallala, Nebr.
84835	Lehigh Metal Prods, Cambridge, Mass. 02140
84971	TA Mfg Corp, Los Angeles, Calif.
86577	Precision Metal Prods, Stoneham, Mass. 02180
86684	RCA (Elect. Comp & Dev), Harrison, N.J.
86687	REC Corp, New Rochelle, N.Y. 10801
86800	Cont Electronics Corp, Brooklyn, N.Y. 11222
88140	Cutler-Hammer Inc, Lincoln, Ill.
88219	Gould Nat. Batteries Inc, Trenton, N.J.
88419	Cornell-Dubilier, Fuquay-Varina, N.C.
88627	K & G Mfg Co, New York, N.Y.
89482	Holtzer-Cabot Corp, Boston, Mass.
89665	United Transformer Co, Chicago, Ill.
90201	Mallory Capacitor Co, Indianapolis, Ind.
90750	Westinghouse Electric Corp, Boston, Mass.
90952	Hardware Products Co, Reading, Penn. 19602
91032	Continental Wire Corp, York, Penn. 17405
91146	ITT (Cannon Electric Inc), Salem, Mass.
91293	Johanson Mfg Co, Boonton, N.J. 07005
91506	Augat Inc, Attleboro, Mass. 02703
91598	Chandler Co, Wethersfield, Conn. 06109
91637	Dale Electronics Inc, Columbus, Nebr.
91662	Elco Corp, Willow Grove, Penn.
91719	General Instruments, Inc, Dallas, Texas
91929	Honeywell Inc, Freeport, Ill.
92519	Electra Insul Corp, Woodside, L.I., N.Y.
92678	E.G.&G., Boston, Mass.
93332	Sylvania Elect Prods, Inc, Woburn, Mass.
93916	Cramer Products Co, New York, N.Y. 10013
94144	Raytheon Co, Components Div, Quincy, Mass.
94154	Tung Sol Electric Inc, Newark, N.J.
95076	Garde Mfg Co, Cumberland, R.I.
95121	Quality Components Inc, St. Mary's, Penn.
95146	Alco Electronics Mfg Co, Lawrence, Mass.
95238	Continental Connector Corp, Woodside, N.Y.
95275	Vitramon, Inc, Bridgeport, Conn.
95354	Methode Mfg Co, Chicago, Ill.
95412	General Electric Co, Schenectady, N.Y.
95794	Anaconda Amer Brass Co, Torrington, Conn.
96095	Hi-Q Div. of Aerovox Corp, Orlean, N.Y.
96214	Texas Instruments Inc, Dallas, Texas 75209
96256	Thordarson-Meissner, Mt. Carmel, Ill.
96341	Microwave Associates Inc, Burlington, Mass.
96791	Amphenol Corp, Jonesville, Wisc, 53545
96906	Military Standards
98291	Sealectro Corp, Mamaroneck, N.Y. 10544
98474	Compar Inc, Burlingame, Calif.
98821	North Hills Electronics Inc, Glen Cove, N.Y.
99180	Transitron Electronics Corp, Melrose, Mass.
99313	Varian, Palo Alto, Calif. 94303
99378	Atlee Corp, Winchester, Mass. 01890
99800	Delevan Electronics Corp, E. Aurora, N.Y.

GENERATOR AND DETECTOR-SWITCHING ELECTRICAL REPLACEABLE PARTS

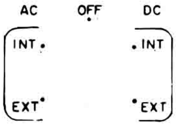
Ref. Desig.	*Description*	*GR Part No.*	*Fed. Mfg. Code*	*Mfg. Part No.*	*Fed. Stock No.*
CAPACITORS					
C530	Electrolytic, 10 μF 25 V	4450-3800	56289	30D106G025BB4M1	5910-952-8658
C556	Wax 0.22 μF ±10% 400 V	5020-0500	80183	78P22494S3	5910-726-5003
DIODES					
D400	Type 1N3253	6081-1001	79089	IN3253	5961-814-4251
D401	Type 1N3253	6081-1001	79089	IN3253	5961-814-4251
RESISTORS					
R400	Composition, 4.7 kΩ ±5% 1/2 W	6100-2475	01121	RC20GF472J	5905-279-3504
R401	Composition, 47 kΩ ±5% 1/2 W	6100-3475	01121	RC20GF473J	5905-254-9201
R403	POTENTIOMETER, 5 kΩ ±5%	0971-4210	24655	0971-4210	-
R562	POTENTIOMETER, 50 kΩ ±10%	6030-0350	01121	JU, 50 kΩ ±10%	-
TRANSFORMER					
T400		0746-4360	24655	0742-4360	
METER					
M400	-10 — 0 — +10, 650 Ω ±20%	5730-1092	24655	5730-1092	

MISCELLANEOUS ELECTRICAL REPLACEABLE PARTS

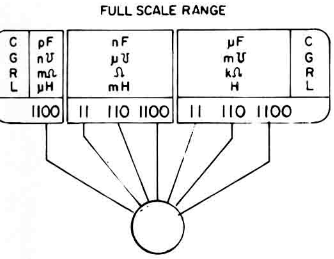
Ref. Desig.	*Description*	*GR Part No.*	*Fed. Mfg. Code*	*Mfg. Part No.*
JACKS				
J1	Binding Post, UNKNOWN-LOW	0938-3002	24655	0938-3002
J2	Binding Post, UNKNOWN	0938-3002	24655	0938-3002
J3	Binding Post, BIAS +	0938-3002	24655	0938-3002
J4	Binding Post, BIAS -	0938-3002	24655	0938-3002
J5	Binding Post, EXT DQ	0938-3002	24655	0938-3002
J6	Binding Post, EXT DQ	0938-3002	24655	0938-3002
J7	Binding Post, EXT GEN	0938-3002	24655	0938-3002
J8	Binding Post, EXT GEN, Uninsulated	0938-3022	24655	0938-3022
J9	Binding Post, DET OUT	0938-3000	24655	0938-3000
J10	Binding Post, DET OUT, Uninsulated	0938-3022	24655	0938-3022
J11	Binding Post, 3RD WIRE GROUND (rear)	0938-3002	24655	0938-3002
J12	Binding Post, CHASSIS (rear)	0938-3022	24655	0938-3022
J13	Binding Post, EXT METER -A (rear)	0938-3002	24655	0938-3002
J14	Binding Post, EXT METER -B (rear)	0938-3002	24655	0938-3002
J15	Binding Post, EXT METER -C (rear)	0938-3002	24655	0938-3002
SWITCHES				
S1	Rotary Wafer, BRIDGE SELECTOR	7890-2100	76854	213858-L5
S2	Rotary Wafer, FULL SCALE RANGE	7890-2110	76854	213860-H5C
S3	Rotary Wafer, Function	7890-2120	76854	213859-H6C
S4	Rotary Wafer, GEN LEV	7890-2130	76854	Type H
S5	Rotary Wafer, DET SENS	7890-2140	76854	211795-H2



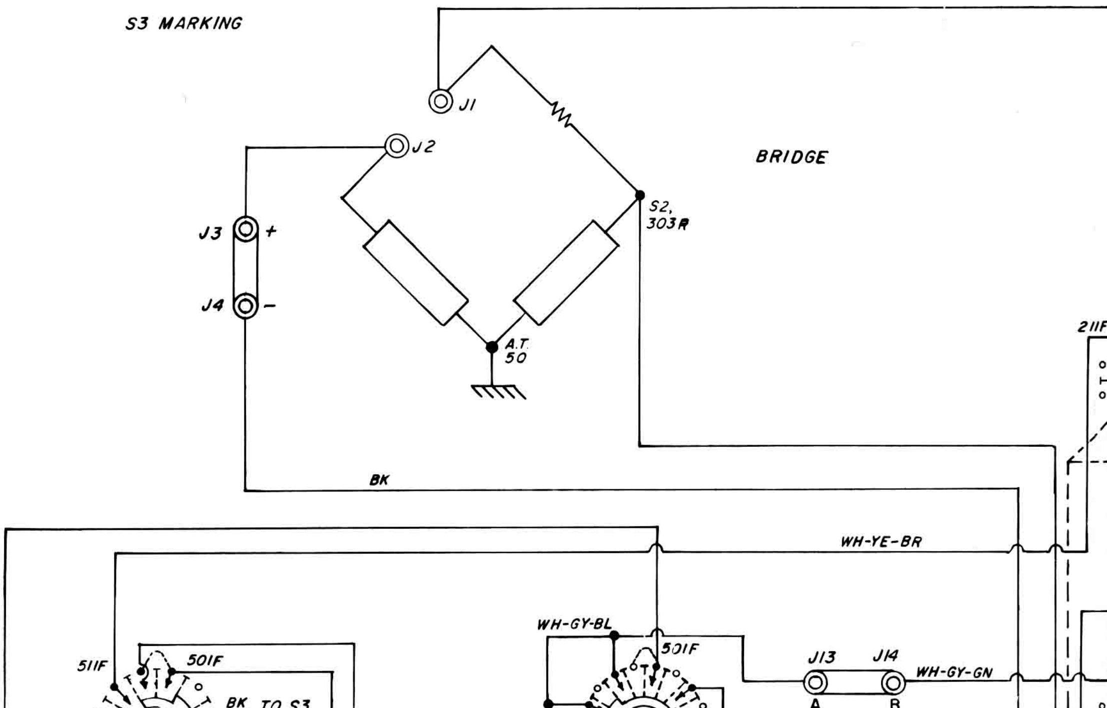
S2 MARKING

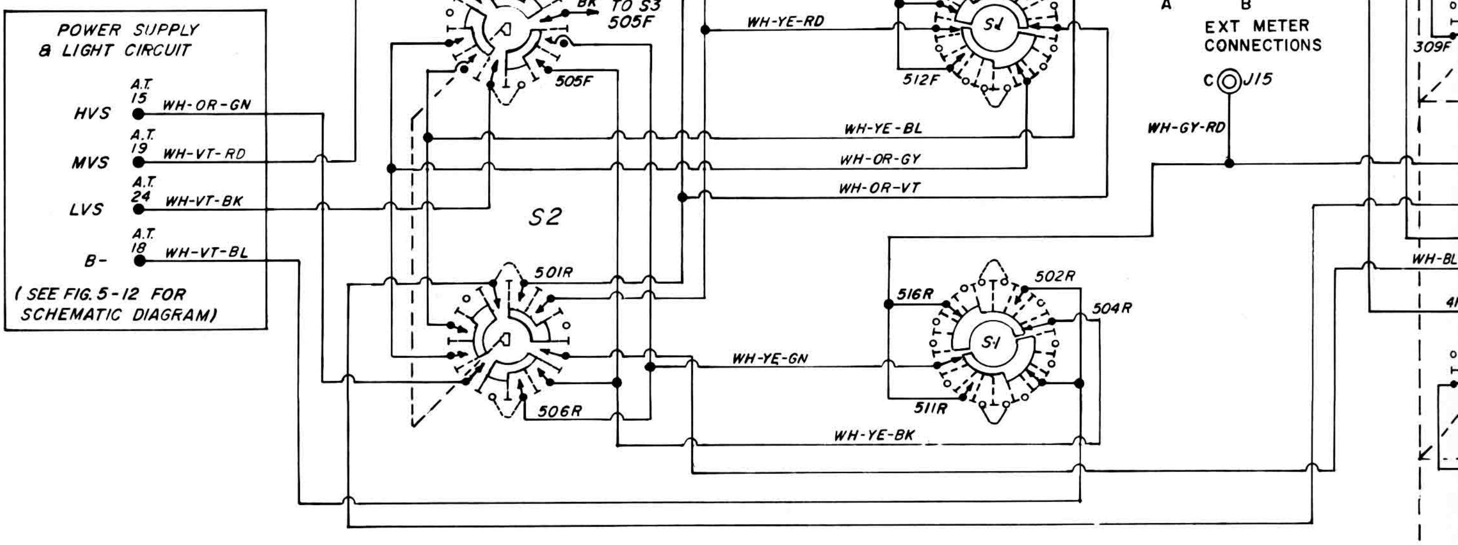


S3 MARKING



S1 MARKING





NOTES:

POSITION OF ALL SWITCHES SHOWN (COUNTERCLOCKWISE FOR ROTARY)
CONTACT NUMBERING OF SWITCHES EXPLAINED ON SEPARATE SHEET SUPPLIED IN INSTRUCTION BOOK

RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED
RESISTANCE IN OHMS UNLESS OTHERWISE SPECIFIED
K=1000 M=1 MEGOHM
CAPACITANCE VALUES ONE AND OVER IN PICOFARADS, LESS THAN ONE IN MICROFARADS, UNLESS OTHERWISE SPECIFIED

○ KNOB CONTROL

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

n the
ntact
rest
The
1 is
usu-
other
etc),
uffix
nt or

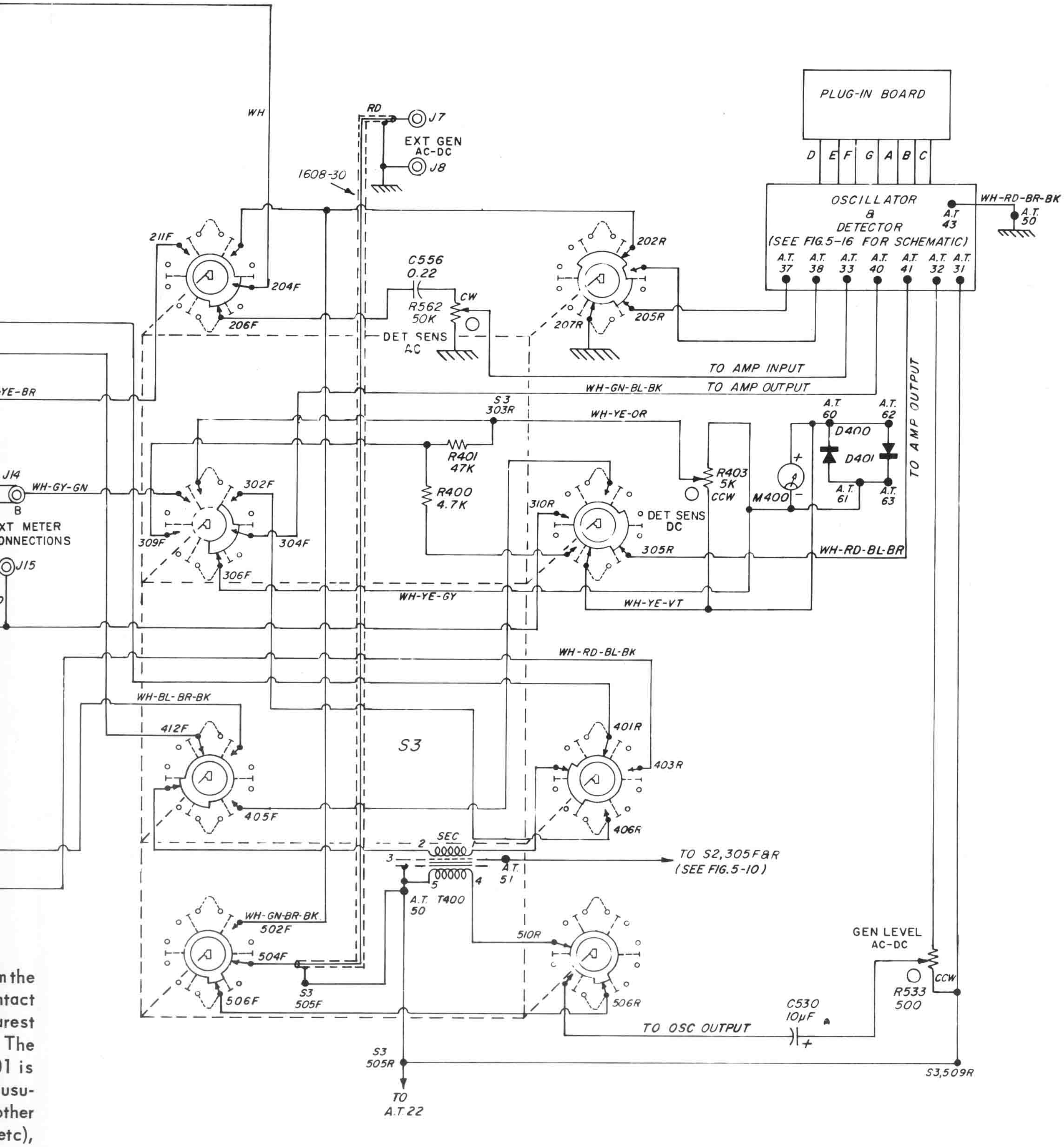


Figure 5-13. Schematic diagram of generator and detector switching.

OSCILLATOR AND DETECTOR ELECTRICAL REPLACEABLE PARTS

Ref. Desig.	*Description*	*GR Part No.*	*Fed. Mfg. Code*	*Mfg. Part No.*	*Fed. Stock No.*
CAPACITORS					
C500	Mica, 0.02 µF ±1% 300 V	4560-0400	14655	1AD3S2FF	5910-931-4151
C501	Mica, 0.02 µF ±1% 300 V	4560-0400	14655	1AD3S2FF	5910-931-4151
C502	Mica, 0.01 µF ±1% 500 V	4560-0300	14655	1A, 0.01 µF ±1% 500 V	5910-843-2984
C503	Mica, 0.02 µF ±1% 300 V	4560-0400	14655	1AD3S2FF	5910-931-4151
C504	Mica, 0.01 µF ±1% 500 V	4560-0300	14655	1A, 0.01 µF ±1% 500 V	5910-843-2984
C525	Electrolytic, 50 µF 3 V	4450-5590	37942	TT, 50 µF 3 V	-
C526	Electrolytic, 40 µF 6 V	4450-3600	37942	20-40707S4	5910-952-0467
C527	Electrolytic, 25 µF 50 V	4450-3000	56289	D33883	5910-799-9285
C528	Electrolytic, 10 µF 25 V	4450-3800	56289	30D106G025BB4M1	5910-952-8658
C550	Electrolytic, 25 µF 50 V	4450-3000	56289	D33883	5910-799-9285
C551	Electrolytic, 10 µF 25 V	4450-3800	56289	30D106G025BB4M1	5910-952-8658
C552	Ceramic, 0.1 µF +80-20% 50 V	4403-4100	80131	CC63, .1 µF +80-20%	5910-811-4788
C553	Electrolytic, 25 µF 50 V	4450-3000	56289	D33883	5910-799-9285
C554	Electrolytic, 10 µF 25 V	4450-3800	56289	30D106G025BB4M1	5910-952-8658
C555	Electrolytic, 1 µF 35 V	4450-4300	56289	150D105X0035A2	5910-726-5003
C557	Electrolytic, 15 µF 15 V	4450-3700	37942	TT, 15 µF 15 V	
C558	Ceramic, 220 pF ±10% 500 V	4400-4655	00656	BC1-I, 200 pF 10%	
C559	Electrolytic, 10 µF 25 V	4450-3800	56289	30D106G025BB4M1	5910-952-8658
C560	Electrolytic, 10 µF 25 V	4450-3700	37942	TT, 15 µF 15 V	
C561	Electrolytic, 1 µF 35 V	4450-4300	56289	150D105X0035A2	5910-726-5003
C562	Electrolytic, 10 µF 25 V	4450-3800	56289	30D106G025BB4M1	5910-952-8658
C563	Ceramic, 0.01 µF +80-20% 50 V	4401-3100	80131	CC61, .01 µF +80-20%	5910-974-5697
C564	Mica, 18 pF ±10% 500 V	4620-0300	72136	CM-15, 18 pF ±10%	
DIODES					
D525	Type 1N91	6081-1009	24446	IN91	5960-677-4865
D526	Type 1N91	6081-1009	24446	IN91	5960-677-4865
D550 through D552	Type 1N3253	6081-1001	79089	IN3253	5961-814-4251
D553 through D556	Type 1N191	6082-1008	93916	IN191	5961-296-3360
TRANSISTORS					
Q525	Type 2N520A-BR	8210-5200	72699	2N520A-BR	
Q526	Type 2N1415	8210-1415	24454	2N1415	
Q550	Type 2N929	8210-1002	01295	2N929	5960-226-8578
Q551	Type 2N445A-BR	8210-4451	93916	2N445A-BR	5960-828-0776
Q552	Type 2N445A-BR	8210-4451	93916	2N445A-BR	5960-828-0776
Q553	Type 2N520A-BR	8210-5200	72699	2N520A-BR	-
Q554	Type 2N455A-BR	8210-4451	93916	2N445A	5960-226-8578
Q555	Type 2N520A-BR	8210-5200	72699	2N520A-BR	-
RESISTORS					
R500	Film, 8.25 kΩ ±1% 1/4 W	6350-1825	75042	CEB, 8.25 kΩ ±1%	5905-556-3772
R501	Film, 7.68 kΩ ±1% 1/4 W	6350-1768	75042	CEB, 7.68 kΩ ±1%	-
R502	Film, 15.8 kΩ ±1% 1/4 W	6350-2158	75042	CEB, 15.8 kΩ ±1%	-
R503	Film, 15.8 kΩ ±1% 1/4 W	6350-2158	75042	CEB, 15.8 kΩ ±1%	-
R504	Film, 7.87 kΩ ±1% 1/4 W	6350-1780	75042	CEB, 7.87 kΩ ±1%	5905-577-0933
R505	POTENTIOMETER, 1 kΩ ±20%	6040-0400	01121	FWC, 1 kΩ ±20%	-
R525	Composition, 3 kΩ ±5% 1/2 W	6100-2305	01121	RC20GF302J	5905-279-1751
R526	Composition, 22 kΩ ±5% 1/2 W	6100-3225	01121	RC20GF223J	5905-171-2004
R527	Composition, 62 Ω ±5% 1/2 W	6100-0625	01121	RC20GF620J	5905-279-1760
R528	Composition, 150 Ω ±5% 1/2 W	6100-1155	01121	RC20GF151J	5905-299-1541
R529	POTENTIOMETER, 1 kΩ ±20%	6040-0400	01121	FWC, 1 kΩ ±20%	
R530	Composition, 62 Ω ±5% 1/2 W	6100-0625	01121	RC20GF620J	5905-279-1760
R531	Composition, 22 kΩ ±5% 1/2 W	6100-3225	01121	RC20GF223J	5905-171-2004
R532	Composition, 6.8 kΩ ±5% 1/2 W	6100-2685	01121	RC20GF682J	5905-279-3503
R533	Composition, 500 Ω ±10%	Part of 1608-4040	24655	1608-4040	
R550	Composition, 100 kΩ ±5% 1/2 W	6100-4105	01121	RC20GF104J	5905-195-6761
R551	Composition, 47 kΩ ±5% 1/2 W	6100-3475	01121	RC20GF473J	5905-254-9201
R552	Composition, 20 kΩ ±5% 1/2 W	6100-3205	01121	RC20GF203J	5905-192-0649
R553	Composition, 1 kΩ ±5% 1/2 W	6100-2105	01121	RC20GF102J	5905-195-6806
R554	Composition, 10 kΩ ±5% 1/2 W	6100-3105	01121	RC20GF103J	5905-185-8510
R555	Composition, 4.7 kΩ ±5% 1/2 W	6100-2475	01121	RC20GF472J	5905-279-3504
R556	Composition, 10 kΩ ±5% 1/2 W	6100-3105	01121	RC20GF103J	5905-185-8510
R557	Composition, 100 kΩ ±5% 1/2 W	6100-4105	01121	RC20GF104J	5905-195-6761
R558	Composition, 10 kΩ ±5% 1/2 W	6100-3105	01121	RC20GF103J	5905-185-8510
R559	Composition, 2.2 kΩ ±5% 1/2 W	6100-2225	01121	RC20GF222J	5905-279-1876

Ref. Desig.	Description	GR Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
RESISTORS (Cont)					
R560	Composition, 100 kΩ ±5% 1/2 W	6100-4105	01121	RC20GF104J	5905-195-6761
R561	Composition, 22 kΩ ±5% 1/2 W	6100-3225	01121	RC20GF223J	5905-171-2004
R563	Composition, 100 kΩ ±5% 1/2 W	6100-4105	01121	RC20GF104J	5905-195-6761
R564	Composition, 1 kΩ ±5% 1/2 W	6100-2105	01121	RC20GF102J	5905-195-6806
R565 through R568	Composition, 4.7 kΩ ±5% 1/2 W	6100-2475	01121	RC20GF472J	5905-279-3504
R569	Composition, 1 kΩ ±5% 1/2 W	6100-2105	01121	RC20GF102J	5905-195-6806
R570	Composition, 150 kΩ ±5% 1/2 W	6100-4155	01121	RC20GF154J	5905-279-2522
R571	Composition, 18 kΩ ±5% 1/2 W	6100-3185	01121	RC20GF183J	5905-279-3500
R572	Composition, 4.7 kΩ ±5% 1/2 W	6100-2475	01121	RC20GF472J	5905-279-3504
R573	Composition, 4.7 kΩ ±5% 1/2 W	6100-2475	01121	RC20GF472J	5905-279-3504
R574	Composition, 10 kΩ ±5% 1/2 W	6100-3105	01121	RC20GF103J	5905-185-8510
R575	Composition, 10 kΩ ±5% 1/2 W	6100-3105	01121	RC20GF103J	5905-185-8510
R576	Composition, 1 kΩ ±5% 1/2 W	6100-2105	01121	RC20GF102J	5905-195-6806

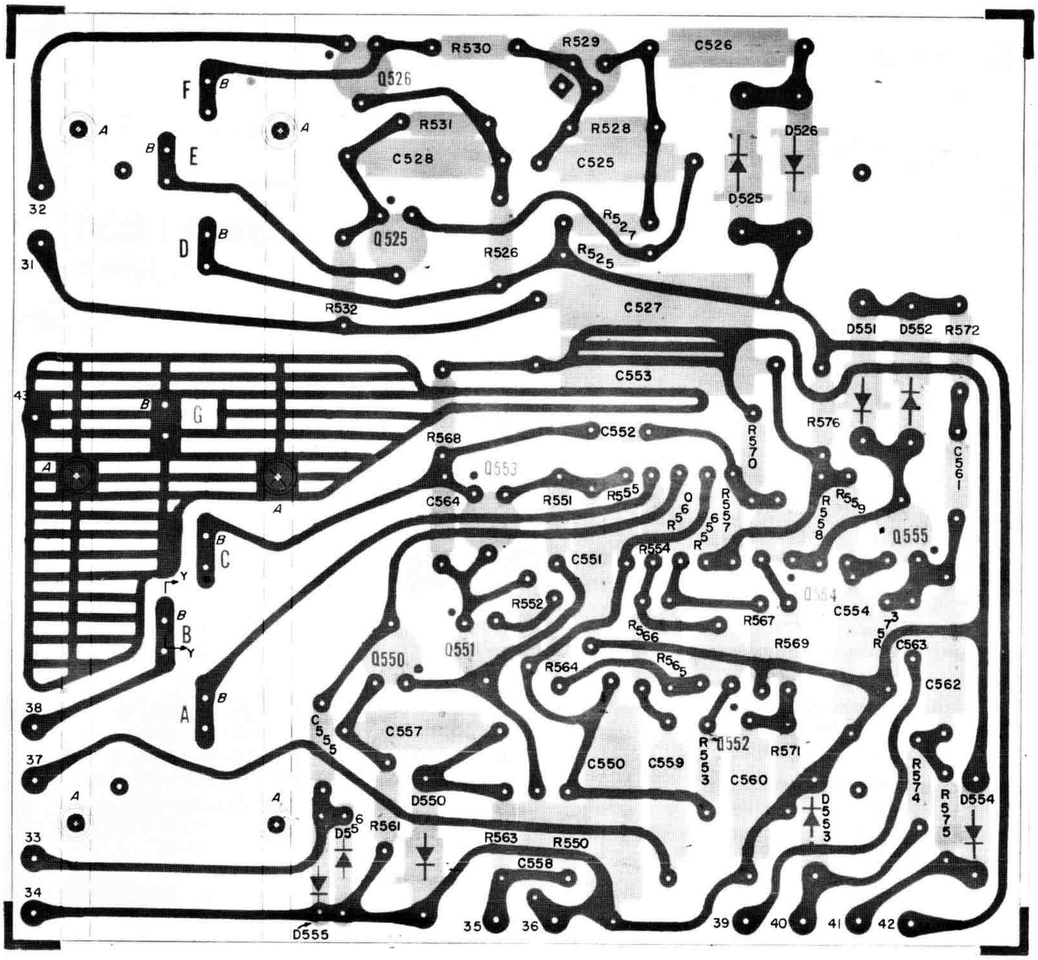


Figure 5-14. Etched-circuit board assembly, oscillator and detector (P/N 1608-2722).

NOTE

The number shown on the foil side of the board is not the part number for the complete assembly. This assembly number is given in the caption.

The dot on the foil at the transistor socket indicated the collector lead.

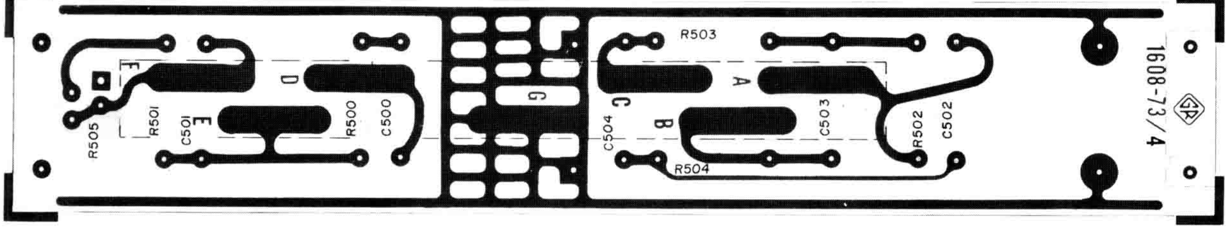
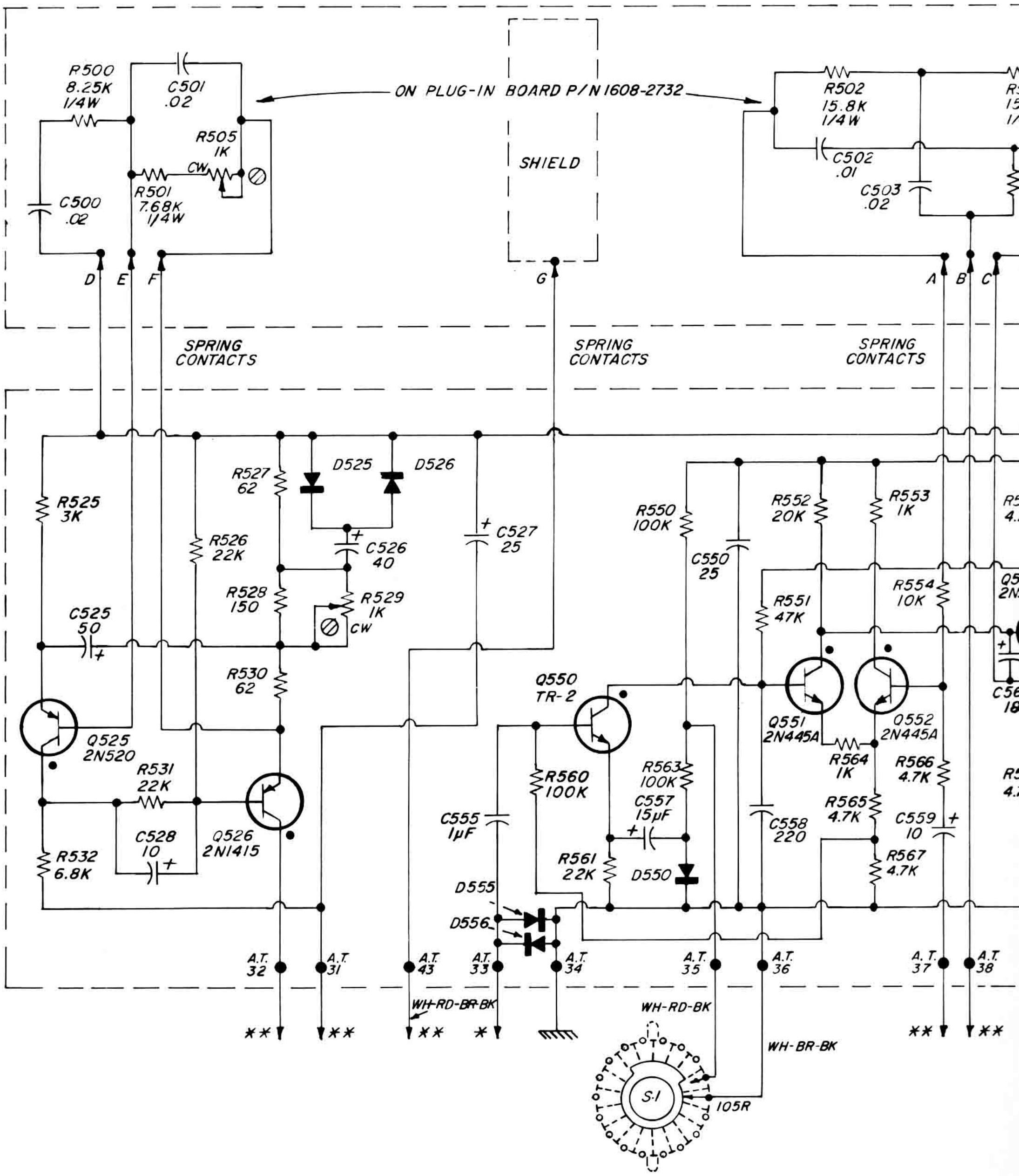


Figure 5-15. Etched-circuit board assembly, oscillator and detector (P/N 1608-2732).



R500
8.25K
1/4W
C501
.02
ON PLUG-IN BOARD P/N 1608-2732
R502
15.8K
1/4W
R505
1K
CW
R501
7.68K
1/4W
C500
.02
SHIELD
C502
.01
C503
.02
D
E
F
G
A
B
C
SPRING
CONTACTS
SPRING
CONTACTS
SPRING
CONTACTS
R527
62
D525
D526
R525
3K
R526
22K
C526
40
C527
25
R550
100K
C550
25
R552
20K
R553
1K
R528
150
R529
1K
CW
R551
47K
R554
10K
C525
50
R530
62
Q550
TR-2
Q551
2N445A
Q552
2N445A
Q525
2N520
R531
22K
R560
100K
R563
100K
C557
15μF
R564
1K
R566
4.7K
C528
10
Q526
2N1415
C555
1μF
C558
220
R565
4.7K
C559
10
R532
6.8K
R561
22K
D550
R567
4.7K
D555
D556
A.T. 32
A.T. 31
A.T. 43
A.T. 33
A.T. 34
A.T. 35
A.T. 36
A.T. 37
A.T. 38
WH-RD-BR-BK
WH-RD-BK
WH-BR-BK
S-1
105R
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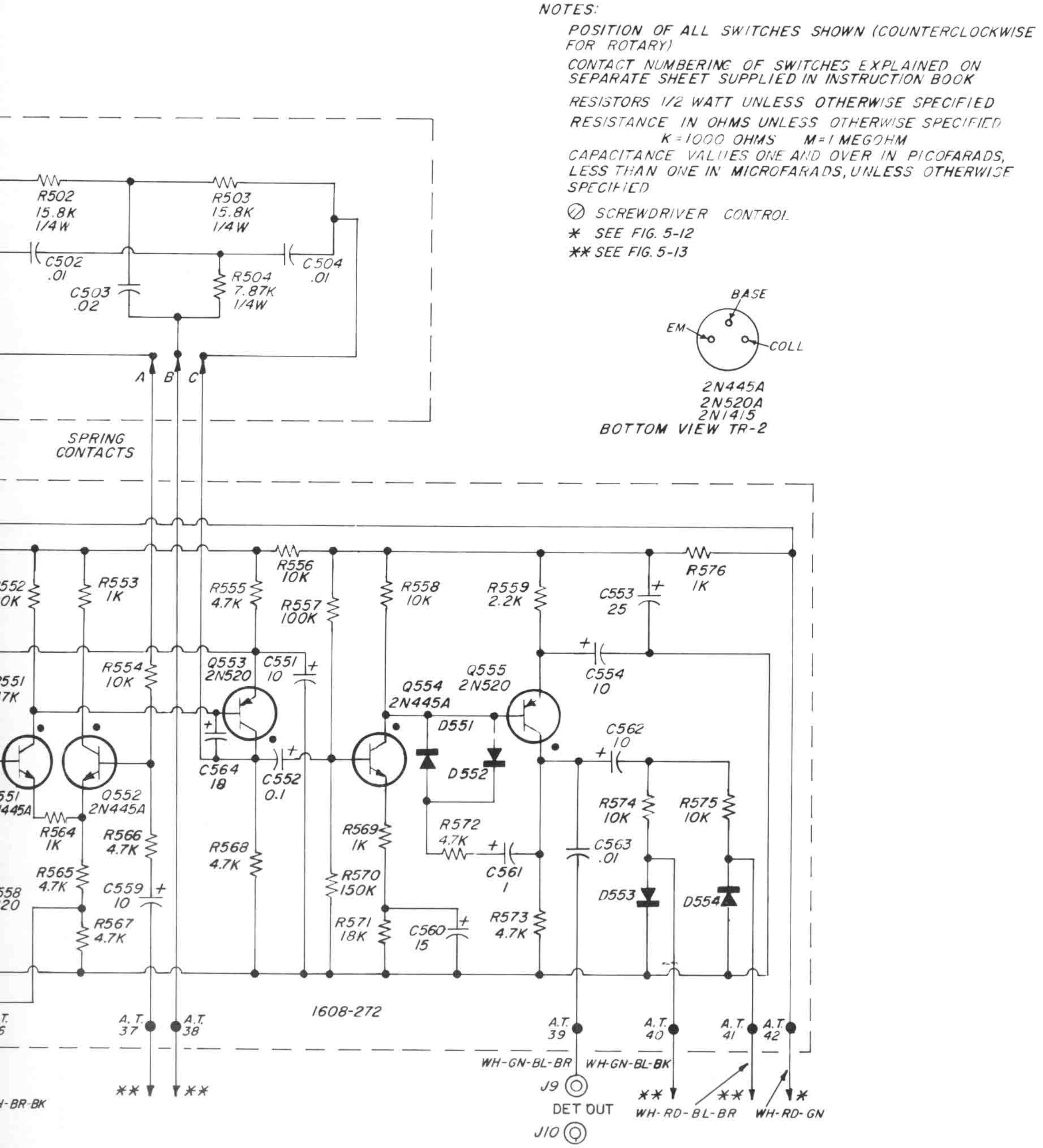

NOTES:

POSITION OF ALL SWITCHES SHOWN (COUNTERCLOCKWISE FOR ROTARY)

CONTACT NUMBERING OF SWITCHES EXPLAINED ON SEPARATE SHEET SUPPLIED IN INSTRUCTION BOOK

RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED

RESISTANCE IN OHMS UNLESS OTHERWISE SPECIFIED
K = 1000 OHMS M = 1 MEGOHM

CAPACITANCE VALUES ONE AND OVER IN PICOFARADS, LESS THAN ONE IN MICROFARADS, UNLESS OTHERWISE SPECIFIED

⊘ SCREWDRIVER CONTROL

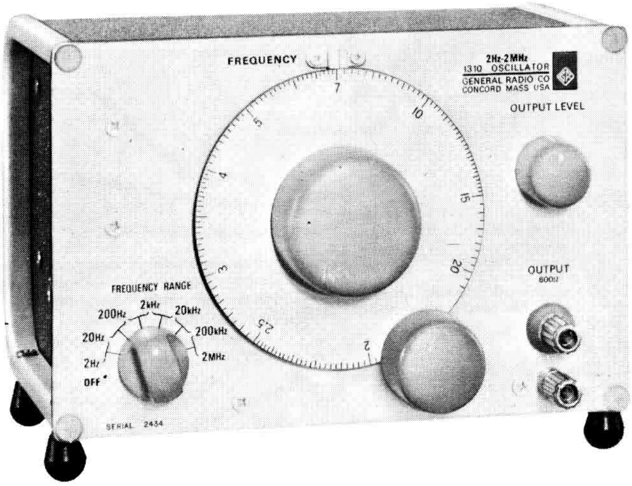
✱ SEE FIG. 5-12

✱✱ SEE FIG. 5-13

Figure 5-16. Oscillator and detector schematic diagram.

OSCILLATOR

Type 1310-A



- 2 Hz to 2 MHz
- 20-V, constant output, ±2%
- 0.25% distortion

The superior characteristics of this oscillator make it an exceptionally useful laboratory signal source.

Constant output over a very wide frequency range facilitates frequency-response measurements.

High-resolution dial and exceptional amplitude and frequency stability are important for measurements of filters and narrow-band devices.

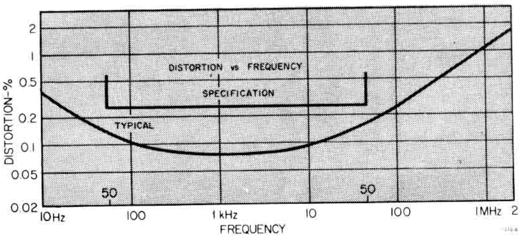
Equally useful in 600-ohm and 50-ohm circuits, since distortion is independent of load, even a short circuit.

When phase-locked to a frequency standard, the oscillator can deliver a high-level standard-frequency output with adjustable amplitude and low distortion.

DESCRIPTION

A capacitance-tuned, RC Wien-bridge oscillator drives a low-distortion output amplifier, which isolates the oscillator from the load and delivers a constant voltage behind 600 ohms.

A jack is provided for introduction of a synchronizing signal for phase locking or to furnish a signal, independent of the output attenuator setting, to operate a counter, or to synchronize an oscilloscope or another oscillator.



Seven transistors, one nuvistor, and ingenious design make the 1310-A Oscillator not only rugged, reliable, and insensitive to mechanical vibration but also compact and light in weight.

— See **GR Experimenter** for August 1965.

specifications

FREQUENCY

Range: 2 Hz to 2 MHz in 6 decade ranges. Overlap between ranges, 5%.

Accuracy: ±2% of setting.

Stability (typical at 1 kHz): Warmup drift, 0.1%. After warmup: 0.003% short term (10 min), 0.03% long term (12 h).

Controls: Continuously adjustable main dial covers decade range in 305°, vernier in 4 turns.

Synchronization: Frequency can be locked to external signal. Lock range ±3% per volt rms input up to 10 V. Frequency dial functions as phase adjustment.

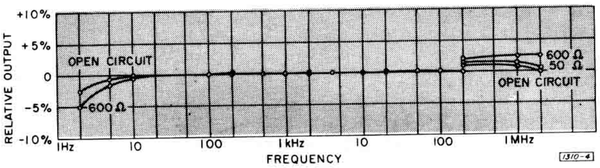
OUTPUT

Voltage: >20 V open circuit.

Power: >160 mW into 600 Ω.

Impedance: 600 Ω. One terminal grounded.

Attenuation: Continuously adjustable attenuator with >46-dB range.



Distortion: <0.25%, 50 Hz to 50 kHz with any linear load. Oscillator will drive a short circuit without clipping.

Hum: <0.02%, independent of attenuator setting.

Amplitude vs Frequency: ±2%, 20 Hz to 200 kHz, into open circuit or 600-Ω load.

Synchronization: Constant-amplitude (0.8-V), high-impedance (27-kΩ) output to drive counter or oscilloscope.

GENERAL

Power Required: 105 to 125, 195 to 235, or 210 to 250 V, 50 to 400 Hz, 12 W.

Terminals: Output, GR 938 Binding Posts; sync, side-panel telephone jack.

Accessories Supplied: Power cord, spare fuses.

Accessories Available: Adaptor cable 1560-P95 (telephone plug to double plug); rack-adaptor set.

Mounting: Convertible-bench cabinet.

Dimensions (width x height x depth): 8 x 6 x 8⅛ in. (205 x 155 x 210 mm).

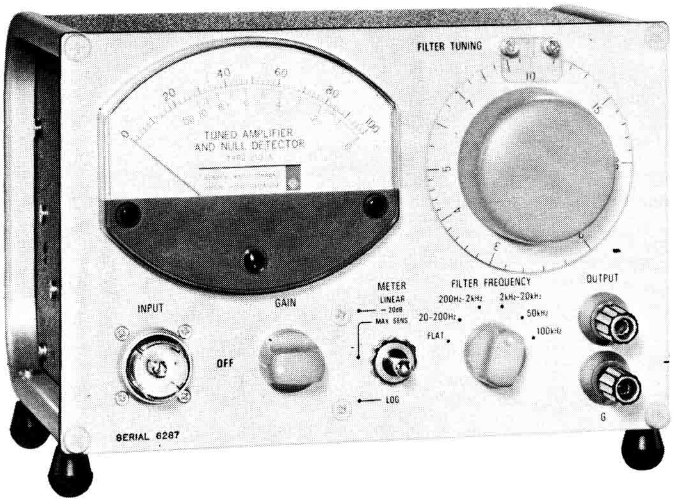
Weight: Net, 7¾ lb (3.6 kg); shipping, 10 lb (4.6 kg).

Catalog Number	Description
1310-9701	**1310-A Oscillator**
1560-9695	**1560-P95 Adaptor Cable**
0480-9838	**480-P308 Rack-Adaptor Set**

TUNED AMPLIFIER AND NULL DETECTOR

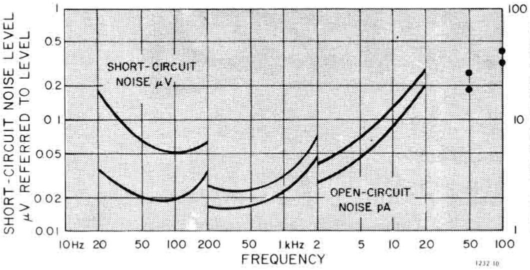
Type 1232-A

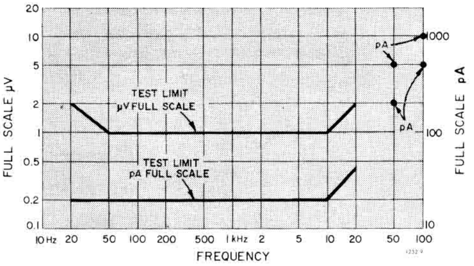
- 20 Hz to 20 kHz, 50 and 100 kHz
- 0.1-μV sensitivity
- bandwidth approx 5%
- 120-dB gain



This battery-operated, solid-state amplifier will excel in common applications and fit many unusual requirements with its combined high sensitivity, low noise, choice of narrow or broad bandwidth, high gain, portability, and accessories for added versatility. Use it as a

- bridge detector at audio frequencies; with the 1232-P2 Preamplifier it is equally sensitive for extremely high-impedance, low-frequency balances. With the 1232-P1 RF Mixer it is a sensitive, heterodyne, rf detector to 10 MHz with excellent harmonic rejection.
- audio preamplifier and general-purpose, tunable or broadband audio amplifier
- a-m detector for 0.5- to 500-MHz carrier frequencies when used with an 874-VQ Voltmeter Detector;
- sensitive audio wave analyzer for approximate measurements.





(Left) Typical noise levels as a function of frequency. (Right) Minimum input for full-scale meter deflection as a function of frequency, when amplifier is tuned to peak response.

specifications

Frequency Response:

Tunable Filters — 20 Hz to 20 kHz in 3 ranges; between 2% and 6% bandwidth to 15 kHz; 2nd harmonic at least 34 dB down from peak, 3rd at least 40 dB down; rejection filter on two highest ranges reduces 60-Hz level to at least 60 dB below peak (50 dB at 50 Hz). Dial accuracy is ±3%.

50- and 100-kHz Filters — 2nd harmonic 44 and 53 dB down, respectively.

Flat Response — ±3 dB 20 Hz to 100 kHz.

Sensitivity: See plot. Typically better than 0.1 μV over most of the frequency range.

Noise Level Referred to Input: See plot. Noise figure at 1 kHz is less than 2 dB at an optimum source impedance of 27 kΩ.

Noise Level Referred to Output: Less than 5 mV on FLAT filter-frequency position, min gain setting, and —20-dB switch position; less than 50 mV in MAX SENS position.

Input Impedance: Approx 50 kΩ at max gain; varies inversely with gain to 1 MΩ at min gain.

Max Safe Input Voltage: 200 V ac or 400 V dc.

Voltage Gain: Approx 120 dB on the tunable ranges; 100 dB, flat range; 106 dB at 50 kHz; 100 dB at 100-kHz position.

Output: 1 V into 10,000 Ω. Internal impedance is 3000 Ω.

Meter Linearity: DB differences are accurate to ±5% ±0.1 division for input of less than 0.3 V.

Compression (on LOG position): Reduces full-scale sensitivity by 40 dB. Does not affect bottom 20% of scale.

20-dB Position: Reduces gain by 20 dB in linear mode.

Distortion (in FLAT position): Less than 5% (from meter rectifiers).

Power Supply: 12 V dc, from 9 mercury (M72) cells in series. Est battery life 1500 hours. Optionally, a rechargeable battery (non-mercury) can be supplied on special order.

Accessories Available: 1232-P1 RF Mixer for heterodyne operation to 10 MHz; 1232-P2 Preamplifier to maintain sensitivity of 1232-A at low frequencies when operating from a source impedance above 100 kΩ; rack-adaptor sets (see below) convert 1232 and companion instruments to 19-in. rack-mount width.

Terminals: Input, GR874 coaxial connector; output, binding posts.

Mounting: Convertible-Bench Cabinet.

Dimensions (width x height x depth): 8 x 6 x 7½ in. (205 x 155 x 190 mm).

Weight: Net, 5¾ lb (2.7 kg); shipping, 8 lb (3.7 kg).

Catalog Number	Description
1232-9701	**1232-A Tuned Amplifier and Null Detector**
1232-9829	**1232-AP Tuned Amplifier and Null Detector,** with preamplifier
	Rack-Adaptor Sets
0480-9838	**480-P308,** for 1232-A alone
0480-9836	**480-P316,** for 1232-A with 1310 or 1311 oscillator or similar 8-in. wide instrument with convertible-bench cabinet
0480-9837	**480-P317,** for 1232-AP (with preamp) and companion 8-in. instrument

STANDARD RESISTOR

Type 1440

- accuracy ±0.01%
- stability ±10 ppm per year
- low thermal emf to copper

These extremely stable resistors are intended for use as laboratory or production standards for calibrating resistance bridges and for substitution measurements.

They are card-type, wire-wound resistors, carefully wound and adjusted. Low-temperature-coefficient Evanohm* wire is used for values above 10 ohms, manganin for the lower-resistance units. All units are heat cycled to reduce strains and are repeatedly checked to eliminate any that show abnormal behavior. They are encased in sealed, oil-filled, diallylphthalate boxes to promote long-term stability and to provide mechanical protection.

The 1440 resistors have low-thermal-emf binding posts and removable banana plugs to provide the four terminals necessary for accurate measurements at low values of resistance. A label on the reverse side lists initial calibration and date, space for future calibration data, and serial number. — See **GR Experimenter** for October 1965.

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* Registered trademark of the Wilbur B. Driver Company.

specifications

Accuracy: ±0.01% for all units except those of 1 Ω, which are ±0.02%. This accuracy is guaranteed for our standard warranty period of two years, unless the resistor has been damaged by excessive current. Measurements on the low-value units should be made with a four-terminal connection. All measurements at 23°C.

Calibration Accuracy: Resistors are calibrated by comparison, to a precision of ±20 ppm, with working standards whose absolute values are known typically to ±10 ppm as determined and measured in terms of reference standards periodically measured by the National Bureau of Standards. The measured deviation from nominal value, at 23°C and 0.01 watt, is entered on the label on the reverse side of the resistor.

Stability: Typically ±10 ppm per year.

Temperature Coefficient (Max): ±10 ppm/°C for resistances above 10 Ω; ±20 ppm/°C for 10 Ω and below.

Power Rating: 1 W. The corresponding current is indicated on the resistor and in the table below. This dissipation will cause a temperature rise of approx 25°C and a resulting temporary resistance change due to the temperature coefficient. If this rating is exceeded, permanent changes may result.

Residual Impedances: Approx shunt capacitance (2-terminal measurement), 2.5 pF; less for 3-terminal measurement. Typical series inductance, see table.

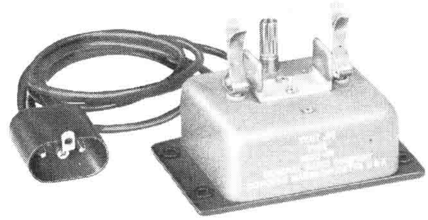
Approx Frequency Characteristic: See table.

Terminals: Gold-plated jack-top copper binding posts (¾-in. spacing) with banana plugs that are removable and can be replaced by 6-32 screws for installation of soldering lugs.

Dimensions (less terminals): 2¼ x 2$\frac{15}{32}$ x $\frac{11}{32}$ in. (58 x 64 x 10 mm).

Net Weight (approx): 2 oz (60 g).

Catalog Number	Resistance	Max Current	Typical Inductance	Approx Frequency for 0.1% Resistance Change	
				Series R	Parallel R
1440-9601	1 Ω	1.0 A	0.12 μH	300 kHz	30 kHz
1440-9611	10 Ω	310 mA	0.13 μH	1 MHz	300 kHz
1440-9621	100 Ω	100 mA	0.20 μH	3 MHz	1 MHz
1440-9631	1 kΩ	30 mA	2.5 μH	2 MHz	1 MHz
1440-9641	10 kΩ	10 mA		200 kHz	1 MHz
1440-9651	100 kΩ	3 mA		20 kHz	100 kHz
1440-9661	1 MΩ	1 mA		2 kHz	10 kHz



TEST JIG

Type 1650-P1

This test-jig adaptor is used to connect components quickly to a pair of terminals and can be placed on the bench directly in front of the operator. Thus, the test jig and 1650-B or 1608-A Impedance Bridge make a rapid and efficient component sorting device when the panel meter of the bridge is used as a limit indicator.

The test jig makes a three-terminal connection to the bridge, so that the residual zero capacitance is negligible. The lead resistance (0.08 ohm total) has effect only when very low impedances are measured, and the lead capacitance affects only the measurement of the Q of inductors, introducing a small error in D $\left(\text{or } \frac{1}{Q}\right)$ of less than 0.007.

Weight: Net, 10 oz (285 grams); shipping, 4 lb (1.9 kg).

Catalog Number	Description
1650-9601	**1650-P1 Test Jig**

STANDARD RESISTOR

Type 1440

- accuracy ±0.01%
- stability ±10 ppm per year
- low thermal emf to copper

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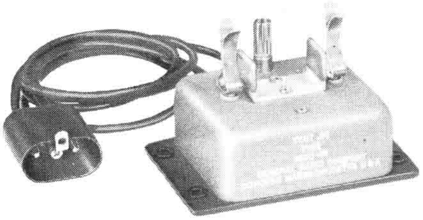

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Weight: Net, 10 oz (285 grams); shipping, 4 lb (1.9 kg).

Catalog Number	Description
1650-9601	**1650-P1 Test Jig**

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Printed in USA

October, 1973

CHANGE NOTICE

For

Instruction Manual

Type 1608-A Impedance Bridge

Form No. 1608-0100D

January, 1969

Please make the following changes as indicated to update your manual to reflect improved instrument accuracy (ID No. 2846 and higher):

<u>Specification Page:</u> Substitute the following:

Accuracy:

C, G, R, L

At 1 kHz: ±0.05% ±0.005% of full scale except on lowest R and L ranges and highest C and G ranges, where it is ±0.2% ±0.005% of full scale.

Additional error terms for high frequency and large phase angle:

C and L: $[\pm 0.001(f_{kHz})^2 \pm 0.1Df_{kHz} \pm 0.5D^2]\%$ of measured value.

R and G: $[\pm 0.002(f_{kHz})^2 \pm 10^{-6}(f_{kHz})^2 \pm 0.1Q]\%$ of measured value.

Residual Terminal Impedance: $R \cong 0.001\ \Omega$, $L \cong 0.15\ \mu H$, $C \cong 0.25$ pF.

The accuracy statement also appears in the following places:

Page 4.	Para. 1.5.1
Page 10.	Para. 2.3.2 line 2.
Page 13.	Para. 2.4.1.2 line 2.
	Para. 2.4.2.2 line 2.
Page 15.	Para. 2.4.3.2 line 2.
Page 31.	Para. 5.2.1 line 9 change 1409-T calibration from ±0.03% to "should be ±0.01%."
Page 32.	Para. 5.2.1 step a (cont), change error from 0.05% to 0.025%. step c line 5, change 1409 value from .01 μF to 0.1 μF.
Page 44.	Make the following substitutions: Transistor Q301 was Type 2N445-A now 2N1308.
Page 48.	Make the following substitutions: Transistors Q551/Q552/Q554 were Type 2N445-A now 2N1308. Transistors Q525/Q553/Q555 were Type 2N520-A now 2N1377.

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