Combination Instrument Measures R, C, and L Accurately

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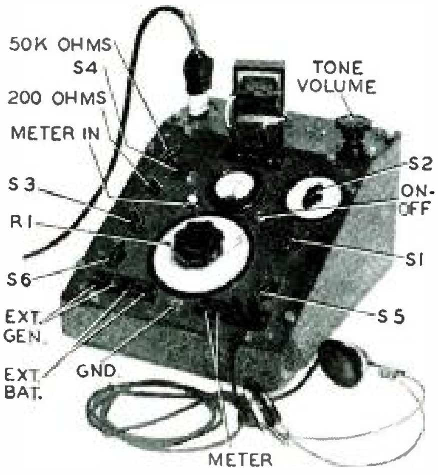

Generator and bridge are in a single cabinet.

IT IS often necessary for an experimenter or engineer to make various kinds of measurements. Everyone is familiar with the common instruments for measuring current and voltage, but not always with the impedance bridge, which can be used for measurements of resistance, inductance or capacitance. The general principle of bridges is shown in Fig. 1.

Fig. 1-a is the Wheatstone bridge. The unknown resistance is R_x while R_c is variable. The resistors R_A and R_B are the *ratio arms*. If R_c is calibrated, and we know the ratio of R_B to R_A, the value of the unknown resistor R_x is equal to

$$\frac{R_B}{R_A} \times R_c,$$

after adjusting R_c so that there is no potential difference between the galvanometer terminals (the *null* adjustment).

Fig. 1-b is a Maxwell bridge. The unknown inductance is L_x; in the opposite arm we have a standard capacitance C_A. R_c is again a calibrated variable resistor. The Maxwell bridge compares an inductance with a capacitance. After adjusting R_c and R_A for null,

$$L_x = R_c R_B C_A, \text{ and}$$
$$R_x = \frac{R_c}{R_A} \times R_B.$$

It would be very difficult to obtain a true null point if we had only the standard capacitor in the A-arm, due to the resistive losses in the inductance L_x. These losses can be represented by an imaginary resistor R_x; by connecting a variable resistor R_A in parallel with the standard capacitor C_A and adjusting this resistor along with the R_c, we can balance out R_x and obtain a very sharp null in the phones.

Fig. 1-c is the circuit for a usual capacitance bridge (in principle a Wien bridge). C_x is the unknown capacitance and the standard capacitor is C_A. R_c is the calibrated variable resistor. Note that C_x and R_c are in opposite arms. Because the reactance of a capacitor is inversely proportional to the capacitance, the value of C_x is equal to

$$\frac{R_c}{R_B} \times C_A.$$

Capacitors also have losses. To obtain a true null, R_A is connected in series with C_A; by adjusting it along with R_c, we can again obtain a very sharp null in the phones. The bridge is perfectly balanced when

$$C_x = \frac{R_c}{R_B} \times C_A \text{ and } R_x = \frac{R_B}{R_c} \times R_A.$$

The impedance bridge

The circuit diagrams of a bridge and generator built by the writer are shown in Figs. 2 and 3. The photos show the complete instrument and bottom views of the bridge chassis and the generator. The following ranges are covered with the bridge:

With the S3 in the Ω position and S2 on 10, values up to 10 ohms can be read from the big dial scale on the potentiometer R1. With S3 in the KΩ position and S2 on 10,000, values up to 10 megohms can be measured.

The inductance ranges are also divided into two S3 positions, MH and H. With S3 in the MH position and S2 on 0.1, values up to 0.1 mh can be read from the scale. By switching S3 to the H position and S2 to 100, values up to 100h can be measured.

In the same way, capacitances to 100 μμf can be measured with S3 in the μμf position, and values up to 100 μf with the switch in the position marked NF. The expression nf (nano-farad) has been employed by the author to make it possible to use the same scale for μμf and μf measurements (1,000 nf is equal to 1 μf).

The accuracy of the bridge depends upon the accuracy of the resistors and the potentiometer R1. All resistors must be wirewound and carefully calibrated with a precision resistance bridge. The potentiometer must be of good quality and preferably one with a large diameter. The scale on the potentiometer must also be calibrated with a precision bridge. Good capacitors must be used for the 1,000-μμf and 1-μf units. By selecting capacitors with values smaller than 1,000 μμf and 1 μf and shunting them with others, the exact values can be obtained.

Switch S5 shunts the galvanometer with a suitable resistor RS so when the bridge, in measuring resistances, is far from balance, the galvanometer deflection is not too big. In the first position an external detector (headphones or an amplifier) can be used when measuring inductances and capacitances. The normally open push-button switch in series with the galvanometer makes it possible to see more easily when the current through the galvanometer is zero by interrupting and closing the galvanometer circuit. The galvanometer is also connected to the terminals marked METER; therefore, it can be used for other purposes.

When measuring resistances, S6 should be in the position marked DC and S7 must be closed. An internal d.c. voltage is then connected to the bridge.

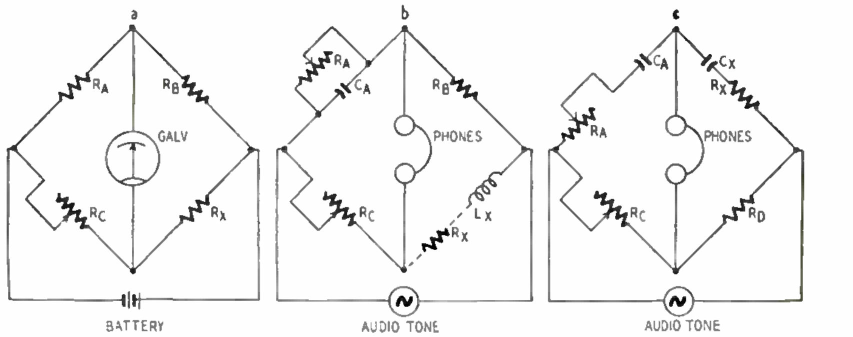

Fig. 1—Wheatstone, Maxwell, and capacitance bridges illustrate general working principles.

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External batteries can be used by opening S7 and connecting the battery to the terminals marked EXT BAT for more accurate measurement of high resistances.

When measuring inductances and capacitances, S5 should be in the EXT position and S6 in the INT position. An 800-cycle audio note is then connected to the bridge. If an audio note of another frequency should be needed, an external generator can be connected to the terminals marked EXT GEN and the switch turned to the position marked EXT.

In the author's bridge, a switch S4 had to be installed to short the 500,000-ohm potentiometer because it was impossible to find a potentiometer which could reach zero ohms. If the 500,000- and 200-ohm potentiometers are furnished with calibrated scales, the power factor can be calculated from the readings.

When making measurements on capacitors of low value, it is desirable to determine the capacitance of the bridge itself. In the bridge shown, this capacitance is very close to 5 μμf; and, when measuring capacitors up to 100 and 1,000 μμf, this value should be subtracted.

Fig. 3 shows the generator. It has cathode output. The home-made transformer T has 2,500 turns of No. 38 enameled wire on the primary and two 1,250-turn windings of the same wire on the secondary. Between the primary and the copper screen is an electrostatic shield—a single-layer winding of No. 31 enameled wire. The screen encloses completely the secondary winding. The cross section of the core in the transformer is ⅞ x 1 inch.

An extra winding on the high-voltage transformer gives 25 volts to a selenium rectifier for the d.c. voltage to the bridge. A 200-ohm current-limiting resistor and a 50-μf electrolytic capacitor are connected between the rectifier and the bridge.

The generator is located in the upper end of the steel box (see photos) and connected to the bridge *via* a five-prong socket. The dimensions of the steel box are 7 x 11 x 14 inches. All parts of the bridge are mounted on a bakelite panel.

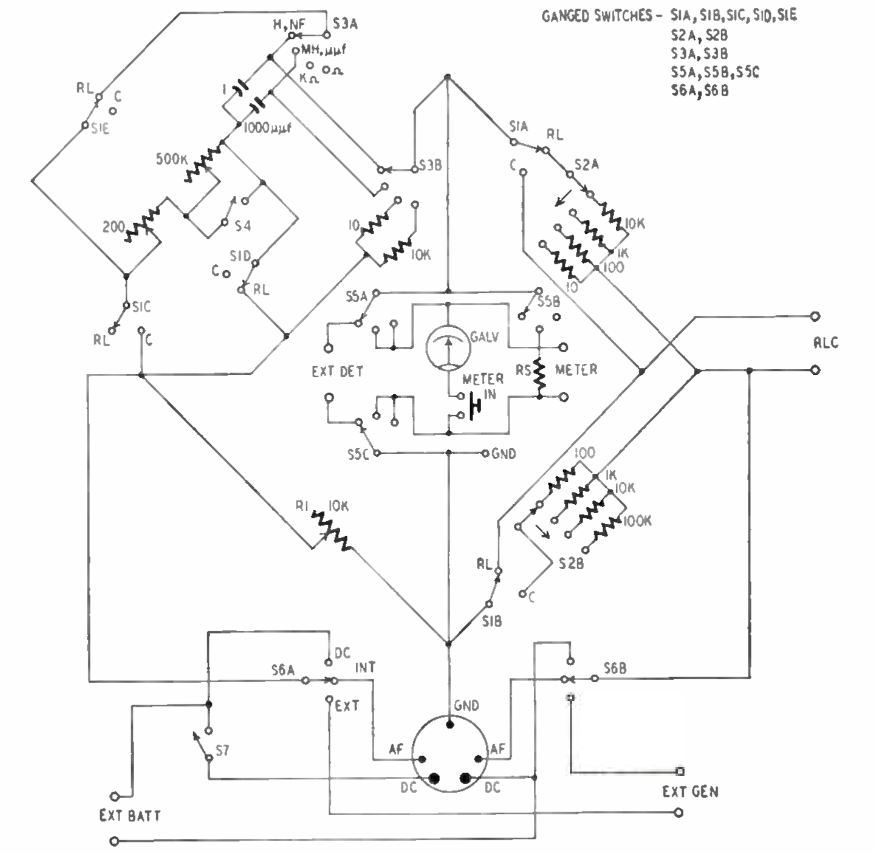


Fig. 2—Switches and controls in the bridge circuit provide for four ranges of R, C, and L.

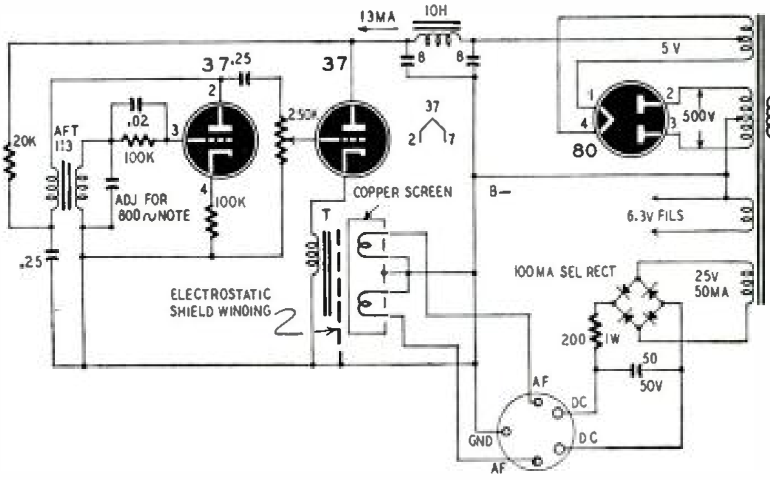


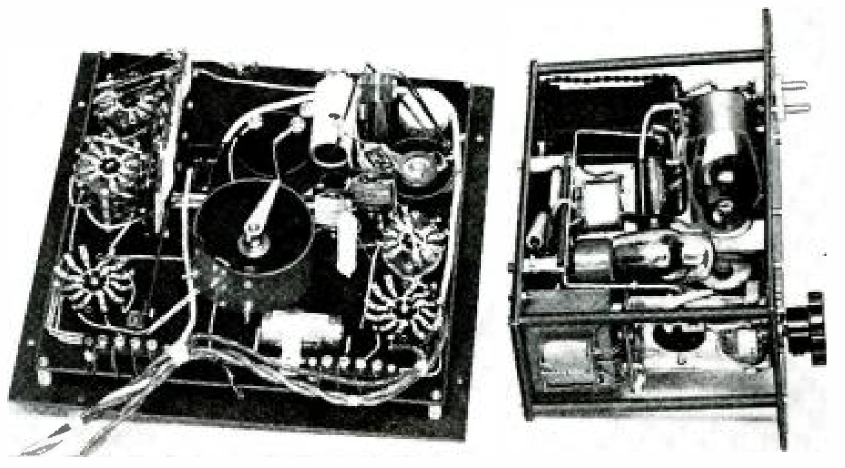
Fig. 3—The tone generator. Note how the output is balanced to avoid upsetting the bridge.

MATERIALS FOR BRIDGE—Fig. 2

Resistors: 2—10, 2—100, 2—1,000, 3—10,000 1—100 000 ohms, precision, ½ to 1 watt; 1—200, 1—10,000 ohms, wire-wound potentiometers; 1—500,000 composition potentiometer.
Capacitors: 1—1.0, 1—.001 μf, precision, paper, 50 volts.
Switches: 1—2-position, 5-circuit, 2—4 position, 2-circuit, 1—3-position, 2-circuit, 1—3-position, 3-circuit, rotary, non-shorting, 2—s.p.s.t. toggle.
Miscellaneous: 1—galvanometer; 1 5-prong male plug; necessary binding posts, terminals, dials and scales, hardware, etc.

MATERIALS FOR SIGNAL SOURCE—Fig. 3

Resistors: 1—20,000, 2—100,000 ohms, ½ watt; 1—200 ohms, 1 watt; 1—250,000-ohm potentiometer.
Capacitors: 1—50 μf, 50 volts, electrolytic; 2—8 μf, 450 volts, electrolytic; 1—0.2, 2—0.25 μf, 600 volts, paper.
Tubes: 2—37, 2—80.
Miscellaneous: 1—4-prong, 2—5-prong tube sockets; 1—1-3 ratio audio interstage transformer; 1—power transformer, 500 volts center-tapped at 75 ma or more, 6.3 volts at 500 ma, 5 volts at 2 amperes, 25 volts at 50 ma; 1—10-h, 75-ma filter choke; 1—5-prong female plug; 4—100-ma selenium rectifiers; necessary hardware.



The bridge (left) and generator-power supply (right) are easily disassembled for service.