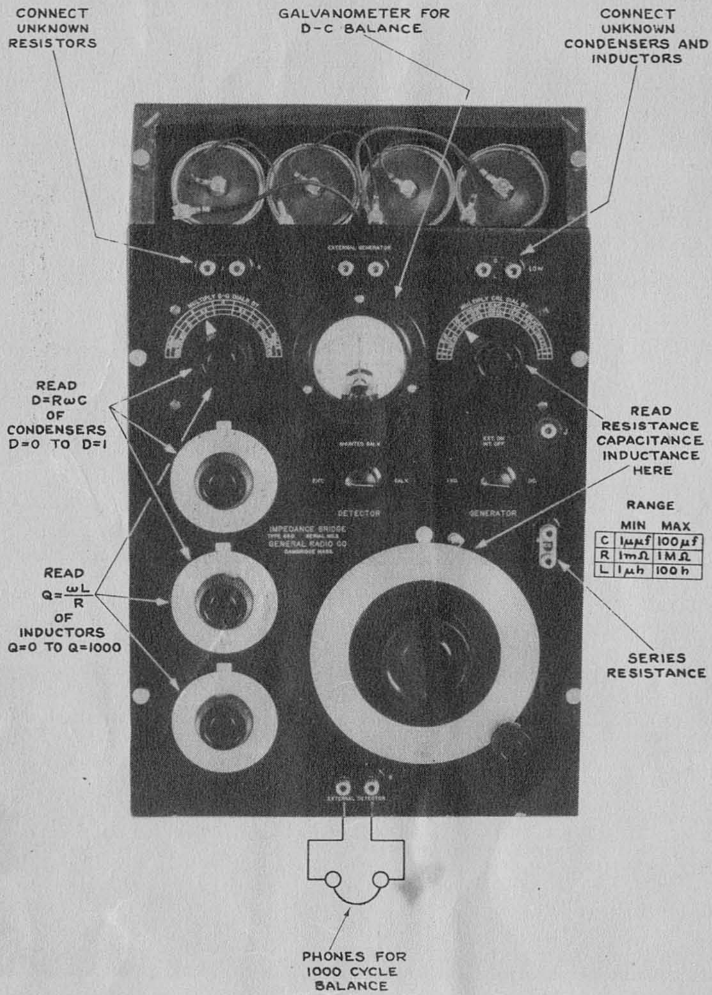
OPERATING INSTRUCTIONS FOR TYPE 650-A IMPEDANCE BRIDGE

FORM 346-B

GENERAL RADIO COMPANY
CAMBRIDGE A, MASSACHUSETTS



Frontispiece. This photograph of the panel supplies sufficient information for operating the Type 650-A Impedance Bridge. More detailed instructions are given in Part 3 of this booklet.

TABLE OF CONTENTS

OPERATING INSTRUCTIONS
FOR
TYPE 650-A
IMPEDANCE
BRIDGE

PART 1
PURPOSE

GENERAL The Type 650-A Impedance Bridge is a direct-reading, self-contained bridge for making the following types of measurements rapidly and conveniently:

a) Resistors
   1. Direct-current resistance
   2. Alternating-current resistance at 1000 cycles

b) Condensers
   1. Capacitance at 1000 cycles
   2. Dissipation factor (RωC) at 1000 cycles

c) Inductors
   1. Inductance at 1000 cycles
   2. Energy factor $Q = \frac{\omega L}{R}$ at 1000 cycles

RANGE AND ACCURACY The ranges over which measurements can be made together with the accuracies that can be expected in normal use are summarized in Table I.

SYMBOLS AND ABBREVIATIONS The following symbols and abbreviations used on the bridge and in this instruction book are those given in the 1933 Report of the Standards Committee of the Institute of Radio Engineers. Table II shows the significance of these symbols.

TABLE II
RESISTANCE

1 Ω = 1 ohm
1 kΩ = 1 kilohm = 1000 ohms = .001 MΩ
1 MΩ = 1 megohm = 1,000,000 ohms = 1000 kΩ
1 mΩ = 1 milliohm = 0.001 ohm

CAPACITANCE

1 μf = 1 microfarad
1 mμf = 1 millimicrofarad = 0.001 μf = 1000 μμf
1 μμf = 1 micromicrofarad = 1 μf x 10^{-6} = 0.001 mμf

INDUCTANCE

1 h = 1 henry
1 mh = 1 millihenry = 0.001 henry = 1000 μh
1 μh = 1 microhenry = 0.001 mh

TABLE I

Quantity	Range Minimum	Range Maximum	Error* Minimum	Error* Maximum
Resistance	1 mΩ	1 MΩ	1% or 2 mΩ	2%
Capacitance	1 μμf	100 μf	1% or 2 μμf	2%
Dissipation Factor	.002	1	5% or .005	15%
Inductance	1 μh	100 h	2% or 2 μh	10%
Energy Factor	.02	1000	5% or .5	15%

*These values define the limits between which the error will lie. For a discussion of the accuracies obtainable under various conditions of measurement, see Part 3, pages 2, 3, 4 and 5.

PART 2
INSTALLATION

ACCESSORIES SUPPLIED With each Type 650-A Impedance Bridge are supplied the following accessories:

1 type 274-M Plug for use with head telephones
3 spade-tipped connectors for interconnecting dry cells.

ACCESSORIES REQUIRED The following accessories are required in order to operate the bridge:

4 six-inch dry cells (Eveready No. 6, Burgess No. 7111 or equivalent).

1 pair head telephones for A-C measurements (Western Electric 1002C or equivalent in sensitivity and resistance).

POWER SUPPLY To install the four dry cells in the compartment at the back of the cabinet, proceed as follows:

1. Turn the GENERATOR switch to the EXT. ON, INT. OFF position.
2. Remove the cover.
3. Install the four dry cells as shown in the frontispiece.
4. Connect cells in series by means of the spade-tipped connectors and connect the terminals of the combination to the two spade-tipped leads. The red lead is positive, the black, negative.
5. Replace cover.

The bridge is now ready for operation.

PART 3
MEASUREMENTS IN THE DIRECT-READING RANGE

A. DIRECT-CURRENT RESISTANCE MEASUREMENTS

PROCEDURE To make direct-current resistance measurements, proceed in the following manner:

1. Check the zero of the galvanometer, setting the pointer exactly to zero by means of the zero adjusting screw.
2. Throw the DETECTOR switch to SHUNTED GALV.
3. Set GENERATOR switch on DC.
4. Set D-Q multiplier switch on R.
5. Connect unknown resistance to R terminals.
6. With the CRL dial set in the vicinity of one, turn the CRL switch in the direction to bring the galvanometer to zero, choosing that position which leaves the pointer to the left of zero.
7. Increase the setting of the CRL dial until the pointer is within one division of zero.
8. Throw DETECTOR switch to GALV. position.
9. Rebalance by means of CRL dial, bringing galvanometer indication to zero.
10. The reading of the CRL dial multiplied by the factor indicated by the CRL switch on the circular row R is the value of the resistance under measurement in the unit given.

EXAMPLE:

CRL dial	CRL switch	Resistance	
2.67	10Ω	26.7Ω	
2.67	10 kΩ	26700Ω	26.7 kΩ

ACCURACY The accuracy of these readings is 1% between 1.2 ohms and 100 kilohms, increasing to 2% at 1 megohm, when the CRL dial is set on its main decade between 1.0 and 10. The small decades below 1.0 are provided for convenience in obtaining an initial balance and to allow the measurement of small resistances. Their accuracy is determined by the spacing of their graduations. The zero resistance of the bridge may be measured by short-circuiting the R terminals. It is about 0.01 ohm. The short-circuiting bar should be a heavy copper wire securely clamped in the terminals. The resistance of the lead wires used in connecting an unknown resistor to the bridge may be measured by connecting their free ends together. By using such zero corrections resistances up to 0.2 ohm may be measured to 0.002 ohm and above 0.2 ohm to 1%.

For resistances between 100 kilohms and 1000 kilohms the sensitivity of the galvanometer is not sufficient to allow the bridge to be balanced to 1%. The use of an external 45-volt dry battery will provide sufficient power to raise the accuracy of setting to 1%. Connect this battery to the EXTERNAL GENERATOR terminals and throw the GENERATOR switch to EXT. ON. The maximum voltage which may be safely applied to the bridge for each setting of the CRL switch and the fraction of this battery voltage placed across the unknown resistor at balance is given in Table III below.

TABLE III

CRL Switch Row R	Arm B	Arm A	Ratio B/A	$\frac{B}{A + B}$	40°C Rise for A & B E Max.
.1Ω	1Ω	10,000Ω	0.0001	0.000100	71 volts
1 Ω	10Ω	10,000Ω	0.001	0.000999	73 "
10 Ω	100Ω	10,000Ω	0.01	0.00990	78 "
100 Ω	1,000Ω	10,000Ω	0.1	0.0909	93 "
1 kΩ	10,000Ω	10,000Ω	1	0.5	141 "
10 kΩ	100,000Ω	10,000Ω	10	0.909	200 "
100 kΩ	100,000Ω	1,000Ω	100	0.990	200 "

B. ALTERNATING-CURRENT RESISTANCE MEASUREMENTS

PROCEDURE To make 1000-cycle alternating-current resistance measurements, proceed in the following manner:

1. Set DETECTOR switch on EXT.

2. Connect unknown resistance to R terminals.

3. Set GENERATOR switch on 1 KC. A faint 1-kilocycle hum should be heard coming from the microphone hummer under the panel.

4. Connect a pair of head telephones to the EXTERNAL DETECTOR terminals. A loud 1-kilocycle tone will be heard in the telephones.

5. With the CRL dial set in the neighborhood of 1.0, turn the CRL switch in such a direction as to decrease the intensity of this tone, choosing that position which yields the least sound. Adjust the setting of the CRL dial until silence or minimum sound is obtained. If a balance cannot be obtained, change the setting of the CRL multiplier switch until a satisfactory balance is reached.

6. The resistance of the unknown resistor is the reading of the CRL dial multiplied by the factor indicated by the CRL switch on the circular row R.

ACCURACY The same accuracy statements that were given for direct-current resistance measurement hold for this measurement as well.

A good null balance can be obtained only when the unknown resistance has a small reactance comparable to that of the various resistors which make up the remainder of the bridge circuit, because for this connection the bridge has only one control. The criterion of a good null balance is that as the CRL dial is moved off balance the passage of the sliding contact over the individual wires may be detected. In general, this condition limits this type of measurement to resistors and resistance boxes.

When the unknown resistor has considerable reactance, a balance may be obtained by connecting a condenser across one of the bridge arms, as explained in Part 4-E, A-C RESISTANCE WITH REACTANCE.

C. CAPACITANCE MEASUREMENTS

PROCEDURE To make alternating-current capacitance measurements at 1000 cycles, proceed as follows:

1. Connect the unknown condenser to the CL terminals at the right with its shield (if any) connected to the LOW terminal.

2. Set the DQ switch on C-DQ and the DQ dial, which is then connected to the bridge, at zero.

3. Set the DETECTOR switch at EXT. and the GENERATOR switch at 1 KC. A faint 1-kilocycle hum should be heard coming from the microphone mounted below the panel. A loud 1-kilocycle note will be heard in the telephones.

4. Ground the bridge at any terminal marked G.

5. With the CRL dial set in the neighborhood of 1.0, turn the CRL switch in such a direction as to decrease the intensity of this note, choosing that position which yields the least sound.

6. Vary the CRL dial until minimum sound is obtained.

7. Increase the setting of the DQ dial to obtain a better minimum.

8. Alternately adjust the CRL and DQ dials until the setting of each is unchanged on further adjustment of the other. When the final balance is obtained, it is possible to detect the passage of the sliding contact over the individual wires if either dial is moved off balance. This condition should always be obtained for the CRL dial. It will be found that when the setting of the DQ dial is greater than 2 (a condition which seldom occurs), the successive settings of the CRL and DQ dials progress across the dials. This is because the two balances of the bridge are not independent. The number of successive settings which must be made before a good null balance is reached may be reduced by taking advantage of the orderly progression of the settings and slightly oversetting each one in the direction it will move the next time. When the true balance point is passed on one dial, the progression of the other dial in its next setting will be reversed.

9. The series capacitance of the unknown condenser is then given by the reading of the CRL dial multiplied by the factor indicated by the CRL switch on the circular row C. The parallel capacitance of the condenser may be calculated from the formula $C_P = \frac{C_S}{1 + D^2}$.

10. The dissipation factor D of the unknown condenser is the reading of the DQ dial multiplied by the factor indicated by the DQ switch on the circular row marked MULTIPLIER. If the setting of the DQ dial is less than one, greater accuracy may be attained by resetting the DQ switch at C-D and rebalancing the bridge by means of the D dial.

Dissipation factor is the ratio of resistance to reactance.

$$D = \frac{R}{X} = R\omega C$$

It may have any value from zero to infinity.

11. The series alternating-current resistance of the condenser may be calculated from the expression

$$R = \frac{D}{\omega C}$$

The frequency of the microphone hummer is 1.00 ± 0.05 kilocycle. The parallel resistance of the condenser may be calculated from the formula

$$R_P = \frac{1+D^2}{D^2} R_S = \frac{1+D^2}{D\omega C_S} = \frac{1}{D\omega C_P}$$

EXAMPLES:

CRL Dial	CRL Switch	Capacitance			
2.67	100µµf	267µµf	.267mµf	.000267µf	
2.67	1mµf	2670µµf	2.67mµf	.00267µf	
2.67	100mµf		267mµf	.267µf	
2.67	10µf			26.7µf	

DQ Dial	D Dial	D Switch	Dissipation Factor	
2.6		.1	.26	26%
	1.96	.01	.0196	1.96%

ACCURACY The accuracy of the capacitance readings is 1% between 1000 micromicrofarads and 10 microfarads, increasing to 2% at 100 microfarads, when the CRL dial is set on its main decade between 1.0 and 10. The small decades below 1.0 are provided for convenience in obtaining an initial balance and to allow the measurement of small capacitances. Their accuracy is determined by the spacing of their graduations. The zero capacitance of the bridge may be measured by leaving the CL terminals open. It is about 10 micromicrofarads. The capacitance of the lead wires used in connecting the unknown condenser to the bridge may be measured by disconnecting the lead running from the left CL terminal to the unshielded terminal of the condenser at the condenser, being careful not to alter the relative position of the leads. By using such zero corrections, capacitances up to 200 micromicrofarads may be measured to 2 micromicrofarads and above 200 micromicrofarads to 1%.

The accuracy of the dissipation factor readings is 15% or 0.005, whichever is the larger, for capacitances greater than 100 micromicrofarads. This relatively large error is due to the reactances of the ratio arms which change with settings of the CRL switch and dial.

D. INDUCTANCE MEASUREMENTS

PROCEDURE To make alternating-current inductance measurements at 1000 cycles, proceed as follows:

1. Connect the unknown inductor to the CL terminals at the right with the shield (if any) connected to the LOW terminal.

2. Set the DQ switch at L-DQ and the DQ dial at 10.

3. Set the DETECTOR and GENERATOR switches at the same points as for capacitance measurements (see above) and ground the bridge at any terminal marked G.

4. With the CRL dial set in the vicinity of 1.0, turn the CRL switch in such a direction as to decrease the intensity of the tone heard in the telephones, choosing that position which yields the least sound.

5. Turn the CRL dial so as to give minimum sound.

6. Turn the DQ dial until a better minimum is reached. If it appears necessary to increase the setting of the DQ dial above 10, reset the DQ switch at L-Q and rebalance the bridge by means of the Q dial.

7. Alternately adjust the CRL and DQ or Q dials until the setting of each is unchanged on further adjustment of the other. When a satisfactory null balance is reached, the passage of the sliding contact over the individual wires may be detected if either dial is moved off balance. This condition should always be attained for the CRL dial. It will be found that when the setting of the DQ dial is less than five, the successive settings of the CRL and DQ dials progress across the dials as pointed out under CAPACITANCE MEASUREMENTS, page 3.

8. The series inductance of the unknown inductor is the reading of the CRL dial multiplied by the factor indicated by the CRL switch on the circular row L. The parallel inductance of the inductor may be calculated from the formula

$$L_P = \frac{1+Q^2}{Q^2} L_S$$

9. The energy factor Q of the unknown inductor is the reading of the DQ or Q dial multiplied by the factor indicated by the DQ switch on the circular row marked MULTIPLIER. Energy factor is the ratio of reactance to resistance

$$Q = \frac{X}{R} = \frac{\omega L}{R} = \frac{1}{D}$$

It may have any value from zero to infinity. It is the reciprocal of the dissipation factor D.

10. The series alternating-current resistance of the inductor may be calcu-

lated from the expression

$$R = \frac{\omega L}{Q}$$

The frequency of the microphone hummer is 1.00 ± 0.05 kilocycle. The parallel resistance of the inductor may be calculated from the formula

$$R_P = (1+Q^2)R_S = Q(1+Q^2)\omega L_S = Q\omega L_P$$

EXAMPLES:

CRL Dial	CRL Switch	Inductance		
2.67	100 µh	267 µh	.267 mh	.000267h
2.67	1 mh	2670 µh	2.67 mh	.00267h
2.67	100 mh		267.mh	.267h
2.67	10 h			26.7h

DQ Dial	Q Dial	D-Q Switch	Energy Factor
2.6		1	2.6
	41	100	41.

ACCURACY The accuracy of the inductance readings is 2% between 50 microhenrys and 1 henry, increasing to 5% at 10 henrys and 10% at 100 henrys, when the CRL dial is set on its main decade between 1.0 and 10. The small decades below 1.0 are provided for convenience in obtaining an initial balance and to allow the measurement of small inductances. Their accuracy is determined by the spacing of their graduations. The zero inductance of the bridge may be measured by short-circuiting the CL terminals. It is less than 2 microhenrys and is, generally, negligible. The inductance of the lead wires used in connecting the unknown inductor to the bridge may be measured by connecting their free ends together, being careful not to alter the relative position of the leads. By using this zero correction, inductances up to 100 microhenrys may be measured to 2 microhenrys and above 100 microhenrys to 2%. The increasing error appearing as the inductance increases is caused by the effect of the capacitance to ground of the various parts of the bridge. These have a considerable effect when the reactance being measured is large.

The accuracy of the energy factor readings is 15% or 0.5, whichever is the larger, up to a Q of 30. Beyond that value the error increases in proportion to the value of Q. This relatively large error is due to the reactances of the ratio arms, which change with the settings of the CRL switch and dial.

SUMMARY Table IV below indicates the settings of the controls for the types of measurement just discussed.

TABLE IV
SUMMARY

Type of Measurement	Detector Switch	Generator Switch	CRL-Switch	D-Q Switch
D.C.Resistance	1. Shunted Galv. 2. Galv.	D.C.	As necessary for balance	R
1000-cycle Resistance	EXT*	1 KC	"	R
Inductance	EXT*	1 KC	"	L (Q or DQ)
Capacitance	EXT*	1 KC	"	C (D or DQ)

*Connect a pair of head telephones to the EXTERNAL DETECTOR terminals and balance for minimum sound.

PART 4
OTHER MEASUREMENTS

A. ACCESSORIES

AMPLIFIER The self-contained power supply consisting of four 1.5-volt dry cells for d-c measurements and a Type 572-B Microphone Hummer for 1000-cycle a-c measurements is sufficient for the attainment of the accuracies mentioned in PART 1 except as noted on page 2. For a-c measurements, the telephones must be of good quality, equivalent in sensitivity and resistance to W. E. telephones Type 1002-C. For less sensitive telephones, for greater accuracy of setting, or for greater ease and convenience in obtaining a balance, an amplifier is very useful. The General Radio Type 514-A Amplifier* is suitable.

*Consult the General Radio catalog for data.

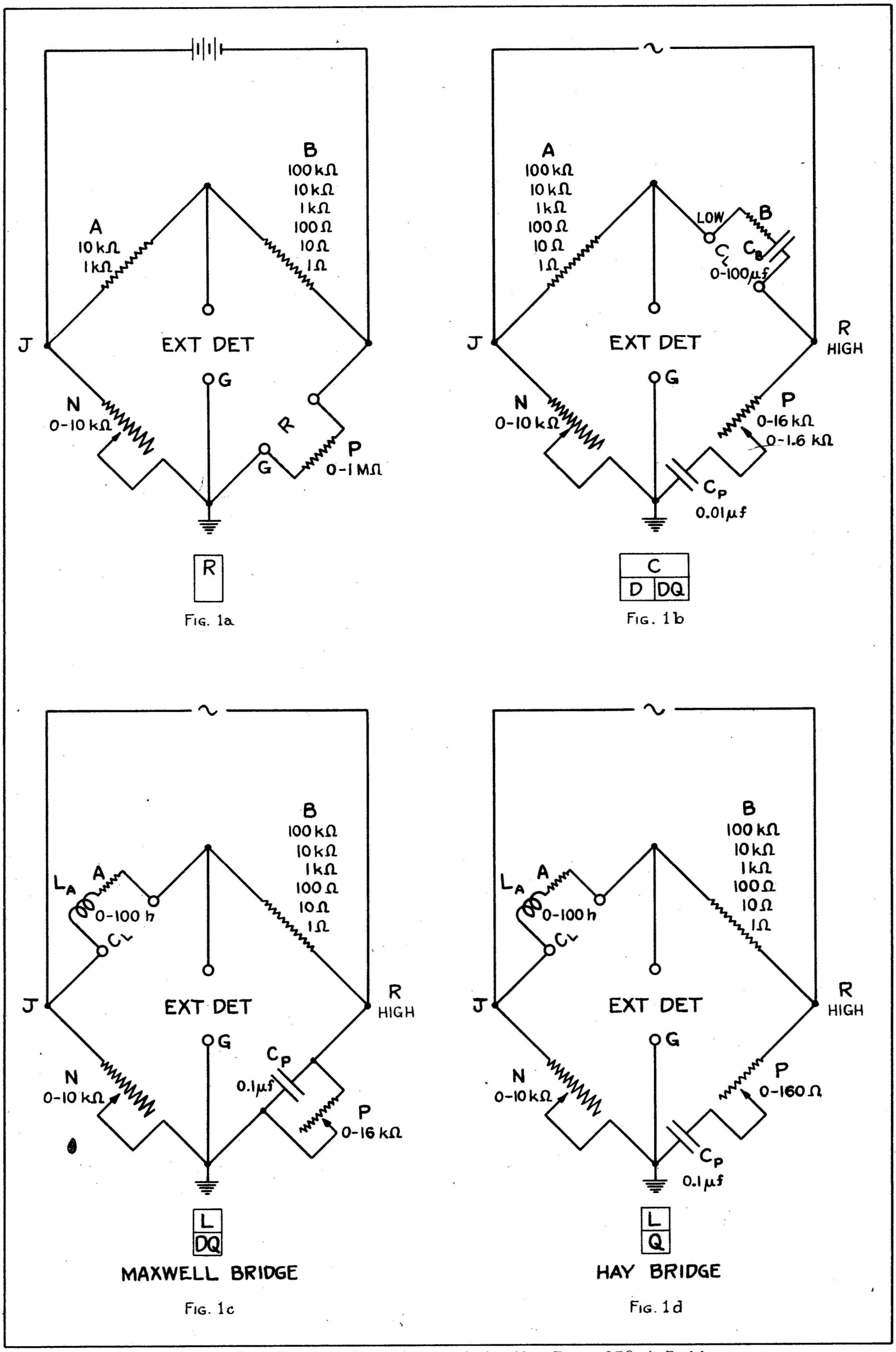


Figure 1. Basic circuits used in the Type 650-A Bridge.

TABLE V

CRL Switch C	row	L	A for C B for L	E max	I max
10 µf		100 µh	1Ω	0.7 volts	707 ma
1 µf		1 mh	10Ω	2.2 "	224 ma
100 mµf		10 mh	100Ω	7.1 "	71 ma
10 mµf		100 mh	1,000Ω	22.4 "	22 ma
1 mµf		1 h	10,000Ω	71 "	7 ma
100 mµf		10 h	100,000Ω	200 "	2 ma

FILTERS The harmonics introduced by high-loss condensers, iron-core inductors, and non-linear circuit elements such as copper-oxide rectifiers may be eliminated by the use of low-pass filters. Band-pass filters, obtainable as separate units or made up from low- and high-pass sections* will also eliminate the 60-cycle alternating-current hum induced in iron-core inductors and condensers of large physical dimensions. Type 330 Filter Sections† and Type 534 Band-Pass Filters† are available for these purposes.

B. VOLTAGE LIMITS

D-C RESISTANCE MEASUREMENTS An external battery may be used for direct-current measurements by connecting it to the EXTERNAL GENERATOR terminals and setting the GENERATOR switch at EXT. ON, as mentioned on page 2. Care must be taken that the voltage applied to the bridge does not exceed the limits of safe operation for the bridge elements.

Figure 1a shows the bridge circuit used for resistance measurements. The battery voltage is applied across the ratio arms and across the unknown in series with the CRL rheostat. The safe operating limits for the ratio arms are given in Table III, page 2, corresponding to a temperature rise of 40°C. Under these conditions 70 volts can be safely applied to the ratio arms. Two other conditions must also be met; first, the current through the CRL rheostat should not exceed 40 milliamperes, and second, the voltage across the unknown resistor should not exceed its rated operating value. Under some conditions, therefore, the voltage limit will depend on either or both of these factors.

A resistance of 60 ohms is connected in series with the bridge to protect the CRL rheostat when the zero resistance of the bridge is being determined. This limits the current drawn from the 6-volt internal battery or a 6-volt external battery to 100 milliamperes.

Table III, page 2, gives the resistance values of the ratio arms for all multiplier settings. The ratio $\frac{B}{A+B}$, which, at balance, is the fraction of the total battery voltage appearing across the unknown resistor, is also given.

A-C RESISTANCE MEASUREMENTS An external oscillator may be used by connecting it to the EXTERNAL GENERATOR terminals and setting the GENERATOR switch at EXT. ON. The voltage applied to the bridge must not exceed the limits of safe operation for the bridge elements. These are the same as those described for D-C RESISTANCE MEASUREMENTS. An oscillator having a maximum output of 0.5 watt may be used under all conditions.

CAPACITANCE AND INDUCTANCE MEASUREMENTS The maximum safe voltage for capacitance and inductance measurements is determined from a consideration of the bridge circuits used as shown in Figure 1b, for the former, and Figures 1c and 1d, for the latter. The voltage is applied across the ratio arm A or B in series with the unknown reactor, and also across the arm N containing the CRL rheostat in series with the standard condenser and one of the D-Q rheostats. The maximum voltage for ratio arms A or B is given in Table V. The maximum voltage for the standard condensers is 350 volts. The current ratings of the D-Q rheostats are given in Table VI.

TABLE VI

Rheostat	R max	I max	R
CRL	11.5 kΩ	40 ma	setting (kΩ)
D	1.6 kΩ	80 ma	.1592 x setting (kΩ)
DQ	16 kΩ	25 ma	1.592 x setting (kΩ)
Q	.16kΩ	250 ma	.01592 ÷ setting (kΩ)

C. GROUND CAPACITANCE ERRORS

INTERNAL GENERATOR Ground capacitances appearing across the various arms of the bridge introduce

*Robert F. Field, "Eliminating Harmonics in Bridge Measurements" General Radio Experimenter, VI, December, 1931.

†Consult the General Radio catalog for data.

errors in the reading of the D-Q dials when they are across resistances, and in the reading of the CRL dial when they are across the standard condenser. When using the internal generator these errors are negligible for the CRL dial, but may amount to 15%, in certain cases, for the D-Q dials, as stated in Part 3-C and 3-D under ACCURACY.

The error in dissipation factor or energy factor may be corrected by making the energy factors of the two ratio arms equal, by adding capacitance across that arm having the lower energy factor. Since, however, one ratio arm is continuously variable, equality of energy factor may be obtained only for a particular setting. The correct value of this added capacitance may be found by measuring a standard reactor of known dissipation or energy factor.

Since the junction of the CRL rheostat and the standard condenser is grounded, these ground capacitances are placed across this rheostat and the standard condenser. This causes the bridge to read low on capacitance, inductance and dissipation factor, and high on energy factor.

The fractional error in capacitance and inductance is the ratio of the ground capacitance placed across the standard condenser to the capacitance of the standard condenser. The error in dissipation factor and energy factor is the product $R\omega C$, where C is the ground capacitance placed across and R is the resistance of the CRL rheostat. The error in dissipation and energy factor caused by the presence of ground capacitance across the standard condenser is usually negligible.

EXTERNAL GENERATOR An external generator always has a considerable ground capacitance. The division of capacitance between its terminals may be determined by the effect of the use of such an oscillator on the measurement of a condenser which has been previously measured with the internal power supply.

When one terminal of the oscillator is grounded to its panel, almost the entire ground capacitance is associated with the grounded terminal and will affect only one arm of the bridge. Under these conditions, representative values of ground capacitance are 30 µµf for a battery-operated oscillator and 300 µµf for an a-c operated oscillator, the increase representing the interwinding capacitance of the power-supply transformer. In general, the oscillator should be so connected to the bridge that this capacitance is placed across the arm containing the standard condenser. The errors introduced in the reading of the CRL dial range from 0.03% for a battery-operated oscillator and an inductance measurement to 3.0% for an a-c operated oscillator and a capacitance measurement.

SHIELDED TRANSFORMER The use of a shielded transformer between oscillator and bridge will suppress the effect of the ground capacitances of the oscillator, but will introduce similar effects on its own. The Type 578-A Shielded Transformer is recommended for this use. Its terminal capacitances may be made equal and of a value of 15 µµf each, or the whole capacitance of 30 µµf may be associated with either terminal. The errors which it will introduce will be comparable with those of a battery-operated oscillator. For 60-cycle measurements the 2400-turn winding of this transformer may be connected directly to the 115-volt supply. Head telephones cannot be used at 60 cycles because of their lack of sensitivity. A Type 514-A Amplifier and Type 488-DM Oxide-Rectifier Voltmeter are recommended.*

D. EXTENSION OF RANGE

FREQUENCY The reading of the CRL dial is independent of frequency but, since both dissipation factor and energy factor depend upon frequency, multiplying factors must be applied to the readings of the D-Q dials. Dissipation factor at any frequency is the observed value of D multiplied by the frequency expressed in kilocycles. Energy factor at any frequency is the observed value as obtained from the DQ dial multiplied by, or the observed value as obtained from the Q dial divided by the frequency expressed in kilocycles.

The resistances used in these three rheostats are chosen to give the ranges stated in Table I at 1 kc. At lower frequencies the upper limit for dissipation factor will be less than unity, and for energy factor the DQ and Q dials will not overlap. At higher frequencies the ranges of all rheostats will be more than sufficient to overlap.

An additional rheostat may be placed in series with the D or DQ rheostat for the measurement of dissipation factor by connecting it to the SERIES RES terminals, the short-circuiting link being removed. The values needed in order to maintain the ranges of the D and DQ dials at different frequencies are given in Table VII. Dissipation factor is calculated from the expression D=0.0628 fR (kilocycles, kilohms). The readings of this added resistor and of the D or DQ dial are additive when expressed in the same units.

*See General Radio catalog for data.

TABLE VII

Values of Resistance needed for given values of D, Q, and f

DIAL	D	DQ	DQ	Q
f	D = 0.1	D = 1	Q = 10	Q = 10
0.01 kc	160 kΩ	1600 kΩ	1600 kΩ	16 kΩ
0.02 kc	80 kΩ	800 kΩ	800 kΩ	8 kΩ
0.05 kc	32 kΩ	320 kΩ	320 kΩ	3.2 kΩ
0.1 kc	16 kΩ	160 kΩ	160 kΩ	1.6 kΩ
0.2 kc	8 kΩ	80 kΩ	80 kΩ	.8 kΩ
0.5 kc	3.2 kΩ	32 kΩ	32 kΩ	.32 kΩ
1 kc	1.6 kΩ	16 kΩ	16 kΩ	.16 kΩ
2 kc	.8 kΩ	8 kΩ	8 kΩ	.08 kΩ
5 kc	.32 kΩ	3.2 kΩ	3.2 kΩ	.032 kΩ
10 kc	.16 kΩ	1.6 kΩ	1.6 kΩ	.C16 kΩ

When the DQ and Q dials do not overlap for the determination of energy factor at frequencies lower than 1 kc, the DQ dial must be replaced by a resistor of more than 16 kΩ connected across the R terminals, the D-Q switch being turned to L-Q and the Q dial turned to maximum. Energy factor is calculated from the expression Q = .0628 fR (kilocycles, kilohms).

Under the same conditions the Q dial must be replaced by a resistor of more than 160Ω connected across the SERIES RES terminals. For values of $Q > 10$ the simple expression for energy factor may be used,

$$Q = \frac{1.592}{fR} \text{ (kilocycles, kilohms).}$$

Type 526 Mounted Rheostats are recommended as these added resistors.*

E. SPECIAL APPLICATIONS

A-C RESISTANCE WITH REACTANCE — A resistance having considerable reactance, such as a transmission line or electrolytic cell, may be measured by connecting it to the R terminals as described in Part 3-B. The resistance component is obtained from the reading of the CRL dial. The reactance component is balanced out by means of a condenser placed across one of the bridge arms. All four corners of the bridge are available, being brought out to the pairs of terminals, EXT DET high and G, R high and G, and the single terminal J, as shown in Figure 1a. The energy factor of the unknown impedance is in all cases of the form $R\omega C$, where R is the resistance of the arm across which the capacitance C is placed. The kind of reactance which may be measured in this manner and the terminals across which the added condenser is placed are shown in Table VIII. The resistances, as obtained from the reading of the CRL dial, are series for the condenser across arm A and parallel for the other positions. The formulae given in Parts 3-C-10 & 11 and 3-D-8 & 9 may be used for calculating other resistances not obtained directly.

For the fourth position the bridge is used as a parallel resonance bridge. It is equally possible to balance out the inductive reactance by connecting the added condenser in series with the unknown impedance, thus forming a series resonance bridge. The arm P is made a pure resistance, whose value is obtained from the reading of the CRL dial. The series inductance is calculated from the formula

$$L = \frac{1}{\omega^2 C}$$

*See the General Radio catalog for data.

TABLE VIII

Arm	Terminals	Resistance	Q	Reactance
A	EXT DET high & J	Series	$A\omega C_A$	+ or L
B	EXT DET high & R high	Parallel	$B\omega C_B$	- or C
N	EXT DET G & J	Parallel	$N\omega C_N$	- or C
P	R high & R G	Parallel	$P\omega C_P$	+ or L
P	In series	Series		+ or L

NATURAL FREQUENCY The natural frequency of a tuned circuit or inductor may be found by using an oscillator whose frequency is continuously variable, such as the Type 613-B and 713-A Beat-Frequency Oscillators.* The unknown impedance is connected to the R terminals as described in Part 3-B. The bridge is balanced by means of the CRL switch and dial and by varying the oscillator frequency. This is best accomplished by using a Type 514-A Amplifier and Type 488-DM Oxide-Rectifier Voltmeter.* The reading of the CRL dial gives the parallel resistance of the unknown impedance. Whatever capacitance exists across the R terminals due to the bridge wiring is added to that of the inductor being measured and lowers its natural frequency.

PARALLEL INDUCTANCE AND RESISTANCE The parallel inductance and resistance of an unknown inductor, such as an iron-core choke coil or transformer, may be found by setting the D-Q switch at L-Q, and the Q dial at infinity. An additional resistor is inserted at the SERIES RESISTANCE terminals. The parallel inductance is read directly from the CRL dial and switch in the usual manner. The parallel resistance is the ratio of the resistance of the ratio arm controlled by the CRL switch to the added resistance multiplied by 1000 times the reading of the CRL dial. When the added resistance is less than 160 ohms, the Q rheostat itself may be used. Its resistance is given in Table VI. Type 526 Mounted Rheostats* are recommended as this added resistance.

PARALLEL CAPACITANCE AND RESISTANCE The parallel capacitance and resistance of an unknown condenser may be found by setting the D-Q switch at either C-D or C-DQ and the D or DQ dials at zero. An additional resistor is connected across the R terminals. The parallel capacitance is read directly from the CRL dial and switch in the usual manner; and the parallel resistance is the value of the added resistance multiplied by the resistance of the ratio arm controlled by the CRL switch, as given in Table V, and divided by 1000 times the readings of the CRL dial. Type 526 Mounted Rheostats* are recommended as this added resistance.

D-C POLARIZING VOLTAGE FOR CONDENSERS A d-c polarizing voltage may be applied to electrolytic condensers in two ways, depending on whether the internal or an external power supply is used. For the internal microphone hummer, the polarizing battery must be connected in series with the condenser being measured. It should be connected with its positive side to the right, CL terminal marked EXT DET and its negative side to the negative terminal of the electrolytic condenser. Not more than 200 volts should be used. The leakage current may be measured by a milliammeter connected between the battery and the right CL terminal. For an external oscillator, the direct-current polarizing battery may be placed as just ~~discussed~~ or in series with the oscillator. Its capacitance to ground is added to whichever side of the oscillator it is connected.

*See the General Radio catalog for data.

D-C MAGNETIZING CURRENT FOR IRON-CORE COILS A d-c magnetizing current may be obtained for an iron-core choke coil by connecting a battery in series with a choke coil having a low direct-current resistance across the EXTERNAL DETECTOR terminals in parallel with the telephones. Types 166, 359, 666 Transformers* are suitable for this purpose. The magnetizing current may be read on an ammeter placed in series with the battery. For the L-Q setting of the D-Q switch (Q>10) all the battery current passes through the unknown inductor. For the L-DQ setting there is a second path through the ratio arm controlled by the CRL switch and the DQ rheostat. The resistance of this path will usually be high compared to that of the circuit through the unknown inductor and CRL rheostat. The actual resistances of these paths may be calculated from Table V and the settings of these rheostats. In case of doubt, the ammeter and, for that matter, the battery may be placed in series with the unknown inductor in the lead connected to the CL terminal marked LOW. Their resistance and inductance will be negligible compared to those of inductors being measured. The maximum magnetizing current is 40 ma.

DIRECT CAPACITANCE The direct capacitance† of a three terminal condenser may be measured by connecting the terminals of the direct capacitance desired across the CL terminals and the third terminal, usually the shield, to any terminal marked G. Of the other two direct capacitances in the network, one is placed across the detector and the other across the standard condenser. The error thus introduced is usually negligible because of the size of the standard condenser, 0.01 µf, being only 1% for 100 µµf. A zero reading for the purpose of

†Robert F. Field, "Direct Capacitance and its Measurement" General Radio EXPERIMENTER, VIII, November, 1933.

eliminating the zero capacitance across the CL terminals is taken by disconnecting the lead to the high CL terminal, leaving the other two leads connected.

Because neither of the CL terminals is grounded, every capacitance measured on the bridge is a direct capacitance in the sense that the capacitances of both terminals to ground are eliminated. It is, therefore, possible to measure the direct capacitance between two unshielded terminals, each having a capacitance to ground.

TERMINAL CAPACITANCE The terminal capacitances between the terminals of an inductor and its shield may be measured by connecting the terminal whose capacitance is desired to the CL terminal marked LOW, the other terminal to any terminal marked G and the shield to the high CL terminal. The other terminal capacitance and the ground capacitance of the shield are placed across the standard condenser. The error thus introduced may amount to 5%, for terminal capacitances of 500 μμf are not uncommon in shielded transformers. The reactance of the inductor is placed across the detector and must not be so low as to seriously impair the sensitivity of the bridge balance. The second terminal capacitance may be measured by reversing the connections to the inductor. The capacitances thus measured are equal to the true terminal capacitances, which depend upon the relation of the shield potential to that of the terminals, only when they are concentrated at the terminals. This condition usually exists in multilayer coils because only the capacitances of the two end layers are effective.

PART 5
ELECTRICAL CIRCUITS

GENERAL The Type 650-A Impedance Bridge uses conventional bridge circuits of various forms. All adjustable circuit elements are resistances which vary logarithmically with dial position. This gives a constant fractional accuracy of reading and contributes a great deal to the ease of balancing.

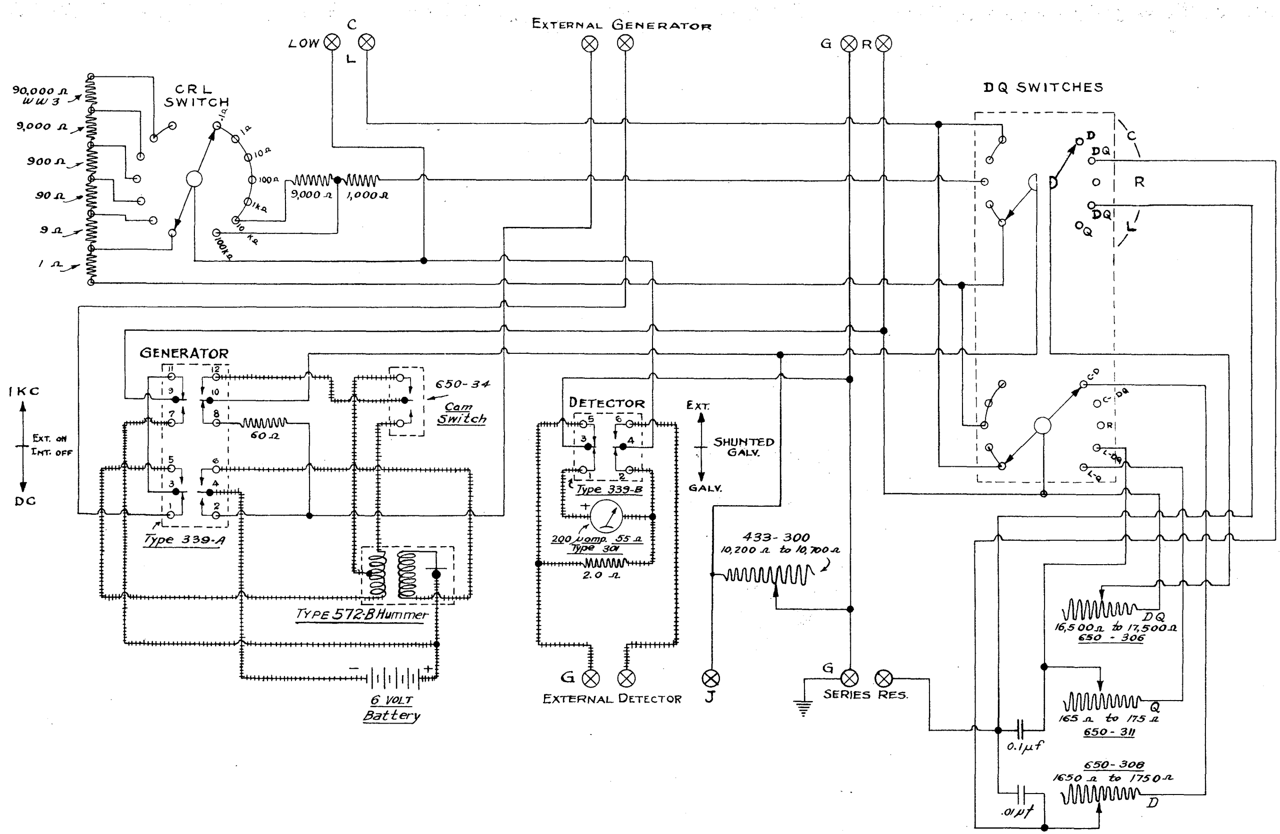
Values of R, L, or C are read on the CRL dial and the CRL switch selects the desired ratio arms. The D-Q switch selects the proper D-Q rheostat and makes up the bridge circuit according to the diagrams of Figure 1.

RESISTANCE MEASUREMENTS For both direct- and alternating-current resistance measurements, the Wheatstone bridge circuit of Figure 1a is used.

CAPACITANCE MEASUREMENTS A Wheatstone bridge with two resistance arms and two capacitance arms, as shown in Figure 1b, is used for both C positions of the D-Q switch in the measurement of capacitance and dissipation factor.

INDUCTANCE MEASUREMENTS For the L-DQ position of the D-Q switch, the circuit is arranged as a Maxwell bridge and for the L-Q position of the switch, a Hay bridge is used. These are shown in Figure 1c and Figure 1d respectively.

REFERENCES All the above circuits are treated in detail in "Alternating-Current Bridge Methods", by B. Hague, published by Sir Isaac Pitman and Sons, Ltd., London.



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