A NEW UNIVERSAL IMPEDANCE BRIDGE

Accuracy, versatility, and convenience are combined to an unusual degree in the new General Radio Type 1650-A Impedance Bridge. Successor to the well-known and widely used Type 650-A,[1] the new bridge incorporates the many desirable features of its predecessor, plus a host of improvements that contribute greatly to its accuracy and operating convenience.

The older bridge has long been a standard fixture in laboratories, plants, and schools. Rugged and reliable, it is undoubtedly the best-known instrument in General Radio's extensive line. Many of the early models are still in use — an example of the quality and long life of General Radio instruments — but time has shown many improvements to be both practical and desirable. These, together with several completely new features, make an impressive list of reasons why the new bridge is even more useful and reliable than its predecessor.

Two of the improvements stand out in importance:

(1) Increased accuracy. Measurements of D and Q can be made with an accuracy of 5%, which, together with the basic accuracy of 1% for R, L, and C, holds over the entire range of the bridge.

(2) The patented *Orthonull* feature, which eliminates sliding balances, permitting the measurement of low-Q inductors and high-D capacitors.

Two completely new features contribute greatly to convenience in use and portability:

(3) Unique cabinet, which allows the bridge panel to be tilted and held at any convenient angle and which, when

[1] Robert F. Field, "The Convenient Measurement of R, L, and C," *General Radio Experimenter*, Vol. 7, Nos. 11 and 12, April-May, 1933.

Figure 1. Panel view of the Type 1650-A Impedance Bridge. Note the many new features: Orthonull; built-in generator and detector; single D-Q dial; single pair of UNKNOWN terminals; bias terminals. For other external features, see cover.

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closed, forms a protective cover and carrying case.

(4) Completely transistorized generator and detector.

Still other improvements and extensions of original features include:

(5) A single dial for all D and Q readings.

(6) A single pair of terminals for all measurements.

(7) A full decade extension of the upper limit of R, L, and C measurement.

(8) Increased upper frequency limit (20 kc).

(9) Meter null indication for both ac and dc measurements, eliminating the need for earphones.

(10) Built-in generator and detector.

(11) The ability to measure 3-terminal components in the presence of large terminal capacitances.

(12) Externally supplied dc polarizing voltage or current can be used.

A more detailed discussion of these features will help to emphasize their utility and desirability.

THE BRIDGE CIRCUITS

While specialized and unusual circuits often have advantages for single-purpose bridges, no satisfactory replacements have been found for the simple, classical circuits in a general-purpose bridge. Their accuracy and simplicity are difficult to surpass for direct measurements of inductance, capacitance, storage factor, dissipation factor, and both dc and ac resistance. In this bridge, therefore, the well-known circuits are used, but, in order to maintain the desired accuracy over wide ranges, several refinements have been introduced. In addition, the so-called sliding balance, which has been the main disadvantage of the classic circuits when used to measure D and Q directly, has been eliminated by the *Orthonull* feature.

The several circuits are shown schematically in Figure 2. Note that a parallel-capacitance bridge is now included as well as the series type; this makes possible not only the measurement of parallel capacitance, but also the extension of the range of accurate D measurements.

The range of measurement of each bridge configuration has been extended upward by one decade to give maximum limits of 1000 microfarads, 1000 henrys, and 10 megohms.

Careful compensation of phase angle in the bridge arms has greatly improved the accuracy of D and Q measurement and has made possible accurate measurements of L and C at frequencies from 20 c to 20 kc.[2]

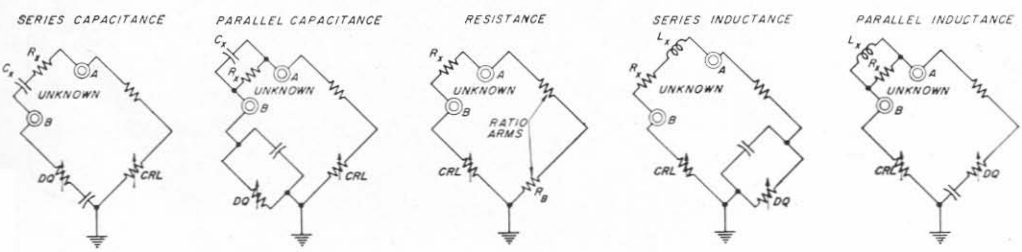
Residual bridge errors have been greatly reduced; the limiting factors are the inductance, resistance, and capacitance of the UNKNOWN terminals themselves. These are equal to or less than the smallest measurable quantities (one micromicrofarad, one microhenry, and one milliohm).

STANDARDS AND COMPONENTS

The standard capacitor is a 0.1-μf silvered-mica unit of General Radio manufacture. A shunt capacitance of

[2] With external generator.

Figure 2. The five circuits used in the bridge.



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1000 $\mu\mu$f across this capacitor causes an error of only 1%, and, therefore, 3-terminal direct capacitances can be measured accurately when the smaller of the stray terminal capacitances is well below this value.

The fixed resistors are General Radio precision, wire-wound types except for the one megohm ratio arm, which is a precision film unit. The phase angles of these resistors are sufficiently small to permit ac resistance measurements on high valued resistors. The variable resistors are General Radio potentiometers with exponential tapers and logarithmic scales. The *D-Q* potentiometer covers a total span of 54 db, which makes possible a wide range of measurement and provides complete *D* and *Q* coverage at measurement frequencies down to 100 cycles and, with only a small gap in coverage, down to 60 cycles.

GENERATOR AND DETECTOR

The generator and detector are completely transistorized, making possible the light weight and low power consumption desired in a portable instrument. The LC oscillator and the three-stage transistor amplifier draw a total current of less than 10 ma, which makes possible the long battery life with readily available "D" cells. For measurements on nonlinear elements, such as iron-cored inductors, where the applied signal should be small, an oscillator level control is provided. The amplifier, which has a voltage gain of over 64 db, can be made selective at 1 kc with over 20 db second-harmonic rejection or flat for measurements at other frequencies. The amplifier drives the panel meter to give a visual ac null indication so that headphones are not necessary, although they can be used if desired. A meter sensitivity control is also provided.

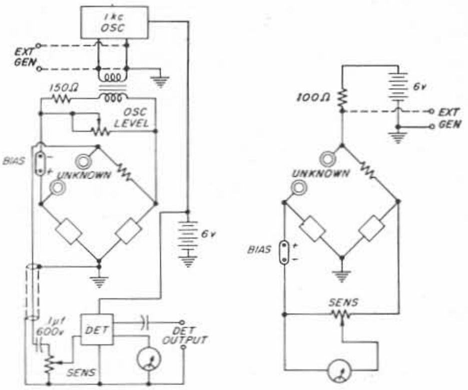

Figure 3. Block schematic of the bridge generator and detector. External-generator connections are shown by dashed lines.

The internal dc source is 6 volts. Provision is made for the connection of external ac and dc sources. External ac generators can be connected to the bridge through the internal isolating transformer provided, thus effectively eliminating the measurement errors that can result from generator-to-ground capacitances.

Block schematics of the complete instrument are given in Figure 3.

ORTHONULL

Those who have tried to balance low-*Q* components on a conventional bridge have experienced the frustrating "sliding balance," which is the slow balance convergence resulting from the interdependence between the two balance adjustments. This phenomenon makes balances tedious when *Q* is less than 2 and virtually impossible when *Q* is less than ½.

"Sliding balance" occurs in any bridge that measures impedance in a nonorthogonal coordinate system. Balances made with controls that balance inductance on one dial, for instance, and *Q* on another inherently slide, because reactance

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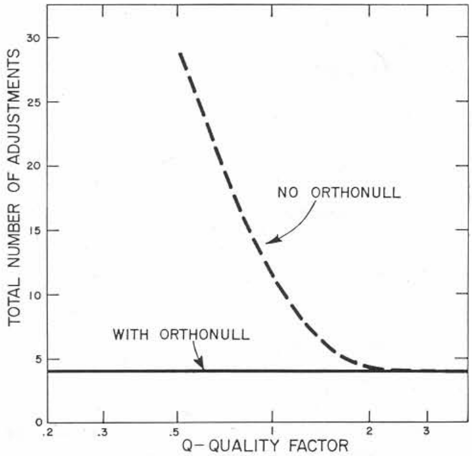


TOTAL NUMBER OF ADJUSTMENTS NECESSARY TO GET WITHIN 1% FOR A GIVEN Q.

Figure 4. Plot of total number of balances required to achieve final balance, with and without *Orthonull*, as a function of Q.

($j\omega L$) is a component in a Cartesian coordinate system while Q ($=\frac{\omega L}{R}$) is a measure of angle in a polar coordinate system, and they are consequently non-orthogonal.[3]

To eliminate this difficulty, the TYPE 1650-A Impedance Bridge is equipped with an exclusive, patented feature, known as *Orthonull*.[4] This name was chosen because the null is obtained by balances which are essentially orthogonal and therefore converge rapidly. *Orthonull* gangs the two adjustments non-reciprocally in such a manner as to cancel the electrical interdependence, leaving the two adjustments independent of one another. As a result the full Q range is useful and balances are easily made. (This device will be described in detail in an early issue of the *Experimenter*.) Figure 4 shows a comparison of the number of successive balances required for low-Q measurements, with and without *Orthonull*, and is a striking illustration of the advantages of the *Orthonull* feature.

MECHANICAL FEATURES

Another novel development is the unique carrying case and tilting arrangement shown in Figure 5. The cover may be latched closed to form a protective cover for carrying or storage, it may be latched with the bridge open, or it may be used as a support which allows the bridge to be tilted and operated at any convenient angle. This type of case approaches the ideal for portable instruments. You will see it on other General Radio products in the future.

The panel controls (see Figure 1) are arranged for the convenience of the operator, and the terminals are placed for efficient use. The switching arrangement and panel engraving make the operation of the bridge self-explanatory to the user.

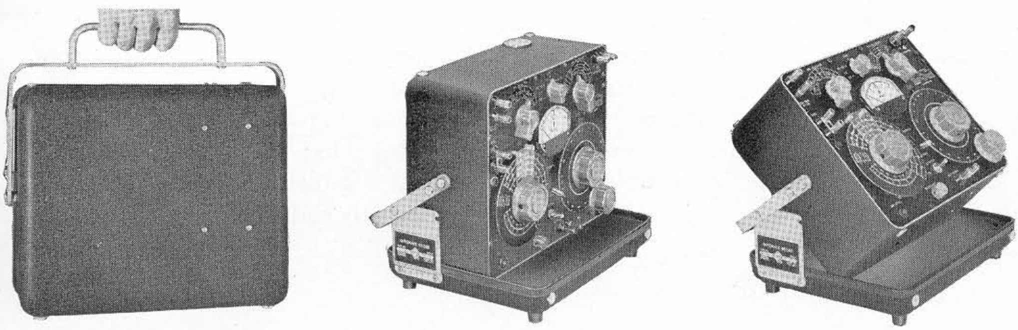
APPLICATIONS

The basic use of this type of bridge is in the everyday measurements of re-

[3]G. B. Hoadley, "The Science of Balancing an Impedance Bridge," *Journal of the Franklin Institute*, Vol. 228, No. 6, pp. 733-754; December, 1939.

[4]U. S. Patent No. 2,872,639.

Figure 5a (*Left*). Bridge cabinet when closed is an easily carried, protective case. Figure 5b (*Center*). Bridge, when cabinet is opened, can be used with panel vertical or, as shown in Figure 5c (*right*), tilted at any desired angle.



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sistors, capacitors, and inductors, and for this application the wide ranges, efficient layout, and uniform accuracy of the TYPE 1650-A Impedance Bridge are important.

These same features, however, make possible additional types of measurement that illustrate the inherent versatility of the bridge.

Frequency Characteristics — The wide frequency response facilitates studies of the variations in component parameters over the entire audio-frequency range. An example of this is shown in Figure 6. The recommended external source for these measurements is the TYPE 1210-C Unit R-C Oscillator.

DC Bias — Panel terminals are provided for the application of a dc polarizing voltage to the element under measurement. Up to 600 volts of dc bias voltage can be applied to a capacitor being measured on any of the bridge ranges. DC current can be supplied to inductors or resistors by either of two methods. One permits currents ranging from 100 ma for 0.01 ohm or 0.01 henry to 0.5 ma for one megohm or one henry; the other permits 40 ma under any conditions.

Voltage Coefficients — DC bias makes possible the study of the variation in the capacitances of a ceramic or electrolytic capacitor as a function of voltage as shown in Figure 7. In measurements of this sort the very low values of dissipation factor which can be measured greatly extend the field of applications of the bridge.

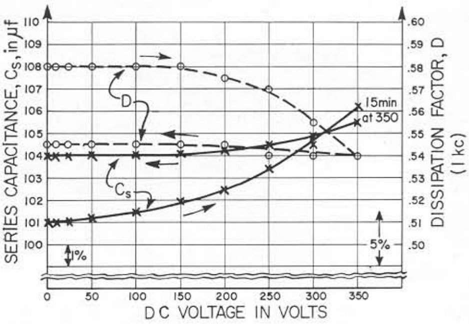

Figure 7. Measured capacitance and dissipation factor of a new electrolytic capacitor as a function of impressed dc voltage as it is passed to its rated voltage, then returned to zero bias.

Iron-Core Inductors — In the measurement of iron-cored coils, the ability to adjust the generator voltage and the high selectivity of the detector are useful in the measurement of inductance as a function of voltage. The data thus obtained can then be extrapolated to zero voltage to determine the inductance at zero permeability.

In such measurements as the determination of inductance of a radio-frequency choke, which usually has low Q's at 1 kc, the *Orthonull* mechanism makes possible accurate measurements which otherwise would be impossible.

Resistance — DC resistances up to 100 kilohms can be balanced with a precision of 1%. Above this magnitude, an external dc source should be used for maximum precision. With an external source, measurements can be made with standard EIA test voltages over most of the resistance range. Alternatively, the resistance at 1 kc can be measured. The

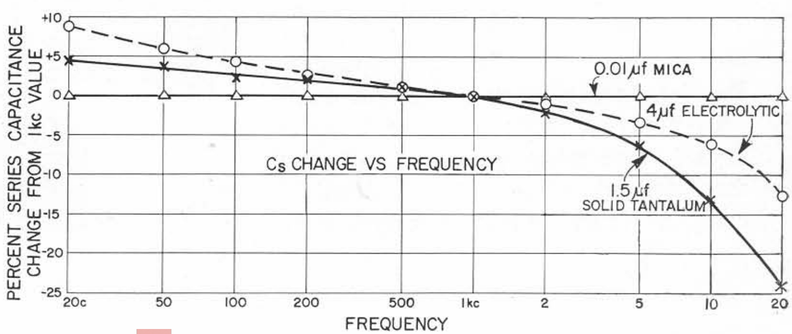

Figure 6. Plots of capacitance vs. frequency for three types of capacitors, as measured on the Type 1650-A Impedance Bridge. The 1210-C Unit R-C Oscillator was the external, variable-frequency generator.

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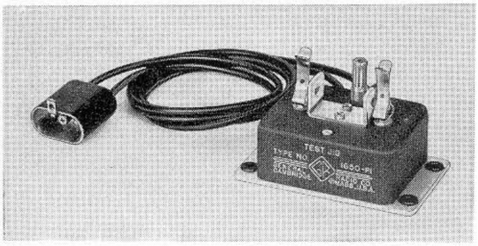


Figure 8. View of the Type 1650-P1 Test Jig.

greater sensitivity available for the ac measurement permits higher resistance magnitudes to be measured with the internal 1-kc generator. For most types of resistors, there is no appreciable difference between dc and 1-kc values. With an external ac generator, the behavior of resistive elements that vary with frequency can be studied. If an appreciable reactance is associated with the ac resistance, it can usually be cancelled by an external capacitor.

The resonant frequency of tuned circuits can also be determined through the measurement of ac resistances over a range of frequencies (up to about 5 kc) supplied by an external oscillator.

AC resistance measurements with dc bias can be used to study the characteristics of diodes, varistors, thermistors, and other nonlinear resistive elements.

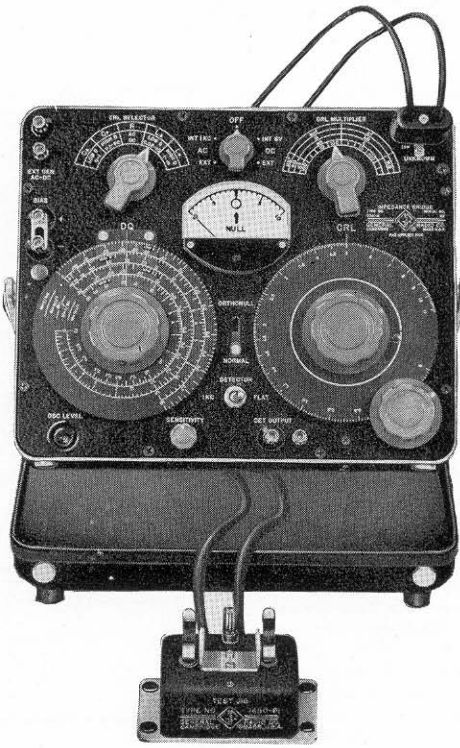
3-Terminal Capacitors — As previously mentioned, the high capacitance of the standard capacitor makes possible the measurement of direct capacitance even when the associated terminal capacitances are of considerable magnitude. One of the terminal capacitances appears across the detector and has no effect upon the measurement. The other appears across the standard capacitor. Here, a terminal capacitance of 1000 $\mu\mu$f produces an error of only 1% in the capacitance measurement. Thus the measurement of shielded 3-terminal components and of remote capacitances with shielded leads is quite feasible. In the latter class is the measurement of elements in conditioning chambers; in this application small changes can be determined to a degree of accuracy limited only by the resolution of the dial scales.

Limit Testing — A test jig, Type 1650-P1, facilitates the routine testing of identical components. The sensitivity of the bridge can be set to give a conveniently read deflection of the null indicator for any given tolerance.

ACKNOWLEDGMENTS

The well-integrated electrical and mechanical design of this bridge is the result of the combined efforts of many individuals. Every effort has been made to produce an accurate, convenient, flexible, and attractive instrument. Par-

Figure 9. Bridge with Test Jig connected.



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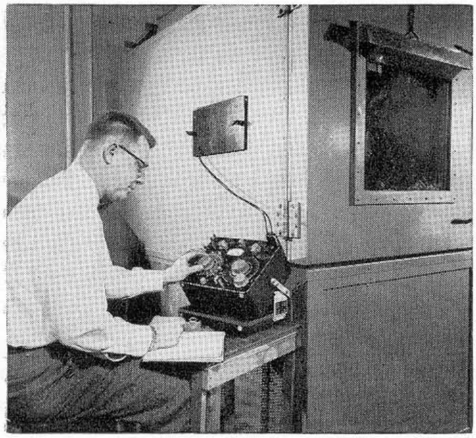

Figure 11. Bridge in use for 3-terminal measurements of sample in conditioning chamber.

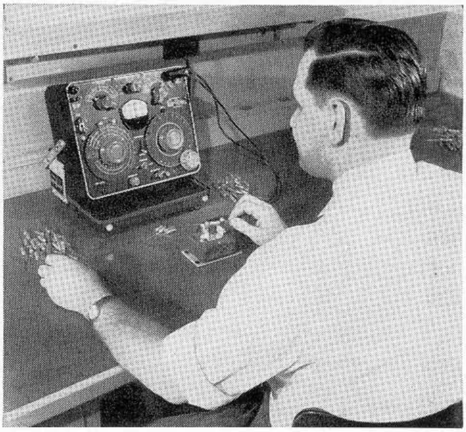

Figure 10. With the Test Jig, as shown here, the bridge can be set up for go-no-go testing to preset limits.

ticular credit should go to H. C. Littlejohn for developing the tilting case; to G. A. Clemow for working out the mechanics of the *Orthonull* mechanism; to H. G. Sterling and G. C. Oliver for layout; and to R. G. Fulks for helping with the testing. The instrument also embodies the suggestions of D. B. Sinclair, I. G. Easton, and R. A. Soderman, all of whom followed the project with interest and enthusiasm.

— HENRY P. HALL

SPECIFICATIONS

Ranges:
- Resistance, 1 mΩ to 10 MΩ, 8 ranges, ac or dc
- Capacitance, 1 μμf to 1000 μf, 7 ranges, Series or Parallel
- Inductance, 1 μh to 1000 h, 7 ranges, Series or Parallel
- D (of series capacitance), 0.001 to 1 at 1 kc
- D (of parallel capacitance), 0.1 to 50 at 1kc ($C_s = C_p$ within 1% if $D < 0.1$)
- Q (of series inductance), 0.02 to 10 at 1 kc
- Q (of parallel inductance), 1 to 1000 at 1 kc ($L_s = L_p$ within 1% if $Q > 10$)

Accuracy:
- Resistance*, ± 1% ± 1 mΩ (Residual $R \approx$ 1 mΩ)
- Capacitance, ± 1% ± μμf (Residual $C \approx$ 0.5 μμf)
- Inductance, ± 1% ± 1μh (Residual L <0.2 μh)
- D ± 5% ± .001 at 1 kc or lower
- $1/Q$, ± 5% ± .001 at 1 kc or lower

Frequency Range: (1 kc supplied internally)
1% accuracy for L and C, 10 c to 20 kc; for R, 10 c to 50 kc.
(D and Q ranges are functions of frequency.)

Internal Oscillator Frequency†: 1 kc ± 2%.

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

Internal DC Supply: 6 v, 60 ma max.

Power Supply: 4 "D" cells, supplied. Current drain (ac measurements) 10 ma.

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

Accessories Supplied: One TYPE 274-MB Double Plug.

Other Accessories Available: TYPE 1650-P1 Test Jig.

Other Accessories Required: None. Earphones may be used where high precision is required at the extremes of the bridge ranges.

Mounting: Aluminum cabinet, with captive cover.

Dimensions: 7¾ x 12¾ x 12½ inches including handle.

Weight: 17 pounds.

Type		*Code Word*	*Price*
1650-A	**Impedance Bridge‡**	BATON	**$440.00**

‡U. S. Patent No. 2,872,639.
*External DC Supply required for 1% accuracy above 100 kΩ.
†External ac and dc sources can also be used.

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TYPE 1650-P1 TEST JIG

This test-jig adaptor provides a way to connect components quickly to a pair of terminals which can be placed on the bench directly in front of the operator. Thus the test jig and 1650-A Bridge make a rapid and efficient component sorting device when the panel meter of the 1650-A 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 (or $\frac{1}{Q}$) of less than 0.007.

Type		*Code Word*	*Price*
1650-P1	**Test Jig..........**	LOCAL	**$19.00**

TYPE 1205-B ADJUSTABLE REGULATED POWER SUPPLY

A new idea in voltage regulation has made possible the high efficiency of the TYPE 1205-B Adjustable Regulated Power Supply. This new instrument, which delivers 120 watts, has an over-all volume of less than ⅕ that of conventional supplies.

The features of the series regulator and the controlled rectifier are combined in this instrument. The fast-acting series regulator provides a low output impedance over a wide bandwidth, while the high-efficiency controlled rectifier maintains constant voltage drop across

Figure 1. Panel view of the Adjustable Regulated Power Supply.

File Courtesy of GRWiki.org