



GenRad

**impedance
measuring
instruments**

electronic instrument division

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Impedance Measurement

Null methods have long been recognized as the most precise way to measure all types of impedances — resistive and reactive, inductive and capacitive, from low frequencies to uhf. Most null-type instruments evolved from the century-old Wheatstone Bridge, still the fundamental circuit for measuring dc resistance. Other null circuits, such as the admittance meter and transfer-function bridge, have been developed by GenRad to meet the diverse requirements of modern measurement. In all, GR produces bridges that cover virtually the entire field of impedance measurement. Some of these bridges include built-in generator and detector and are thus complete, self-contained measurement systems. Others are available in combination with various GenRad oscillators and detectors, as complete assemblies.

DC BRIDGES

The Wheatstone bridge measures an unknown resistance, R_x , in terms of calibrated standards of resistance connected as shown in Figure 1. The relation is:

$$R_x = \frac{R_N R_B}{R_A} \quad (1)$$

which is satisfied when the voltage across the detector terminals is zero.

AC BRIDGES

The Wheatstone bridge circuit is easily adapted to ac measurement. With complex impedances, two balance conditions must be satisfied, one for the resistive component and one for the reactive component. At balance:

$$Z_x = R_x + jX_x = Z_N Y_A Z_B \quad (2)$$

$$\text{or} \quad Y_x = G_x + jB_x = Y_N Z_A Y_B \quad (3)$$

Equation (2) expresses the unknown in terms of impedance components; equation (3) expresses the unknown as an admittance. To satisfy these equations, at least one of the three arms A, B, or N must be complex.

The reactance X_x can be measured in terms of a similar reactance in an adjacent arm (Figure 2) or an unlike reactance in the opposite arm (Figure 3).

The complex arm required to satisfy the balance conditions of equation (2) or (3) is a combination of a resistance

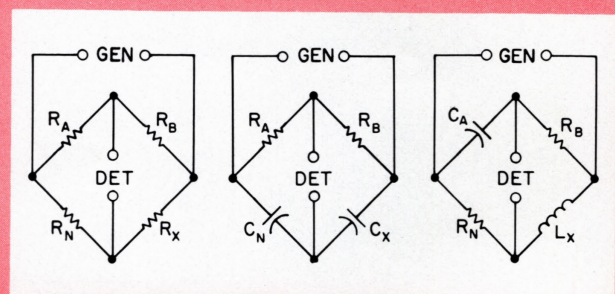


Figure 1. The general Wheatstone bridge circuit.

Figures 2 and 3. Circuits for capacitance bridges in which like reactances (left) or unlike reactances (right) are compared.

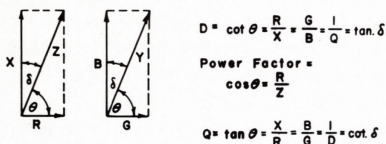


Figure 4. Vector diagram showing the relations between factors D and Q, and angles θ and δ

and a reactance, in series or in parallel. With a **series** combination in an arm **adjacent** to the unknown or a **parallel** combination in the arm **opposite** the unknown, the bridge measures the equivalent series components of the unknown. Conversely, an adjacent parallel or an opposite series combination will yield a measurement of equivalent parallel components. (Every impedance can be expressed in terms of either series or parallel equivalents, as discussed below.)

If both components of this complex arm are adjustable, the balances for the real and imaginary parts of the unknown will be independent of each other and orthogonal. If only one component of the combination is adjustable, this component will be proportional to either the D or the Q of the unknown impedance. If the adjustable component is the more prominent of the two, as it is when very low-Q inductors are measured, the balance convergence is slow, if not impossible. The general-purpose 1650 Impedance Bridge and the 1617 Capacitance Bridge use a mechanical ganging of the bridge controls (called Orthonull®) to facilitate convergence.

D AND Q

An important characteristic of an inductor or a capacitor, and often of a resistor, is the ratio of resistance to reactance or of conductance to susceptance. The ratio is called dissipation factor, D, and its reciprocal is storage factor, Q. These terms are defined in Figure 4 in terms of phase angle θ and loss angle δ . Dissipation factor is directly proportional to energy dissipated, and storage factor to energy stored, per cycle. Power factor ($\cos \theta$ or $\sin \delta$) differs from dissipation factor by less than 1% when their magnitudes are less than 0.1.

In Figure 4, R and X are series resistance and reactance, and G and B are parallel conductance and susceptance, of the impedance or admittance involved.

Dissipation factor, D, which varies directly with power loss, is commonly used for capacitors. Storage factor, Q, is more often used for inductors because it is a measure of the voltage step-up in a tuned circuit. Q is also used for resistors, in which case it is usually very small.

Most GenRad capacitance and inductance bridges also measure D or Q.

SERIES AND PARALLEL COMPONENTS

Many GR impedance bridges give the user the option of measuring the unknown in terms of either its series or parallel equivalents. The choice is a matter of convenience for the problem at hand. Since the distinction between series and parallel equivalents is sometimes over-

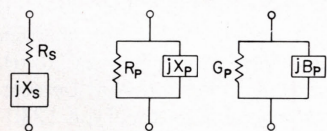


Figure 5. Series and parallel components of impedance.

looked in texts, we will briefly summarize the relationships here.

Regardless of physical configuration, every impedance can be expressed, for any given frequency, as either a series or a parallel combination of resistance and reactance, as shown in Figure 5. The relations between the elements of Figure 5 are:

$$R_p = \frac{1}{G_p} = \frac{R_s^2 + X_s^2}{R_s} = R_s(1 + Q^2)$$

$$X_p = \frac{1}{B_p} = \frac{R_s^2 + X_s^2}{X_s} = X_s(1 + D^2)$$

In terms of series and parallel capacitive and inductive reactances, these relations become:

$$C_p = C_s \left(\frac{1}{1 + D^2} \right)$$

$$C_s = C_p (1 + D^2)$$

$$L_p = L_s \left(1 + \frac{1}{Q^2} \right)$$

$$L_s = L_p \left(\frac{Q^2}{1 + Q^2} \right)$$

Where:

$$Q = \frac{X_s}{R_s} = \frac{R_p}{X_p} = \frac{B_p}{G_p} = \frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p} = \frac{1}{D}$$

and

$$D = \frac{1}{Q} = \frac{R_s}{X_s} = \frac{X_p}{R_p} = \frac{G_p}{B_p} = \omega R_s C_s = \frac{1}{\omega R_p C_p} = \frac{1}{Q}$$

If Q is 10 or more (or if D is 0.1 or less), the difference between series and parallel reactance is no more than 1%. For very low Q's or high D's, however, the difference is substantial; when Q = 1, X_p is twice X_s . If there were no losses in the reactive elements (i.e., D = 0), X_s and X_p would be equal.

SUBSTITUTION METHODS

In many ac bridges, the unknown is connected in series or in parallel with the main adjustable component, and balances are made before and after the unknown is connected. The magnitude of the unknown then equals the change made in the adjustable component, since the total impedance of the unknown arm remains constant. The chief advantage of this substitution technique is that its accuracy depends only on the calibration of the adjustable arm and not on the other bridge arms (as long as they are constant). The substitution principle can also be used to advantage with any bridge if the balances are made with an external, calibrated, adjustable component.

BRIDGES WITH ACTIVE ELEMENTS

If a potentiometer-amplifier combination is connected as a bridge element, fixed capacitance and conductance standards can be used, with current adjusted by variation of voltage rather than of impedance magnitude. The principle is used in the Type 1633-A Incremental-Inductance Bridge, which can accurately measure nonlinear elements.

THE TRANSFORMER RATIO-ARM BRIDGE

Transformer ratio arms, introduced almost a century ago, have recently come into considerable favor because of certain outstanding advantages. Ratio accuracies of a few parts per million are possible, even for transformer ratios of up to 1000 to 1, and the ratio is virtually unaffected by age, temperature, or voltage. Examples of the transformer bridge are the 1615 Capacitance Bridge and the 1682 Automatic Capacitance Bridge.

Figure 6. A capacitance bridge with transformer ratio arms.

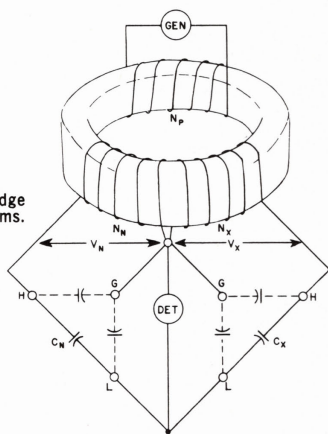


Figure 6 shows a transformer bridge in elementary form. The balance condition for capacitance is

$$\frac{C_x}{C_n} = \frac{N_n}{N_x}$$

Figure 6 also explains the exceptional ability of the transformer bridge to make three-terminal measurements without the use of a guard circuit or auxiliary balance. Capacitances from the H terminals appear across the low-impedance transformer winding, while those from the L terminals are across the detector, where they do not enter the balance expression. These capacitances are thus excluded from the measurement of direct capacitance, C_x , between H and L terminals. Because this type of bridge can tolerate relatively large capacitances from both sides of the unknown to the guard point, long cables with guard shields can be used for remote measurement, and circuit capacitances can often be measured *in situ*.

Conventional bridges can also be adapted for three-terminal measurements (although they generally cannot tolerate as low an impedance to guard). On the Types 1650 and 1608 Impedance Bridges and 1617 Capacitance Bridge any stray capacitance is in parallel with a standard capacitor of at least 0.1 μF and usually has negligible effect. On the Type 1654 Impedance Comparator an electronic amplifier provides a guard point.

LIMIT BRIDGES AND COMPARATORS

In limit bridges, the unbalance voltage of the bridge actuates a meter, which indicates the degree of deviation of one impedance from another. The Type 1662 Resistance Limit Bridge, which includes an adjustable standard resistor, can limit-test resistors over a wide range. The Type 1654 Impedance Comparator indicates the magnitude and phase differences between the unknown and an external standard. On this instrument, the availability of several sensitive ranges enables the user to measure small differences very accurately.

THE AUTOMATIC BRIDGE

The ultimate in convenience is a bridge that balances itself. The 1682 Automatic Capacitance Bridge, the 1686-A Digital Capacitance Meter, the 1685 Digital Impedance Meter, the 1657 Digibridge™ and the 1683 Automatic RLC Bridge fully automate the balance procedure — selecting range, balancing, and presenting readout in both visual and digital data form.

The implications of such automatic measurement are far-reaching. The conversion of bridge-measured data into digital and binary-coded form gives the bridges access to the whole modern arsenal of data-processing equipment — computers, printers, tape-punchers, sorters, etc. Speed is one obvious byproduct of automatic equipment: GR's new automatic bridges take about one-half second to achieve balance.

COAXIAL-LINE INSTRUMENTS

The Slotted Line

The upper-frequency limit of conventional bridge circuits using lumped-parameter elements depends on the magnitude of the residual impedances of the elements and leads. The corrections for these usually become unmanageable at frequencies above a few hundred megacycles, and circuits based on coaxial-line techniques are more satisfactory.

One of the basic methods of measuring the impedance of a coaxial device is the measurement of the standing-wave ratio it introduces in a uniform line. The measurement is best made by a slotted line. GenRad offers two slotted lines: the Type 874-LBB, for general impedance measurements, and the highly accurate Type 900-LB, the most advanced slotted line available commercially.

GENERATORS AND DETECTORS

Several GR bridges includes both generator and detector. Some others — the Types 1615-A Capacitance Bridge and 1633 Inductance Bridge — are available as complete measuring assemblies, with generator, detector, interconnecting cables, relay rack, and other accessories. Unless one obtains such a complete system, he must carefully choose generator and detector to ensure satisfactory measurement results. (Even with a complete system, the user may at times wish to connect a different generator or detector to the bridge, and almost all GR bridges include panel connectors for such use.)

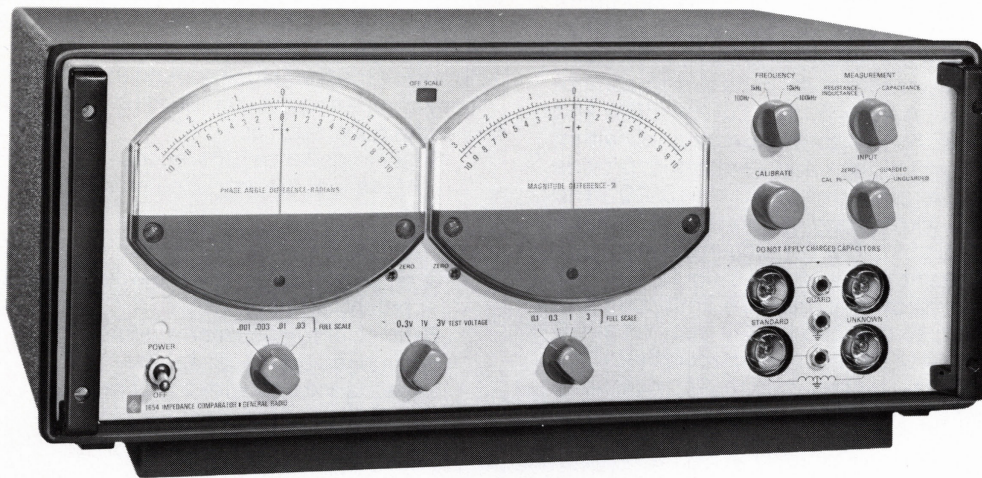
The chief generator requirements are good frequency stability, adequate power output, and low harmonic content. A wide choice of GR oscillators is available, covering the frequency range from audio to microwave.

Desirable detector characteristics are

- (1) High sensitivity, preferably the ability to detect a few microvolts or less.
- (2) High selectivity, to reject harmonics, noise, and other interfering signals. This is particularly important in measurements on iron-core coils and other nonlinear elements.
- (3) Logarithmic or nearly logarithmic response, to minimize gain adjustment during the balancing procedure.
- (4) Good shielding, to prevent errors from extraneous pickup.

At audio frequencies, GR's Type 1232-A Tuned Amplifier and Null Detector is recommended for its high sensitivity and for its general versatility in the lab. Crystal mixers are available for both the detectors, extending their frequency ranges to about 60 MHz. At these and higher frequencies, the heterodyne type of detector is preferred, because of its wide frequency range and excellent shielding.

One of the most popular generator-detector combinations, the Type 1311-A Audio Oscillator (50 Hz to 10 kHz) with the Type 1232-A Tuned Amplifier and Null Detector, is now available in a single assembly as the Type 1240-A Generator-Detector Assembly.



1654 Impedance Comparator

- **0.003% impedance-difference resolution**
- **100 Hz to 100 kHz — 4 fixed frequencies**
- **wide impedance ranges:**
 - 2 Ω to 20 M Ω**
 - 0.1 pF to 1000 μ F**
 - 20 μ H to 1000 H**
- **stable solid-state circuits**
- **fast sorting —**
 - > 10,000/h, with accessory limit comparator**

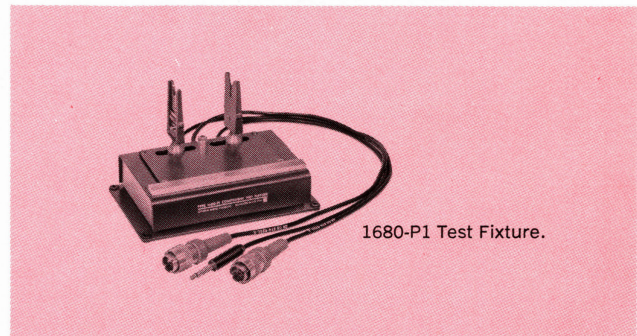
The GR 1654 Impedance Comparator indicates on large panel meters and by analog output voltages the difference in magnitude and phase angle between two external impedances, usually a standard and an unknown. Owing to its speed and percent-deviation readout, the 1654 is of great value in the sorting, selecting, and adjusting of components in production and inspection applications.

Accurate Because the 1654 measures differences to an accuracy of 3% of full scale, the measurement accuracy and resolution as a percent of the total impedance are considerably better, with comparison precisions to $\pm 0.003\%$. In addition, the magnitude channel of the 1654 has been linearized to ensure accurate readings without correction for up to 30% impedance differences. Solid-state circuits are used in the 1654 so that drift of the meter zero is negligible, permitting more certain accuracy and fewer interruptions for readjustment.

Versatile Test voltage, frequency, and measurement ranges of impedance and phase-angle differences are all selected by front-panel controls. Test voltage and measurement ranges are related and their panel switches interlocked to reflect this relationship. Four measurement ranges can be used with each test voltage. The highest test level, 3 volts, gives the greatest sensitivity: 0.1% and 0.001 radian, full scale. The lower levels, 1.0 and

0.3 volt, permit measurement of more fragile components, allow easy voltage-coefficient tests, and (while limiting maximum sensitivity) extend large-difference capability to 30% and 0.3 radian, full scale.

Wide ranges of impedance, resistance, capacitance, and inductance can be compared with the 1654. Since it is a transformer bridge, its accuracy is little affected by loading or by stray impedances for most measurements. A guard terminal is provided for making three-terminal connections to minimize the effects of stray fixture and cable capacitance.



1680-P1 Test Fixture.

HIGH-SPEED SORTING, SYSTEMS EXPANSION

The 1654 measures the difference between two externally connected components. For comparison measurements you need a standard. For rapid sorting you need either a limit comparator or an alert operator who can mentally juggle up to six numbers simultaneously. You can solve these problems neatly by adding to the basic impedance comparator or, more neatly yet, by letting us do the adding in the form of one of several models of the 1654-Z Sorting System.

One model of the 1654-Z contains, in addition to the 1654 Impedance Comparator, one of our latest and best decade capacitors. A second model contains a versatile limit comparator especially designed for the 1654, and a third model contains both.

The 1413 Precision Decade Capacitor provides a range of from 0 to 1.11111 μF , an accuracy of 0.05%, and a resolution of 1 pF. Any value in its range is set easily by six in-line readout dials, and it may be connected to either the front or the rear of the 1654.

The 1782 Analog Limit Comparator provides four limits that you may use as your needs dictate: a high and low limit for both magnitude and phase, two values of magnitude only or phase only, or four high limits to sort components into five categories (say 5, 10, 20 and 30% and reject). All limits can be set to an accuracy of within $\pm 2\%$ of full scale and bright-light panel indicators provide results of the comparison in terms of GO or NO GO. The 1782 is available also with a relay option to control automatic sorting mechanisms. The components can be applied manually or automatically at rates up to four per second. For special applications, up to 16 limit comparators can be connected to the 1654. Call your local GR sales engineer for further details on incorporating additional limit comparators or other automatic measuring and sorting equipment.

TYPICAL USES

Rapid sorting and matching of precision components, subassemblies, and networks, manually or with automatic equipment.

Measuring the effects of time and environment on components, with high precision and continuous indication.

Rapid testing of the tracking of ganged potentiometers and variable capacitors.

Studying the frequency dependence of components.

Easy comparison of quantities usually requiring laboratory techniques, such as:

Small impedance differences.

D of low-loss dielectric materials.

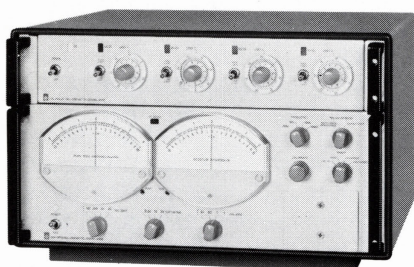
$D \left(= \frac{1}{Q} \right)$ of inductors.

Q or phase angle of wire-wound resistors or potentiometers.

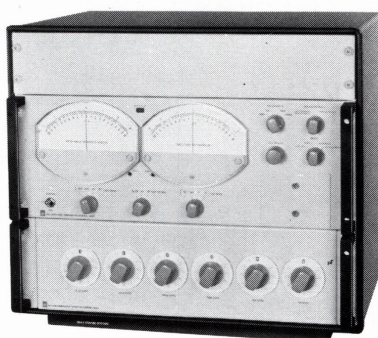
Balance of transformer windings.

Semiconductor capacitances.

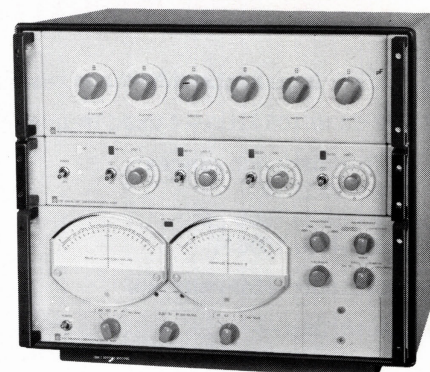
Capacitance drift with temperature.



1654-Z1 Sorting System includes limit comparator for additional limits.



1654-Z2 Sorting System contains precise capacitance decade standard.



1654-Z3 Sorting System includes both a limit comparator and capacitance decade standard.

SPECIFICATIONS

Frequencies: Internal only 100 Hz, 1, 10, and 100 kHz, $\pm 1\%$.

Ranges: 0.1% to 30% full-scale impedance difference; 0.001 to 0.3 radian full-scale phase-angle difference. Available ranges depend on test voltage selected as shown in the following table.

Test Voltage	Impedance Difference						Phase-Angle Difference					
	Full-scale Range — %						Full-scale Range — Radian					
	0.1	0.3	1	3	10	30	0.001	0.003	0.01	0.03	0.1	0.3
0.3 V			x	x	x	x			x	x	x	x
1 V		x	x	x	x	x		x	x	x	x	x
3 V	x	x	x	x			x	x	x	x		

Impedance Ranges (0.3-V test voltage*)

Freq	Resistance	Capacitance	Inductance
100 Hz	2 Ω — 20 M Ω	1000 pF — 1000 μF	5 mH — 1000 H
1 kHz	2 Ω — 2 M Ω	50 pF** — 100 μF	500 μH — 100 H
10 kHz	2 Ω — 200 k Ω	50 pF** — 10 μF	50 μH — 1 H
100 kHz	10 Ω — 10 k Ω	50 pF** — 0.1 μF	20 μH — 10 mH

* Low R and L limits are increased and upper C limit decreased by 10:1 for 1-V test voltage and by 100:1 for 3-V.

** To 0.1 pF by substitution method.

Resolution: Meter, 0.003% and 0.00003 radian. Analog-voltage output, 0.001% and 0.00001 radian.

Accuracy: 3% of full scale.

Voltage Across Standard and Unknown: 0.3, 1, or 3 V selected by front-panel control. Test voltage of 2 V (with 0.6 and 6 V) can be obtained on special order.

Analog-Voltage Outputs: Voltages proportional to meter deflections at two rear-panel connectors: ± 10 V full scale behind $< 10 \Omega$ for 1782 Analog Limit Comparator; ± 3 V or ± 10 V (depending on range) full scale behind 2 k Ω for DVM, A-D converter or other use.

Test Speed: About 1 component per second with meter, max. With analog output voltage, about 4 components per second, except about 1 component per second at 100 Hz.

Power: 105 to 125 or 210 to 250 V, 50-60 Hz, 15 W except 1654-Z1, 35 W.

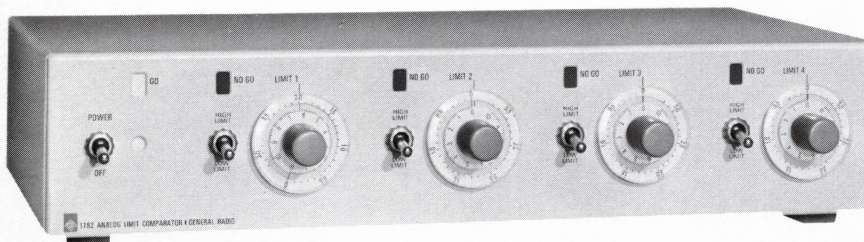
Supplied: Multiple-contact connector and power cord.

Available: 1782 ANALOG LIMIT COMPARATOR (supplied with -Z1 and -Z3); 1413 PRECISION DECADE CAPACITOR (supplied with -Z2 and -Z3) and other GR decade boxes and standards of resistance, capacitance, and inductance; 1680-P1 TEST FIXTURE for rapid connection of components (includes con-

necting cables); 1654-9600 ADAPTOR KIT for components with 3/4-in. spaced leads; 874-MB COUPLING PROBES for components with 1 1/4-in. spaced leads; and 874-R33 PATCH CORDS for connection to GR874®-terminated standards or unknowns.

Mechanical: 1654, bench or rack models; 1654-Z, all units mounted in a single cabinet with necessary interconnections made. DIMENSIONS (wxhxd): 1654 bench, 19.5x8.75x15 in. (495x222x381 mm); 1654 rack, 19x7x13.5 in. (483x178x343 mm); 1654-Z1, 12x19.5x15 in. (305x222x381 mm); 1654-Z2, -Z3, 17.5x19.5x15 in. (445x222x381 mm). WEIGHT: 1654 bench, 40 lb (19 kg) net, 60 lb (28 kg) shipping; 1654 rack, 25 lb (12 kg) net, 40 lb (19 kg) shipping; 1654-Z1, 51 lb (24 kg) net, 63 lb (29 kg) shipping; 1654-Z2, 66 lb (30 kg) net, 79 lb (36 kg) shipping; 1654-Z3, 77 lb (35 kg) net, 90 lb (42 kg) shipping.

Description	Catalog Number
1654 Impedance Comparator	
Bench Model	1654-9700
Rack Model	1654-9701
1654-Z Sorting Systems (bench only)	
1654-Z2 includes 1413 Decade Capacitor	(Describe exactly as shown at left.)
1654-Z1 includes 1782 Limit Comparator	
1654-Z3 includes 1413 and 1782	
Select, if desired, with -Z1 and -Z3 only	
OP6 Relay Output	
Accessories Available	
1680-P1 Test Fixture	1680-9601
1654-9600 Adaptor Kit	1654-9600
874-MB Coupling Probe (2 req'd for each term pair)	0874-9666
874-R33 Patch Cord (2 req'd for each term pair)	0874-9690



1782 Analog Limit Comparator

- accessory to 1654 Impedance Comparator
- 4 independent limits — use for high or low
- 2% of full scale accuracy
- GO/NO GO lights, optional contact closures

The GR 1782 Analog Limit Comparator increases the speed at which the 1654 Impedance Comparator will operate in sorting applications. It compares the analog-voltage output of the 1654 against high and low limits set on the 1782 front panel and displays GO or NO GO lights for manual sorting. Optional relay-equipped models will operate external automatic-sorting devices. Up to 4 com-

ponents per second can be measured with the two instruments together.

Four controls on the front panel permit the limits to be set to 1% resolution; each control can act as either a high limit or a low limit as selected on an adjoining switch and for ΔZ or $\Delta \theta$ as selected by a rear-panel switch.

SPECIFICATIONS

Input: ANALOG VOLTAGE: ± 10 V full scale. RESISTANCE (of each comparator): 66 k Ω , approx.

Output: ANALOG VOLTAGE: Identical to input. DECISION OUTPUTS: Visual or relay contacts. *Visual:* NO-GO lamp for each limit; GO lamp indicates measurement is within all limits. *Relay Contacts* (optional): 5 SPDT contacts, 115 V rms, 0.1 A rms, max.

Accuracy: $\pm 2\%$ of full scale.

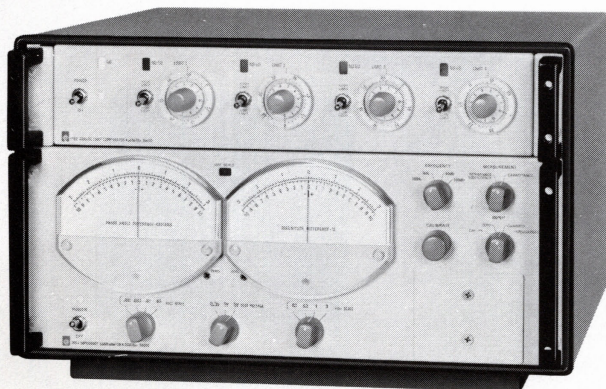
Limit Controls: Four independent limits; can be set for + (high) or - (low) with switch adjoining each control. DUAL CONTROLS: Inner scale calibrated 0 to 100 (each division corresponds to 100 mV), outer scale calibrated 0 to 30 (316 mV per division).

Test Speed: Approx 10 tests per second, max, for visual output.

Power: 105 to 125 or 210 to 250 V, 50 to 60 Hz, 20 W.

Supplied: 24-contact connector with relay models only, input-signal cable, power cord.

Mechanical: Convertible bench cabinet. DIMENSIONS (wx hxd): Bench, 17x3.88x9.88 in. (432x99x251 mm); rack, 19x 3.5x8.63 in. (483x89x220 mm). WEIGHT: 9 lb (4 kg) net, 15 lb (7 kg) shipping.



The 1782 is shown here with the 1654 Impedance Comparator to form one version of the 1654-Z Sorting System.

Description	Catalog Number
1782 Analog Limit Comparator	
Bench Model, without relays	1782-9700
Rack Model, without relays	1782-9701
Bench Model, with relays	1782-9702
Rack Model, with relays	1782-9703



1656 Impedance Bridge

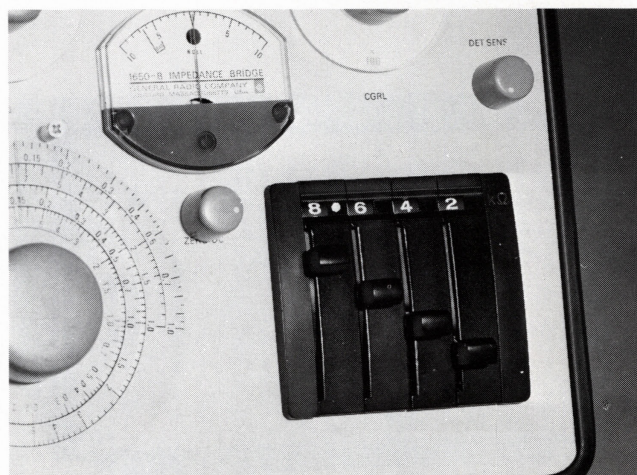
- measures R, L, C, and G
- 0.1% basic accuracy
- fast lever balancing
- digital readout of RLC and G
- portable, self-contained

Today's components demand high-precision measurements; today's schedules demand fast answers. GR's 1656 meets these demands. A precision adaptation of a long-time favorite bridge, the 1656 simplifies 4-place balancing with lever switches and reduces possible reading error with in-line digital readout of impedance.

Though of laboratory accuracy, the 1656 is also the ideal general-purpose instrument for production, inspection, and field use. It's fully portable and self-contained for both ac and dc measurements and demands no special training for proper use.

Measure extremely large or small value of R or G with ease — you will appreciate the extraordinary sensitivity of the detector in this instrument. Indeed, there are few

impedance measurements that will challenge it, whether dc or audio-frequency. Notice the width of the ranges specified below.



Lever-arm switches on 1656 permit fast balances and easy-to-read answers.

SPECIFICATIONS

Range	Resolution (one digit on lowest range)	Accuracy*	
		Frequencies ≤ 1 kHz and small phase angle (f_s = full scale)	Frequencies > 1 kHz or large phase angle Typical additional error terms
Capacitance: 0.1 pF to 1100 μ F Series or parallel, 7 ranges	0.1 pF	$\pm(0.1\%$ of reading $+ 0.01\%$ of f_s $+ 0.2\%$ of reading on highest range)	$\pm[0.2 D f_{kHz} + 0.5 D^2 + 0.002 (f_{kHz})^2]\%$
Inductance: 0.1 μ H to 1100 H Series or parallel, 7 ranges	0.1 μ H	$\pm(0.1\%$ of reading $+ 0.01\%$ of f_s $+ 0.2\%$ of reading on lowest range)	$\pm[0.2 f_{kHz}/Q + 0.5/Q^2 + 0.002 (f_{kHz})^2]\%$
Resistance: 0.1 m Ω to 1.1 M Ω Ac or dc, 7 ranges	0.1 m Ω	$\pm(0.1\%$ of reading $+ 0.01\%$ of f_s $+ 0.2\%$ of reading on lowest range)**	$\pm[Q f_{kHz} + 0.003 (f_{kHz})^2]\%^{**}$
Conductance: 0.1 n Ω to 1.1 Ω Ac or dc, 7 ranges	0.1 n Ω	$\pm(0.1\%$ of reading $+ 0.01\%$ of f_s $+ 0.2\%$ of reading on highest range)**	$\pm[Q f_{kHz} + 0.003 (f_{kHz})^2]\%^{**}$
Dissipation Factor, D: series capacitance 0 to 1	—	$\pm(0.001 \pm 5\%$ of reading)	$\pm(0.001 f_{kHz} + 5\%$ of reading)
parallel capacitance 0.1 to 50	—	$\pm 5\%$ of reading (sliding null at high D)	$\pm 5\%$ of reading
Storage Factor, Q: series inductance 0.02 to 10	—	$\pm 5\%$ of reading (sliding null at low Q)	$\pm 5\%$ of reading
parallel inductance .1 to ∞	—	$\pm(5\%$ of reading $+ 0.001)$ for $1/Q$	$\pm(5\%$ of reading $+ 0.001 f_{kHz})$ for $1/Q$

* Full accuracy applies from 15 to 35°C, <85% RH (useful from 0 to 45°C). Residual terminal impedances of ≈ 0.3 pF, 0.15 μ H, and 1 m Ω must be corrected to obtain specified accuracy.

** Terms apply to ac measurements when external phase balance is properly adjusted; otherwise accuracy is 0.5% of reading.

Generator: Internal, 1 kHz $\pm 2\%$ ac, 1.5 V dc. External, 20 Hz to 20 kHz ac; Type 1310 or 1311 Oscillator recommended.

Detector: Internal, 1 kHz ac with >20 -dB rejection at 2nd harmonic or flat, meter indication; 10- μ V/mm dc meter sensitivity. External, Type 1232 Tuned Amplifier and Null Detector recommended.

Bias: 600 V max on capacitors; small currents allowable on inductors and resistors; external only.

Terminals: $\frac{3}{4}$ -in.-spaced binding posts for unknown; pin jacks for external ac generator and capacitor for ac phase balance; phone jacks for external detector, bias, and DQ adjustment.

Supplied: Batteries.

Available: 1650-P1 TEST JIG for rapid and convenient connection of axial-lead components to bridge. Permits 3-terminal connection for negligible zero capacitance, introduces 80-m Ω total lead resistance (which only affects measurements on very low impedances), and adds a D or $1/Q$ error of less than 0.007.

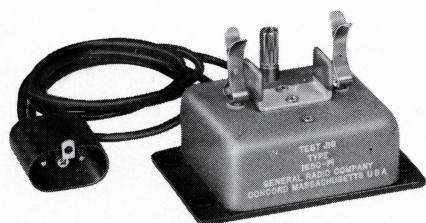
Power: 5 D-cells, supplied; battery checks provided.

Mechanical: Flip-Tilt case and rack mount. DIMENSIONS (wxhxd): Portable, 13.25x12.87x6.69 in. (337x327x170 mm); rack, 19x12.25x5.75 in. (483x311x146 mm). WEIGHT: Portable, 15 lb (7 kg) net, 21 lb (10 kg) shipping; rack, 16 lb (8 kg) net, 28 lb (13 kg) shipping.



Flip-Tilt case provides complete protection.

Description	Catalog Number
1656 Impedance Bridge	
Portable Model	1656-9701
Rack Model	1656-9702
D Cell , replacement battery for 1656 (5 req'd)	8410-0200



1650-P1 Test Jig

This test-jig adaptor is used to connect components quickly to a pair of terminals and can be placed on the bench directly in front of the operator. Thus, the test jig and 1650-B, 1656, or 1608-A Impedance Bridge make a

rapid and efficient component sorting device when the panel meter of the bridge 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.

Weight: Net, 10 oz (285 grams); shipping, 4 lb (1.9 kg).

Description	Catalog Number
1650-P1 Test Jig	1650-9601



1608-A Impedance Bridge

- measures C, R, L, and G with digital readout
- $\pm 0.05\%$ accuracy
- 20 Hz to 20 kHz (external generator)
- internal 1-kHz oscillator and detector
- measures impedance of any phase angle
- accurate D and Q readings

This wide-range bridge will measure precision components to an accuracy of 0.05% — capacitance, inductance, and ac as well as dc resistance and conductance. An almost error-free readout and rapid-balance adjustments allow accurate and fast laboratory or production tests. Six bridge circuits cover all possible phase angles so that any network can be measured, even such "black boxes" as filters, transducers, and equalizers.

In ac resistance and conductance measurements, a Q adjustment for precise balancing gives phase information useful in predicting high-frequency behavior. This capability is also useful for measuring lossy reactances, such as rf chokes, without a sliding null. The high phase precision of ± 0.0005 radian makes D or Q measurements meaningful on low-loss reactances, which must often have tight D or Q tolerances for use in precision networks.

The 1608-A will measure resistors at EIA-specified dc voltages, three-terminal capacitors and small capacitors remotely located, voltage-biased capacitors or current-biased inductors and resistors. Almost any impedance is measurable over the audio-frequency range.

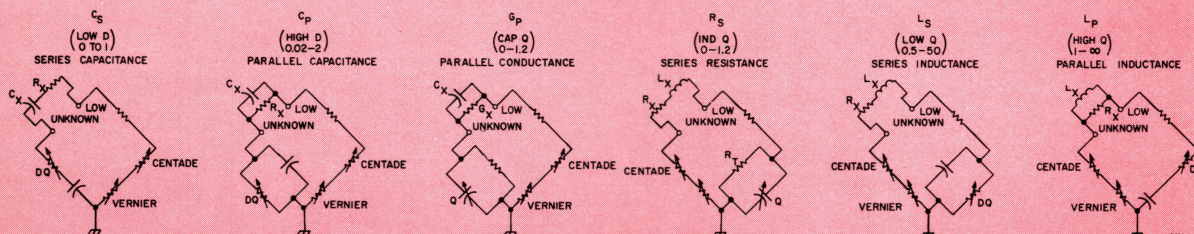
The ability to measure small capacitances by a three-terminal connection makes possible the measurement of the capacitance between components, wires, or mounting structures. Long, shielded cables can be used without significantly affecting the accuracy of the measurement.

For production testing of components, the 1650-P1 test jig is recommended.

This self-contained bridge system includes six bridges, along with suitable ac and dc sources and detectors. The bridge elements are precision units. The wire-wound resistors are similar to those used in GR decade resistance boxes; the standard capacitor is a combination silver-mica and stabilized-polystyrene unit, with a low temperature coefficient.

The readout system is digital for C, R, L, and G, as well as for the Q of resistors. D and Q for capacitors and inductors are read from a dial with the correct scale illuminated. Decimal points and units are indicated automatically, and there are no multiplying factors for any quantity at 1 kHz or dc.

The C-R-L-G readout has both coarse and fine adjustments controlled by concentric knobs.



Elementary schematics of the capacitance, conductance, resistance, and reactance bridges.

The 1-kHz frequency-selective networks for the internal oscillator and tuned detector are on a plug-in module, which can be easily replaced with modules available for other internal test frequencies. Provision is made for use with an external oscillator and detector. Three dc supplies are included to obtain maximum sensitivity over a wide range of resistance.

SPECIFICATIONS

Ranges:

Capacitance: 0.05 pF to 1100 μ F in seven ranges, series or parallel.

Inductance: 0.05 μ H to 1100 H in seven ranges, series or parallel.

Resistance: (series) 0.05 milliohm to 1.1 megohms, ac or dc.

Conductance: (parallel) 0.05 nanomho to 1.1 mhos, ac or dc (20,000 megohms to 0.9 ohm).

D: (of series capacitance) — 0.0005 to 1 at 1 kHz.

(of parallel capacitance) — 0.02 to 2 at 1 kHz.

Q: (of series inductance) — 0.5 to 50 at 1 kHz.

(of parallel inductance) — 1 to 2000 at 1 kHz.

(of series resistance) — 0.0005 to 1.2 inductive at 1 kHz.

(of parallel conductance) — 0.0005 to 1.2 capacitive at 1 kHz.

Frequency: 1 kHz with internal oscillator module supplied; 20 Hz to 20 kHz with external oscillator.

Accuracy:

C, G, R, L

At 1 kHz: $\pm 0.05\% \pm 0.005\%$ 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: $[\pm 0.001(f_{kHz})^2 \pm 0.1Df_{kHz} \pm 0.5D^2]\%$ of measured value.

R and G: $[\pm 0.002(f_{kHz})^2 \pm 10^{-6}(f_{kHz})^2 \pm 0.1Q]\%$ of measured value.

Residual Terminal Impedance: $R \approx 0.001 \Omega$, $L \approx 0.15 \mu H$, $C \approx 0.25 pF$.

DC Resistance and Conductance: Same as for 1-kHz measurement, except that accuracy is limited by sensitivity at the range extremes. Balances to 0.1% are possible from 1 ohm to 1 megohm with the internal supply and detector.

D (or $\frac{1}{Q}$) of C or L: $\pm 0.0005 \pm 5\%$ at 1 kHz or lower.
 $\pm 0.0005f_{kHz} \pm 5\%$ above 1 kHz.

Q of R or G: $\pm 0.0005f_{kHz} \pm 2\%$.

Generator: Internal, 1 kHz $\pm 1\%$ module normally supplied; plug-in modules for other frequencies available on special order. Level control provided. With external generator, frequency range of bridge is 20 Hz to 20 kHz. Type 1310-B Oscillator recommended if external generator required. Internal dc supply 3.5, 35, and 350 V, adjustable; power limited to $\frac{1}{3}W$ or less.

Detector: Internal or external; ac; can be used either flat or selective at frequency of plug-in module (normally 1 kHz); other frequencies available; second-harmonic rejection of 25 dB. Sensitivity control provided. Type 1232-A Tuned Amplifier and Null Detector recommended when external generator is used.

Dc Bias: Capacitors can be biased to 500 V from external source; bias current up to 40 mA can be applied to inductors.

Supplied: Power cord, spare indicator lamps.

Available: 1650-P1 TEST JIG.

Power: 105 to 125 or 210 to 250 V, 50 to 60 Hz; 10 W.

Mechanical: Rack-bench cabinet. DIMENSIONS (wxhxd): Bench, 19x12.5x11.5 in. (483x318x293 mm); rack, 19x12.25x10 in. (483x312x254 mm). WEIGHT: 37 lb (17 kg) net, 54 lb (25 kg) shipping.

Description	Catalog Number
1608-A Impedance Bridge	
Bench Model, 115 V	1608-9801
Bench Model, 230 V	1608-9802
Rack Model, 115 V \diamond	1608-9811
Rack Model, 230 V	1608-9812

1650-B Impedance Bridge

- measures L, C, and loss; R and G
- 1% accuracy
- 20 Hz to 20 kHz, internal 1 kHz and dc
- portable, self-contained, battery-operated

The 1650 Impedance Bridge will measure the inductance and storage factor, Q, of inductors*, the capacitance and dissipation factor, D, of capacitors, and the ac and dc resistance or conductance of resistors.

Three-terminal measurements can be made in the presence of considerable stray capacitance to ground.

This bridge is completely self-contained and portable. Battery-powered, low-drain solid-state oscillator and detector are included. The panel meter indicates both dc and ac bridge unbalances.

The measured quantities, R, G, L, C, D, and Q, are indicated directly on dials with logarithmic scales for constant percentage accuracy. Multipliers and the units of measurement are indicated by the range setting.

The bridge circuit elements are high-quality, stable components that ensure long-term accuracy. The Ortho-null® balance finder, a patented mechanical-ganging device, is used to make a low-Q (high-D) balance possible without a sliding null. This mechanism, which may be switched in or out as desired, adds accuracy as well as



convenience to low-Q measurements that are practically impossible on other impedance bridges.

The Flip-Tilt case provides a convenient handle and a captive protective cover and base that allow the bridge panel to be tilted for use at any angle.

* Including such low-Q inductors as rf coils measured at 1 kHz.

SPECIFICATIONS

Ranges of Measurement	Accuracy		
	20 Hz to 20 kHz†	DC	Residuals
Capacitance 1 pF to 1100 μ F, series or parallel, 7 ranges	$\pm 1\% \pm 1$ pF	—	≈ 0.5 pF
Inductance 1 μ H to 1100 H, series or parallel, 7 ranges	$\pm 1\% \pm 1$ μ H	—	≈ 0.2 μ H
Resistance ac or dc, 1 m Ω to 1.1 M Ω , 7 ranges	$\pm 1\% \pm 1$ m Ω	$\pm 1\%$, 1 Ω to 100 k Ω , ext supply or detector required for > 100 k Ω and < 1 Ω .	≈ 1 m Ω
Conductance ac or dc, 1 n Ω to 1.1 Ω , 7 ranges	$\pm 1\% \pm 1$ n Ω	$\pm 1\%$, 10 $\mu\Omega$ to 1 Ω , ext supply or detector required for < 10 $\mu\Omega$.	
Dissipation Factor, D , at 1 kHz: 0.001 to 1, of series C, 0.1 to 50, of parallel C.	$\pm 5\% \pm 0.001$ at 1 kHz and lower	—	
Storage Factor, Q , at 1 kHz: 0.02 to 10, of series L, 1 to 1000, of parallel L.	1/Q accurate to $\pm 5 \pm 0.001$ at $f \leq 1$ kHz	—	

† Bridge operates up to 100 kHz with reduced accuracy.

Generator: Internal; 1 kHz $\pm 2\%$. Type 1310 or 1311 Oscillator recommended if external generator is required. Internal dc supply, 6 V, 60 mA, max.

Detector: Internal or external; internal detector response flat or selective at 1 kHz; sensitivity control provided. Type 1232-A Tuned Amplifier and Null Detector is recommended if external detector is required. Combination of 1311 oscillator and 1232 detector is available as the 1240 Bridge Oscillator-Detector.

DC Polarization: Capacitors can be biased to 600 V from external dc power supply for series capacitance measurements.

Required: None. Earphones can be used for high precision at extremes of bridge ranges.

Available: Type 1650-P1 TEST JIG.

◆ National stock number 6625-00-435-5470

Power: 4 size-D cells, supplied.

Mechanical: Flip-Tilt case and rack mount. **DIMENSIONS** (wxhxd): Portable, 13x6.75x12.25 in. (330x171x311 mm); rack, 19x12.25x4.13 in. (483x311x105 mm). **WEIGHT:** Portable, 17 lb (8 kg) net, 21 lb (10 kg) shipping; rack, 18 lb (9 kg) net, 30 lb (14 kg) shipping.

Description	Catalog Number
1650-B Impedance Bridge	
Portable Model ◆	1650-9702
Rack Model	1650-9703
Replacement Battery , size D cell, 4 req'd	8410-0200

Patent Number 2,966,257.



New

1657 RLC Digibridge™

- Automatically measures R, L, C, D and Q
- 0.2% Basic accuracy
- Five-digit display for R, L and C
- Four-digit display for D and Q
- Microprocessor-directed ranging
- Selectable test frequencies of 1 kHz and 120 Hz (100 Hz)
- Series or parallel measurement mode selection
- Built-in Kelvin test fixture tests radial and axial lead components

The GR 1657 Digibridge™ is an automatic microprocessor-based bridge designed to measure R, L, C, D and Q at a test time faster than three measurements per second, unqualified. Basic accuracy for R, L and C is 0.2%.

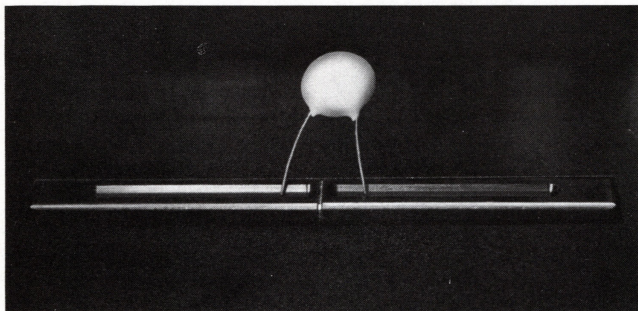
A **five**, full-digit LED readout is displayed for R, L and C and **four** full digits are displayed for D and Q. This broad visual display capability is augmented with microprocessor-directed ranging and automatic decimal point positioning.

Microprocessor-directed ranging takes the guess-work out of setting the correct range. Lighted arrows on the front panel indicate which range button is to be depressed and thus, automatically, the correct range is identified. Whether measuring impedance or loss/quality factor, the GR 1657's microprocessor directs the instrument and the operator to achieve optimum ranging. No chance for operator mistakes, as no operator decisions are required.

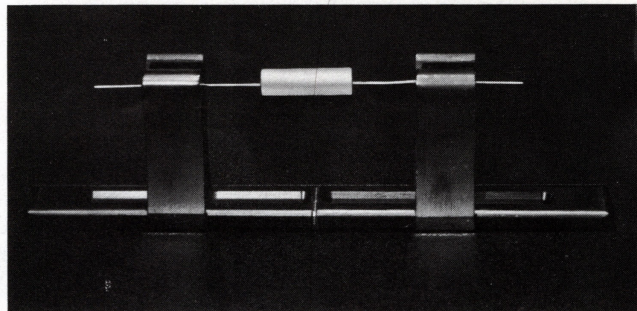
Three range positions provide measurements in multiples of 100, as each range has two full decades of measurement capability, a feature made possible by automatic decimal point positioning. In conjunction with the microprocessor-directed ranging, the automatic decimal point positioning causes the measurement to be made on the lowest possible range, so maximum resolution is always achieved. Residual errors inherent in all measurement instruments, such as ± 1 count error, therefore become negligible for most GR 1657

measurements. The automatic decimal-point-positioning feature plus the use of full digits for the most significant digit allows D measurement from 10^{-4} to 10^1 .

Either a 1-kHz or 120-Hz (100-Hz) test frequency can be selected by the operator. Series or parallel measurement modes are operator selectable across the full measurement range of every test parameter.



The high reliability Kelvin test fixture accommodates either radial or axial lead components. Test radial lead components by removing the two test clips, or insert the clips and test axial lead components. Each test clip can be moved to the right or left to accommodate various size components. The Kelvin test method assures more accurate measurement.



SPECIFICATIONS

Measurement Mode: Measures R series or parallel; L and Q series or parallel; C and D series or parallel. All measurement modes are pushbutton selectable.

Measurement Speed: Greater than three measurements per second, unqualified.

Test Frequencies: 1 kHz and 120 Hz. Also 100 Hz in place of 120 Hz. Pushbutton selectable.

Ranges: Pushbutton selectable.

Three ranges for R, L and C (multiples of 100)

R = 00.001 Ω to 99.999 M Ω

L = 0.0001 mH to 9999.9 H

C = 0.0001 nF to 99999. μ F

One range for D and Q

D = .0001 to 9.999

Q = 00.01 to 999.9

Accuracy: R, L and C = $\pm 0.2\%$ of reading covering the following ranges of value.

MODE	FREQUENCY	MIN	MAX
R	120 Hz or 1 kHz	2.0 Ω	1.9999 M Ω
L	1 kHz	200 μ H	199.99 H
L	120 Hz	2.0 mH	1999.9 H
C	1 kHz	200 pF	199.99 μ F
C	120 Hz	2.0 nF	1999.9 μ F

For values outside of these ranges, or for values for high-phase components or networks, contact your local GenRad sales office.

$$D = \pm [0.001 + 0.002 (1 + D) D]$$

$$Q = \pm [0.01 + 0.002 (1 + Q) Q]$$

Display: R, L and C — Five full digits (99999), LED display with automatic decimal point positioning.

D and Q — Four full digits (9999), LED display with automatic decimal point positioning.

Applied Voltage: 0.3 V rms maximum.

Supplied: Power cord.

Power: 90 to 127 or 180 to 254 V, 48 to 62 Hz. Voltage selected by rear-panel switch. 25W maximum.

Mechanical: Bench model. DIMENSIONS (wxhxd): 14.75x4.37x13.00 in. (356.35x101.97x330.20 mm). WEIGHT: 12.5 lb (5.7 kg) net, 22 lb (10 kg) shipping.

Description

Catalog Number

1657 RLC DigiBridge™

120-Hz and 1-kHz Test Frequencies

1657-9700

100-Hz and 1-kHz Test Frequencies

1657-9800

Extender Cable (for remote measurements)

1657-9600



1683 Automatic RLC Bridge

- Resistance: $1 \mu\Omega$ to $2 \text{ M}\Omega$
- Inductance: 0.1 nH to 2000 H
- Capacitance: 0.01 pF to 0.2 F
- 0.1% basic accuracy
- up to 20 measurements per second

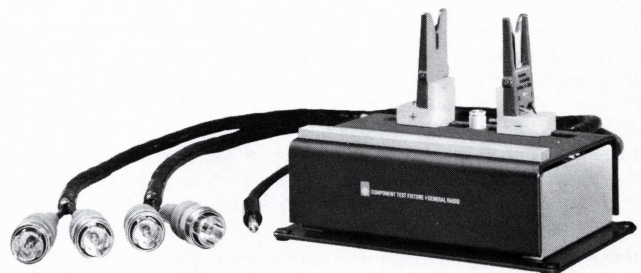
The 1683 Automatic RLC Bridge is a fully-automatic, low-frequency, five-terminal impedance bridge that measures capacitance, inductance, and resistance with loss expressed as a series element. It is a true bridge whose accuracy depends on stable passive standards. The automatic nature of the bridge allows unskilled personnel to make precision measurements at the push of a button.

The accuracy and rapid speed of balance make the 1683 a natural choice for incoming inspection, quality control, and high-volume production applications where a large number of components must be measured in as short a time as possible. The wide range of the 1683 enables it to measure almost any type of component.

The data-output option enables you to retrieve, record, analyze, and utilize volumes of data in a minimum of time. The bridge is designed to interface with scanners, comparators, card- and tape-punch machines, recorders, and computers.

The programming option allows for external control of the bridge functions. This is desirable for fully-automated testing where a master computer may be controlling one or more bridges and other accessory equipment. The computer would function as controller, data retriever, data analyzer, and decision maker to reduce the possibility of error. Such a controlled system would provide for extremely fast, accurate, and economical component evaluation.

The five-terminal feature provides you with the ability to measure accurately low-impedance and high-impedance components far removed from the bridge. The Kelvin-type connection lessens the effects of lead impedance and enables milliohms of impedance to be measured at the end of several feet of cable. The fifth terminal, the cable shield, is used to reduce the effect of stray capacitances on measurements of high impedance. This feature is especially useful when a series of small-valued capacitors is measured in sequence with a scanner system.



The bias feature and leakage option provide the ability to characterize large-valued tantalum- and electrolytic-class capacitors at one station. The equivalent-series-resistance (ESR) option provides you with another means to express loss in capacitor measurements as required by some MIL specifications.

The many features incorporated in the 1683 Automatic RLC Bridge allow you to accomplish fast, accurate, and economical testing of resistors, inductors, and capacitors in a number of applications ranging from laboratory use to the most sophisticated of computer-controlled systems.

Measurement	Range		Accuracy (% of reading) \pm (% of full scale)
	at 120 Hz	at 1 kHz	
CAPACITANCE With concurrent loss measurement (that can be displayed as dissipation factor or equivalent series resistance) and optional GO, NO-GO leakage-current test.	0000.1 pF to 1999.9 μ F 02.000 mF to 19.999 mF 020.00 mF to 199.99 mF	000.01 pF to 199.99 μ F 0200.0 μ F to 1999.9 μ F 02.000 mF to 19.999 mF	$\pm 0.1\% \pm 0.005\%$ $\pm 1\% \pm 0.5\%$ $\pm 5\%*$ (typically 1%) $\pm 0.5\%$
INDUCTANCE With concurrent loss measurement expressed as series resistance.	00.001 μ H to 19.999 μ H 020.00 μ H to 199.99 μ H 0200.0 μ H to 1999.9 H	0000.1 nH to 1999.9 nH 02.000 μ H to 19.999 μ H 020.00 μ H to 199.99 H	$\pm 5\%*$ (typically 1%) $\pm 0.5\%$ $\pm 1.0\% \pm 0.1\%$ $\pm 0.1\% \pm 0.01\%$
RESISTANCE Simple resistance, or series resistance with inductance measurements.	00.001 m Ω to 19.999 m Ω 020.00 m Ω to 199.99 m Ω 0200.0 m Ω to 1999.9 k Ω		$\pm 5\%*$ (typically 1%) $\pm 0.5\%$ $\pm 1\% \pm 0.5\%$ $\pm 0.1\% \pm 0.005\%$
DISSIPATION FACTOR (D) Concurrent with capacitance measurements.	0.0000 to 1.9999 accuracy differs on the following capacitance ranges: 0.2000 mF to 19.999 mF 0200.0 μ F to 1999.9 μ F 20.000 mF to 199.99 mF 02.000 mF to 19.999 mF		$\pm 1\% \pm 0.05\%$ $\pm 1\% \pm 0.5\%$ $\pm 5\% \pm 5\%$
EQUIVALENT SERIES RESISTANCE (Option 4) Concurrent with capacitance measurements.	00.001 m Ω to 19.999 m Ω 020.00 m Ω to 1999.9 k Ω with C reading of: 03000 to 19999 02000 to 02999 01000 to 01999		$\pm 5\%*$ (typically 1%) $\pm 0.5\%$ $\pm 1\% \pm 0.1\%$ $\pm 1\% \pm 0.125\%$ $\pm 1\% \pm 0.5\%$
LEAKAGE CURRENT (Option 3) GO, NO-GO indication concurrent with capacitance measurement.	2.5 μ A to 25 mA in 5 ranges		2% of reading

* In single or variable measurement mode; $\pm 1\%$ of reading plus $\pm 0.1\%$ of full scale in tracking mode.

SPECIFICATIONS

Display: Reactive and resistive readouts, each with 4½-digit resolution, high-intensity neon readout tubes, decimal point, and unit of measurement. Display also indicates measurement frequency, unbalanced condition, manual- or remote-ranging condition, and GO or NO-GO result of leakage current measurement.

Speed: Measurement rate at 1 kHz is ≈ 20 measurements per second for $\pm 1\%$ of full-scale change in unknown, 16/s for $\pm 10\%$ change, and 8/s for $\pm 100\%$ change; at 120 Hz, rates 10 times slower. Interval between measurements can be infinite (measurements initiated by front-panel pushbutton or external closure to ground) or from ≈ 20 ms to 1 s as set by front-panel control so that measurements are repetitive. Speed may be decreased slightly when D is measured near the low end of each capacitance range.

Terminals: Five; 4-terminal connection minimizes errors due to lead impedance and ground terminal minimizes error due to stray capacitance. Connections to unknown are made by coaxial cables at the front and the rear of the instrument. A 1683-P1 Test Fixture is available for the rapid connection of axial-lead components and contains a start button to initiate the measurements. Stray capacitance up to 2 pF across the test fixture can be cancelled by an adjustment on the rear of the 1683.

Ranges: Nine for all measurements except five for leakage current. Ranging can be automatic, manual, or remote except leakage current which has no automatic ranging.

Oscillator Level: Voltage applied to unknown can be reduced from the normal 2.2 V rms for special applications.

Sensitivity: Can be manually or remotely reduced from maximum, with consequent loss of resolution, to overcome problems with non-linear or rapidly changing unknown or external noise or hum pickup.

Bias: 0 to 3 V internal, manually or remotely set; 600 V max, external.

Leakage-Current Test (Option 3): NO-GO limit can be manually set with 2% accuracy or remotely measured with 2% accuracy from 1 μ A (under vernier control) to 25 mA. External monitoring of leakage current or of a dc voltage proportional to leakage current provided.

Interface:

Low-Level Data Output (Option 5A): 50-pin Amphenol Type 57 connector provides 11 digits of measurement data (5 for reactance, 5 for resistance, 1 for range) plus various control inputs and outputs for systems use. Digits are 1-2-4-8-weighted BCD at standard TTL logic levels (logic "0" \approx ground with 10-mA sink capability, logic "1" ≥ 3.5 V).

High-Level Data Output (Option 5B): Same as low-level except all outputs are 15-V swing (logic "0" \approx ground with 10-mA sink capability, logic "1" $\approx +15$ V behind 12 k Ω).

Remote Programmability (Option 2): 50-pin Amphenol Type 57 connector provides terminals for external remote programming of all control functions except line-voltage control. Functions are controlled by closures to ground or standard TTL levels.

Environment: TEMPERATURE: +10 to +40°C operating.

Available: 1683-P1 TEST FIXTURE, 2995-9158 BIAS SUPPLY, printers, recorders, card-punch couplers, scanners.

Power: 100 to 125 and 200 to 250 V, 50-60 Hz, 110 W.

Mechanical: Bench or rack models. DIMENSIONS (wxhxd): Bench, 19x7.88x25.38 in. (483x200x645 mm); rack, 19x7x23.75 in. (483x178x604 mm). WEIGHT: Bench, 60 lb (28 kg) net, 74 lb (34 kg) shipping; rack, 50 lb (23 kg) net, 67 lb (31 kg) shipping.

Description	Catalog Number
1683 Automatic RLC Bridge Bench Model, power freq: 60 Hz Bench Model, power freq: 50 Hz Rack Model, power freq: 60 Hz Rack Model, power freq: 50 Hz	(Describe exactly as shown at the left.)
Select following options, if desired OP2 Remote Programmability OP3 Leakage Current OP4 ESR Readout OP5A* Low-Level Data Output OP5B* High-Level Data Output	
Accessory available 1683-P1 Test Fixture for axial leads	



A complete incoming-inspection station for passive components

1685 Digital Impedance Meter

- Automatically measures R, L, and C on each range. Automatic GO/NO GO limits for D and Q.
- Measures series C and L at either 120 Hz or 1 kHz.
- Measures resistance at dc.
- 0.1% basic accuracy for dc and 1-kHz measurements and 0.5% for 120-Hz measurements.
- C range is 0.01 pF to 20,000 μ F; L range, 0.01 μ H to 2000 H; R range, 0.1 m Ω to 20 M Ω .
- Built-in limit comparator (optional) provides fast GO/NO-GO sorting.

Up to now, an incoming-inspection station for passive components typically consisted of several interconnected instruments that involved a great deal of manual manipulation on the part of the inspector to achieve proper results. Now, most (if not all) of those instruments can be replaced by GR's new 1685 Digital Impedance Meter. And, what is more important, many of the operations have been automated, which greatly speeds up the inspection process whether you screen many of the same type of component or measure the value of several different components.

The GR 1685 has many convenient features that make it an operator-oriented instrument, particularly when used with its optional built-in limit comparator and test fixture. After reviewing the following GR 1685 operating features and their benefits you will agree that GR has greatly simplified impedance measurements with this new instrument. **Range switch with directional arrows.** Arrows at the top of the RANGE switch indicate which way to turn the 9-position switch to set the correct range. When at the correct range, both arrows are extinguished. No thinking is required with this step — just follow the arrows.

Clear digital readout of measurement. The R, L, or C measurement clearly appears on a 4½-digit LED display. There is no doubt what the measurement value is.

Selectable measurement modes. A MEASUREMENT MODE switch allows the operator to make a single measurement or to make repetitive measurements at rates ranging from four per second to one every 10 seconds. This, of course, allows

you to measure value changes as the device being measured is subjected to environmental changes.

Easy parameter selection. A clearly marked, five-position PARAMETER switch sets the instrument for the proper measurement with minimum effort. It has separate 1-kHz and 120-Hz positions for capacitance and inductance measurements.

D and Q dial with directional arrows. Lighted directional arrows above the D and Q dial guide you in determining the D or Q of a device under test or when a D or Q limit has been exceeded. To find the value of D or Q, you simply turn the dial until the lit arrow goes off and read the values on the dial. If you wish to set a high-D or low-Q limit, set the value on the dial and the red and green arrows will give a GO/NO GO indication.

Limit comparator speeds up inspection process. Once the upper and lower measurement limits of the devices being checked have been set with the 5-digit limit switches, measuring is just a matter of inserting devices in the test fixture and watching the indicator lights. If the measurement is within the set limits, the GO light goes on and you make your next measurement. If it is outside the limits, the LOW or HIGH light will go on and you reject the device. When checking D or Q against a set limit, the HIGH D light will turn on for either a high D or low Q.

A red lamp tells you when the instrument is making a measurement.

Test fixture has PASS/FAIL lights. Normally, these two lights are all an inspector need pay attention to when inspecting a batch of components that are approximately the same value. The lights work in conjunction with the limit comparator.

Provisions have been made for the GR 1685 to operate with external equipment such as additional limit comparators, handlers, data printers, and card punches. Meter output levels are standard TTL, open collector, for total interface flexibility. The GR 1685 comes supplied with an output-data connector set by which you connect to external equipment. A GR 1784 Multiple-Limit Comparator is also available as an accessory. It makes comparisons of up to four sets of limits, each having a high and low limit.

SPECIFICATIONS

RLC Ranges:

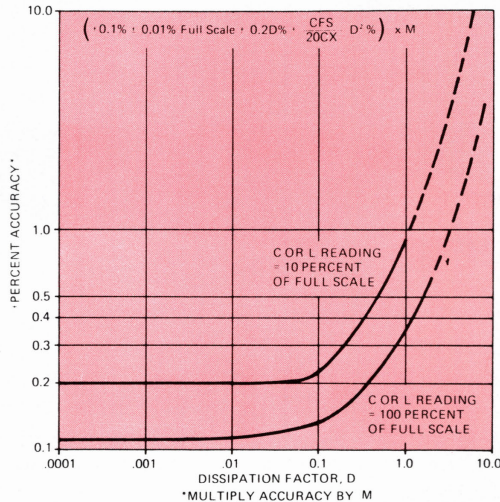
FULL-SCALE READINGS AND ACCURACY MULTIPLIER

Switch Position	Capacitance				Resistance		Inductance				Voltage Multiplier A
	1 kHz	M	120 Hz	M	DC	M	120 Hz	M	1 kHz	M	
1	1999.9μF*	10	19.99mF**	4	199.99mΩ*	20	199.9μH*	10	19.999μH*	10	0.1
2	199.99μF	3	1.999mF	2	1999.9mΩ	3	1.999mH	2	199.99μH	3	0.1
3	19.999μF	1	199.9μF	1	19.999Ω	1	19.99mH	1	1999.9μH	1	1
4	1999.9nF	1	19.99μF	1	199.99Ω	1	199.9mH	1	19.999mH	1	1
5	199.99nF	1	1.999μF	1	1999.9Ω	1	1.999H	1	199.99mH	1	1
6	19.999nF	1	199.9nF	1	19.999kΩ	1	19.99H	1	1999.9mH	1	1
7	1999.9pF	2	19.99nF	1	199.99kΩ	1	199.9H	1	19.999H	1	1
8	199.99pF	3	1.999nF	2	1999.9kΩ	3	1.999kH	2	199.99H	3	5
9	—	—	—	—	19.999MΩ	5	—	—	—	—	5

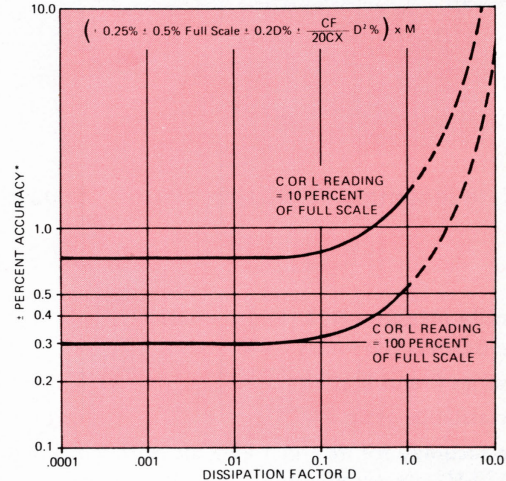
*Not recommended

**Extends to 0.1F at reduced accuracy

M = Accuracy Multiplier (see below)



C and L accuracy at 1 kHz Test Frequency



*MULTIPLY ACCURACY BY (2) FOR THE 1.999 mF AND 1.999 nF RANGES

C and L accuracy at 120 Hz Test Frequency

Accuracy: Basically, 0.1% for dc and 1-kHz measurements; 0.5% for 120-Hz measurements. See curves for exact accuracies. ($\pm 0.1\%$ $\pm 0.1\%$ full scale) $\times M$ for dc resistance. See "RLC Ranges" table for values of M.

Dissipation Factor/Q Factor: D = 0 to 10; Q = 0.1 to ∞ .

$$D \text{ accuracy} = \pm \left(0.001 + 0.0002 \frac{(L \text{ or } C) \text{ Full Scale}}{(L \text{ or } C) \text{ reading}} + 5.0\% \text{ of } D \text{ reading} + 5 D\% \right) \times M$$

where M = Accuracy Multiplier

Q accuracy is same as D accuracy since dial indicates both D and Q. Dial reads both D and Q, and may be set to give D or Q limit or adjusted to give D or Q value.

Display: 4½ digits, LED display with decimal point and over-range indication. Display normally reads C, R, or L.

Applied Voltage: AC: A $\times 1$ V rms max. DC: A $\times 2$ V max, where A = voltage multiplier (see "RLC Ranges" table): Maximum power is 1/8 W.

Frequency: 1 kHz $\pm 2\%$ and 120 Hz, synchronized to line (100 Hz test frequency for 50-Hz line).

Bias: For capacitors, 2V internal and 0-100 V external; for inductors, allowable bias current depends on range.

Measurement Speed/Mode: Measurements made on command or repetitively at times from 0.25 s to 10 s. Previous measurement is held during period of new measurement.

Data Outputs (TTL Logic): Open collector, active low. Each of the following outputs will sink 40 mA (max) from an external source of +30 V (max). Low output = +0.4 V (max): BCD measurement value, decimal points, DQ high, reset, strobe, over range.

Data Inputs: REMOTE START: A positive transition of $< 1 \mu s$ rise time from 0 V $< V_L < 0.4$ V to +2 V $< V_H < +30$ V initiates a measurement. LAMP TEST: A ground lights all segments of the right-most four digits of the LED display (8 8 8 8) to check operation of all indicator segments.

Limit Option: DATA OUTPUTS (TTL LOGIC): Open collector, active low. Each of the following outputs will sink 40 mA (max)

from an external source of +30V (max). Low output = +0.4V (max): busy, go, DQ high, high limit, low limit, fail. SUPPLEMENTARY OUTPUTS: (**Clamp**) This line is to be tied to the external supply (+30V max) to suppress inductive transients from external relay coils. Audio output line to drive a miniature speaker (or headphone) tied between this output and ground. Signal gives $\approx 1/4$ sec audio burst, when measured value falls outside the selected high and low limits. (Not activated by DQ failures).

(**Interface**): Lines for interfacing with a digital printer (i.e., GR 1785), a component sorter, a component handler for a specific application, and/or to interface with a multiple limit comparator. DATA INPUTS: (**Remote Start**) A positive transition of $< 1 \mu s$ rise time from 0 V $< V_L < 0.4$ V to +2 V $< V_H < +30$ V initiates a measurement. (**Limit Disable**) Performs the same function as the toggle switch on the front panel of the limit option module: High input turns limit option OFF, OPEN is equivalent to V_L . (0 V $< V_L < +0.4$ V, +2 V $< V_H < +30$ V.)

Environment: TEMPERATURE: 0 to +50°C operating (increase accuracy multipliers by 10% for each °C above 35°C or below 15°C), -40 to +75°C storage. HUMIDITY: 95% at 35°C.

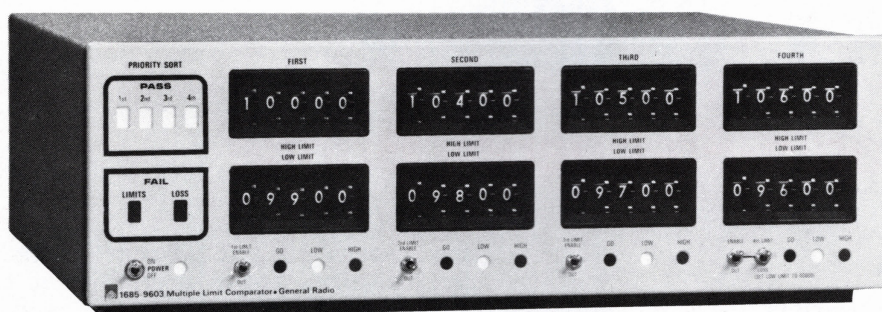
Supplied: Power cord, measurement cable, output-data connector set.

Power: 90 to 127 or 180 to 253 V, 48 to 440 Hz, 40 W max.

Mechanical: Bench or rack models. DIMENSIONS (wxhxd): Bench, 17.00x5.59x16.25 in. (432x142x413 mm); rack, 19.00x5.22x16.63 in. (483x133x422 mm). WEIGHT: Bench, 22.5 lb (10.2 kg) net, 31 lb (14.1 kg) shipping; rack, 23.25 lb (10.54 kg) net, 31.75 lb (14.4 kg) shipping.

Description	Catalog Numbers	
	60-Hz Models	50-Hz Models
1685 Digital Impedance Meter		
Bench model without Limit Comparator	1685-9700	1685-9800
Bench model with Limit Comparator	1685-9702	1685-9802
Rack model without Limit Comparator	1685-9701	1685-9801
Rack model with Limit Comparator	1685-9703	1685-9803
1685-P1 Test Fixture, Kevin clips	1685-9600	

*50-Hz line frequency, 100-Hz test frequency.



1784 Multiple-Limit Comparator

For GO/NO-GO or multiple-category sorting of components in high-volume testing and sorting applications.

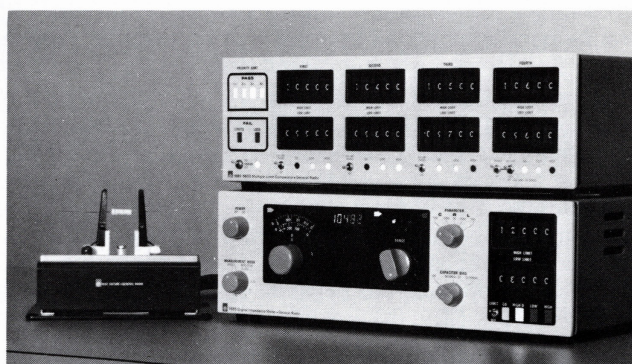
- Four sets of High/Low limits, each with corresponding HIGH, LOW, GO lamps.
- Each limit has five digits, thumbwheel adjustable.
- Both visual and electrical outputs provided.
- Can sort up to ten separate categories around some nominal value of reactance.

The 1784 Multiple-Limit Comparator is designed specifically for use with the 1686 Digital Capacitance Meter, the 1682 Automatic Capacitance Bridge, the 1685 Digital Impedance Meter and the 1683 Automatic RLC Bridge, although it can be adapted by the user for use with other instruments containing 1-2-4-8 BCD weighted outputs. It is a solid-state instrument that finds use in fully automatic, semi-automatic, or manual sorting systems. You can stack units if you need more than four sets of limits.

A "Priority Sort" feature indicates the first set of limits for which the measurement is within tolerance limits. If the measurement falls outside of all preset limits, or if the loss factor is out of tolerance, red FAIL lamps go on (and a corresponding electrical signal is applied to the output).

Each set of limits has an ENABLE switch which allows those limits to be switched in or out at random. In addition, the fourth set of limits, when enabled, can be used either as a fourth limit set for reactance or as a separate limit set for loss factor (when used with a GR 1683 Bridge).

Using the four sets of limits you can sort up to ten separate categories around some nominal value (eight categories when the fourth set of limits is used for loss).



Multiple-Limit Comparator in operation with a GR 1685 Digital Impedance Meter and a GR 1685-P1 Test Fixture.

SPECIFICATIONS

Data Inputs (TTL logic): $0 \leq V_{\text{Low}} \leq +0.4 \text{ V}$; $+2\text{V} \leq V_{\text{High}} \leq +5\text{V}$

Data Outputs: PARALLEL DATA: Input data are available on a parallel-output connector so that units can be stacked. SORTING INFORMATION AND CONTROL SIGNALS: Signals used for controlling mechanical sorters, etc are available on the data-output connector. These are open-collector, active low and will sink 40 mA (max) from an external source of 30V (max).

Power: 105 to 125 or 210 to 250V, 50 to 60 Hz, 25W.

Mechanical: Bench or [rack] models. DIMENSIONS (wxhxd): Bench, 17.00x5.59x15.00 in. (432x142x381 mm); [rack, 19.00x5.22x16.38 in. (483x133x416 mm)]. WEIGHT: Bench, 20 lb (9.1 kg) net, 28.5 lb (12.9 kg) shipping; [rack, 21 lb (9.5 kg) net, 29.5 lb (13.4 kg) shipping].

Description

Catalog Number

1784 Multiple-Limit Comparator

Select following options, if desired:
 OP1 Input cable for 1685 Meter
 OP2 Input cable for 1682/1683 Bridges
 OP3 Rack-Mount Kit
 OP4 Stacking Cable

(Describe exactly as shown at left)



1606-B Radio-Frequency Bridge

- 400 kHz to 60 MHz
- direct reading in ohms
- adaptable to coaxial connectors
- accurate, compact, simple operation

The 1606-B accurately and easily measures the resistance and reactance of antennas, transmission lines, networks, and components. It is particularly well suited for measuring low values of impedance of rf devices. Its range can be extended by means of an external parallel capacitor to measure high impedances.

Precision Coaxial Connections In this latest model of the popular 1606 RF Bridge, the Unknown terminals are adaptable to coaxial connectors, in particular the GR900. This is a significant advantage that not only permits the measurement of components having coaxial fittings but also ensures better repeatability and more accurate definition of the measurement plane. This permits the 1606 to be precision calibrated against coaxial standards such as the various GR900® precision components: open- and

short-circuits, 50- and 100-ohm Standard Terminations, and the various lengths of precision air line.

Accessory Adaptor Kit With the 1606-P2 adaptor kit, the 1606-B can be fitted to accept GR900 and GR874® connectors (the adaptors include compensation to match 50-ohm standards and components). The kit will also adapt to a 14-mm flange connector (a GR900 flange is included to convert GR900 connectors), or to other common connectors (N, BNC, TNC, etc) by the use of GR900 adaptors.

Description Measurements are made by a series-substitution method in which the bridge is first balanced with a short circuit across the Unknown terminals. The short is then removed, the unknown impedance connected, and the bridge rebalanced.

The entire mechanical design is such that the instrument can operate under difficult environmental conditions similar to those specified for testing military electronics equipment. The 1606-B bridge is therefore an excellent instrument for field use.

SPECIFICATIONS

Ranges of Measurement	Accuracy
Reactance: $\pm 5000 \Omega$ at 1 MHz. This range varies inversely as the frequency; at other frequencies the dial reading must be divided by the frequency in MHz. Resistance: 0 to 1000 Ω .	Reactance: At frequencies up to 5 MHz, $\pm 2\% \pm (1 + 0.004 Rf) \Omega$; 5 to 50 MHz, $\pm 2\% \pm (1 + 0.0008 Rf) \Omega$; where R is the measured resistance in ohms and f is the frequency in MHz. Resistance: At frequencies up to 50 MHz, $\pm \left[1\% + 0.0024f^2 \left(1 + \frac{R}{1000} \right) \right] \pm \frac{10^{-4} X}{f} \Omega + 0.1 \Omega$ (where X is the measured reactance in ohms). Subject to correction for residual parameters.

Frequency: 400 kHz to 60 MHz.

Satisfactory but somewhat less accurate operation can be obtained at frequencies as low as 100 kHz and somewhat above 60 MHz.

Generator: External only (not supplied), to cover desired frequency range.

Detector: External only (not supplied). A well shielded radio receiver is recommended.

Supplied: 2 leads of different lengths to connect unknown impedance to bridge terminals; 1/2-in. spacer and 3/4-in. screw to mount component to be measured directly on bridge terminals; 874-R22LA Patch Cord.

Available: 1606-P2 PRECISION COAXIAL ADAPTOR KIT.

◆ National stock number 6625-00-432-5414

Mechanical: Bench cabinet. DIMENSIONS (wxhxd): 12.5x 9.5x10.25 in. (318x242x261 mm). WEIGHT: 23 lb (11 kg) net, 30 lb (14 kg) shipping.

SPECIFICATIONS FOR 1606-P2

Capacitance Added: By adaptor to GR900, 0.38 pF at reference plane (less fringing capacitance); by flange adaptor, 0.18 pF.

Weight: Net, 10 oz (283 g); shipping, 12 oz (340 g).

Description	Catalog Number
1606-B Radio-Frequency Bridge ◆	1606-9702
1606-P2 Precision Coaxial Adaptor Kit	1606-9602

Capacitance Bridges

TWO-TERMINAL AND THREE-TERMINAL CONNECTIONS

Most capacitors can be represented by the three capacitances shown in Figure 1: the direct capacitance C_{HL} , capacitance between the plates of the capacitor and the two terminal capacitances, C_{HG} and C_{LG} , which are capacitances from the corresponding terminals and plates to the capacitor case, surrounding objects, and to ground (to which the case is connected either conductively or by its relatively high capacitance to ground).

In the two-terminal connection, the capacitor has the L and G terminals connected together, i.e., the L terminal is connected to the case. The terminal capacitance, C_{LG} , is thus shorted, and the total capacitance is the sum of C_{HL} and C_{HG} . Since one component of the terminal capacitance C_{HG} is the capacitance between the H terminal and surrounding objects, the total capacitance can be changed by changes in the environment, particularly by the introduction of connecting wires. Such changes can cause uncertainties of a few tenths of a picofarad in the calibration of two-terminal capacitors that use banana pins for the connection. More accurate two-terminal calibrations, with connection uncertainties no more than a few femtofarads (thousandths of a picofarad) can be made by use of precision coaxial connectors such as the GR900® connectors. For accuracy at high frequencies, i.e. around 1 MHz, such precision two-terminal connections are necessary. At lower frequencies, i.e. around 1 kHz, precision two-terminal connections are useful, but here most of the connection uncertainties can be eliminated by the use of three-terminal capacitors and measurements¹.

A three-terminal capacitor (Figure 1) has connected to the G terminal a shield that completely surrounds at least one of the terminals (H), its connecting wires, and its plates except for the area that produces the desired direct capacitance to the other terminal (L). Changes in the environment and the connections can vary the terminal capacitances, C_{HG} and C_{LG} , but the direct capacitance C_{HL} is determined only by the internal geometry.

This direct capacitance can be calibrated by three-terminal measurement methods, which use guard circuits or transformer-ratio-arm bridges to exclude the terminal capacitances.

The direct capacitance can be made as small as desired, since the shield between terminals can be complete except for a suitably small aperture. The losses in the direct capacitance can also be made very low because the dielectric losses in the insulating materials can be made a part of the terminal impedances. When the three-terminal capacitor is connected as a two-terminal, the two-

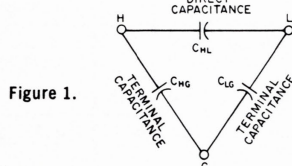


Figure 1.

terminal capacitance will exceed the calibrated three-terminal value (C_{HL}) by at least the terminal capacitance C_{HG} .

Measurements on very large capacitors are subject to uncertainties due to series impedance that can be avoided by four-terminal measurements, a technique regularly used in precision measurement of low resistance.

AUTOMATIC BRIDGES

GR automatic bridges combine the accuracy and stability of classical bridge techniques with digital logic circuits to form automatic instruments which permit high-speed measurements of impedance. The basic instruments feature short measurement time, completely auto-

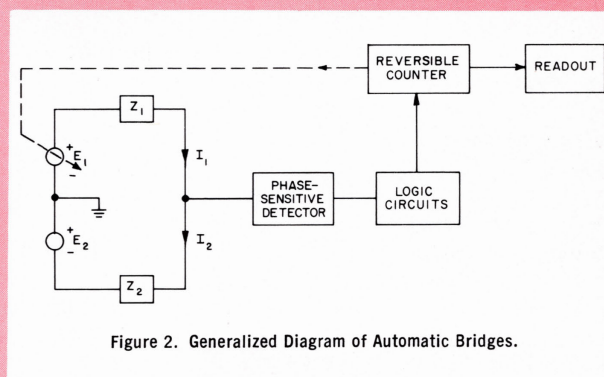


Figure 2. Generalized Diagram of Automatic Bridges.

matic operation, and accuracies sufficient for most high-volume testing of components. They provide coded data outputs for automatic error-free recording of data and for use in completely automatic systems.

The basic bridge circuit (Figure 2) of the GR 1682 automatic bridge is similar to that of the transformer-ratio-arm bridge.²

In this circuit the bridge is at balance when $I_1 = I_2$. If the bridge is unbalanced and, say, current I_1 is greater than I_2 , the phase-sensitive detector and logic circuitry cause the reversible counter to count in a reverse direction. This counter controls electronic switches to decrease the value of the voltage E_1 until balance is achieved. At balance the counter displays the value of the unknown.

Only one set of controls has been shown—actually there are two which simultaneously balance the in-phase and quadrature components of the signal. When a null in both components is achieved, the bridge simultaneously displays the value of both the reactive and resistive parts

¹ John F. Hersh, "A Close Look at Connection Errors in Capacitance Measurements," *General Radio Experimenter*, July 1959.

² M. C. McGregor, J. F. Hersh, R. D. Cutkosky, F. K. Harris, and F. R. Kotter, "New Apparatus at the National Bureau of Standards for Absolute Capacitance Measurements," *IRE Transactions on Instrumentation*, vol. I-7, pp 253-261; December, 1958.

of the component's impedance.

This bridge method is superior to the direct-measurement method which was in use before automatic bridges were first introduced in 1964. In the direct method, an ac voltage is applied directly to the component under test and the resulting current is measured with a phase-sensitive detector and digital voltmeter. While simple in principle, it is very difficult to build a phase detector with the required characteristics. To measure accurately a capacitor's dissipation factor of 0.001, for example, requires the accurate measuring of a signal in the presence of an out-of-phase signal 1000 times larger. Very small phase shifts could cause severe errors so that time-consuming adjustments were often necessary to attain the required accuracy. In GR automatic bridges, the phase detector is used only to control the direction of balance — its amplitude and exact phase characteristics are not important. In common with other bridge circuits, the accuracy is determined by the value of stable, passive impedance standards.

In the 1683, a bridge circuit using active elements provides a much wider impedance range than is possible with

the transformer-ratio-arm circuit described above. This arrangement also makes it convenient to measure resistance and inductance as well as capacitance. Accurate measurements of impedance as low as a few milliohms (capacitances as high as 200,000 μ F) cannot be made on a transformer-ratio-arm bridge because the low impedance would load the ratio transformer to the point where it would no longer appear as an ideal voltage source. The use of precision dividers and "ideal" amplifiers in the bridge circuit provides the necessary isolation so that wide variations in impedance level do not affect accuracy. The amplifiers are "ideal" in the sense they have high enough open-loop gain so that their transfer function essentially depends only upon the ratio of two fixed passive components. The high open-loop gain also permits their input and output impedances to appear infinite or zero (depending upon their use in the bridge) compared with the impedance levels of adjacent circuitry. These amplifiers also make possible the display of the loss term for capacitance measurements in terms of dissipation factor (D) or equivalent series resistance (ESR). Finally, the use of active circuitry in the bridges makes possible four- and five-terminal connections that enable measurements with micro-ohm resolution.

MANUAL OR AUTOMATIC?

	Manual Bridges	Manual Impedance Comparators		Automatic Bridges	Automatic Bridge Systems
Measurement Rate	<300/h	300 to 3000/h			>3000/h
Data Recording and Sorting Decisions		Manual			automatic
Absolute Values Deviation from Standard	R, L, C —	—	R, L, C	C, G R, L, C	
Operator Skill Needed	moderate	low			

APPLICATION AREAS

Application Area	1682	1683	1685	1686-A	1657
Capacitance Measurements General use, mica, plastic, paper	Direct reading in C and G over 4 decade ranges, 20 measurements per second	Direct reading in C and D over 9 decade ranges, 4 measurements per second	Direct reading in C and D over 9 decade ranges, 4 measurements per second	Direct reading in C and D over 9 decade ranges, 4 measurements per second	Direct reading in C and D (simultaneous), wide measurement ranges
Ceramics	1-MHz, 0.5 to 500-mV signal	1-kHz, 0 to 2.2-V signal	1 kHz		
Low-loss plastic and glass	G resolution 0.01 μS	D accuracy 0.001			D accuracy 0.0001
Semiconductor	1-MHz, low-level signal, adjustable dc bias, no errors due to strays or lead impedances	1-kHz signal, no errors due to strays or lead impedances			Low signal level
Electrolytics	————	Accurate to 200,000 μF , <1-second balance at 120 Hz, reads series ESR and tests leakage current, no errors due to lead impedances	20,000 μF	200,000 μF	99,999 μF
Inductance Measurements	————	Direct reading in inductance			Direct reading in inductance
Resistance Measurements	Reads conductance	Direct reading in resistance	DC resistance		Wide range of ac resistance
Sorting, Inspection, QC	Wide range, fast and simple operation, data output				Fast, inexpensive, simple operation
Material Studies	Fast, automatic operation, 1 MHz, adjustable signal level and dc bias	Fast, automatic operation, 120, 1000 Hz, adjustable signal level and dc bias	Fast, automatic operation, 120, 1000 Hz, dc bias	Fast, automatic operation, 120, 1000 Hz, adjustable signal level and dc bias	Fast, automatic, 120 Hz or 1 kHz
Process Control	Programmable controls, data output, rapid balances, tracking mode over all ranges		Data output, rapid balances, tracking mode over all ranges		Rapid balance



1686-A Digital Capacitance Meter

- C from 0.01 pF to 200,000 μ F
- 0.1% basic accuracy
- Fast: 250-millisecond unqualified measurement time
- 120-Hz and 1-kHz test frequencies
- Automatic GO/NO GO indications for C and D
- Automatic measurement
- Internal and external bias
- Adjustable test voltage
- Data output (BCD)
- Over-range to one full farad

GR's 1686-A Digital Capacitance Meter provides the rapid throughput you need for high-volume testing **plus** the high accuracy you need for lab and QC work. Add to these two features wide measurement range, a built-in limit comparator, two test frequencies, and an attractive low price and you can easily get the idea that GenRad has a performance/price breakthrough in measuring capacitance.

Anyone can master the 1686's operation in a matter of minutes, partly because of the GO/NO GO lights on both

the instrument and on the optional test fixture. Normally, these two lamps are all the operator needs to look at. If either capacitance or dissipation factor is out-of-tolerance, the red NO GO lamp is lit. Otherwise, the bright green GO lamp is lit.

Connect your component and turn the RANGE knob as directed by the arrows. No decisions are required. The measurement units light up automatically. A clear, bright 4½-digit LED display indicates value.

Make a single measurement or repeat at rates from 4 per second to one every 10 seconds. This is a great feature for tracking value changes as you stress a component.

The built-in limit comparator greatly speeds up and simplifies capacitor inspection and sorting. High- and Low-capacitance limits are easily set with thumbwheel switches. The dissipation-factor limit is set by rotating the DF dial to the desired value.

On range positions 2 through 6, the test voltage can be varied from 1 V to 0.05 V, and on range position 1 it can be varied from 5 V to 0.25 V.

A 2-volt internal bias may be selected or a 0 to 100-volt external bias may be used.

An optional Kelvin test fixture accommodates either radial or axial lead components. External bias can be applied to the component directly at the fixture.

SPECIFICATIONS

Ranges: Full scale readings, accuracy multipliers, and applied-voltage multipliers.

Capacitance:

Switch Position	C 1 kHz	M	C 120 Hz	M	Voltage Multiplier A
1	199.99 pF	3	1.999 nF	2	5
2	1999.9 pF	1	19.99 nF	1	1
3	19.999 nF	1	199.9 nF	1	1
4	199.99 nF	1	1.999 μ F	1	1
5	1999.9 nF	1	19.99 μ F	1	1
6	19.999 μ F	1	199.9 μ F	1	1
7	199.99 μ F	3	1.999 mF	2	.1
8	1999.9 μ F	10	19.99 mF	3	.1
9	-----	---	199.9 mF**	6*	.1

*Typical value. **Extends to 999.9 mF.

M = Accuracy Multiplier (see below).

A = Applied Voltage Multiplier.

Dissipation Factor: D = 0.001 to 10

Accuracy: CAPACITANCE: Basically 0.1% for 1-kHz measurements; 0.5% for 120-Hz (100-Hz) measurements. See curves for exact accuracies.

DISSIPATION FACTOR:

$$\text{Error} = \pm \left[0.001 + 0.0002 \frac{C_{\text{full scale}}}{C_{\text{reading}}} + 0.05 (1+D)D \right] M$$

where M = Accuracy Multiplier. (See Range table).

Speed: 250 ms for single step or operator-variable from 0.25 s min. to 10 s max.

Display: 4½ digits, LED display with decimal point and over-range indication.

Applied Voltage (Variable): Max. Applied voltage is 1 V \times A (A=Voltage Multiplier. See range table). Applied voltage is variable from max to 1/20 max on range positions 1 through 6. Maximum power is 1/8 W.

Frequency: 1 kHz \pm 2% and 120 Hz, synchronized to line (100-Hz test frequency for 50-Hz line).

Bias: 2V internal and 0-100 V external.

Measurement Mode: Measurements made on command or repetitively at times from 0.25 s to 10 s. Previous measurement is held during period of new measurement.

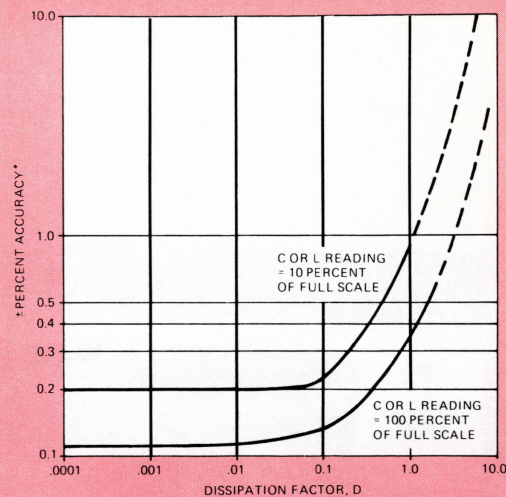
Data Outputs (TTL Logic): Open collector, active low.

Data Inputs: REMOTE START: A positive transition of $<1 \mu$ s from $0V < V_L < 0.4 V$ to $+2V < V_H < +30 V$ initiates a measurement. LAMP TEST: A ground lights all segments of the right-most four digits of the LED display (8 8 8 8) to check operation of all indicator segments.

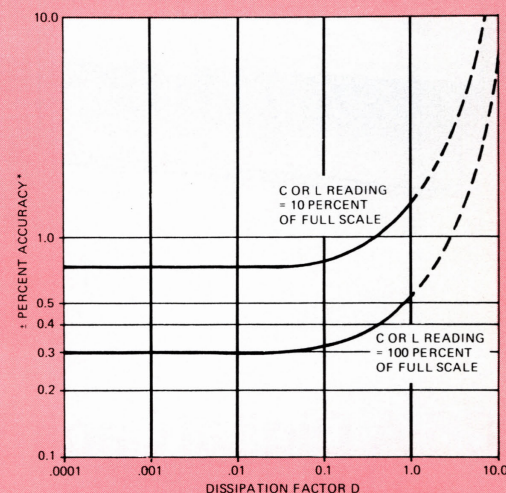
Limits: DATA OUTPUTS (TTL LOGIC): Open collector, active low. Audio output (\approx 250 Hz) line drives a miniature speaker (or headphone). Signal gives 1/4-s burst of audio when measured value falls outside the selected high and low limits. (Not activated by D failures.)

Supplied: Power cord, measurement cable, output-data connector set.

Power: 90 to 127 or 180 to 253 V, 48 to 440 Hz, 40W max.



C and L accuracy at 1 kHz Test Frequency



C and L accuracy at 120 Hz Test Frequency

*Multiply Percent Accuracy By M (see Range table).

Mechanical: Bench or rack models. DIMENSIONS (wxhxd): Bench, 17.00x5.59x16.25 in. (432x142x413 mm); rack, 19.00x5.22x16.63 in. (483x133x422 mm). WEIGHT: Bench, 22.5 lb (10.2 kg) net, 31 lb (14.1 kg) shipping; rack, 23.25 lb (10.54 kg) net, 31.75 lb (14.4 kg) shipping.

Description	Catalog Number
1686-A Digital Capacitance Meter	
60-Hz Line Frequency	1686-9700
120-Hz Test Frequency	
50-Hz Line Frequency	1686-9800
100-Hz Test Frequency	
Rack Hardware Kit	0480-9703
1686-P1 Test Fixture, Kelvin Clips	1686-9600



1682 Automatic Capacitance Bridge, 1 MHz

- 0.001 pF to 0.02 μ F
- 0.2% basic accuracy
- 20 measurements per second
- 0 to 100 V built-in bias

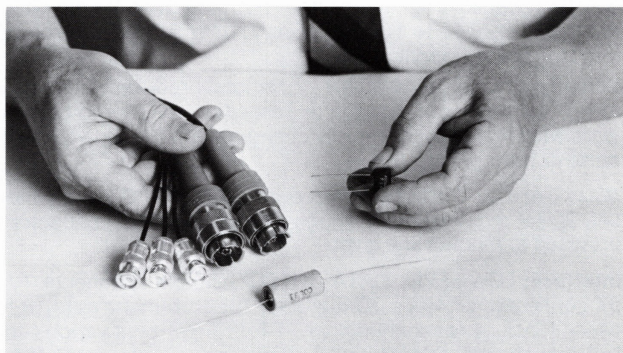
Why measure capacitance at 1 MHz? Whatever your reason, you'll find that with the GR 1682 it is as easy at 1 MHz as at much lower frequencies. Use of 1 MHz as the test frequency permits accurate measurement of small values of capacitance in the presence of large values of shunt conductance as found in many semiconductor devices and in rf networks. Many military and commercial test specifications require 1-MHz measurement of small solid-dielectric capacitors, like "ceramics," whose capacitance may vary with frequency.

The 1682 is a true bridge with transformer ratio arms and precision impedance standards for high accuracy and ensured long-term stability. Five-terminal connection for the unknown capacitor minimizes the effects of lead impedances. This is a second-generation automatic GR bridge that is fast and reliable.

The 1682 provides five-digit resolution for capacitance measurements and four-digit resolution for concurrent loss measurements, expressed as parallel conductance. All measurements can be made with internal bias voltages from 0 to 100 V or any external bias voltage up to 200 V. The measuring signal level on unknown capacitors

of <200 pF can be reduced to accommodate voltage sensitive characteristics.

A continuous-tracking mode is provided for voltage- and temperature-coefficient studies. Full programmability is available with an array of inputs and outputs for such enhancements as data printing, card punching, and computer control.



5 Wires for a 2-Terminal Device? Yes! The four-terminal (Kelvin) connections minimize lead-impedance effects and preserve the accuracy of the bridge *at the component* even with low-impedance unknown capacitors. And the fifth, or ground, terminal provides a similar safeguard with high impedances whose measurement might otherwise be affected by stray capacitance to ground.

SPECIFICATIONS

Parameters Measured: Parallel Capacitance C_x and Conductance G_x .

Range	Capacitance	Digits	Each Count	Basic Accuracy, % of C_x	G_x Units
1	0 – 19.999 pF	5	.001 pF	0.2% $\pm(1 + 0.6 G_x)$ Counts	$\mu \Omega$
2	0 – 199.99 pF	5	.01 pF	0.2% $\pm(1 + 0.02 G_x)$ Counts	$\mu \Omega$
3	0 – 1999.9 pF	5	.1 pF	0.2% $\pm(1 + 0.006 G_x)$ Counts	$\mu \Omega$
4	0 – 19.99 nF	4	.01 nF	10.0% $\pm(1 + 1.0 G_x)$ Counts	m Ω
Range	Conductance	Digits	Each Count	Basic Accuracy, % of G_x^*	C_x Units
1	0 – 19.99 $\mu \Omega$	4	0.01 $\mu \Omega$	1.0% $\pm(1 + 2.5 C_x)$ Counts	pF
2	0 – 199.9 $\mu \Omega$	4	0.1 $\mu \Omega$	1.0% $\pm(1 + 0.1 C_x)$ Counts	pF
3	0 – 1999. $\mu \Omega$	4	1. $\mu \Omega$	1.0% $\pm(1 + .025 C_x)$ Counts	pF
4	0 – 19.9 m Ω	3	0.1 m Ω	5.0% $\pm(1 + 1.0 C_x)$ Counts	nF

* Note: Limit of offset on any G range is $G_0 = \pm 10$ counts, max. It is defined at $C_x = 0$, $G_x = 0$. Subtract G_0 from reading to obtain basic accuracy.

Display: 5-digit capacitance readout (4 digits on highest range, 0.001 to 20 nF) and 4-digit conductance readout (3 digits on highest range, 1 to 20 m Ω ; each with high-intensity neon readout tubes, decimal point, and unit of measurement. Display also indicates unbalanced condition.

Speed: Measurement rate is ≈ 20 measurements per second for $\pm 10\%$ of full-scale change in unknown, up to 50/s for closer tolerance unknowns, 6/s for full-scale change, and 2/s with range changes. Interval between measurements can be infinite (measurements initiated by front-panel pushbutton or external closure to ground) or from ≈ 1 to 0.02 s as set by front-panel control so that measurements are repetitive. A TRACKING MODE provides continuous balances to monitor changing unknowns.

Terminals: Five-terminal connection that minimizes errors due to lead impedance and stray capacitance to ground are made by coaxial cables at the front of the instrument. A 1682-P1 Test Fixture is available for the rapid connection of axial-lead components and contains a start button to initiate the measurements. A 1682-P2 Test Fixture is available for the connection of GR900® connector-terminated components. A 1682-P3 Test Fixture is available for the connection of GR 874® connector-terminated components such as the GR 1403 Standard Capacitors or, by means of a 777-Q3 Adaptor, to any component with $\frac{3}{4}$ -in.-spaced binding posts. STRAY CAPACITANCE: Up to 0.5 pF across the test fixtures can be cancelled on lowest two ranges by an adjustment at the rear of the 1682.

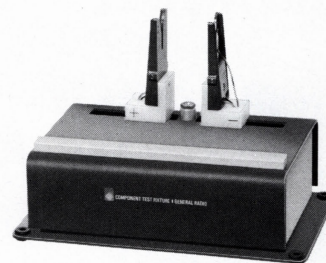
Ranges: Four. Top of each range: 20 pF, 200 pF, 2000 pF, 20 nF. Ranging can be automatic, manual, or remote.

Oscillator Level: Measuring voltage applied to the unknown C can be reduced from the normal 500 and 50 mV rms on the lower two ranges to 50 and 25 mV, with a 1-digit resolution loss, for special applications.

Sensitivity: Can be manually or remotely reduced from maximum, with consequent loss or resolution, to overcome problems with nonlinear or rapidly changing unknowns, or external noise or hum pickup.

Bias: 0 to 100 V internal, source impedance 100 k Ω , manually set; 200 V max external through 100 k Ω . A BNC connector is provided to monitor the level.

Interface: LOW-LEVEL DATA OUTPUT: 50-pin Amphenol Type 57 connector provides 10 digits for measurement data (5 for capacitance, 4 for conductance, 1 for range) plus various control inputs and outputs for systems use. Digits are 1-2-4-8-weighted BCD at standard TTL logic levels (logic "0" \approx ground with 10-mA sink capability, logic "1" $\approx +3.5$ V). HIGH-LEVEL DATA OUTPUT: same except all outputs are 15-V swing (logic "0" \approx ground, with 10-mA sink capability, logic "1" $\approx +15$ V behind 12 k Ω). REMOTE PROGRAMMABILITY — OPTION 2: 50-pin Amphenol Type 57 connector provides terminals for external remote programming of all control functions except bias and line-voltage control. Functions are controlled by closures to ground or standard TTL or DTL signals.



1682-P1 Test Fixture for axial-lead components



1682-P2 Test Fixture with GR900 terminals



1682-P3 Test Fixture with GR874 terminals

Available: 1682-P1, -P2, and -P3 TEST FIXTURES, printers, recorders, card-punch couplers, limit comparators. Extender boards are useful for servicing the bridge.

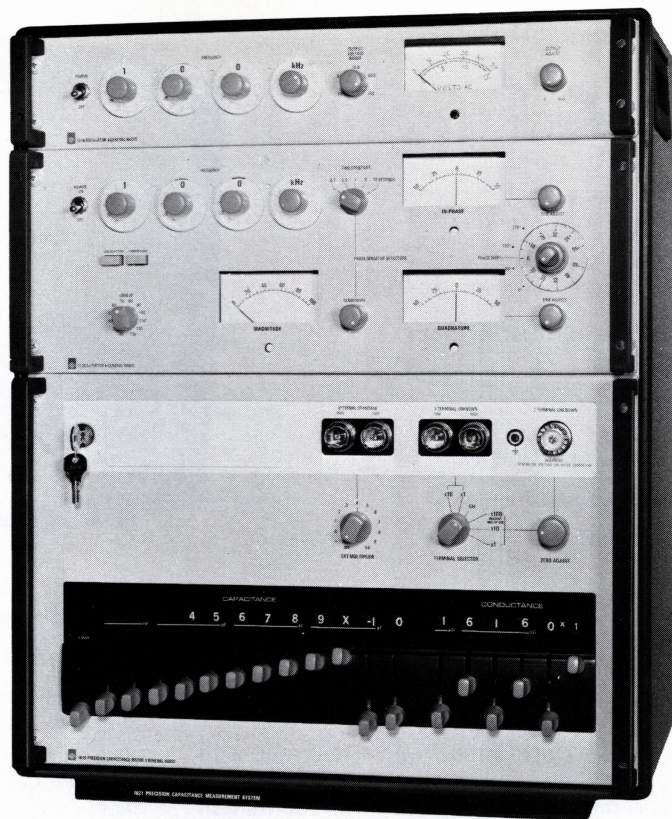
Power: 100 to 125 and 200 to 250 V, 50-60 Hz, 60 W.

Mechanical: Bench or rack models. DIMENSIONS (wxhxd): Bench, 19x7.88x24.75 in. (483x200x628 mm); rack, 19x7x23.13 in. (483x178x588 mm). WEIGHT: Bench, 59 lb (27 kg) net, 74 lb (34 kg) shipping; rack, 50 lb (23 kg) net, 67 lb (31 kg) shipping.

Description	Catalog Number
1682 Automatic Capacitance Bridge (1 MHz)	
Bench Model	
Rack Model	
Select following options, if desired	
OP2 Remote Programmability (not available without option 5A or 5B)	
OP5A* Low-Level Data Output	
OP5B* High-Level Data Output	
Accessories available	
1682-P1 Test Fixture, for axial leads	1682-9601
1682-P2 Test Fixture, GR900® terminals	1682-9602
1682-P3 Test Fixture, GR874® terminals	1682-9603
Extender Board	4215-2700
Extender Board (2 req'd)	4215-2701

* Not available together in the same instrument. Patent Numbers 3,562,641 and 3,227,893.

(Describe exactly as shown at the left.)



1621 Precision Capacitance - Measurement System

- **10⁻⁷ pF to 10 μ F**
12-digit readout, 10-ppm basic accuracy
- **10⁻¹⁰ μ V to 1000 μ V**
5-digit readout, 0.1% basic accuracy
- **10 Hz to 100 kHz**
- **3-terminal measurements**
with 2- or 3-terminal connection
- **comparison measurements**
- **simple lever balance with in-line readout**

The whole of precision The 1621 represents the first major improvement in nearly a decade in ultra-precise laboratory capacitance intercomparisons and dielectric measurements. It is a completely self-contained system capable of capacitance measurements in increments as small as 0.1 aF (10⁻⁷ pF) and conductance measurements in increments as small as 100 aV (10⁻¹⁰ μ V; equivalent to a shunt resistance of 10¹⁰ M Ω). Measurements are three terminal, with 2- or 3-terminal connection, and provision is also made for the connection of an external standard for comparison measurements.

Such capability and precision are usually accompanied by restricted frequency and complex operation. The 1621, however, avoids these difficulties. Little degradation of performance occurs from 10 Hz to 10 kHz and operation to 100 kHz is possible. Balances are achieved by in-line readout lever switches — easily adjusted and read correctly. All digits of capacitance and conductance, as well as pertinent multipliers, are also provided by BCD-coded contact closures, available at rear-panel connectors for use by printers or data-processing equipment.

Three integrated units The 1621 is an assembly of three integrated instruments: A precision ratio-arm bridge, a highly stable oscillator, and an extremely sensitive detector. Most of the bridge's internal standards are enclosed in an insulated housing to reduce the effects of ambient temperature changes; unused standards are disconnected to reduce shunt capacitance at the detector input. The oscillator provides up to 125 V or 5 A for sufficient signal to be detected even with unbalances as small as one part in 10⁸ of 10 pF. The detector contains three meters to help you speed the balance: One displays the magnitude and the other two simultaneously display the in-phase and quadrature components of any unbalance.

SPECIFICATIONS

(See 1616 for performance specifications)

Frequency: 10 Hz to 100 kHz.

Supplied: 1616 Precision Capacitance Bridge, 1316 Oscillator, 1238 Detector, all necessary interconnection cables, and power cord.

Available: 1408 REFERENCE STANDARD CAPACITORS (10 pF and 100 pF) for calibration.

Power: 100 to 125 and 200 to 250 V, 50 to 60 Hz, 51 W.

Mechanical: Bench or rack models. **DIMENSIONS** (wxhxd): Bench, 19.75x24.25x15 in. (502x616x381 mm); rack, 19x20.91x11.44 in. (483x531x291 mm). **WEIGHT:** Bench, 105 lb (48 kg) net, 140 lb (64 kg) shipping; rack, 90 lb (41 kg) net, 125 lb (57 kg) shipping.

Description

Catalog Number

1621 Precision Capacitance-Measurement System

Bench Model, 60-Hz
Rack Model, 60-Hz
Bench Model, 50-Hz
Rack Model, 50-Hz

1621-9701
1621-9702
1621-9703
1621-9704

1616 Precision Capacitance Bridge

- 10⁻⁷ pF to 10 μ F — 12-digit readout
- 10⁻¹⁰ μ Ω to 1000 μ Ω — 5-digit readout
- 10 Hz to 100 kHz
- up to 150-V input from oscillator
- 3-terminal measurements
- coaxial measurements



The heart of precision The 1616 is the heart of the 1621 Capacitance-Measuring Assembly. The bridge is also available separately for use where oscillator and detector are on hand or in applications in which they must be specialized for a unique need.

The 1616 employs a transformer ratio-arm bridge with which unbalances as small as 0.1 aF (10⁻⁷ pF) and 100 aΩ (10⁻¹⁰ μ Ω) can be resolved. Detection of such small unbalances is aided by ratio-transformer voltage capabilities up to 160 volts at 1 kHz and by range switching that disconnects the unused internal standards in order to reduce shunt capacitance across the detector input.

SPECIFICATIONS

Capacitance measurement, 3-terminal: DECADES: 12. RANGE: 0.1 aF to 1 μ F (10⁻⁹ to 10⁻⁶ F). ACCURACY: * \pm 10 ppm, when most-significant decade is 1, 10, or 100 pF per step; otherwise, and at other frequencies, accuracy is \pm [50 ppm + (0.5 + 20 C_{ME}) (f_{kHz})² ppm + (f_{kHz}) aF].

Capacitance, 2-terminal: Same as above, except as follows. RANGE: One additional decade, to 10 μ F (10⁻⁹ to 10⁻⁵ F).

Conductance measurement, 3-terminal: DECADES: 5 (virtually extended to 11 by G multiplier). RANGE: 100 aΩ to 100 μ Ω (10⁻⁶ to 10⁻⁴ Ω). ACCURACY: * \pm (0.1% + 1 step in least significant decade). There is a small reduction in conductance accuracy at frequencies other than 1 kHz. RESIDUAL C (across conductance standards): \pm ($<$ 0.03 pF).

Conductance, 2-terminal: Same as above, except as follows. RANGE: One additional decade, to 1000 μ Ω (10⁻⁶ to 10⁻³ Ω).

Multipliers: FOR 3-TERM: X1, X10; FOR 2-TERM: X1, X10, X100; affect both C and G. FOR CONDUCTANCE ONLY: X1, X10⁻¹, . . . X10⁻⁶ (7 positions). Effects of these multipliers are included in the specified ranges.

Frequency: 10 Hz to 100 kHz.

Standards: CAPACITANCE: Air dielectric with TC $<$ +20 ppm/°C and D $<$ 10 ppm for 8 lowest decades; Invar†, air dielectric with TC of +3 \pm 1 ppm/°C and D $<$ 10 ppm for 3 middle decades; mica dielectric with TC of 20 \pm 10 ppm/°C and D $<$ 200 ppm for 2 highest decades. ADJUSTMENTS for all capacitance standards available through key-locked door on panel. THERMAL LAG: C standards for first 8 decades mounted in an insulated compartment with a thermal time constant of 6 h (time required for compartment interior to reach 63% of ambient change). CONDUCTANCE: Metal-film resistors in T networks with small phase angles.

*Accuracy stated as fraction of measured value, for these conditions: frequency, 1 kHz, except as noted; temperature, 23° \pm 1°C; humidity, $<$ 50% RH.

†Registered trademark of the Carpenter Steel Co.

For thermal stability in precision intercomparisons, eight of the twelve internal capacitance standards are mounted in an insulated compartment to reduce the effects of ambient temperature changes. Misreading the values at balance is virtually impossible due to direct-reading lever switches that control the balance for both capacitance and conductance. Panel layout is unusually neat — only the unknown capacitor and, if desired, an external standard for comparison measurements are connected to the front panel; the oscillator and detector are connected to the rear as are the BCD data-output channels.

Comparison: Terminals provided to connect external standard for comparison measurements; 13-position panel switch multiplies standard by -0.1, 0 . . . +1.

Input: The smaller of 160 f_{kHz} or 350 V rms can be applied to the bridge transformer at the GENERATOR terminal without waveform distortion; 500 V rms max, depending on conductance range, when GENERATOR and DETECTOR connections are interchanged.

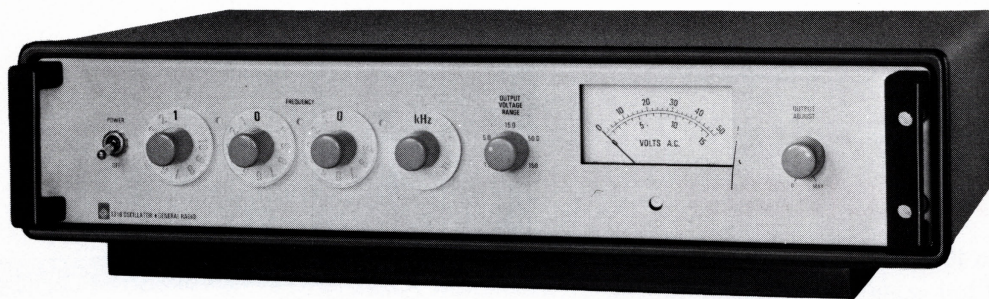
Interface: GR900® locking coaxial connector on panel to connect 2-terminal unknowns, 2 gold-plated GR874® locking coaxial connectors on panel to connect 3-terminal unknowns and 2 to connect external standard. DATA OUTPUT: 50-pin and 36-pin type 57 connectors on rear provide connection to 8-4-2-1 weighted BCD contacts (rated at 28 V, 1 A) on each switch for capacitance and conductance values respectively. OSCILLATOR and DETECTOR: Connect to rear BNC connectors.

Required: OSCILLATOR: GR 1316 recommended. DETECTOR: GR 1238 recommended. The 1616 Bridge is available with this oscillator and detector as the 1621 Capacitance-Measuring Assembly.

Available: 1316 OSCILLATOR, 1268 DETECTOR, a broad line of capacitance and resistance standards, and coaxial cables for connection of unknowns and standards.

Mechanical: Bench or rack model. DIMENSIONS (wxhxd): Bench, 19.75x13.81x12.88 in. (502x351x327 mm); rack, 19x12.22x10.56 in. (483x310x268 mm). WEIGHT: Bench, 57 lb (26 kg) net, 69 lb (32 kg) shipping; rack, 49 lb (23 kg) net, 61 lb (28 kg) shipping.

Description	Catalog Number
1616 Precision Capacitance Bridge	
Bench Model	1616-9700
Rack Model	1616-9701



1316 Oscillator

- 10 Hz to 100 kHz
- up to 125 V or 5-A output
- output level adjustable and metered
- in-phase and quadrature reference outputs
- in-line readout dials
- current-limited output — short circuits OK

Convenience and performance Set four controls and the 1316 provides any frequency from 10 Hz to 100 kHz with 1% accuracy and with little chance of an improper setting — the dials provide in-line readout, including decimal point and frequency units. Set two more controls, and the 1316 provides up to 1.6 watts of output power (125 V open circuit or 5 A short circuit), low distortion, and accurate metering.

These features alone would qualify the 1316 as an excellent general-purpose oscillator but it offers more: Output constant within $\pm 2\%$, excellent stability (only 0.005% drift over a 12-hour period), and a synchronizing feature that allows the oscillator to be locked to an external standard for even greater accuracy and stability.

Excellent bridge oscillator The 1316 is a high-performance bridge oscillator specifically intended for use with the 1238 Detector and the 1616 Precision Capacitance Bridge. The oscillator supplies 2 references (in quadrature) for the 2-phase phase-sensitive detector, which enables you to make independent and ultra-precise balances of the conductance (real part) and capacitance (imaginary part) of capacitive devices.

The 1316 contains a Wien-bridge oscillator isolated from the load by a low-distortion transformer-coupled power amplifier. The oscillator circuit includes a provision to introduce a synchronizing signal for phase locking or to extract a signal, independent of the output setting, to operate a counter or to synchronize an oscilloscope.

SPECIFICATIONS

Frequency: 10 Hz to 100 kHz in 4 decade ranges. Controlled by one 11-position and one 10-position switch for the most-significant digits and a continuously adjustable dial with detented zero position for the third digit; in-line readout with decimal point and frequency units.

Accuracy: $\pm 1\%$ of setting with continuously adjustable dial at zero detent position. **DRIFT** (typical at 1 kHz): Warmup 0.1%,

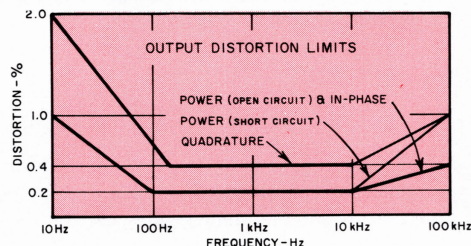
short-term (10 min) 0.001%, long-term (12 h) 0.005%. **RE-SETTABILITY:** Within 0.005%.

Power Output: CONTROLLED by 5-position switch and uncalibrated vernier. MONITORED by meter with $\pm 3\%$ accuracy. AVAILABLE at rear BNC connector.

	Output Range				
	1.5 V	5 V	15 V	50 V	150 V
Open circuit E, rms	≥ 1.25 V	≥ 4 V	≥ 12.5 V	≥ 40 V	≥ 125 V
Distortion	$< 0.2\%$ from 100 Hz to 10 kHz				
Hum	0.003% of max output				
Response	output constant within $\pm 2\%$ from 10 Hz to 100 kHz*				
Short Circuit I	5 A	1.6 A	0.5 A	0.16 A	0.05 A
Distortion	$< 0.2\%$ from 100 Hz to 10 kHz				
Impedance	0.25 Ω	2.5 Ω	25 Ω	250 Ω	2.5 k Ω
Power	1.6 W max into matched load				

* $\pm 5\%$ for outputs > 30 V rms at frequencies > 50 kHz.

Reference Outputs: Quadrature output lags in-phase output by 90° . Each available at rear BNC connectors.



	In-Phase	Quadrature
Output, open-circuit	1.25 ± 0.25 V rms	
Distortion, 100 Hz to 10 kHz	$< 0.2\%$	$< 0.4\%$
Response, 10 Hz to 10 kHz	$\pm 2\%$	
10 kHz to 100 kHz	$\pm 4\%$	
Minimum Load	47 k Ω	

Synchronization: INPUT: Frequency can be locked to external signal; lock range, $\pm 1\%$ /V rms input up to 10 V; frequency controls function as phase adjustment. OUTPUT: ≥ 0.3 V rms behind 27 k Ω ; useful to sync oscilloscope or to drive a counter or another oscillator. Single rear BNC connector serves as both input and output terminal.

Power: 100 to 125 and 200 to 250 V, 50 to 60 Hz, 36 W.

Mechanical: Bench or rack mount. **DIMENSIONS** (wxhxd): Bench, 19.75x5x13.06 in. (502x127x332 mm); rack, 19x3.47x11.44 in. (483x88x291 mm). **WEIGHT:** Bench, 26 lb (12 kg) net, 32 lb (15 kg) shipping; rack, 21 lb (10 kg) net, 27 lb (12 kg) shipping.

Description	Catalog Number
1316 Oscillator	
Bench Model	1316-9700
Rack Model	1316-9701

1238 Detector

- 10 Hz to 100 kHz
- 100-nV full-scale sensitivity
- magnitude, in-phase, and quadrature meters for rapid bridge balances
- excellent bridge detector

Designed for the difficult If you've ever had to extract a small signal from noise or to resolve a signal into its in-phase and quadrature components, you can appreciate the advantages of the 1238. With its high gain — 130 dB — and meters not only for magnitude of the input signal but for the in-phase and quadrature components as well, the 1238 lends itself handily to the most exacting applications.

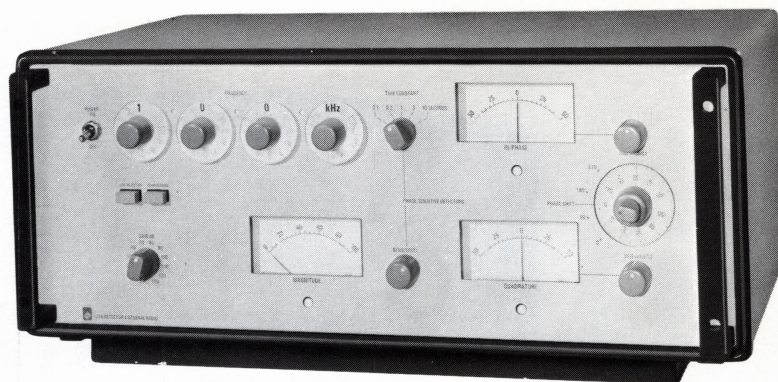
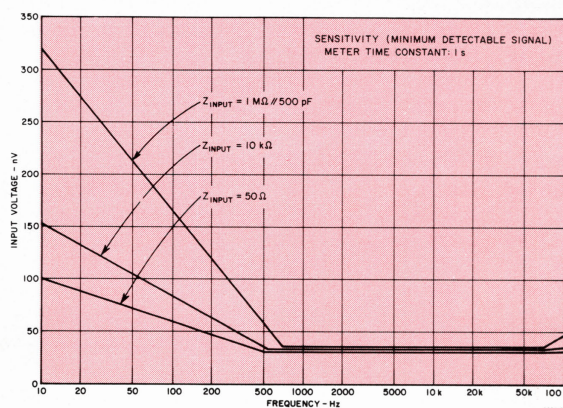
This high-performance detector is attractive in other respects also, including 1-G Ω input impedance for minimum loading, overload protection against signals up to 200 V, and flat or tuned frequency response (with or without line-frequency rejection) to tailor the detector to your signal no matter how "tainted" it might be.

Excellent bridge detector In combination with a special oscillator, GR 1316, that supplies the necessary quadrature reference channels, this detector is superb for sensitive audio-frequency detection. The combination is specifically intended for use with the 1616 Precision Capacitance Bridge, enabling resolutions of one part in 10⁸ of 10 pF. Refer to the 1621 Precision Capacitance-Measurement System.

SPECIFICATIONS

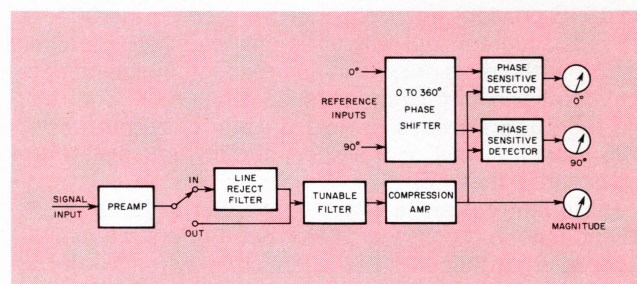
Frequency: 10 Hz to 100 kHz, flat or tuned. **FLAT:** ± 5 dB from 10 Hz to 100 kHz. **TUNED:** Set by 4 in-line readout dials with $\pm 5\%$ of reading accuracy, 2 to 4% bandwidth, and second harmonic ≥ 30 dB down from peak. **LINE-REJECTION FILTER:** Reduces line level by ≥ 40 dB while signal is down 6 to 10 dB at 10 Hz from line frequency; filter can be switched out.

Signal Input from bridge or other source: Applied to rear BNC connector. **SENSITIVITY:** Also see curve; 100 nV rms typical for full-scale deflection at most frequencies, compression can be switched in to reduce full-scale sensitivity by 20 dB. **IMPEDANCE:** 1 G Ω /20 pF. **MAXIMUM INPUT:** 200 V rms. **VOLTAGE GAIN:** ≈ 105 dB in flat mode, ≈ 130 dB in tuned mode, set by 12-position switch. **SPOT NOISE VOLTAGE:**



The 1238 Detector consists of a high-impedance low-noise preamplifier, a tuned amplifier, a compression amplifier, and two phase-sensitive detectors. Three panel meters provide the indications: one displays the magnitude of the input signal and two others simultaneously display its in-phase and quadrature components. The reference signals can be rotated continuously from 0 through 360° to ensure that the phase meters respond independently to the components of significance to you, for the most rapid bridge balances or signal analysis.

The effects of noise, hum, or any other input-signal contaminants are normally reduced or eliminated from your measurements by means of a tunable filter, line-rejection filter, and selectable time constants in the phase-sensitive detector circuits — all controlled from the front panel by the simple push of a button or turn of a knob.



$< 30\text{ nV} \times \sqrt{\text{bandwidth}_{\text{Hz}}}$ at 1 kHz with input impedance of 70 M Ω /500 pF. **MONITORED** by magnitude, in-phase, and quadrature meters; phase-sensitive detectors contain time-constant variable from 0.1 to 10 s in 5 steps.

Reference Inputs from oscillator: Applied to rear BNC connectors. Two ≥ 1 -V rms reference signals required, with 90° phase difference between them. **PHASE SHIFTER** rotates both references continuously from 0 to 360° and two verniers rotate each reference individually $\approx 10^\circ$.

Outputs: **MAIN AMPLIFIER:** 4 V rms (approx 2.3 V for full scale on Magnitude meter) available at rear BNC connector. **MAGNITUDE:** 6 V dc for full scale deflection; **PHASE DETECTORS:** Up to 1 V dc each for full scale deflection (depending on Sensitivity setting); available at rear 5-pin type 126 jack.

Environment: **TEMPERATURE:** 0 to +55°C operating, -40 to +75°C storage. **BENCH HANDLING:** 4 in. or 45° (MIL-810A-VI). **SHOCK:** 30 G, 11 ms (MIL-T-4807A-4.5-3A).

Required: Oscillator with 0 and 90° outputs; the 1316 Oscillator is recommended.

Power: 100 to 125 and 200 to 250 V, 50 to 60 Hz, 15 W.

Mechanical: Bench or rack models. **DIMENSIONS (wxhxd):** Bench, 19.56x6.66x12.94 in. (497x169x329 mm); rack, 19x5.22x13.06 in. (483x133x332 mm). **WEIGHT:** Bench, 27 lb (13 kg) net, 40 lb (19 kg) shipping; rack, 21 lb (10 kg) net, 34 lb (16 kg) shipping.

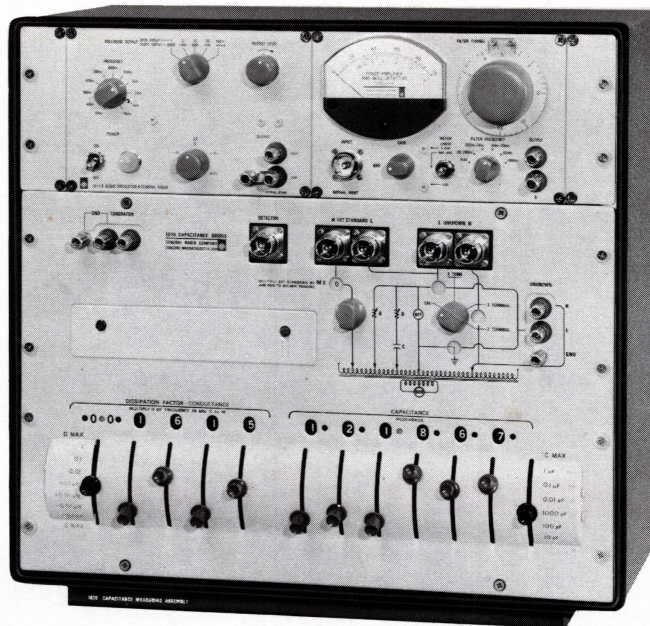
Description

1238 Detector

- 60-Hz Bench Model
- 60-Hz Rack Model
- 50-Hz Bench Model
- 50-Hz Rack Model

Catalog Number

- 1238-9700
- 1238-9701
- 1238-9703
- 1238-9704



1620-A Capacitance-Measuring Assembly

- 10^{-5} pF to $11.1 \mu\text{F}$, 2- or 3-terminal
- 0.01% accuracy, 1-ppm resolution
- lever balance, in-line readout
- reads dissipation factor or conductance

The 1620-A is a self-contained assembly of the GR 1615-A Capacitance Bridge with appropriate oscillator and null detector for measurements at 11 frequencies between 20 Hz and 20 kHz. For applications requiring other or higher frequencies, to 100 kHz, the 1615-A bridge can be supplied separately and the oscillator and detector selected to meet your needs.

The 1620-A is intended for

- accurate and precise measurements of capacitance and dissipation factor
- measurement of circuit capacitances
- dielectric measurements
- intercomparison of capacitance standards differing in magnitude by as much as 1000:1

The 1615-A Capacitance Bridge brings to the measurement of capacitance, to the intercomparison of standards, and to the measurement of dielectric properties an unusual degree of accuracy, precision, range, and convenience.

High accuracy is achieved through the use of precisely wound transformer ratio arms and highly stable standards fabricated from Invar and hermetically sealed in dry nitrogen. For calibration these standards can be intercompared.

Two- or Three-Terminal Connection Accurate three-terminal measurements can be made even in the presence of capacitances to ground as large as $1 \mu\text{F}$, as might be encountered with the unknown connected by means of long cables. The bridge has the necessary internal shielding to permit one terminal of the unknown capacitor to be directly grounded, so that true two-terminal and

three-terminal measurements can both be made over the whole capacitance range.

Convenient Operation For both capacitance and dissipation factor, the balance controls are smoothly operating, lever-type switches. The readout is digital and the decimal point is automatically positioned. Each capacitance decade has a -1 position to facilitate rapid balancing.

The 1615 elementary diagram is also clearly delineated on the front panel of the bridge. Changes in connections and grounds are automatically indicated, as you switch the bridge terminals for different measurement conditions.

Extend Range to $11.1 \mu\text{F}$ With the 1615-P1 Range-Extension Capacitor, the 1615-A will measure to a maximum of $11.11110 \mu\text{F}$. This capacitor plugs into front-panel bridge terminals and can be adjusted for calibration to the bridge standards.

SPECIFICATIONS

Performance: Refer to the 1615 Bridge.

Frequency: 50, 60, 100, 120, 200, 400, 500, 1000, 2000, 5000, and 10,000 Hz. For use below 100 Hz, 1620-AP (with preamplifier) should be used for resolution beyond 0.01% or 0.01 pF.

Generator: 1311-A Oscillator.

Detector: 1232-A Tuned Amplifier and Null Detector. 1232-P2 Preamplifier added in 1620-AP.

Power: 105 to 125 or 210 to 250 V, 50 to 400 Hz, 22 W for oscillator. Null detector and preamplifier operate from internal battery, 9 Burgess Type E4 cells or equivalent.

Mechanical: Bench cabinet. DIMENSIONS (wxhxd): 19.75x19x11 in. (502x483x280 mm). WEIGHT: 59 lb (27 kg) net, 96 lb (44 kg) shipping.

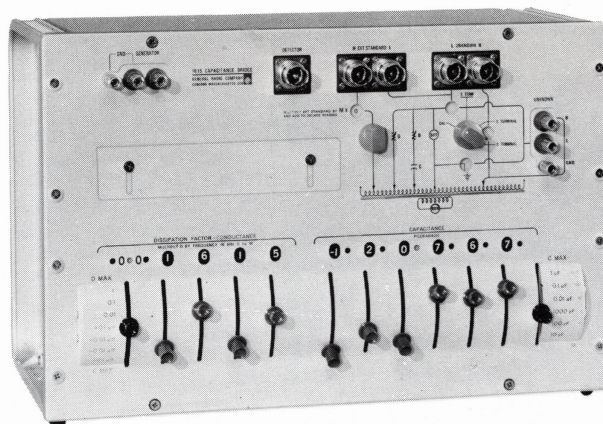
Description

Catalog Number

Capacitance-Measuring Assembly

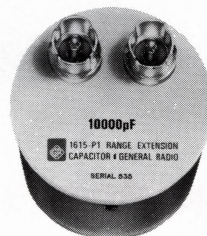
- 1620-A, 115 V ♦
- 1620-A, 230 V
- 1620-AP, with 1232-P2, 115 V
- 1620-AP, with 1232-P2, 230 V
- Replacement Battery (9 used)

- 1620-9701
- 1620-9702
- 1620-9829
- 1620-9830
- 8410-1372



1615-A Capacitance Bridge

The 1615-A is an accurate, high-precision bridge for the measurement and intercomparison of standard capacitors, circuit component capacitors, or dielectric materials. It is available with oscillator and detector in the 1620 assembly. Or, to take full advantage of its wide frequency range, the bridge can be ordered separately for use with oscillator and detector especially selected for your purposes.



1615-P1



1615-P2

SPECIFICATIONS

RANGES

Capacitance, 10 aF to 1.11110 μ F (10^{-17} to 10^{-6} farad) in 6 ranges, direct-reading, 6-figure resolution; least count 10^{-17} F (10 aF). With Range-Extension Capacitor, upper limit is 11.11110 μ F.

Dissipation Factor, D, At 1 kHz, 0.000001 to 1, 4-figure resolution; least count, 0.000001 (10^{-6}); range varies directly with frequency.

Conductance, G, 10^{-6} μ U to 100 μ U, 2 ranges +, 2 ranges -, 4-figure resolution, least count 10^{-6} μ U, independent of frequency; range varies with C range.

ACCURACY

At 1 kHz, $\pm(0.01\% + 0.00003 \text{ pF})$. At higher frequencies and with high capacitance, additional error is

$$[\pm 3 \times 10^{-5}\% + 2 (C_{\mu\text{F}}) \times 10^{-3}\% \pm 3 \times 10^{-7} \text{ pF}] \times (f_{\text{kHz}})^2.$$

At lower frequencies and with low capacitance, accuracy may be limited by bridge sensitivity.

Comparison accuracy, unknown to external standard, 1 ppm.

$$\pm[0.1\% \text{ of measured value} + 10^{-5} (1 + f_{\text{kHz}} + 5 f_{\text{kHz}} C_{\mu\text{F}})]$$

$$\pm[1\% \text{ of measured value} + 10^{-5} \mu\text{U} + 6 \times 10^{-2} f_{\text{kHz}} C_{\mu\text{F}} \times (1 + f_{\text{kHz}} + 5 f_{\text{kHz}} C_{\mu\text{F}}) \mu\text{U}]$$

Standards: 1000, 100, 10, 1, 0.1, 0.01, 0.001, 0.0001 pF. Temperature coefficient of capacitance is less than 5 ppm/ $^{\circ}$ C for the 1000-, 100-, and 10-pF standards, slightly greater for the smaller units.

Frequency: Approx 50 Hz to 10 kHz. Useful with reduced accuracy to 100 kHz. Below 100 Hz, resolution better than 0.01% or 0.01 pF requires preamplifier or special detector.

Generator: GR 1310 or 1311-A oscillator recommended. Max safe generator voltage ($30 \times f_{\text{kHz}}$) volts, 300 V max. If generator

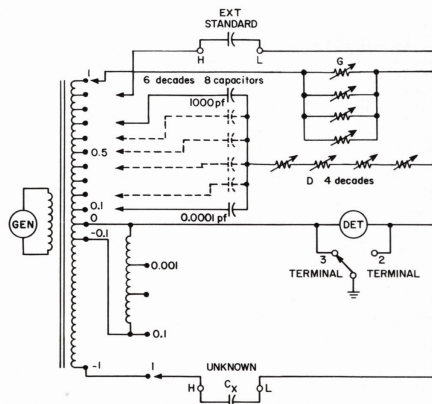
and detector connections are interchanged, 150 to 500 V can be applied, depending on switch settings.

Detector: GR 1232-A Tuned Amplifier and Null Detector recommended. For increased sensitivity needed to measure low-loss small capacitors (on lowest C and D ranges simultaneously) at frequencies below 1 kHz, use 1232-AP or 1238 (with 1311 oscillator).

Supplied: 874-WO Open-Circuit Termination, 874-R22A Patch Cord, 274-NL Patch Cord.

Available: Type 1615-P1 RANGE-EXTENSION CAPACITOR; 1615-P2 COAXIAL ADAPTOR converts 2-terminal binding-post connection on 1615 bridge to GR900[®] Precision Coaxial Connector for highly repeatable connections and enables measurements with adaptor to be direct-reading by compensating for terminal capacitance.

Mechanical: Rack-bench cabinet. DIMENSIONS (wxhxd): Bench, 19x12.75x10.5 in. (483x324x267 mm); rack, 19x12.25x8.5 in. (483x311x217 mm); 1615-P1 (dia x ln): 3.06x4.87 in. (78x124 mm). WEIGHT: 39 lb (18 kg) net, 58 lb (27 kg) shipping.



Elementary schematic diagram.

Description

1615-A Capacitance Bridge

Bench Model
Rack Model

1615-P1 Range-Extension Capacitor

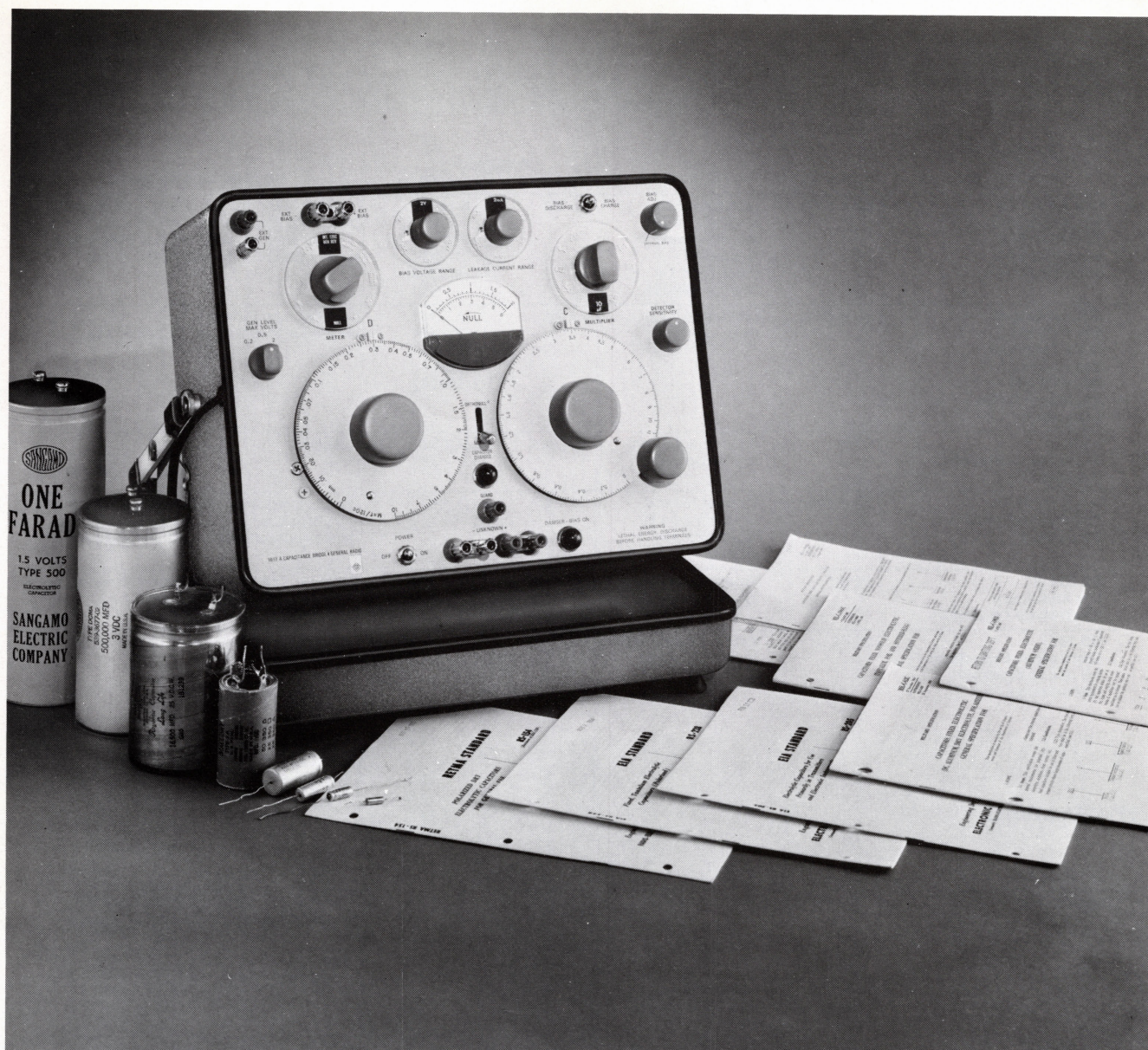
1615-P2 Coaxial Adaptor, GR900 to binding posts

Catalog Number

1615-9801
1615-9811

1615-9601

1615-9602



1617-A Capacitance Bridge

- 1 pF to 1.1 farads
- 20 Hz to 1 kHz
- 1% accuracy
- 2-, 3-, or 4-terminal connections

Self-Contained bridge The 1617-A was specifically designed for measuring capacitance, dissipation factor, and leakage current of electrolytic capacitors, but it will also find considerable use as a general-purpose 1% bridge. It is completely self-contained, including a 120-Hz generator, null detector, dc polarizing-voltage supply, and metering for bias voltage and leakage current. At frequencies other than 120 Hz, use an external oscillator.

Multiterminal connections An unknown capacitor can be connected to the bridge by means of three- or four-terminal connections, as well as the usual two-terminal. The four-terminal connection permits accurate measure-

ment of large capacitance by reducing the effect of the resistance and inductance of leads and connections. Correct measurements of small capacitances are assured by the three-terminal connection, which reduces the effect of stray lead capacitance. A multiterminal configuration is necessary for accurate measurement of capacitors connected by long cables leading, for instance, from the bridge on a nearby bench into an environmental test chamber.

This bridge includes an Orthonull® balance finder, which speeds up measurements of high-dissipation-factor capacitors by eliminating troublesome sliding balance. The operator's safety is enhanced by warning lights indicating the presence of voltage on the bridge terminals.

Electrolytics The 1617 Capacitance Bridge is designed especially for measuring large-valued capacitors like those in table, as well as other electrolytic types, most of which require the special measurement conditions prescribed by MIL or EIA specifications:

Specification and Capacitor Type	Frequency	AC Level	Accuracy Loss		DC Polarizing Voltage
MIL C-3965-C MIL C-39006-A Tantalum Foil and Sintered Slug Capacitors	120 \pm 5 Hz	Less than 30% of DCVW or 1 V, pk, whichever is smaller (Less than 1V rms for 39006A)	2%	R or P.F. 2% (P.F. 2% for -39006A)	C—Sufficient for no reversal of polarity. D—"Polarized Capacitance Bridge" Sum of ac and dc shall not exceed DCVW (Less than 2.2 V for 39006A)
MIL C-26655-B MIL C-39003 Solid Tantalum Capacitors MIL C-39018 Aluminum Oxide Capacitors	120 \pm 5 Hz	Limited to 1V, rms	2%	D, 10% (2% for -39003 and -39018)	C—Max bias 2.2 V. D—"Polarized Bridge", 2.2-V dc max.
RS 228 Tantalum Electrolytic Capacitors	120 Hz	Small enough not to change value	$\pm 2\frac{1}{2}\%$	D, 5%	Optional
MIL C-62 B Polarized Aluminum Capacitors	120 \pm 5 Hz	Limited to 30% of DCVW or 4 V, whichever is smaller	2%	D, 2%	No bias required if ac voltage less than 1 V. However, if bias causes differences, measurements with bias shall govern.
RS 154 B Dry Aluminum Electrolytic Capacitors	120 Hz	Small enough not to change value	$\pm 2\frac{1}{2}\%$	R or RC	Optional, but if substantial difference occurs, rated dc should be used.
RS 205 Electrolytic Capacitors for use in Electronic Instruments	120 Hz	Small enough not to change value	$\pm 2\frac{1}{2}\%$	D	Optional

SPECIFICATIONS

Quantity	Frequency	Range	Accuracy *
Capacitance	120 Hz internal	0 to 0.11 F	$\pm 1\%$ ± 1 pF, smallest division 2 pF; residual ("zero") capacitance approx 4 pF
		0.11 F to 1.1 F	$\pm 2\%$
	40 Hz to 120 Hz external (useful down to 20 Hz with reduced accuracy)	0 to 1.1 F	Same as above with suitable generator
	120 Hz to 1 kHz external	0 to $\left(\frac{100}{f_{Hz}}\right)^2$ F	$\pm 1\%$ ± 1 pF with suitable generator and precautions
Dissipation Factor	120 Hz internal or 40 Hz to 120 Hz	0 to $10 \frac{f_{Hz}}{120}$	$\pm 0.001 \pm 0.01$ C $\pm 2\%$ †
	120 Hz to 1 kHz	0 to 10	$(\pm 0.001 \pm 0.01$ C) $\frac{f_{Hz}}{120} \pm 2\%$ †

† Additional error (due to lead resistance) for 4-terminal measurements: For C $< 1\%$, for D < 0.01 , if each lead has $< 1 \Omega$ of resistance, except on the highest measurement range the corresponding lead resistance is 0.1Ω .

* C is expressed in farads.

Frequency: INTERNAL TEST SIGNAL: 120 Hz (synchronized to power line) for 60-Hz model; 100 Hz for 50-Hz model. Phase reversible. Amplitude selected by switch to be 0.2, 0.5, or 2 V max. EXTERNAL TEST SIGNAL: 20 Hz to 1 kHz. (See table for C range.)

Dc Bias Voltage: Internal power supply and meter: 0 to 600 V in 6 ranges. Meter accuracy: $\pm 3\%$ of full scale. External bias limit: 800 V max.

Bias Current (from internal source): ≈ 15 mA max. **METER:** Range, 0 to 20 mA in 6 ranges; resolution, $0.5 \mu A$ (first range); accuracy, $\pm 3\%$ of full scale.

Required, for measurements at frequencies other than twice the line: An oscillator such as the 1311 for spot frequencies or the 1310 for continuous coverage.

Supplied: 4-lead and shielded 2-lead cable assemblies.

Power: 105 to 125 V or 210 to 250 V, 18 W. Both 50 and 60-Hz models.

Mechanical: Flip-Tilt case and rack mount. **DIMENSIONS** (wxhxd): Portable, 16.25x15x9 in. (413x381x229 mm); rack, 19x14x6.13 in. (483x356x155 mm). **WEIGHT:** Portable: 26 lb (12 kg) net, 34 lb (16 kg) shipping; rack, 28 lb (13 kg) net, 43 lb (20 kg) shipping.

Description	Catalog Number
1617 Capacitance Bridge	
Portable Model (115 V, 60 Hz)	1617-9701
Portable Model (230 V, 60 Hz)	1617-9286
Portable Model (115 V, 50 Hz)	1617-9206
Portable Model (230 V, 50 Hz)	1617-9266
Rack Model (115 V, 60 Hz)	1617-9820
Rack Model (230 V, 60 Hz)	1617-9296
Rack Model (115 V, 50 Hz)	1617-9216
Rack Model (230 V, 50 Hz)	1617-9276
Patent Number 2,872,639.	

Resistance Measuring

This section describes a completely self-contained resistance-limit bridge, megohm bridge, and two megohmmeters, one of which measures up to 200 TΩ. These instruments are but a part of our total resistance-measuring capability. Seven other instruments are offered: These are impedance bridges capable of capacitance and inductance measurements as well as resistance measurements. They are shown in the tinted blocks below and are more fully described earlier in this catalog. Of particular interest to those engaged in production testing or incoming inspection is the Type 1662 Resistance-Limit Bridge, capable of up to 4 measurements per second.

50 100
μΩ

1
mΩ

1 2
Ω

1 50
kΩ

1.1 2 20 111
MΩ

200 1000
TΩ

1608: $\pm 0.1\%$ accuracy, comparison precision within 10 ppm. Measurements can be made at dc or from 50 Hz to 10 kHz. Features 6-digit resolution by means of in-line readout dials with automatic-decimal point.

1656: $\pm 0.1\%$ accuracy. Measurements can be made at dc or 1 kHz. Balance is achieved by 4 in-line readout lever switches. Portable, low-cost, high-precision bridge.

1657: $\pm 0.2\%$ accuracy. Measurements can be made at 1 kHz or 120 Hz. Features five full-digit readout display. Fully automatic.

1683: $\pm 0.1\%$ accuracy, automatic bridge. Measurements can be made at 120 Hz or 1 kHz. Fully automatic bridge with 5-digit resolution and provisions for full systems use. 5-terminal connections to unknown.

1685: $\pm 0.1\%$ accuracy, automatic bridge. Measurements are made at dc. Built-in limit comparator.

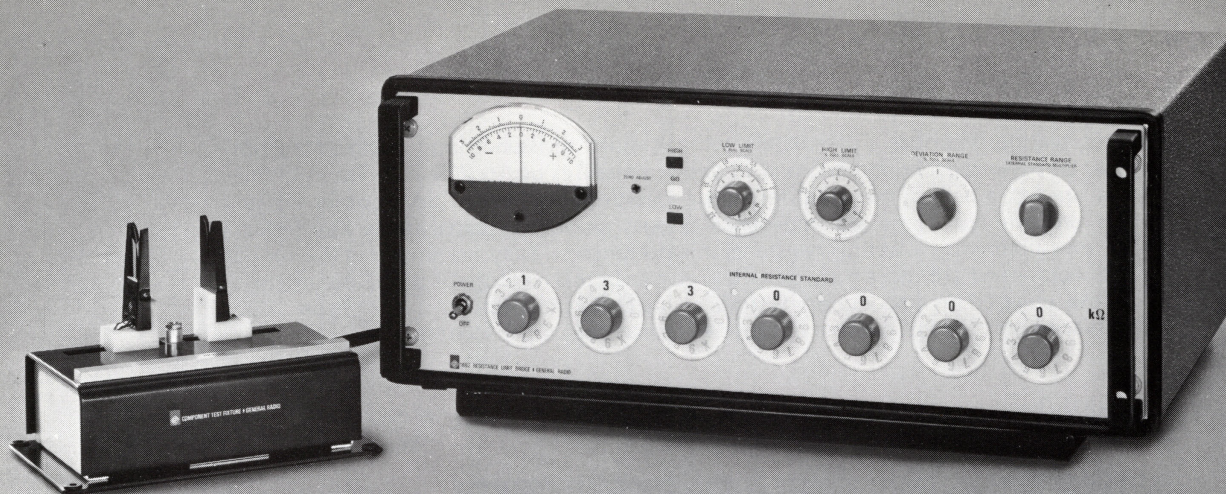
1650-B: $\pm 1\%$ accuracy. Measurements can be made at dc or 1 kHz. Completely self-contained, battery operated. Excellent low-cost, general-purpose bridge.

1662: $\pm 0.01\%$ comparison accuracy. Measures resistance difference from self-contained standard with meter calibrated in percent. Also contains high and low limit settings with go, no-go lamps.

1654: $\pm 0.003\%$ comparison accuracy. Measures resistance differences with meter calibrated in ohms. 1654 systems include standard and limit comparator.

1644: $\pm 1\%$ accuracy. Megohm bridge with 7 test voltages and self-checking internal standards. Resistance difference measurements accurate to $\pm 0.2\%$.

1863, 1864: Up to 3% accuracy. Megohmmeters from 2 to 200 different test voltages (10 to 1000 V) depending on type.



1662 Resistance Limit Bridge

- Resistance range from 1 Ω to 111 M Ω
- 0.01% comparison precision
- GO, NO-GO indications
- up to 4 measurements per second
- deviation range from ± 0.01 to $\pm 30\%$
- four-terminal Kelvin connections

When resistor accuracy or precise resistor matching is crucial to circuit performance, the 1662 is the instrument to use for fast sorting, matching, and measuring.

A precision bridge with 0.01% accurate resistors, the 1662 has a built-in analog comparator and High/Low/Go indicator lights for production-speed test applications. The indicating meter and Limit controls are calibrated directly in percent resistance deviation with full-scale ranges from $\pm 0.3\%$ to $\pm 30\%$, permitting the selection and sorting of a variety of resistor types and qualities.

System Use Four-terminal connections for the unknown resistor permit measurement-at-a-distance; electrical outputs include analog of the deviation and high/low/go decision; both high and low limits are programmable. With these intrinsic features the 1662 can be the keystone of your production measuring system.

Laboratory Bridge The precise internal standards and built-in generator and detector make the 1662 an excellent and convenient laboratory bridge. Precise balancing is made especially easy by the indications of the High/Low lights. A special test fixture facilitates sure, split-second connection of one unknown resistor after another with true Kelvin connections to maintain the basic accuracy of the bridge.

SPECIFICATIONS

Resistance Range: 1 Ω to 111.1111 M Ω , controlled by 4-position multiplier switch and 7 in-line readout dials with decimal point.

Resistance Accuracy: $\pm(0.02\% + 2 \text{ m}\Omega + 0.02\% \text{ long-term})$; long-term factor can be removed by calibration.

Deviation: RANGE: ± 0.01 to $\pm 30\%$, controlled by 5-position range switch with full-scale ranges of 0.3, 1, 3, 10, and 30%. ACCURACY: $\pm 3\%$ of full-scale deviation (e.g., on 0.3% range, meter accuracy is $\pm 0.01\%$).

	Bridge Multiplier (R_x/R_s)			
	0.1	1	10	100
Range of Unknown	1 to 111 k Ω	10 to 11.1 M Ω	100 to 11.1 M Ω	10 k Ω to 111 M Ω
Voltage on Unknown*	0.11 V	0.2 V	1.1 V	10.1 V
Voltage on Standard	1.1 V	0.2 V	0.11 V	0.101 V
Resistance Resolution	0.01 Ω	0.1 Ω	1 Ω	10 Ω

* Varies with deviation from nominal; current is held constant. Power dissipated in unknown is $< 12 \text{ mW}$ from 1 Ω to 111 M Ω .

Displays: Meter indicates percent deviation. Limit lamps indicate High, Go, or Low condition. High and Low limits independently adjustable from 0 to 100% of deviation range with a direct accuracy of $\pm 2\%$ of full scale.

Speed: 1 measurement/s using meter indication, 4 meas/s using limit indications.

Interface: UNKNOWN CONNECTIONS: Cable (supplied), with banana plugs or alligator clips for 4-terminal connection. Test fixture (available) with quick-acting scissor 4-terminal contacts, best suited to axial-lead resistors. ANALOG OUTPUTS: Voltage proportional to meter deflection, $\pm 10 \text{ V}$ full scale with 0.003% resolution, is provided at 2 rear-panel sockets. Output impedances: $< 10 \Omega$ (drives 1782 Analog Limit Comparator) and $\approx 2 \text{ k}\Omega$ (drives a DVM, dc recorder, etc.). LIMIT OUTPUTS (digital): For High, Go, and Low conditions, corresponding lines switch from ≈ 13 to $\approx 0.2 \text{ V}$ (behind 10 k Ω). LIMIT PROGRAMMING: High and low limits programmable with dc analog drives of 0 to -10 V and 0 to $+10 \text{ V}$, respectively, by sources of $< 10 \Omega$ internal impedance. Rear connector.

Environment: Operating temperature, 10 to 40°C . Zero drift $< 2 \text{ ppm}/^\circ\text{C}$ from 10 to 40°C .

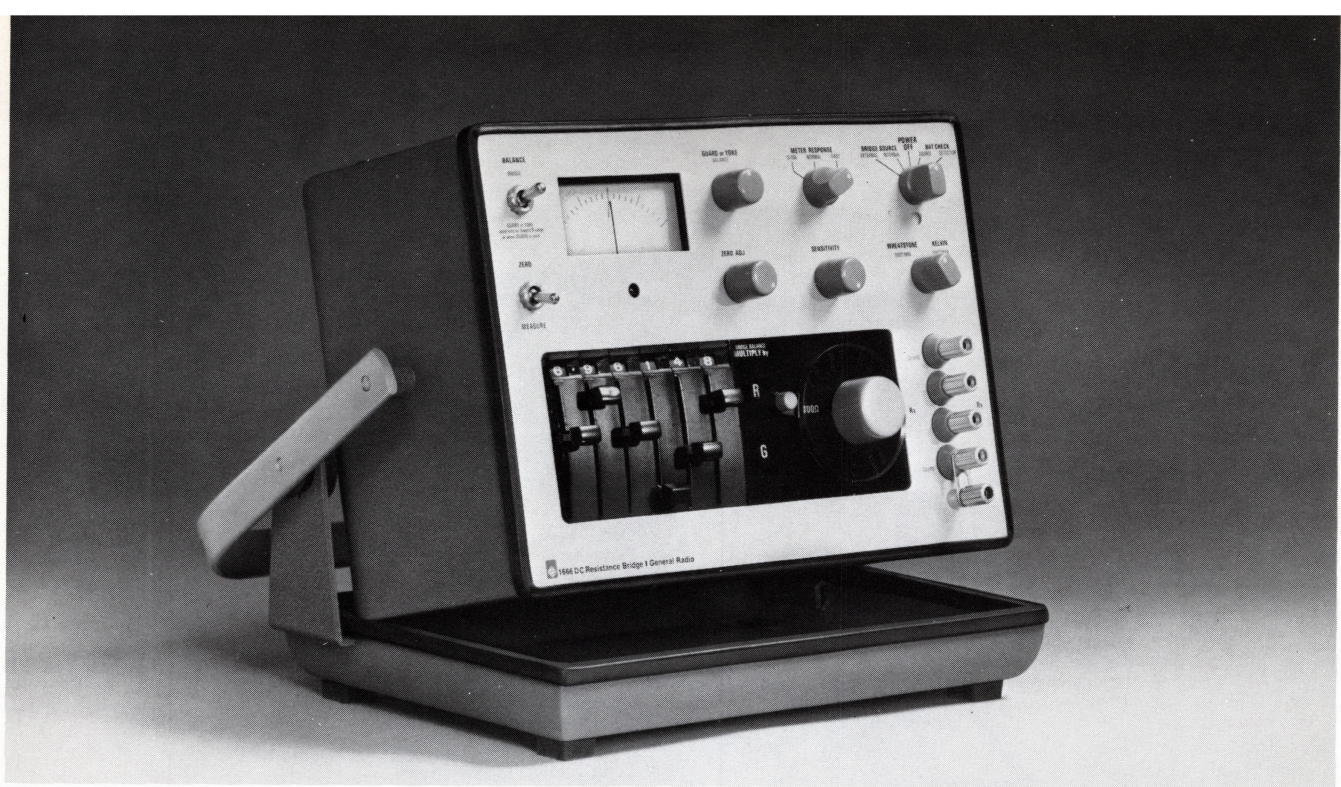
Supplied: 1662-2400 cable for connection to unknown or external-standard resistor, 7- and 9-pin connectors for interface connections, 5 alligator clips, and power cord.

Available: 1782 Analog Limit Comparator for comparisons to additional limits, 1662-P1 Test Fixture, for rapid 4-terminal connection of axial-lead components.

Power: 100 to 125 or 200 to 250 V, 50-60 Hz, 17 W.

Mechanical: Bench or rack models. DIMENSIONS (wxhxd): Bench, 19.75x8.69x14.8 in. (502x221x376 mm); rack, 19x7x14.8 in. (483x178x376 mm). WEIGHT: Bench, 28 lb (13 kg) net, 36 lb (16.5 kg) shipping; rack, 22 lb (10 kg) net, 28 lb (13 kg) shipping.

Description	Catalog Number
1662 Resistance Limit Bridge	
Bench Model	1662-9700
Rack Model	1662-9701
1662-P1 Test Fixture	1662-9601



1666 DC Resistance Bridge

- 0.01% accuracy, direct reading
- six-digit resolution
- 2-, 3-, or 4-terminal resistance or conductance
- 1 $\mu\Omega$ to 1 T Ω range (1 p Ω to 1 M Ω)

The GR 1666 combines the advantages of the Wheatstone and Kelvin bridges in a single instrument that will find application almost anywhere. Whether your requirement is for high accuracy, extremely-low or very-high resistance values, remote measurements, portability, or precise comparison, the 1666 will excel. It can even be set up for rapid sorting of resistors to tight tolerances.

Two-terminal, guarded, or Kelvin connections to the unknown resistor assure that the accuracy inherent in the 1666 can be realized at the point of measurement over the entire range of the bridge from 10^{-6} to 10^{12} ohms. Internal adjustments on all ratio arms and bridge standards allow you to make calibration adjustments conveniently and rapidly, using a set of 1440 Standard Resistors.

The 1666 will make, with ease, such diverse measurements as winding resistance of transformers, switch-contact resistance, diode resistance (forward and reverse), leakage conductance of materials and devices, and the key parameters of resistance thermometers, standard resistors, and decades, by direct and comparison methods. The six lever switches and quick-response detector permit 0.01% balances to be made in less than 10 seconds — part-per-million balances in 20. Resistor sorting can be carried out even faster through use of the null meter as a deviation indicator; overload recovery of the detector is very rapid.

SPECIFICATIONS

Bridge Circuits: Kelvin and guarded Wheatstone in both resistance and conductance configurations.

Ranges: TOTAL MEASUREMENT RANGE, 1 $\mu\Omega$ to 1 T Ω . Resistance ranges, 1 $\mu\Omega$ to 1.1 M Ω in 7 ranges (1 $\mu\Omega$ is one count); conductance ranges, 1 p Ω to 1.1 Ω in 7 ranges (1

p Ω is one count). RECOMMENDED RANGES: Wheatstone, 100 Ω to 1 T Ω ; Kelvin, 1 $\mu\Omega$ to 10 k Ω .

Resolution: Six digits or 1,111,110 counts.

Accuracy (limit of error): DIRECT READING, $\pm(0.01\% + 10$ ppm of full scale). For low-value readings, when first and second digits are zero, $\pm(0.1\% + 3$ ppm of full scale). These limits apply from 20 to 25°C at <75% RH, within 6 months of calibration. Error remains less than $\pm 0.1\%$ from 0 to 25°C at 95% RH and from 0 to 35°C at 85% RH. TWO-YEAR ACCURACY: Add $\pm 0.01\%$ to above. COMPARISON ACCURACY: $\pm[2 + 0.001 \times (\text{ppm difference})]$ ppm of full scale (decade values to 2 ppm where sensitivity is adequate and difference is small).

Sensitivity (with internal source): RESISTANCE: 2 $\mu\Omega$ at very low values; 10 ppm at 1 Ω ; 5 ppm at 10 Ω ; 1 ppm at 0.1, 1, 10, and 100 k Ω ; 5 ppm at 1 M Ω . CONDUCTANCE: 2 p Ω at very low values, 5 ppm at 1 $\mu\Omega$; 1 ppm at 10 and 100 $\mu\Omega$, 1 and 10 m Ω ; 5 ppm at 100 m Ω ; 10 ppm at 1 Ω . An external source can be used for even better sensitivity.

Sources: INTERNAL: 6 V (set of 4 D cells), 0.01 W max for resistance bridge. EXTERNAL: Up to 30 V dc, 0.5 W max.

Detector: SENSITIVITY: Meter deflection ≈ 5 mm/ μ V. INPUT RESISTANCE: approx 20 k Ω . SHORT-CIRCUIT NOISE (slow position): Approx 0.1 μ V pk-pk. DRIFT: Typically 0.5 μ V/h. RESPONSE (slow/normal/fast, respectively): Low-level time constant, 4/2.5/0.7 s; high-level meter reversal, 1/0.5/0.3 s.

Guard (Wheatstone): No error with ≥ 5 M Ω to ground, either terminal.

Lead Error (Kelvin): Less than 2 $\mu\Omega$ additional with $\leq 0.1\Omega$ in any lead.

Supplied: Set of 4 leads with gold-plated copper alligator clips.

Available: 1440 Standard Resistors, for recalibration.

Power: Battery of 8 D cells (Burgess type 1200 or equivalent), i.e., 4 for internal bridge source and 4 for detector power.

Mechanical: Flip-Tilt case. DIMENSIONS: (wxhxd): 15x12x8 in. (381x305x203 mm). WEIGHT: 21 lb (10 kg) net.

Description

1666 DC Resistance Bridge, portable
Replacement Battery (8 req'd)

Catalog Number

1666-9700
8410-0200



1644-A Megohm Bridge

- 10^3 to 10^{15} ohms
- 1% accuracy to 10^{12} ohms
- ΔR measurements to $\pm 0.2\%$
- seven test voltages
- self-checking internal standards

The 1644-A will measure:

- **Insulation Resistance** of cables, transformers, chokes, components, connectors, wiring, terminals, resistors, capacitors, relays, printed circuits, rotating machines, switches, circuit breakers, meters, strain gages, thermocouples, delay lines, slip rings, commutators, heaters, filters, lightning arresters, and other devices.
- **Resistance** of high-valued resistors, resistance films, diodes, transistors, and piezoelectric elements.
- **Voltage and Temperature Coefficients** of resistance.
- **Volume and Surface Resistivity** of solids, such as printed-board material, resins, plastics, potting and casting compounds, rubber, refractories, and semiconductors; of liquids, such as oils, plasticizers, and solvents; and of sheet materials, including plastics, recording tape, and varnished fabrics.

The circuit is a dc Wheatstone bridge with a high-impedance, high-sensitivity detector. Precision, wire-wound resistors are used for the fixed bridge arm and the lowest-valued decade-step arm. For medium values of the ratio arm, precision metal film resistors are used; for the highest values, carbon film resistors with trimmers. The balancing arm is a wire-wound variable resistor.

The guard terminal eliminates the effects of stray resistances to ground. For capacitor leakage resistance measurement, charging time is a fraction of a second.

◆ National stock number 6625-00-867-6628

SPECIFICATIONS

Resistance Range: 1 k Ω to 1000 T Ω (10^3 to 10^{15} Ω) in ten ranges.

Accuracy: 10^3 Ω to 10^{10} Ω , $\pm 1\%$. After self-calibration: 10^{10} to 10^{12} Ω , $\pm 1\%$; 10^{13} Ω , $\pm 2\%$; 10^{14} Ω , $\pm 10\%$; 10^{15} Ω , \pm one scale division.

$\Delta R\%$ Dial: $\pm 5\%$ range; accurate to $\pm 0.2\%$ or, for small changes, to $\pm 0.1\%$.

Test Voltage: Voltage accuracy is $\pm 3\% \pm 0.5$ V.

Fixed Voltages**	10	20	50	100	200	500	1000	V
Minimum Unknown R	1	3	7	20	50	150	500	k Ω
Minimum Test Voltage for 1% Resolution: for approx 1-mm meter deflection	Multiplier Setting			Max R_x		Volts		
	100 G or less			10^{11}		10		
	100 G			10^{12}		100		
	1 T			10^{13}		200		

Short-Circuit Current: <15 mA, 10-50 V; <10 mA, 100-1000 V.

Power: 105 to 125 or 210 to 250 V, 50 to 400 Hz, 13 W.

Mechanical: Flip-Tilt case and rack mount. **DIMENSIONS** (wx hxd): Portable, 12.75x12.5x7.75 in. (324x318x197 mm); rack, 19x12.25x5 in. (483x312x127 mm). **WEIGHT:** 19 lb (9 kg) net, 31 lb (15 kg) shipping.

* At high voltages; 1% accuracy is obtainable at 10 V up to 10^{11} Ω .

** Any voltage between 10 and 1000 V may be obtained using an external resistor.

Description	Catalog Number
1644-A Megohm Bridge	
115-V Portable Model ◆	1644-9701
115-V Rack Model	1644-9820
230-V Portable Model	1644-9711
230-V Rack Model	1644-9821

Patent Number 2,966,257



GR 1863

GR 1864



1863 and 1864 Megohmmeters

GR 1863

- 5 test voltages: 50 to 500 V
- 50 k Ω to 20 T Ω ($2 \times 10^{13}\Omega$)
- economical, simple operation
- direct reading, safe, stable

GR 1864

- 200 test voltages: 10 to 1090 V
- 50 k Ω to 200 T Ω ($2 \times 10^{14}\Omega$)
- direct reading, safe, stable
- simple operation

If one of these GR megohmmeters doesn't exactly suit your high-resistance measurement needs, the other one should. Although the instruments are similar in appearance and accuracy, their operating ranges differ to match differing needs in the laboratory and production area.

Choice for production and inspection The 1863 Megohmmeter will measure resistance at any of five common test voltages up to 500 V, has fewer controls, and is the lower priced model. It is, therefore, the best selection when several test stations are to be equipped, when the operators are inexperienced, or when specifications call for standard insulation-testing voltages.

Choice for laboratory investigations The 1864 is the more flexible of the two instruments. The test voltage can be set to any value from 10 to 109 volts in 1-volt steps and to 1090 volts in 10-volt steps. Thus, the 1864 can be set to any common, or uncommon, test voltage for ceramic, mica or paper capacitors, or other devices. The reverse resistance of rectifiers can be readily measured; the low test voltages available are especially useful in measuring solid-state diodes. An additional range permits measurements up to 2×10^{14} ohms (200 T Ω).

Both instruments are easy to use with direct-reading meter indication and lighted range switch that shows the multiplier for each range and voltage. The maximum current possible at the terminals is limited to a safe 5 milli-

amperes and a panel light near the terminals warns when voltage is present. Stable power supplies and feedback voltmeter circuit minimize drift and time-wasting adjustments. Guard and ground terminals permit measurement of grounded or ungrounded two- or three-terminal resistors. The instruments are supplied for rack mounting or in a convenient, portable Flip-Tilt case that is a stand for the meter in use and protects it in transit and storage.

SPECIFICATIONS

Voltage and Resistance Ranges:

Voltage	R _{min} Full Scale	10% of Scale	R _{max} [†] 2½% of Scale	Useful Ranges
50, 100 V	50 k Ω	Type 1863 500 G Ω 5 T Ω	2 T Ω 20 T Ω	7
200, 250, 500 V	500 k Ω			7
10 to 50 V	50 k Ω	Type 1864 500 G Ω 5 T Ω 5 T Ω 50 T Ω	2 T Ω * 20 T Ω 20 T Ω * 200 T Ω	7*
50 to 100 V	200 k Ω			8
100 to 500 V	500 k Ω			7*
500 to 1090 V	5 M Ω			8

[†] Note: Meter deflects to the left, so 2½% is near the right; however, the meter scale reads naturally, from left to right.

* Recommended limit.

Resistance Accuracy: ± 2 (meter reading + 1)% on lowest 5 ranges (min reading is 0.5). For 6th, 7th, 8th ranges, respectively, add $\pm 2\%$, $\pm 4\%$, —, for the 1863; $\pm 2\%$, $\pm 3\%$, $\pm 5\%$, for the 1864.

Voltage Accuracy (across unknown): $\pm 2\%$.

Short-Circuit Current: 5 mA approx.

Power: 100 to 125 or 200 to 250 V, 50 to 400 Hz, 13 W.

Supplied: Mounting hardware with rack models.

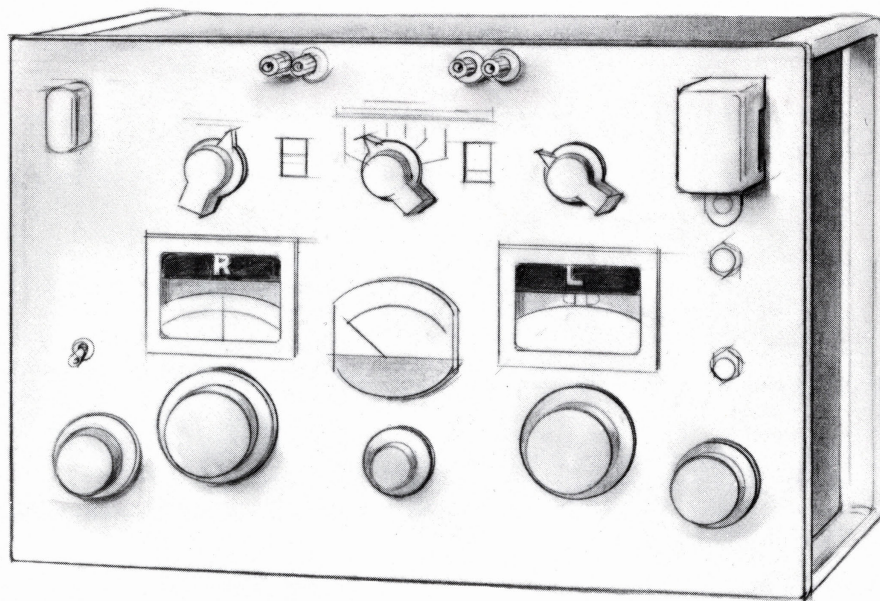
Mechanical: Flip-Tilt case and rack mount. DIMENSIONS (wxhxd): Portable, 6.63x10x6.75 in. (245x254x172 mm); rack, 19x7x4.63 in. (483x178x118 mm). WEIGHT: Portable, 9.5 lb (4.4 kg) net, 14 lb (7 kg) shipping; rack 11 lb (5 kg) net.

Description	Catalog Number
1863 Megohmmeter	
Portable Model	1863-9700
Rack Model	1863-9701
1864 Megohmmeter	
Portable Model	1864-9700
Rack Model	1864-9701

Inductance Measuring

This section describes a completely self-contained inductance system, its bridge, and a power supply that provides up to 400 V or 5 A dc bias. These instruments are but a part of our total inductance-measuring capability. Seven other instruments are offered: These are impedance bridges capable of capacitance and resistance measurements as well as inductance measurements. They are shown in the tinted blocks below and are more fully described earlier in this catalog. Of particular interest to those of you to whom time is money is the 1683 Automatic RLC Bridge – completely automatic, systems oriented, and capable of up to 20 measurements per second.

10 nH	50 nH	100 nH	200 nH	1 μ H	20 μ H	1000 H	1100 H	2000 H	10,000 H
1657: $\pm 0.2\%$ accuracy. Measurements can be made at 120 Hz or 1 kHz. Fully automatic bridge. Five full digit readout display for L and four full digits displayed for Q.									
1683: $\pm 0.1\%$ accuracy, automatic bridge. Measurements can be made at 120 Hz or 1 kHz. Loss is expressed as series resistance from 1 m Ω to 1 M Ω with accuracies up to $\pm 1\%$. Fully automatic bridge with 5-digit resolution and provisions for full systems use. 5-terminal connections to unknown.									
1685: $\pm 0.1\%$ accuracy, automatic bridge. Measurements can be made at 120 Hz or 1 kHz. Q is measured as a GO/NO-GO function. 5-terminal connections to unknown. 5-digit resolution and provisions for full systems use.									
1608: $\pm 0.1\%$ accuracy. Measurements are made at 1 kHz with internal oscillator or from 20 Hz to 20 kHz with external oscillator. Loss is expressed as Q from 0.5 to 2000. Inductance readout is digital and inductors can be biased with currents up to 40 mA.									
1656: $\pm 0.1\%$ accuracy. Measurements are made at 1 kHz and loss is expressed as Q from 0.02 to ∞ , accurate to $\pm 5\%$. Inductance is balanced by 4 lever switches with in-line readout. Small biasing currents possible.									
1630-AV: $\pm 1\%$ accuracy. Measurements can be made from 50 Hz to 15 kHz. Loss is expressed as Q from 1 to ∞ . Supplies up to 5 A dc bias current.									
1650-B: $\pm 1\%$ accuracy. Measurements are made at 1 kHz. Loss is expressed as Q from 0.02 to 1000. Excellent low-cost, general-purpose bridge for lab or production use.									
1654: $\pm 0.003\%$ comparison accuracy. Measures impedance-magnitude and phase-angle differences.									



1633-A Incremental-Inductance Bridge

- direct reading at 9 frequencies in series L and R or Q
- 0.2 μ H to 1000 H
- 20 Hz to 20 kHz
- accuracy $\pm 1\%$
- apply up to 1250 V and 50 A, ac and dc
- numerous safety features

The 1633-A was designed primarily for measuring inductance and loss of transformers, chokes, and similar components at very high levels of ac and dc excitation and over a wide frequency range. Easy to operate and flexible in application, it can also measure other nonlinear elements such as Zener diodes, rectifiers, thermistors, and lamps. The bridge contains a highly selective nine-frequency detector for effective harmonic rejection and can be supplied complete with high-power ac and dc supplies as the Type 1630 Inductance-Measuring Assembly.

The incremental-inductance bridge uses a circuit that incorporates active elements* in stable operational am-

plifiers. Although large signal and bias levels may be applied to the unknown inductor, this circuit keeps signals in the bridge small, minimizes corrections, and eliminates sliding balance. Current and voltage in the unknown inductor are nearly identical in magnitude and waveform to those applied at the GENERATOR terminals. In many instances measurements can be made on the inductor while it is actually operating in your circuit.

Up to 7 amperes rms (combined ac and dc) can be passed through the inductor during measurement, up to 50 amperes if you use the 1633-P1 Range-Extension Unit. The impressed voltage can be as high as 1250 volts. Two power supplies are available, a dc supply and a variable-frequency oscillator, which are designed specifically for use with the bridge. Most conventional power supplies are not suitable.

The internal detector is highly selective at nine frequencies between 50 Hz and 15.75 kHz. Owing to high detector sensitivity and low noise, measurements can be made at excitation levels below one volt on the highest inductance ranges and 10 millivolts on the lowest range.

* H. P. Hall, R. G. Fulks, "The Use of Active Devices in Precision Bridges," *Electrical Engineering*, May 1962.

SPECIFICATIONS

Ranges and Accuracy:

Measurement	Frequency	Full-Scale Ranges						Lowest Scale Division	Accuracy
		a	b	c	d	e	f		
Inductance	50, 60, 100, 120 Hz	10 mH	100 mH	1 H	10 H	100 H	1000 H	20 μ H	$\pm(1\%$ of reading or 0.1% of full scale) $\pm(2\pi f_{kHz}/100 Q_x)\%$ *, $\pm 2\%$ above 10 kHz or $\pm 3\%$ above 15.75 kHz
	400, 800, 1000 Hz	1 mH	10 mH	100 mH	1 H	10 H	100 H	2 μ H	
	10, 15.75 kHz	100 μ H	1 mH	10 mH	100 mH	1 H	10 H	0.2 μ H	
Resistance	All	10 Ω	100 Ω	1 k Ω	10 k Ω	100 k Ω	1 M Ω	10 m Ω	$\pm(2\%$ of reading or 0.1% of full scale) $\pm \frac{4\pi f_{kHz} Q_x}{100}\%$ *
Q		∞ to 1, direct reading at above frequencies Largest scale reading: 1000						0.9	$1/Q$ accuracy = $\pm 2\% \pm 0.001 \pm 0.0005 f_{kHz}$ *
Max rms volts		12.5	125	1250	1250	1250	1250		
Min rms volts for 1% accuracy (internal detector)	50, 60 Hz	0.025	0.25	2.5	2.5	2.5	2.5		
	1 kHz	0.006	0.06	0.6	0.6	0.6	0.6		
Max rms amperes**		7	7	7	2	0.7	0.2		
with extension unit†		50	50	50					

* The frequency-error term is 5 times larger on highest L range.

** Max rms current = $\sqrt{I_{dc}^2 + I_{ac}^2}$

† 1633-P1 Range-Extension Unit contains a 0.1- Ω resistor, which you connect externally to shunt R_s (on the 3 lowest bridge ranges). Inductance and resistance values are reduced by a factor of 10.

Generator: External only (not supplied). For optimum performance when dc bias is used, ac supply must be able to withstand large dc currents in output circuit, and dc supply large ac currents. For dc bias, use 1265-A Adjustable DC Power Supply, 200 W; over the audio-frequency range, use 1308-A Audio Oscillator and Power Amplifier, 200 VA.

Detectors: INTERNAL: Selectively tuned to 50, 60, 100, 120, 400, 800 Hz, 1, 10, and 15.75 kHz; response varies < 3 dB for frequency components within $\pm 1\%$ of the nominal. Response at 2nd harmonic is typically 50 dB lower. EXTERNAL: Use the 1232-A Tuned Amplifier and Null Detector, which is tunable continuously, 20 Hz to 20 kHz.

Available: 1633-P1 Range-Extension Unit, 1232-A Tuned Amplifier and Null Detector, 1308-A Audio Oscillator and Power Amplifier.

Power: 105 to 125 V or 210 to 250 V, 50 to 60 Hz, ≈ 6 W.

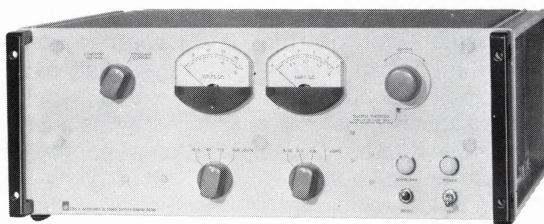
Mechanical: Rack-bench cabinet. DIMENSIONS (wxhxd): Bench, 19x12.75x10.25 in. (483x324x260 mm); rack, 19x12.25x8.75 in. (483x311x222 mm). WEIGHT: 31 lb (14 kg) net, 48 lb (22 kg) shipping.

Description	Catalog Number
1633-A Incremental-Inductance Bridge	
115-V Bench Model \diamond	1633-9801
115-V Rack Model	1633-9811
230-V Bench Model	1633-9802
230-V Rack Model	1633-9812

1265-A Adjustable DC Power Supply

The 1265-A supplies dc bias for the 1633-A Incremental-Inductance Bridge. Its characteristics include wide ranges of current and voltage, a passive low-impedance output circuit that will pass high alternating currents, and a choice of voltage or current regulation.

The instrument has four voltage ranges and four current ranges and will deliver its maximum rated power of 200 watts to 8, 80, or 800 ohms. Range switches are interlocked to prevent most likely overload situations. In addition, electronic circuit prevents damage from overload.



SPECIFICATIONS

Full-Scale Output Ranges: 12.5, 40, 125, 400 V dc; 0.16, 0.5, 1.6, 5 A dc; in any combination up to 200 W.

\diamond National stock number 6625-00-442-3549

Meters: Voltage and current; ranges switch with output ranges.

Overload Protection: Overload circuit trips at approx $1\frac{1}{2}$ times full-scale current.

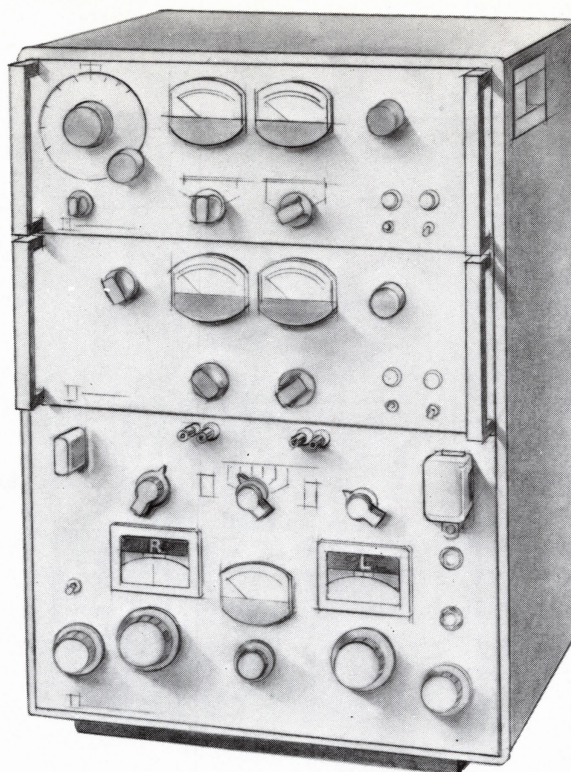
Regulation: VOLTAGE OR CURRENT: 0.2% for 10% line-voltage change; 1% for 100% load change. SPEED OF RESPONSE: Approx 0.1 second.

Hum Level (rms): For 60-Hz operation, approx 70 dB below full-scale dc output (55 dB on 5-A ranges); for 50-Hz operation, 6 dB higher.

Power: 105 to 125 or 210 to 250 V, 50 or 60 Hz, 380 W at rated load. (Specify if for 50 Hz.)

Mechanical: Rack-bench cabinet. DIMENSIONS (wxhxd): Bench, 19x7.5x17.25 in. (483x190x438 mm); rack, 19x7x15 in. (483x178x381 mm). WEIGHT: 70 lb (32 kg) net, 124 lb (57 kg) shipping.

Description	Catalog Number
1265-A Adjustable DC Power Supply	
115-V Models	
60-Hz, Bench	1265-9801
60-Hz, Rack	1265-9811
50-Hz, Bench	1265-9803
50-Hz, Rack	1265-9813
230-V Models	
60-Hz, Bench	1265-9802
60-Hz, Rack	1265-9812
50-Hz, Bench	1265-9804
50-Hz, Rack	1265-9814



1630-AV Inductance-Measuring Assembly

- test levels from millivolts to kilovolts
- L accuracy 1% (R and Q, 2%)
- discrete frequencies: 50, 60, 100, 120, . . . 15.75 kHz

This assembly is a complete system for the measurement of inductance and loss of coils with ferromagnetic cores. It consists of a 1633 Incremental-Inductance Bridge with specially suited dc and ac power supplies in a cabinet-type rack with all necessary interconnecting cables.

The supplies can produce 200-voltampere outputs into a wide range of load impedances and are designed to pass the large dc and ac currents required.

The 1308-A oscillator provides continuous coverage from 20 Hz to 20 kHz. When measurements are required at frequencies other than those given for the internal detector, the 1232-A Null Detector is recommended.

SPECIFICATIONS

Supplied: This assembly includes the 1633 Incremental-Inductance Bridge, 1265 Adjustable DC Power Supply and 1308 Audio Oscillator and Power Amplifier.

Mechanical: Pedestal cabinet. DIMENSIONS (wxhxd): 22.5x43x20 in. (572x1092x508 mm). WEIGHT: 310 lb (145 kg) net, 460 lb (215 kg) shipping.

Description

Catalog Number

1630-AV Inductance-Measuring Assembly

115 V, 60 Hz
115 V, 50 Hz
230 V, 60 Hz
230 V, 50 Hz

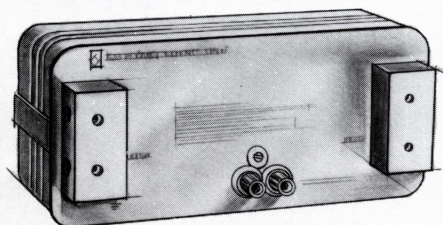
1630-9827
1630-9847
1630-9837
1630-9857

1633-P1 Range-Extension Unit

The 1633-P1 can be used with the 1633-A Incremental-Inductance Bridge to extend the current ratings to 50 amperes. It connects a 250-watt, 0.1-ohm resistor in parallel with one of the bridge arms.

SPECIFICATIONS

Inductance Ranges: Only a, b, and c ranges of the 1633-A bridge; its readout must be multiplied by 0.1 (otherwise it



operates normally); upper limits are 100 mH for $f \leq 120$ Hz, 10 mH for $f \leq 1$ kHz.

Accuracy: Additional $\pm 1\%$ error for $f \leq 400$ Hz; correction can be made for errors at higher f . TEMPERATURE COEFFICIENT of resistance: 20 ppm/°C.

Current Rating: 20 A continuous, 50 A intermittent, (total rms); 50 A continuous with forced air cooling.

Terminals: High-current type accommodates wires up to 0.25 in. dia from generator and unknown inductor; binding posts for connection to bridge.

Supplied: Cable, connects to bridge Unknown terminals.

Mechanical: Lab bench cabinet. DIMENSIONS (wxhxd): 10.5x4.25x5 in. (267x108x127 mm). WEIGHT: 5.3 lb (2.4 kg) net, 7 lb (3.2 kg) shipping.

Description

Catalog Number

1633-P1 Range-Extension Unit

1633-9601



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