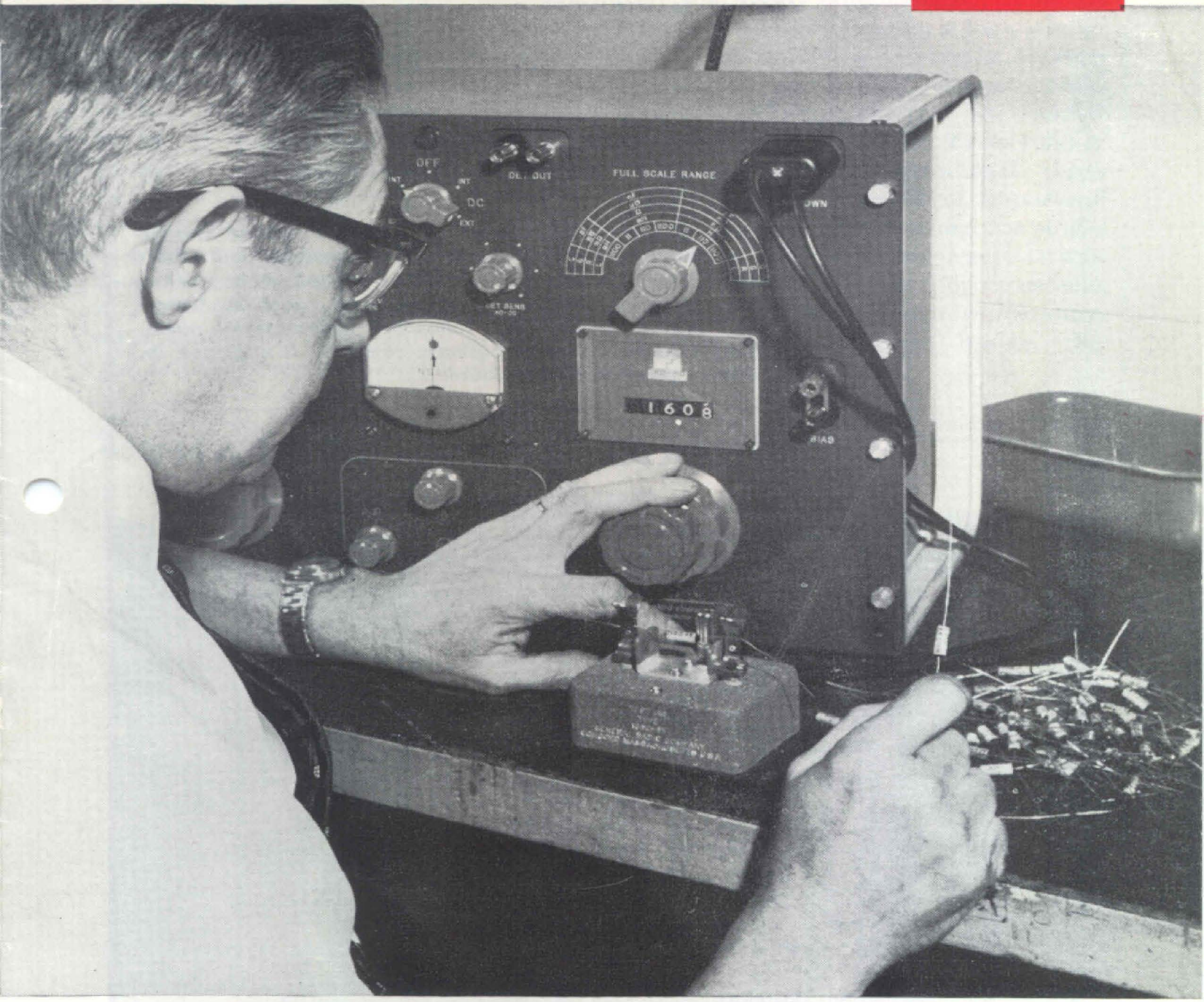
THE GENERAL RADIO

EXPERIMENTER



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New Precision Impedance Bridge

THE GENERAL RADIO

EXPERIMENTER

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COVER

For the rapid measurement of components to 0.1%, the Type 1650-P1 Test Jig can be used with the new Type 1608-A Impedance Bridge, described in this issue.

A PRECISE, GENERAL-PURPOSE IMPEDANCE BRIDGE

A few years ago, when we were considering the redesign of the old, sloping-panel TYPE 650 Impedance Bridge,[1] we had to decide whether to make a 1% bridge, like the 650, or a bridge of higher accuracy for modern precision components. Generally, a redesigned instrument should do all that its predecessor did, only better, by taking advantage of improved components and techniques. We knew that our precision components could be used with confidence in an 0.1% bridge. A 1% bridge, however, has the advantage that the main component (*C*, *R* or *L*) can be presented on a single logarithmic dial, thus providing a simple balance adjustment for rapid measurements. This was so important that we decided to make two bridges. The TYPE 1650-A Impedance Bridge[2] introduced three years ago has a number of important improvements, but it retained the single CRL dial and 1% basic accuracy. It was an immediate best seller. For those who need greater accuracy, we now introduce the precision impedance bridge, the 0.1% TYPE 1608-A.

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

[2]Henry P. Hall, "A New Universal Impedance Bridge," *General Radio Experimenter*, 33, 3, March, 1959.

Figure 1. Panel view of the Type 1608-A Impedance Bridge.

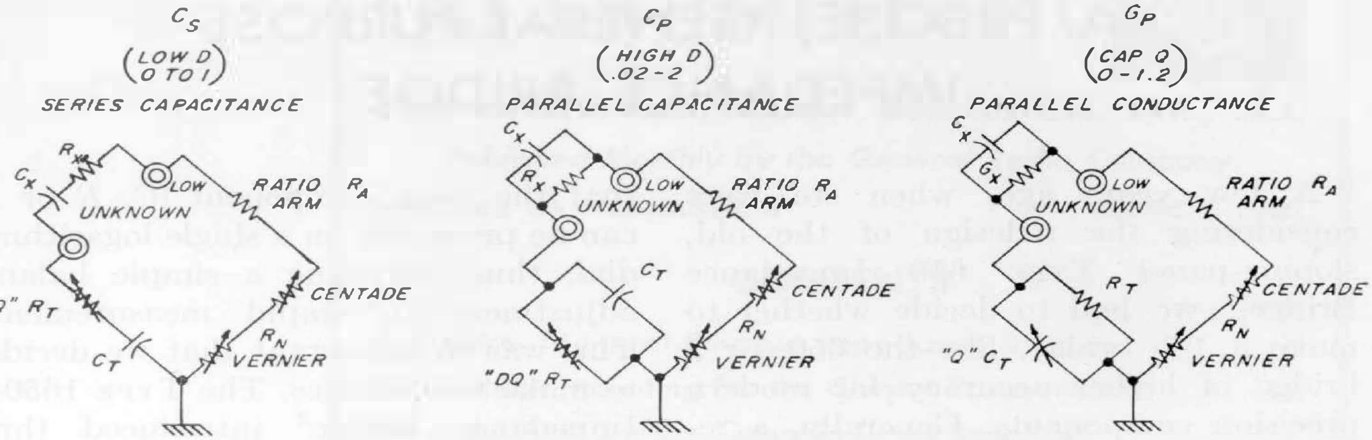


Figure 2a. Elementary schematics of the capacitance and conductance bridges.

This new, self-contained bridge system includes six bridge circuits for complete phase coverage of the passive half of the impedance plane, a 1-kc oscillator and selective detector and three dc power supplies for dc resistance and conductance measurements. The main design objective for this instrument, besides high accuracy, was to get a simply adjusted and easily read balance and readout system. The unique main balance system used is almost as easy to balance as a simple 1% dial and certainly much easier to read.

THE BRIDGE CIRCUITS

The bridge circuits in the TYPE 1608-A, Figure 2, are the familiar series and parallel inductance and capacitance bridges used in the TYPE 1650 and similar instruments. Also included are ac series-resistance and parallel-conductance bridges, both of which have phase (Q) adjustments not found in other bridges of this type. These circuits make possible a precise ac balance on an inductive or capacitive resistor and give a measure of its reactance, which is valuable for predicting the frequency characteristic.

The inclusion of these two bridges is important for more than just measurements on resistors, since they fill out the passive half of the complex plane, as shown in Figure 3. They make possible the measurement of a very lossy inductor or capacitor without a serious "sliding null," since the component can be measured as a resistor and the inductance or capacitance calculated from the measured Q and R (or G). Some bridges have wide D or Q ranges on the appropriate L or C bridge to measure lossy components, but when the Q is below ½ (D above 2), the resulting tedious sliding null makes them useless for practical measurement. The TYPE 1650-A Impedance Bridge uses the patented ORTHONULL®[3] mechanism, which greatly extends the useful range. This device requires a logarithmic CRL adjustment, which would be impractical with the linear digital readout of the new bridge. Although the use of the R and G bridges does require a calculation to get L or C

$$\left(L = \frac{RQ}{\omega}, C = \frac{Q}{\omega R}\right),$$

the high accuracy of the Q reading (±2% ±0.0005) results in better L or C accuracy at very low Q's than does even the ORTHONULL mechanism.

[3] H. P. Hall, "Orthonull — A Mechanical Device to Improve Bridge Balance Convergence," *General Radio Experimenter*, 33, 4, April, 1959.

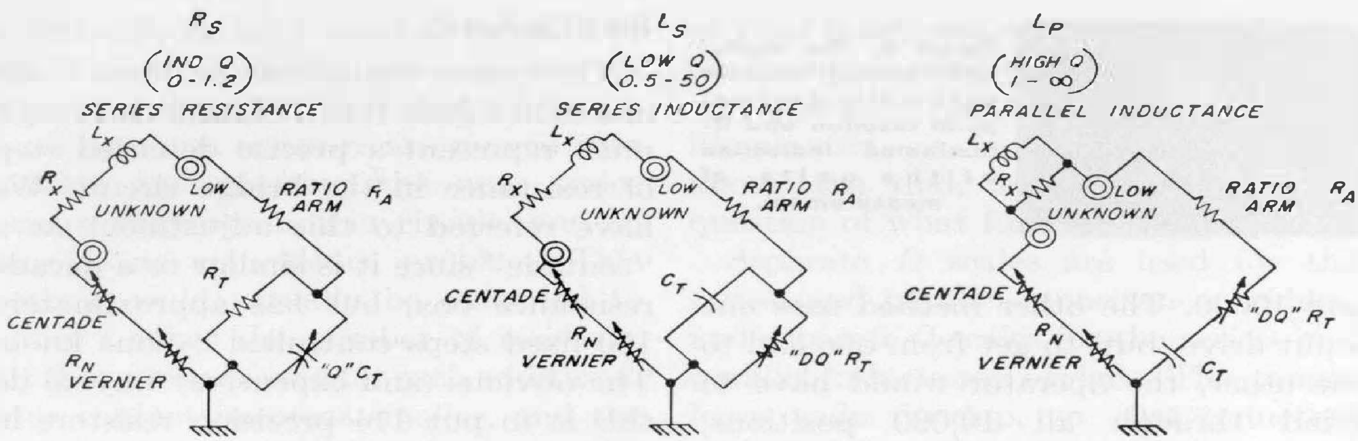


Figure 2b. Elementary schematics of the resistance and inductance bridges.

The bridge ranges extend up to 1100 μf, 1100h, 1.1MΩ and 1.1℧ and down to 0.05pf, 0.05μh, 0.05mΩ and 0.05n℧ (20kMΩ) which is the maximum resolution, corresponding to one-half of the last digit. The *L* and *C* ranges are more than adequate to cover any practical audio-frequency component, and the combination of an *R* and a *G* bridge gives resistance coverage from 0.05mΩ to 20kMΩ with the range from 1Ω to 1MΩ covered on both bridges. These two bridges can be used for both ac and dc measurements.

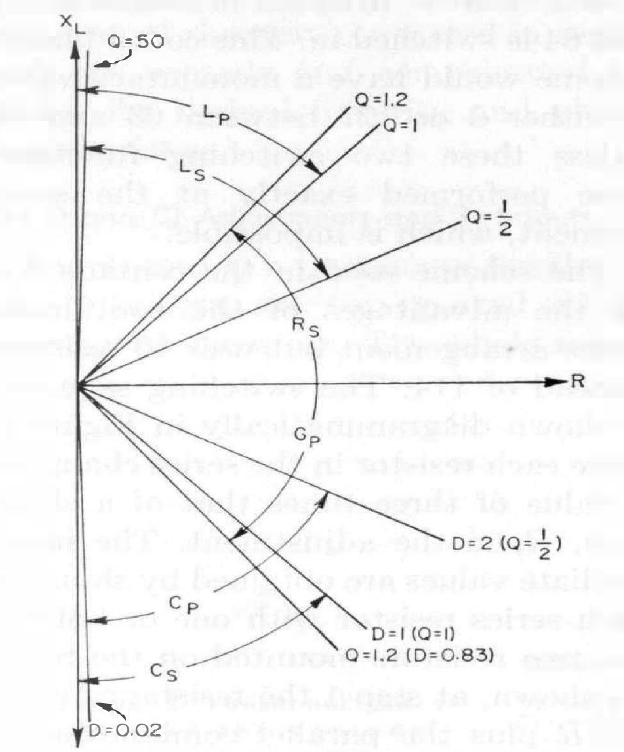


Figure 3. Phase coverage of the Type 1608-A Impedance Bridge.

CONTROLS

The Main Readout (C, G, R, or L)

An important design objective was a readout system that non-technical personnel could read without error. Even the most experienced engineer occasionally makes a mistake in interpolating a scale or applying a multiplying factor, and in an important project one occasional mistake can be costly. For repetitive production testing, the operator may be skilled at reading scales, but few can keep this up all day without a mistake. We felt, therefore, that our customers would value a simple digital display, very similar to an automobile odometer, but with decimal point and unit indicated, as shown in detail in Figure 4. There are two obvious ways to drive such an indicator, which, of course, must accurately track the precision-rheostat balance adjustment. One is to have a separate adjustment for each digit, as is done on a decade box. This requires four knobs, with the resulting annoyance of adjusting all four to vary the setting between 9999

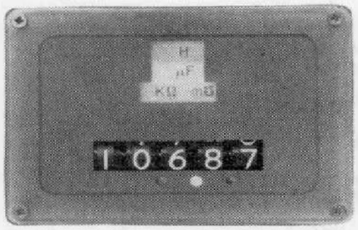


Figure 4. The digital CRL readout includes automatic decimal point location and illuminated indication of the units of measurement.

and 10000. The other method uses one input drive, but, to get from one end to the other, the operator would have to grind through all 10,000 positions, which is tedious and time consuming.

We compromised on two controls, a coarse and a fine, each adjusting two digits (the first actually goes to 114). Each of these controls can be swept through its range in less than one revolution. Therefore, during a balancing procedure when the operator comes to the end of the fine adjustment range, the coarse control is moved one digit, and less than 1 revolution of the fine control will reset it to zero.

To facilitate further this problem of transition between the two adjustments, the vernier scale extends beyond 99 to 106. This overlap of the adjustments is particularly useful for precision components, which are usually in integral values, so that the final adjustment is varied about a reading such as 9999 and 10000. However, the second dial (from the right) could not be labeled 10 since this would give the sequence 9999, 99100, which would be misleading. Also, a little thought will show that a geneva-type transfer to "carry the 1" would cause confusion since the operator would not know where he was on the fine adjustment. Therefore, we have adapted the convention of using X to represent 10 in one digit. The sequence now becomes 9999, 99X0, 99X1, etc., which seems unusual at first, but is easy to master.

The "Centade"

The coarse control of the main readout varies from 0 to 114, and each digit must represent a precise detented step of resistance in the bridge circuit. We have referred to this adjustment as a "centade" since it is similar to a decade resistance box, but has approximately 100 fixed steps controlled by one knob. The obvious (and expensive) way to do this is to put 114 precision resistors in series on a detented switch, which should be a shorting type to avoid discontinuities. The cheap way is to use seven resistors in a binary sequence and code a multiple contact switch to give a decimal scale. This method results in large adjustment discontinuities, which would give large momentary bridge unbalances at those steps where some resistors switched out and others switched in. The worst step is between 63 and 64 where the series combination of $1 + 2 + 4 + 8 + 16 + 32$ is switched out and 64 is switched in. This coded binary scheme would have a momentary value of either 0 or 127 between 63 and 64 unless these two switching functions were performed exactly at the same moment, which is impossible.

The scheme used in the centade has all the advantages of the continuous series arrangement but uses 40 resistors instead of 114. The switching sequence is shown diagrammatically in Figure 5. Here each resistor in the series chain has a value of three times that of a single step, R, in the adjustment. The intermediate values are obtained by shunting each series resistor with one or both of the two resistors mounted on the rotor. As shown, at step 1 the resistance value is $3R$ plus the parallel combination of $3R$, $6R$ and $2R$, which comes out to be a total of $4R$. In step 2 the $2R$ resistor is removed, giving a total of $5R$, and in step 3 both shunting resistors are removed, giving $6R$. Note that when the shunting rotor resistors are moved into position for shunting the next series resistor they are not in circuit, and so there is no coincidence problem. This method could actually be extended to reduce further the number of resistors, but the number saved for each additional rotor contact becomes smaller, and the design becomes more complex.

The switch stator is on an etched board with a rhodium-plated contact pattern similar to that shown diagrammatically in Figure 5, and the precision resistors are mounted directly on this board along with the phase-compensating components (see below). The rotor is a small etched board mounting the two shunting resistors. The contacts are precious metal and the rotor takeoff is a slip ring.

The fine, or vernier, control is a wire-wound rheostat connected in series with the centade and compensated to obtain the desired linearity and phase characteristics.

The D and Q Adjustments and Readouts

The D and Q adjustments for the L and C bridges are two ganged 40-db exponential rheostats. The whole range of D or Q adjustment for each bridge is on a single scale, so that no multiplier is necessary. The appropriate scale is illuminated, as is the letter D or Q above the dial, so that there is no question of what function is being read.

Separate D scales are used for the series- and parallel-capacitance bridges, and separate Q scales for the series- and parallel-inductance bridges. The ranges have wide overlap, so that inductors with Q values from 1 to 50 (or capacitors with D's from 0.02 to 1) can be measured as either a series or parallel configuration. At Q values above 50 (D below 0.02), the difference between the series or parallel value is 0.04%, at most.

The Q balance for resistance or conductance measurements consists of two decades of capacitance and a variable capacitor, with dials arranged to give in-line readout. An indicating light indicates whether the Q balance is inductive (for R measurements) or capacitive (for G measurements). This readout also uses the X indication to facilitate balances that occur in the awkward region beyond 9 on a decade adjustment.

ACCURACY

The basic bridge accuracy of 0.1% at 1 kc is primarily a function of the

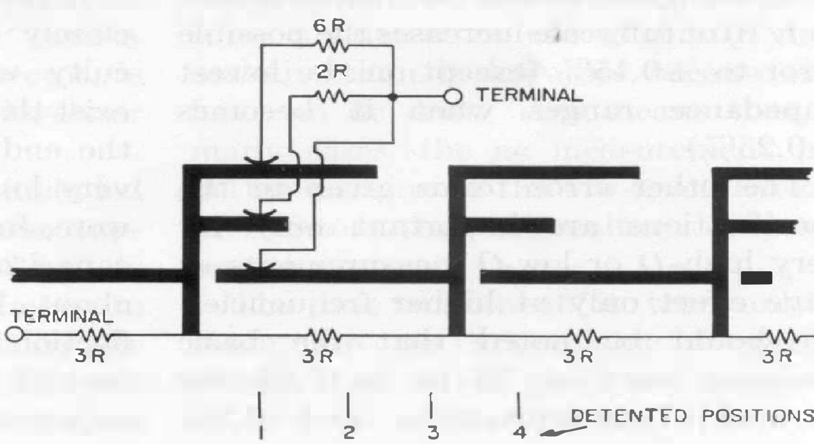


Figure 5. Functional diagram of the centade switching sequence.

calibration and the stability of the standard components used. All the fixed resistors, including those of the centade adjustment, are precision wire-wound units, similar to those used in General Radio decade resistors. The standard capacitor is similar to our precision silver-mica standards, but is shunted by a small, stabilized, polystyrene capacitor to reduce the over-all temperature coefficient. The total capacitance is 0.15 μf, so that in 3-terminal capacitance measurements substantial stray capacitance can be placed across it without causing appreciable error.

On the lowest impedance range of each bridge we have added an additional 0.1% to the accuracy specifications, because this range uses a one-ohm ratio-arm resistor, which is slightly less stable and more affected by possible variations in switch-contact resistance than are those of higher value. The range switches have solid-silver double contacts to keep these variations small.

The accuracy specification also includes a ±0.005%-of-full-scale term, which is ±½ division on the last digit of the indicator. This limitation is imposed by the ability to read the counter, the linearity of the fine adjustment, and backlash in the counter drive. This term reduces the bridge accuracy by a negligible amount at full scale but at 1/10 of full scale increases the possible error to ±0.15% (except on the lowest impedance ranges when it becomes ±0.25%).

The other error terms given in the specifications are important only for very high-D or low-Q measurements or have effect only at higher frequencies. It should be noted that the basic accuracy even at 10 kc is 0.2% for L and C measurements and 0.3% for resistance and conductance.

The residual impedances are the impedances associated with the unknown terminals themselves. An internal four-terminal connection is made to these terminals, so that the resistance is that of the binding post and the inductance is that of the loop completed by the shortest connection between the terminals. The 0.25-pf capacitance of the terminals can be removed by installation of a grounded shield between them.

Substantial effort was put into the design of this instrument to get the fixed phase error term down to ±0.0005 radian (the D of C and L and the Q of R and G) which we felt was necessary for a precise bridge. For example, a 0.1% capacitor to be used in a precision twin-T null circuit requires a dissipation-factor measurement to 0.001, since this D error could cause just as much unbalance in the null circuit as a 0.1% capacitance error. The fixed error term, ±0.0005, is the more important, since it is larger than the 5% term for D values up to 0.01.

With the resistance bridge, this phase precision enables one to check the Q of many bobbin-type, wire-wound resistors, which have appreciable reactance even at audio frequencies.

If the bridge phase shifts were not so closely controlled, a more subtle difficulty would occur. A D error could exist that would put the final balance off the end of the adjustment range for a very low-D component. If this D error were, for example, as great as 0.01, the capacitance balance would be limited to about ½%, since the null-meter deflection is proportional to the square root of the sum of the squares of both adjustment unbalances.

POWER SOURCES AND DETECTORS

An internal, two-transistor *RC* oscillator drives the bridge through a bridge transformer when the instrument is set for 1-kc measurements. It has an adjustable output and applies a maximum of about 1 volt behind 50 ohms. The detector uses six stages to get very high gain and 25-db second-harmonic rejection. This circuit has compression to give added range to the null-meter deflection to reduce the necessity of detector gain adjustments. On the extreme ranges, where more gain is required, an extra 20 db of gain is automatically added by the range switch.

The selective circuits used in the oscillator and detector are mounted on a module that slides in from the rear of the instrument and also provides a panel indication of the internal frequency. A 1-kc module is usually supplied, but other frequencies are available upon request. When modules for other frequencies are used, the proper frequency-dependent multiplication factors for the *D* and *Q* readings are also indicated on the panel. The instrument can also be used with an external oscillator, which is applied through the internal bridge transformer. The internal detector has a flat frequency response for this mode of operation, and an external selective detector, such as the TYPE 1232-A Tuned Amplifier and Null Detector, is useful for measurement at low levels or on nonlinear components.

Three internal dc supplies are included to give good dc sensitivity. These supplies of 350 volts, 35 volts, and 3.5 volts are current limited to avoid damage to the bridge or unknown and are adequate to apply the standard EIA test voltages for various types of resistors over most of the range. The range switch automatically chooses the optimum supply for each range. Moreover, the switching changes the manner in which the source is connected to the bridge to get maximum sensitivity and to prevent excess meter damping for low-resistance measurements.

The dc detector is a sensitive, shaped null indicator. To avoid the necessity of zero adjustment, no dc amplifier is used. With this system, 0.1% balance may be made from 1 ohm to 1 megohm if care is taken in reading the null detector. Provision is made for the use of external dc sources and high-gain dc null detectors.

SOME ADVANTAGES OF AC RESISTANCE MEASUREMENTS

The addition of a *Q* balance for the *R* and *G* bridges makes possible the precise measurement of resistors at 1 kc instead of at dc. This not only overcomes the sensitivity limitation of the dc bridges at the range extremes (see above), but also makes available some general advantages that ac bridges have over dc bridges. If the resistors are going to be used at ac, then an ac measurement is more logical. Further, the *Q* indication is useful in many cases. Ac measurements can be made at a much lower level than dc measurements, since ac detectors are generally more sensitive than dc detectors, because they have no dc drift. This means that, in many cases, the ac measurement is a better measure of the low-level *dc* value of resistors that are voltage or power sensitive.

The last statement is true only if there are no appreciable frequency effects that would make the zero-level ac and dc values different. There are many possible frequency effects to be considered, but the only important ones are distributed capacitance effects which cause difficulties only in the high megohm range at 1 kc. The trick that this bridge uses is that it requires that *series* resistance be measured when the unknown resistor is inductive and that *parallel* conductance be measured when the resistor is capacitive. Series inductance does not affect the value of series resistance, and parallel capacitance does not affect the value of parallel conductance (or parallel resistance). Of course, a resistor will have both series inductance and parallel capacitance, but the resonant frequency of a resistor would have to be 45 kc or lower to get an error of 0.1% at 1 kc. Few self-respecting resistors behave like that. (This does not mean to imply that the ac and dc resistances of a transformer or motor winding are anywhere near equal. Here, iron losses are the main cause of difference.)

APPLICATIONS

R, L, C Components

Bridges of this type are designed primarily to measure resistors, capacitors and inductors, and this one will measure components whose specified tolerances are well below 1%. It is often desirable to measure 1%, or poorer, components to much higher accuracy, for example, in acceptance tests on border-line cases, in quality-control work where a distribution within the tolerance range is desired, or in development work when cumulative tolerance effects are being studied. Although specialized precision bridges are recommended for measurement of reference impedance standards, this bridge is adequate to check most secondary standards used in production testing. Note that it will *compare* two components of decade value to 0.01%, since they can be balanced to the full-scale resolution.

Networks

The wide range and complete phase-angle coverage of this bridge make it useful for measuring the impedance of "black boxes." The bridge will balance for almost all passive impedances at 1 kc, the exceptions being the inductors above 1100h (which would probably be capacitive at 1 kc) and capacities above 1100μf (which should usually be measured at low frequencies). Thus, such things as potted networks, transducer impedances, and amplifier input and output impedances can be measured, and their audio-frequency characteristics plotted if an external oscillator is used.

In-Situ Capacitance Measurements

We've found that the ability to measure small capacitances has been useful for measuring the capacitance between components, wires or mounting structures. The advantage of three-terminal capacitance measurements is useful here, since it is possible to measure such quantities as the capacitance between any two conductors on an etched-board pattern with the others grounded. This ability to make measurements in the presence of large capacitance to ground permits the use of long shielded cables to connect remote or otherwise inaccessible components and to reduce the shunting effect of lead capacitance in the measurement of small capacitors.

Testing

The Type 1650-P1 Test Jig connects conveniently to the bridge (see cover photograph), thus placing quick-connect, spring terminals on the bench directly in front of the operator. If the gain of the instrument is adjusted to give a conveniently read deflection for a given bridge unbalance, this combination provides a versatile and accurate setup for the rapid tolerance testing of components.

— HENRY P. HALL

CREDITS

The TYPE 1608-A Impedance Bridge was developed by H. P. Hall. R. A. Soderman, Administrative Engineer; P. K. Bodge, Design Engineer; C. S. Kennedy, Layout Draftsman; W. H. Higginbotham, Production Engineer; and D. B. Bradshaw, Test Engineer, have all contributed to the final design.

— EDITOR

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: 0.05 mΩ to 1.1 MΩ ac or dc.

Conductance: 0.05 n℧ to 1.1 ℧ ac or dc (20 kMΩ to 0.9 Ω).

***D* of Series *C*:** 0.0005 to 1.

***D* of Parallel *C*:** 0.02 to 2.

***Q* of Series *L*:** 0.5 to 50.

***Q* of Parallel *L*:** 1 to 2000.

***Q* of Series *R*:** 0.0005 to 1.2 inductive.

***Q* of Parallel *G*:** 0.0005 to 1.2 capacitive.

ACCURACY

C, G, R, L

At 1 kc: $\pm 0.1\%$ $\pm 0.005\%$ of full scale except on lowest R and L ranges and highest C and G ranges where it is $\pm 0.2\%$ $\pm 0.005\%$ of full scale.

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

C* and *L

$$\left[\pm 0.001\left(\frac{f}{1\text{ kc}}\right)^2 \pm 0.1D\frac{f}{1\text{ kc}} \pm 0.5D^2\right]\%$$

of measured quantity.

R* and *G

$$\left[\pm 0.002\left(\frac{f}{1\text{ kc}}\right)^2 \pm 0.000001\left(\frac{f}{1\text{ kc}}\right)^4 \pm 0.1Q\right]\%$$

of measured quantity.

Residual Terminal Impedance: $R \simeq 1$ mΩ, $L \simeq$ 0.15 μh, $C \simeq 0.25$ pf.

Dc Resistance and Conductance: Same as for 1-kc measurements, except that accuracy is limited by sensitivity at the range extremes. Balances to 0.1% are possible from 1Ω to 1 MΩ with the internal supply and detector.

$D\left(\text{or } \frac{1}{Q}\right)$ of *C* or *L*:

± 0.0005 $\pm 5\%$ at 1 kc or lower.

$\pm 0.0005\,\frac{f}{1\text{ kc}}$ $\pm 5\%$ above 1 kc.

***Q* of *R* or *G*:** $\pm 0.0005\,\frac{f}{1\text{ kc}}$ $\pm 2\%$.

GENERATOR AND DETECTOR

Internal Oscillator: 1 kc $\pm 1\%$ normally supplied. Plug-in modules for other frequencies available on request. Level control provided.

Internal Ac Detector: Can be used either flat or selective at frequency of plug-in module (normally 1 kc). Second-harmonic rejection approximately 25 db; sensitivity control provided.

Internal Dc Supplies: 3.5 v, 35 v, 350 v; adjustable, and power limited to less than ⅓ watt.

Internal Dc Detector: Null indicator, 1 μa/mm.

External Oscillator and Detector: TYPE 1210-C Unit RC Oscillator and TYPE 1232-A Tuned Amplifier and Null Detector are recommended.

Dc Bias: Provision is made for biasing capacitors to 600 v with external supplies, and for biasing current in inductors.

GENERAL

Accessories Supplied: TYPE CAP-22 3-Wire Power Cord; spare fuses and indicator lamps.

Accessories Available: TYPE 1650-P1 Test Jig; external generator and detector, if used, as listed above.

Power Input: 105 to 125 (or 210 to 250) volts, 50-60 cps, 10 watts.

Mounting: Either relay-rack or bench, as listed below.

Dimensions: Rack model, panel, 19 by 12¼ inches (485 by 315 mm); bench model, width 19, height 12½, depth 11½ inches (485 by 320 by 295 mm), over-all.

Net Weight: 36¾ pounds (17 kg).

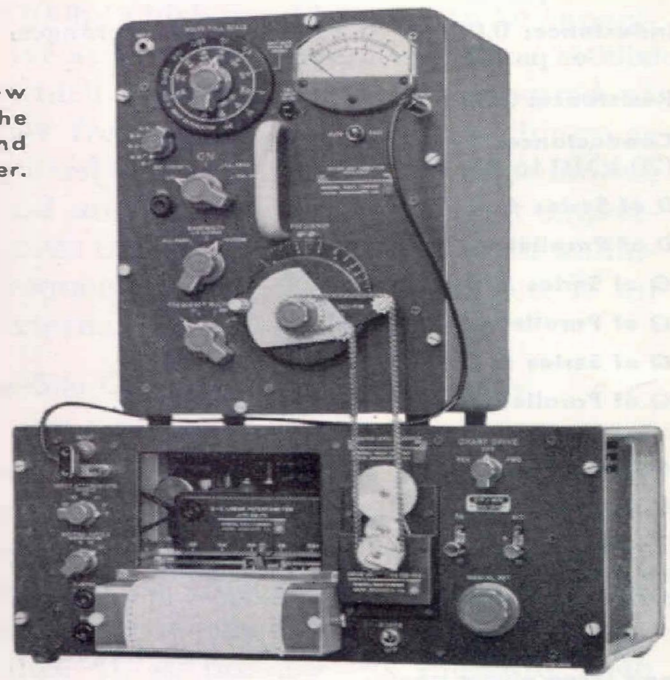
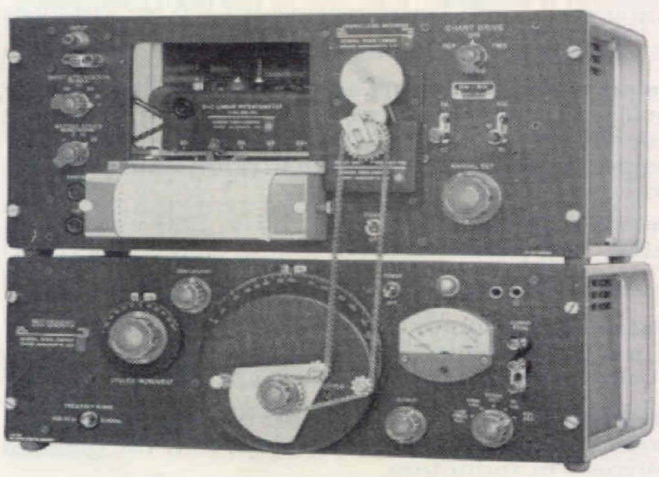
Type		*Code Word*	*Price*
1608-AM	**Impedance Bridge (Bench Mount)**...........	ARGON	**$1175.00**
1608-AR	**Impedance Bridge (Rack Mount)**............	ANVIL	**1175.00**

RELAY-RACK MOUNTING FOR THE OUTPUT POWER METER

The TYPE 1840-A Output Power Meter, described in the January-February issue of the *Experimenter*, can be adapted for relay-rack mounting by the addition of panel extensions. Order TYPE 480-P212 Panel Extensions as listed below.

Type		*Net Weight*	*Code Word*	*Price*
480-P212	Panel Extensions (pair)	4 oz (115 g)	EXPANELBAT	$6.00

NEW LINK UNIT FOR THE GRAPHIC LEVEL RECORDER

The Type 1521-A Graphic Level Recorder with the new Type 1521-P14 Link Unit is shown driving (below) the Type 1304-B Beat-Frequency Audio Generator and (right) the Type 1554-A Sound and Vibration Analyzer.

A new Link Unit, TYPE 1521-P14, is now available to couple the TYPE 1521-A Graphic Level Recorder to the TYPE 1304-B Beat-Frequency Audio Generator or to the TYPE 1554-A Sound and Vibration Analyzer for the automatic recording of frequency response characteristics. With this link unit, the audio generator can be mounted either above or below the recorder. The analyzer is operated above the recorder.

The TYPE 1521-P11 Link Unit, with which the generator could be mounted only above the recorder, is discontinued.

Type		*Code Word*	*Price*
1521-P14	Link Unit	PANIC	$18.00

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