A HANDY PAIR OF BRIDGES

● **IN THE LABORATORY** or on the production line the need frequently arises for the rapid measurement of capacitors or inductors with a moderate degree of precision. For this purpose, a pair of twin units, the TYPE 1614-A Capacitance Bridge and the TYPE 1631-A Inductance Bridge, is now offered, each designed to accomplish a specific purpose at a moderate price consistent with reliable performance and simplicity of operation. To a first approximation these new bridges supply, as separate units and in more portable form, the reactance bridge circuits available in the popular General Radio Impedance Bridge, TYPE 650-A. They do not supersede, but rather supplement the latter.

Each of these self-contained bridges is housed in a covered walnut cabinet measuring 13½″ x 8½″ x 7″ and provided with a handle on one end for easy portability (13 pounds). Mounted on slip hinges, these covers can be opened for exposing the operating panel or removed entirely if desired. Explicit operating instructions are attached to the inside of the cover. While the bridges must be operated with their control panels approximately horizontal, they can be transported or stored in any position.

Either bridge is energized by a one-kilocycle microphone-driven reed "hummer," operated by dry cells which are housed in the cabinet. The hummer unit is provided with a flexible mounting which minimizes injury from shock and reduces the hum tone transmitted to the instrument panel and, hence, into the operating room.

Sufficient bridge sensitivity permits a pair of headphones, without amplification, to be used as the null-balance detector. A pocket compartment is provided in the cabinet for storing these phones. In order that these bridges shall be available for instant use at all times, the phones are internally attached to the instrument so that they cannot conveniently be "borrowed" for another job and thus, perhaps, not be available when wanted.

The main six-inch control dial of each bridge is provided with a slow-motion drive to facilitate accurate adjustment. This dial drives a six-inch rheostat logarithmically wound so that, over the major range of the dial covering two decades of capacitance (1614-A) or of inductance (1631-A), these values can be read with nearly the same fractional accuracy at all scale points. Sufficient overlap is provided at both the upper and lower extremities of this double-decade dial. These large rheostats are equipped with an adjustment cam which permits a differential displacement between the rheostat arm and the control dial, a feature which affords an accurate calibration of each individual dial in the manufacture of these instruments.

The 1614-A Capacitance Bridge

While the Schering bridge provides the most precise measurement of capacitance, it requires expensive adjustable capacitors. Nominal precision can readily be obtained by what is known as the series-resistance bridge circuit depicted in Figure 2. One bridge arm consists of the large logarithmic rheostat controlled by the main dial, which is calibrated directly in microfarads. The multiplier arm consists of one of three fixed resistors selected by a triple position panel switch and providing the following ranges:

Multiplier	*Capacitance Range*
1.0	1 to 100 μf
0.01	.01 to 1 μf
0.0001	.0001 to .01 μf
0.0001	10 to 100 $\mu\mu$f*

*Reduced precision on this lowest decade.

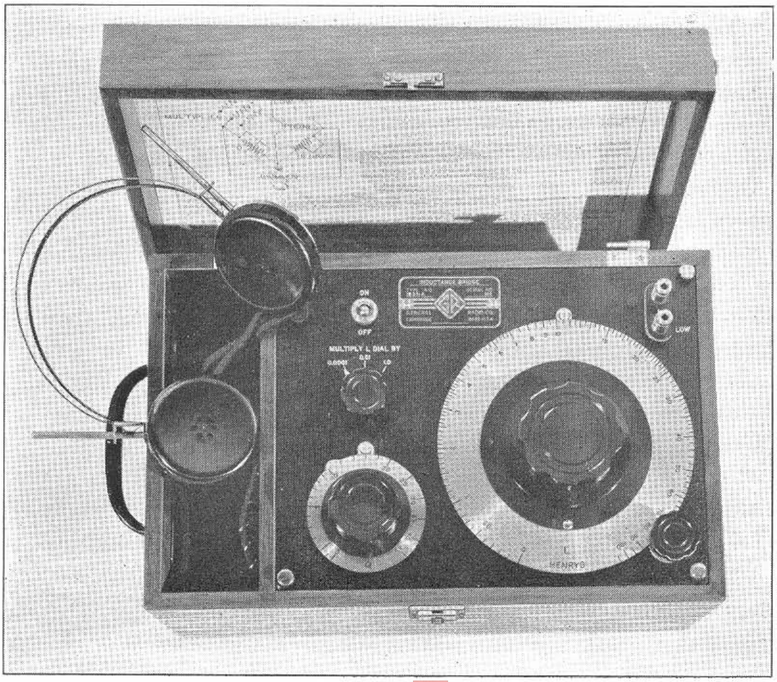

FIGURE 1. View of the TYPE 1631-A Inductance Bridge. Telephones are permanently attached to the instrument, and all necessary operating instructions are mounted in the cover. The TYPE 1614-A Capacitance Bridge is similar in appearance.

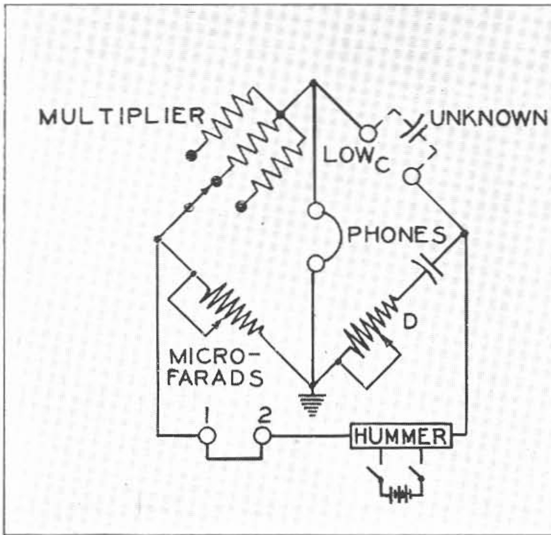

FIGURE 2. Schematic wiring diagram of the TYPE 1611-A Capacitance Bridge.

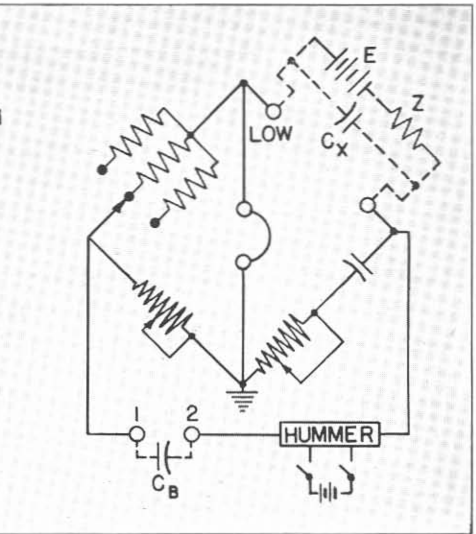

FIGURE 3. Bridge connections for capacitance measurement with polarizing voltage.

This available range is thus ten millionfold. The multiplier switch also changes (not shown) the operating impedance of the hummer in the interests of sensitivity. The arm opposite the microfarads rheostat contains the unknown capacitor under test, while the arm opposite the multiplier contains a high grade standard capacitor in series with a smaller logarithmic rheostat *D*. This rheostat is adjusted by the smaller control dial which is calibrated directly in the dissipation factor of the unknown over a working range from 0 to 0.45. Bridge balance is easily attained by the joint manipulation of the MICROFARADS and D dials, with the multiplier initially set for the appropriate range.

The necessary parameter relationships to achieve a balance of this capacitance bridge are expressed by the two simultaneous equations:

$$C_x = \left(\frac{C_1}{R_3}\right) R_2 \qquad (1)$$

and

$$D_x = (2\pi f C_1) R_1 \qquad (2)$$

where C_1 is the standard capacitor, R_1 the resistance (small rheostat) in series with C_1, R_2 is the large rheostat and R_3 is the multiplier value used. For a fixed value of C_1 it will be seen that the existence of R_2, in Equation (1) only, permits the large dial to be calibrated in terms of C_x for a specific C_1/R_3 ratio, while changing the multiplier R_3, also uniquely in Equation (1), by double decade steps changes one hundredfold the magnitude of C_x for any specific R_2 value. Likewise the existence of R_1, in Equation (2) only, permits the small dial to be calibrated directly in terms of D_x for a specific value of frequency f, — in this case one kilocycle.

By a slight modification indicated in Figure 3, the 1614-A Bridge can be used to measure electrolytic capacitors having an applied polarizing voltage. A suitable d-c voltage source E in series with a resistor Z is applied, with the correct polarity, across the terminals of C_x. To eliminate errors, the value of Z should exceed 100 times the reactance of C_x at 1000 cycles. If C_x passes any leakage current, the actual voltage on C_x will be the value of E diminished by the drop in Z. For this purpose, a jumper connecting the internal points 1 and 2 must be removed and a capacitor C_B (not provided) of 2 μf (or larger) inserted in this position. Space is available for storing this capacitor within the cabinet. For ordinary uses of the bridge, C_B (Figure 2) should be removed and the jumper replaced to achieve maximum sensitivity and precision of balance.

The 1631-A Inductance Bridge

There are several bridge circuits, such as the Owen, Hay, etc., available for the measurement of inductance, but for measuring inductors whose Q value does not exceed about 50, the most convenient circuit is that of the Maxwell bridge depicted in Figure 4. One bridge arm consists of the large logarithmic rheostat controlled by the main dial which is calibrated directly in henrys. Opposite this is the multiplier arm comprising one of three fixed resistors selected by a triple-position panel switch and providing the following ranges:

Multiplier	*Inductance Range*
1.0	1 to 100 henrys
0.01	.01 to 1 henrys
0.0001	.0001 to .01 henrys
0.0001	10 to 100 microhenrys*

The available range is thus ten millionfold. The multiplier switch also changes (not shown) the operating impedance of the hummer in the interests of sensitivity. A third arm of this bridge consists of the unknown inductor under test. The opposite arm contains a high-grade standard capacitor which is shunted by a smaller logarithmic rheostat Q. This rheostat is adjusted by the smaller control dial which is calibrated directly in terms of the storage factor of the unknown over a working range from 0 to 45. With the multiplier initially set for the appropriate range, a bridge balance is easily attained by a joint manipulation of the henrys and Q dials.

*Reduced precision on this lowest decade

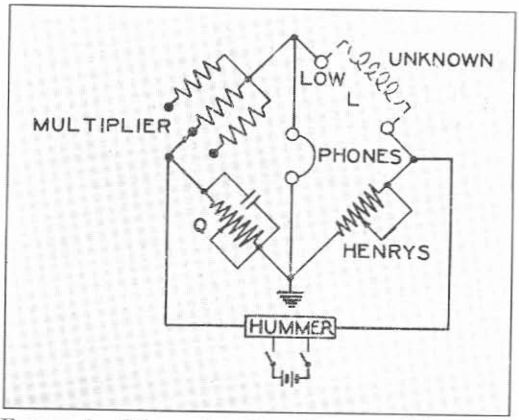

FIGURE 4. Schematic wiring diagram of TYPE 1631-A Inductance Bridge.

A balance of this Maxwell bridge is indicated by the two simultaneous equations:

$$L_x = (R_3C_1)R_2 \quad (3)$$

$$Q_x = (2\pi f C_1)R_1 \quad (4)$$

wherein C_1 is the standard capacitor, R_1 the resistance (small rheostat) in parallel with C_1, R_2 is the large rheostat and R_3 is the multiplier value used. Starting with a fixed C_1 value, since R_2 is uniquely in Equation (3) the large dial can be calibrated in terms of Lx for a specific R_3C_1 product, while changing the multiplier R_3 by a double decade step modifies one hundredfold the magnitude of C_x for any specific R_2 value. Likewise, the existence of R_1, in Equation (4) only, permits the small dial to be calibrated in terms of Q_x for a specific value of frequency f, — in this case one kilocycle.

Parenthetically, Equation (4) sets a maximum limit to the Q_x value attainable, with a specific fC product, as determined by the maximum resistance R_1 for which it is practical to wind a calibrated rheostat. Higher values of Q_x may be measured by the Hay bridge in which the standard capacitor and the small-valued Q rheostat are in series. The Hay bridge, however, requires a troublesome correction factor to be applied to the inductance scale values of low Q inductors. Hence the Maxwell bridge was chosen for this purpose, on the assumption that rarely do the 1-kc Q values of inductors exceed 45.

It should be noted that when iron-cored inductors are measured on such a bridge as this, having no control over the applied generator voltage, the L and Q values obtained are the 1 kc values corresponding to an arbitrary degree of magnetization in the core which is indeterminate unless a vacuum-tube voltmeter is applied across the terminals of the inductor in the balanced bridge. If the ferromagnetic core does not contain an appreciable air gap, this indeterminate magnetization will, in general, considerably exceed that corresponding to initial permeability.

— Horatio W. Lamson

SPECIFICATIONS FOR TYPE 1614-A CAPACITANCE BRIDGE

Capacitance: Range, 10 $\mu\mu$f to 100 μf in three steps: 10 $\mu\mu$f to 10,000 $\mu\mu$f; 0.01 μf to 1.0 μf; and 1.0 $\mu\mu$f to 100 μf.

Accuracy: $\pm 2\%$, except on the lowest range, where, after the zero capacitance of 9 $\mu\mu$f is subtracted, the accuracy is $\pm(2\mu\mu f + 2\%$ of the dial reading).

Dial Calibration: Approximately logarithmic (uniform fractional accuracy) over two main decades, with a compressed lower decade which is used only for measurements below 100 $\mu\mu$f.

Dissipation Factor: Range, 0 to 45%. Accuracy: On the lowest range, the error, expressed in per cent dissipation factor, is $\pm(2\% + 0.1 \times$ dial reading); on the other two ranges, $\pm(0.2\% + 0.1 \times$ dial reading).

Frequency: The internal oscillator furnishes the necessary bridge power at a frequency of 1000 cycles $\pm 5\%$.

Power Supply: 6-volt dry battery. Two Burgess F2BP units connected in series are recommended, and are supplied with the instrument. Space for these is provided in the cabinet.

Accessories Supplied: Head telephones and batteries.

Accessories Required: When a d-c polarizing voltage is used, a 2 μf blocking capacitor is required. This condenser is not supplied with the instrument, but space for a General Electric Type 55X-629 is provided in the cabinet.

Mounting: Walnut cabinet with removable hinged cover.

Dimensions: 13½ x 8½ x 7 inches, overall.

Net Weight: 13¼ pounds.

Type		*Code Word*	*Price*
1614-A	Capacitance Bridge..............	LAPEL	$90.00

SPECIFICATIONS FOR TYPE 1631-A INDUCTANCE BRIDGE

Inductance: Range, 10 μh to 100 h in 3 steps, 10 μh to 10,000 μh; 0.01 h to 1 h; and 1 h to 100 h.

Accuracy: $\pm 2.5\%$ of dial reading between 100 μh and 10 h. Below 100 μh the error varies inversely as the magnitude of the unknown. Above 10 h the error increases to $\pm 10\%$ dial reading at 100 h.

Dial Calibration: Approximately logarithmic (uniform fractional accuracy) over two main decades, with a compressed lower decade which is used only for measurements below 100 μh.

Q: Range, 1 to 45. Accuracy, $\pm 10\%$ of dial reading for values of Q between 2 and 10. For higher values the error increases progressively to $\pm 15\%$ at a Q of 45. For lower values, the error increases to $\pm 20\%$ at a Q of 1.

Other specifications are identical with those for Type 1614-A Capacitance Bridge.

Type		*Code Word*	*Price*
1631-A	Inductance Bridge...............	LARVA	$98.00