GenRad

PRECISION RLC MEASUREMENTS START HERE.

Bridges/Standards

A LOOK AT GENRAD

Founded in 1915 as the General Radio Company, GenRad has earned a strong reputation for product innovation, quality, and reliability in the test and measurement industry.

GenRad pioneered bridges and standards instrumentation, bringing the first commercial bridges to market in the 1920s. We have been improving them ever since.

Today, you'll find GenRad at the forefront of bridges and standards technology. In addition to our broad line of manual and automatic bridges, we are the only manufacturer to offer all three types of standards: capacitance, resistance, and inductance. GenRad supplies a wide range of other test equipment as well, including □ acoustic measurement instruments… □ stroboscopes… □ computer-aided engineering and yield-management software… □ semiconductor and printed-circuit board test systems… □ structural and field service test systems, and more.

For more information about GenRad products not covered in this catalog, please call your local GenRad sales representative.

A LOOK AT OUR PRODUCTS

When you have the capability to catch defective passive components at the earliest stages of R&D and production, you also have the capability to save yourself time and money later on. Undetected, those defective components can mean costly rework, missed schedules, and excessive field repairs.

GenRad's bridges and standards can help you minimize those "downstream" costs. With our instruments, engineers in R&D labs, incoming inspection, quality control, production test, and field service repair can accurately and cost-effectively measure impedance in a variety of passive components.

We offer an unparalleled selection of manual and automatic bridges and standards. This catalog will help you identify and order the GenRad instruments that meet the requirements of your application.

The catalog includes complete specifications on all equipment, warranty and ordering information, and recommended applications for our instruments.

Reliability and Innovation

Built with the quality you expect from GenRad, our bridges and standards are renowned for reliability. Many are still working perfectly after more than 20 years in the field.

They also demonstrate why GenRad has earned a reputation for innovative solutions to impedance measurement.

When you add it all up – GenRad selection, reliability, and innovation – it's obvious.

Precision RLC measurements start here.

TABLE OF CONTENTS

Order Your GenRad Instruments Today.

How to Order
To order by telephone, dial our toll-free number:

Bridges/Standards:
1-800-772-2220
In Massachusetts:
1-617-369-4400
8:30 a.m. to 5:30 p.m.
Eastern Time

When ordering your GenRad equipment by mail, use the following address:

GenRad, Inc.
Instrument Sales Group
300 Baker Avenue
Concord, MA 01742

When placing orders, please list:
1. Quantity of each item
2. Order Number of each item
3. Complete Description of each item
4. Shipping Address
5. Billing Address
6. Purchase Order Number

Confirming Orders
To avoid duplication of a telephone order, please write "Confirming Order" clearly on the order form.

Terms and Conditions of Sale
The determination of prices, the terms and conditions of sale, and the final acceptance of orders are made at the GenRad office in Concord, MA. We will be pleased to furnish quotations either by mail or by telephone.

Terms are net 30 days, if credit has been arranged. Shipments will be made C.O.D. unless payment is received before the ship date.

Minimum Billing
Minimum Billing is $50.00.

Prices
Prices of all instruments and products described in this catalog appear in a separate price list. Call our toll-free number 1-800-772-2220 for price quotes and copies of price lists.

All prices are FOB, Concord, MA. Prices given in the price list are subject to change without notice. GenRad price quotations remain in effect for 30 days.

Shipping Information
Unless specific instructions accompany your order, we will use our judgment as to the most appropriate method of shipment. Your GenRad products can be shipped either by air or surface transportation. For fast delivery at a reasonable premium over other means, we recommend air shipment. Please submit specific requests with your original order.

Return of Items
You must obtain authorization from our Service Department before returning items for any reason. Please call our Service Department in Concord, Massachusetts at 617-369-4400 to request a Return Material Tag, which includes shipping instructions.

Please state the type and serial number of the instrument, date of purchase, and reason for return.

Service Policy
GenRad Service Department representatives will assist you in all matters relating to product maintenance, such as calibration, repair, and replacement parts.

The GenRad Service Department is located at:

GenRad, Inc.
Customer Service
300 Baker Avenue
Concord, MA 01742
Telephone: 617-369-4400

GenRad Warranty

GenRad warrants that this product is free from defects in material and workmanship and, when properly used, will perform in accordance with GenRad's applicable published specifications.

If, within one (1) year after original shipment, it is found not to meet this standard, it will be repaired or, at the option of GenRad, replaced at no charge when returned to our GenRad service facility. Changes in the product not approved by GenRad shall void this warranty.

GenRad shall not be liable for any indirect, special, or consequential damages, even if notice has been given of the possibility of such damages.

This warranty is in lieu of all other warranties, expressed or implied, including, but not limited to, any implied warranty of merchantability or fitness for a particular purpose.

MANUAL BRIDGES

GenRad manufactures a wide range of manual bridges. There is a device to meet the needs of virtually any application and to match every price-performance level. GenRad's manual bridges are:

1656 Impedance Bridge
1654 Impedance Comparator
1615-A Capacitance Bridge
1620-A Capacitance-Measuring Assembly
1666 DC Resistance Bridge
1644-A Megohm Bridge
1863 and 1864 Megohmmeters
1633-A Incremental-Inductance Bridge
1630-AV Inductance-Measuring Assembly

1656 IMPEDANCE BRIDGE

Laboratory Accuracy in an All-Purpose Bridge

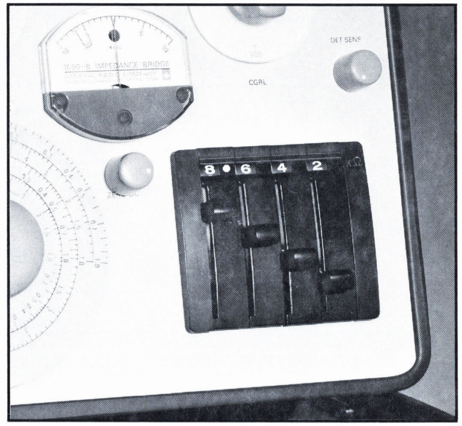
- ☐ Measures wide range of R, L, C, and G
- ☐ Basic accuracy at 0.1% for laboratory precision
- ☐ Digital readouts and lever balancing for ease of use
- ☐ Self-contained for portability

The GenRad 1656 Impedance Bridge offers laboratory precision in a general-purpose instrument that's ideal for production, inspection, and field service applications.

You will be able to measure a wide range of R and G with ease, and 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.

A four-lever switch system simplifies balancing, and the 1656's in-line digital readout of impedance reduces reading errors, making the 1656 easy to use without special training.

The instrument is fully self-contained and portable for both dc and ac measurements.



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

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1656 IMPEDANCE BRIDGE (Cont'd)

SPECIFICATIONS

Range	Resolution (one digit on lowest range)	Accuracy*	
		Frequencies $\leq$1 kHz and small phase angle (fs=full scale)	Frequencies >1 kHz or large phase angle Typical additional error terms
Capacitance: 0.1 pF to 1100 μF Series or parallel, 7 ranges	0.1 pF	$\pm$(0.1% of reading+0.01% of fs+ 0.2% of reading on highest range)	$\pm[0.2\, Df_{kHz} + 0.5\, D^2 + 0.002\, (f_{kHz})^2]\%$
Inductance: 0.1 μH to 1100 H Series or parallel, 7 ranges	0.1 μH	$\pm$(0.1% of reading+0.01% of fs+ 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 mΩ to 1.1 MΩ ac or dc, 7 ranges	0.1 mΩ	$\pm$(0.1% of reading+0.01% of fs+ 0.2% of reading on lowest range)**	$\pm[Qf_{kHz} + 0.003\, (f_{kHz})^2]\%$**
Conductance: 0.1 n℧ to 1.1℧ ac or dc, 7 ranges	0.1 n℧	$\pm$(0.1% of reading+0.01% of fs+ 0.2% of reading on highest range)**	$\pm[Qf_{kHz} + 0.003\, (f_{kHz})^2]\%$**
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 $\approx$0.3 pF, 0.15 μH, and 1 mΩ 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 1311 Oscillator recommended.

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

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

TERMINALS: 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.

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

MECHANICAL: Flip-Tilt case. DIMENSIONS (w$\times$h$\times$d): 13.25$\times$12.87$\times$6.69 in. (337$\times$327$\times$170 mm). WEIGHT: 15 lb (7 kg) net, 21 lb (10 kg) shipping.

ORDERING INFORMATION

Description	Order No.
1656 Impedance Bridge Portable Model	1656-9701

Accessories	Order No.
D Cell, replacement battery for 1656 (5 req'd)	8410-1510

1654 IMPEDANCE COMPARATOR

Accurate Measurements for Incoming Inspection or R&D

- ☐ An impedance-difference resolution of 0.003%
- ☐ Wide impedance ranges from 2 Ω to 20 MΩ, 0.1 pF to 1000 μF, and 20 μH to 1000 H
- ☐ Four fixed frequencies from 100 Hz to 100 kHz for versatility

The GenRad 1654 Impedance Comparator is designed for sorting, selecting, and adjusting of components at incoming inspection, as well as for other laboratory and R&D applications.

The 1654 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 and matching of precision components, subassemblies, and networks; for measuring the effects of time and environment on components; for rapid testing of the tracking of ganged potentiometers and variable capacitors; for studying the frequency dependence of components; and for other laboratory applications.

Accurate and Versatile

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 ±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.

Four measurement ranges can be used with each test voltage. The highest test level, 3 volts, gives the greatest sensitivity: 0.1% and .001 radian, full scale. The lower levels, 1 and 0.3 volt, allow measurement of more sensitive components, providing easy voltage-coefficient tests and extending large-difference capability to 30% and 0.3 radian, full scale.

Since the 1654 is a transformer bridge, its accuracy is only minimally affected 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.

Continued on the next page.

1654 IMPEDANCE COMPARATOR (Cont'd)

SPECIFICATIONS

FREQUENCIES: Internal only 100 Hz, 1, 10, and 100 kHz, ±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	**Impedance Difference** Full-scale Range – %						**Phase-Angle Difference** Full-scale Range – Radian					
Voltage	0.1	0.3	1	3	10	30	0.001	0.003	0.01	0.03	0.1	0.3
0.3V			x	x	x	x			x	x	x	x
1V		x	x	x	x			x	x	x	x	
3V	x	x	x	x			x	x	x	x		

IMPEDANCE RANGES (0.3-V test voltage*):

Freq	Resistance	Capacitance	Inductance
100 Hz	2Ω – 20 MΩ	1000 pF – 1000 μF	5 mH – 1000 H
1 kHz	2Ω – 2 MΩ	50 pF** – 100 μF	500 μH – 100 H
10 kHz	2Ω – 200 kΩ	50 pF** – 10 μF	50 μH – 1 H
100 kHz	10Ω – 10 kΩ	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 <10Ω ±3 V or ±10 V (depending on range) full scale behind 2 kΩ for DVM, A-D converter, or other use.

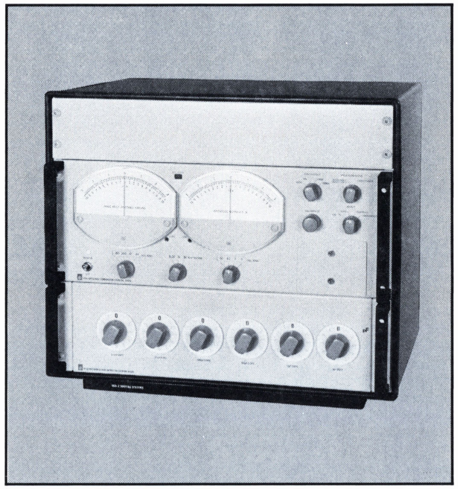
TEST SPEED: About 1 component per second with meter, max. With analog output voltage, about 4 components per second, except about 1 component per second at 100 Hz.

POWER: 105 to 125, or 210 to 250 V, 50-60 Hz, 15 W.

SUPPLIED: Multiple-contact connector and power cord.

AVAILABLE: 1413 Precision Decade Capacitor (supplied with -Z2) and other GenRad decade boxes and standards of resistance, capacitance, and inductance.

MECHANICAL: **1654,** bench or rack models; **1654-Z,** mounted in a single cabinet with necessary interconnections made. DIMENSIONS (w×h×d): **1654** bench, 19.5×8.75×15 in. (495×222×381 mm); **1654** rack, 19×7×13.5 in. (483×178×343 mm); **1654-Z2,** 19.5×17.5×15 in. (445×222×381 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-Z2,** 66 lb (30 kg) net, 79 lb (36 kg) shipping.



1654-Z2 Sorting System

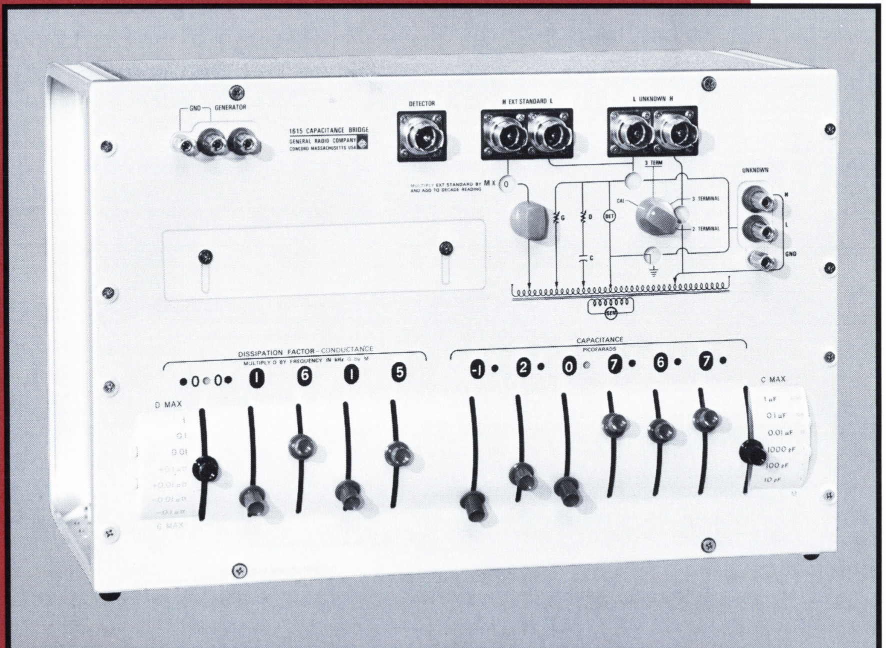
ORDERING INFORMATION

Description	Order No.
1654 Impedance Comparator	
Bench Model	**1654-9700**
Rack Model	**1654-9701**
Accessories	**Order No.**
1654-Z2 Sorting System (bench only) Includes 1413 Decade Capacitor	**1654-9702**

1615-A CAPACITANCE BRIDGE

An Accurate, High-Precision Bridge

- ☐ Accuracy of ±.01% at 1 kHz
- ☐ Capacitance range of 10^{-5}pF to 11.1 μF, 2- or 3-terminal
- ☐ 1-ppm capacitance resolution
- ☐ Digital readouts and lever controls for ease of use



The GenRad 1615-A Capacitance Bridge, our top-of-the-line, high precision manually balanced bridge, is ideal for measuring and comparing standard capacitors, circuit component capacitors, and dielectric materials.

For measurements at 11 frequencies between 20 Hz and 20 kHz, the 1615-A is available with a GenRad oscillator and detector in the self-contained 1620-A Capacitance-Measuring Assembly.

To take full adavantage of its wide frequency range (50 Hz to 100 kHz) the 1615-A can be ordered separately for use with an oscillator and detector specially selected for your purposes.

Unmatched Accuracy

The 1615-A's 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.

Accurate three-terminal measurements are quick and easy, even in the presence of capacitance to ground as large as 1 μF. With the 1615-P1 Range-Extension Capacitor, the 1615-A will measure to a maximum of 11.11110 μF. The 1615-P1 easily plugs into the front-panel bridge terminals.

Ease of Use

For convenient operation, the 1615-A features lever-type balance controls, easy-to-read digital readouts with automatically positioned decimal points, and an elementary diagram on the front panel that indicates changes in connections and grounds as you switch bridge terminals for different measurements.

Continued on the next page.

1615-A CAPACITANCE BRIDGE (Cont'd)

SPECIFICATIONS

Ranges:	Accuracy:
Capacitance: 10 aF to 1.11110 μF (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 μF.	At 1 kHz, ±(0.01% + 0.00003 pF). At higher frequencies and with high capacitance, additional error is $[\pm 3 \times 10^{-5}\% + 2 (C_{\mu F}) \times 10^{-3}\% \pm 3 \times 10^{-7}$ pF$] \times (f_{kHz})^2$. At lower frequencies and with low capacitance, accuracy may be limited by bridge sensitivity. Comparison accuracy, unknown to external standard, 1 ppm.
Dissipation Factor: D, At 1 kHz, 0.000001 to 1, 4-figure resolution; least count, 0.000001 (10^{-6}); range varies directly with frequency.	$\pm[0.1\%$ of measured value $+ 10^{-5}(1 + f_{kHz} + 5 f_{kHz} C_{\mu F})]$
Conductance: G, 10^{-6} μ℧ to 100 μ℧, 2 ranges +, 2 ranges −, 4-figure resolution, least count 10^{-6} μ℧, independent of frequency; range varies with C range.	$\pm[1\%$ of measured value $+ 10^{-5}$ μ℧ $+ 6 \times 10^{-2} f_{kHz} C_{\mu F} \times (1 + f_{kHz} + 5 f_{kHz} C_{\mu F})$ μ℧$]$

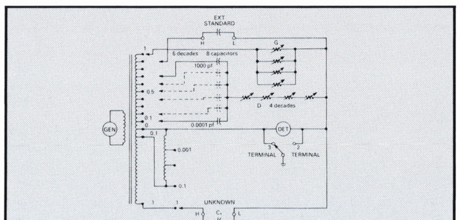
STANDARDS: 1000, 100, 10, 1, 0.1, 0.01, 0.001, 0.0001 pF. Temperature coefficient of capacitance is less than 5 ppm/°C for the 1000-, 100-, and 10-pF standards, slightly greater for the smaller units.

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: GenRad 1311-A Audio Oscillator recommended. Max safe generator voltage (30 × f_{kHz}) volts, 300 V max. If generator and detector connections are interchanged, 150 to 500 V can be applied, depending on switch settings.

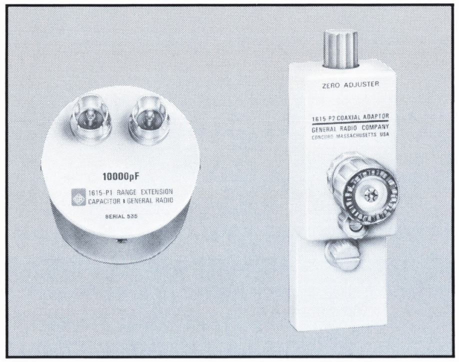
DETECTOR: GenRad 1232-A Tuned Amplifier and Null Detector recommended. For increased sensitivity needed to measure low-loss small capacitors (on lowest C and D ranges simultaneously) at frequencies below 1 kHz, use 1232-AP Tuned Amplifier and Null Detector or 1238 Detector (with 1311-A Audio Oscillator).

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



Elementary schematic diagram.

AVAILABLE: Type 1615-P1 Range-Extension Capacitor; 1615-P2 Coaxial Adaptor converts 2-terminal binding-post connection of 1615-A bridge to GenRad 900 Precision Coaxial Connector for highly repeatable connections and enables measurements with adaptor to be direct-reading by compensating for terminal capacitance.



1615-P1 (left) and 1615-P2

MECHANICAL: Rack-bench cabinet. DIMENSIONS (w × h × d): Bench, 19 × 12.75 × 10.5 in. (483 × 324 × 267 mm); rack, 19 × 12.25 × 8.5 in. (483 × 311 × 217 mm); 1615-P1 (dia × in.): 3.06 × 4.87 in. (78 × 124 mm). WEIGHT: 39 lb (18 kg) net, 58 lb (27 kg) shipping.

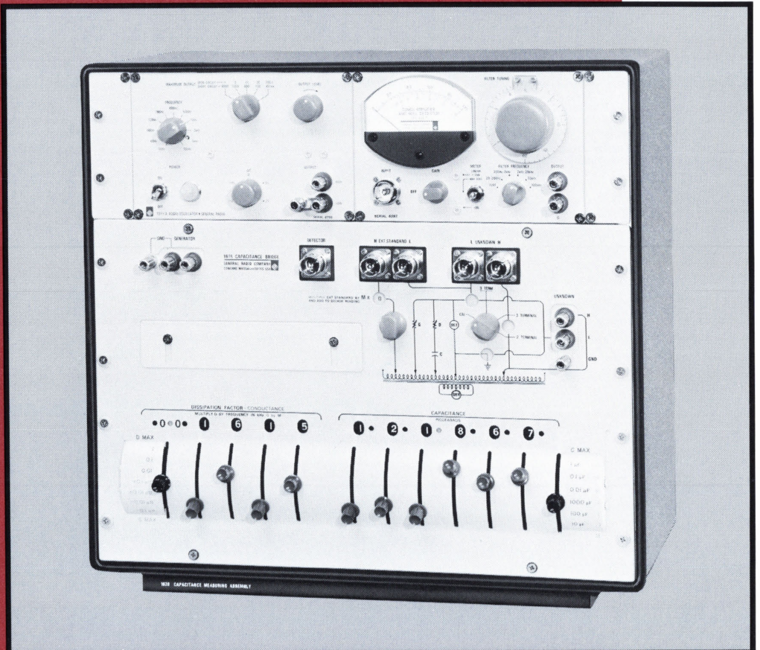
ORDERING INFORMATION

Description	Order No.
1615-A Capacitance Bridge	
Bench Model	1615-9801
Rack Model	1615-9811
Accessories	**Order No.**
1615-P1 Range-Extension Capacitor	1615-9601
1615-P2 Coaxial Adaptor, GenRad 900 to binding posts	1615-9602

1620-A CAPACITANCE-MEASURING ASSEMBLY

Precision Capacitance-Measuring Assembly

- ☐ Capacitance range of 10^{-5}pF to 11.1 μF, 2- or 3-terminal
- ☐ Provides measurements at 11 frequencies between 20 Hz and 20 kHz
- ☐ .01% accuracy with 1-ppm resolution
- ☐ Reads dissipation factor or conductance



The GenRad 1620-A Capacitance-Measuring Assembly is a self-contained assembly featuring the high precision 1615-A Capacitance Bridge with the GenRad 1311-A Audio Oscillator and 1232-A Tuned Amplifier and Null Detector. Measurements at 11 frequencies between 20 Hz and 20 kHz are made quickly and easily with this assembly.

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

Accurate three-terminal measurements can be made even in the presence of capacitances to ground as large as 1 μF, 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 be made over the whole capacitance range.

The optional 1620-AP Assembly contains the GenRad 1232-P2 Preamplifier, which increases the bridge sensitivity below 1000 Hz.

Extend Range to 11.1 μF

With the 1615-P1 Range-Extension Capacitor, the 1615-A will measure to a maximum of 11.11110 μF. This capacitor plugs into the front-panel bridge terminals and can be adjusted for calibration to the bridge standards.

SPECIFICATIONS

PERFORMANCE: Refer to the 1615-A Capacitance 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 Audio 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 (w×h×d): 19.75×19×11 in. (502×483×280 mm). WEIGHT: 59 lb (27 kg) net, 96 lb (44 kg) shipping.

ORDERING INFORMATION

Description	Order No.
Capacitance-Measuring Assembly	
1620-A, 115 V	1620-9701
1620-A, 230 V	1620-9702
1620-AP, with 1232-P2, 115 V	1620-9829
1620-AP, with 1232-P2, 230 V	1620-9830
Accessories	**Order No.**
Replacement Battery (9 req'd)	8410-1372

NOTE: SEE PAGES 79 and 80 FOR ADDITIONAL CAPACITANCE MEASUREMENT INSTRUMENTS

1666 DC RESISTANCE BRIDGE

A Portable and Highly Accurate DC Resistance Bridge

- ☐ Accuracy of .01% direct reading
- ☐ 6-digit resolutions with lever balancing switches
- ☐ 2-, 3-, or 4-terminal resistance or conductance
- ☐ Range of 1 μΩ to 1 TΩ (1 p℧ to 1 M℧)

Whether your requirement is for high accuracy, extremely low or very high resistance values, remote measurements, portability, or precise comparison, the GenRad 1666 DC Resistance Bridge will excel.

This high-precision bridge combines the advantages of Wheatstone and Kelvin bridges in a single instrument. It can even be set up for the rapid sorting of resistors to tight tolerances (using the null meter as a deviation indicator).

The 1666 will make diverse measurements such 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.

Accuracy

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 $10^{12}\Omega$. The six lever switches and quick-response detector permit 0.01% balances to be made in less than 10 seconds. Parts-per-million balances can be made in 20 seconds.

Continued on the next page.

SPECIFICATIONS

BRIDGE CIRCUITS: Kelvin and guarded Wheatstone in both resistance and conductance configurations.

RANGES: TOTAL MEASUREMENT RANGE: 1 μΩ to 1 TΩ. Resistance ranges: 1 μΩ to 1.1 MΩ in 7 ranges (1 μΩ is one count). Conductance ranges: 1 p℧ to 1.1℧ in 7 ranges (1 p℧ is one count). RECOMMENDED RANGES: Wheatstone, 100 Ω to 1 TΩ; Kelvin, 1 μΩ to 10 kΩ.

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

ACCURACY (limit of error): DIRECT READING: ±(0.01% + 10 ppm of full scale). For low-value readings, when first and second digits are zero, ±(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 ±0.1% from 0 to 25°C at 95% RH and from 0 to 35°C at 85% RH. TWO-YEAR ACCURACY: Add ±0.01% to above. COMPARISON ACCURACY: ±[2 + 0.001 × (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 μΩ at very low values; 10 ppm at 1 Ω; 5 ppm at 10 Ω; 1 ppm at 0.1, 1, 10, and 100 kΩ; 5 ppm at 1 MΩ. CONDUCTANCE: 2 p℧ at very low values, 5 ppm at 1 μ℧; 1 ppm at 10 and 100 μ℧, 1 and 10 m℧; 5 ppm at 100 m℧; 10 ppm at 1℧ . 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/μV. INPUT RESISTANCE: approx 20 kΩ. SHORT-CIRCUIT NOISE (slow position): Approx 0.1 μV pk-pk. DRIFT: Typically 0.5 μV/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 MΩ to ground, either terminal.

LEAD ERROR (Kelvin): Less than 2μΩ additional with ≤ 0.1Ω in any lead.

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

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: (w×h×d): 15×12×8 in. (381×305×203 mm). WEIGHT: 21 lb (10 kg) net.

ORDERING INFORMATION

Description	Order No.
1666 DC Resistance Bridge Portable	1666-9700
Accessories	**Order No.**
Replacement Battery (8 req'd)	8410-1510

1644-A MEGOHM BRIDGE

Fast, Accurate Measurements of High-Resistance Over a Wide Range of Voltages

- ☐ 1% accuracy to $10^{12}\Omega$
- ☐ Measurements from 10^3 to $10^{15}\Omega$
- ☐ Seven test voltages for a range of applications
- ☐ Self-checking internal standards for reliability

The GenRad 1644-A Megohm Bridge is a Wheatstone bridge designed for measuring high-value resistors at seven test voltages for a wide range of applications.

The 1644-A, with a high-impedance, high-sensitivity detector, accurately measures the resistance of high-value resistors, resistance films, diodes, transistors, and piezoelectric elements; the voltage and temperature coefficients of resistance; and the volume and surface resistivity of various solids, plastics, and sheet materials.

A Precision Design

Precision, wire-wound resistors are used for the fixed bridge arm and lowest-value decade-step arm. Precision metal film resistors are used for medium values of the ratio arm. Carbon film resistors with trimmers are used for the highest values. 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.

SPECIFICATIONS

RESISTANCE RANGE: 1 kΩ to 1000 TΩ (10^3 to 10^{15} Ω) in ten ranges.

ACCURACY: 10^3 Ω to 10^{10} Ω, ±1%. After self-calibration: 10^{10} to 10^{12} Ω, ±1%*; 10^{13} Ω, ±2%; 10^{14} Ω, ±10%; 10^{15} Ω, ± one scale division.

ΔR% DIAL: ±5% range; accurate to ±0.2% or, for small changes, to ±0.1%.

TEST VOLTAGE: Voltage accuracy is ±3% ±0.5 V.

Fixed Voltages **	10	20	50	100	200	500	1000	V
Minimum Unknown R	1	3	7	20	50	150	500	kΩ

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 (w×h×d): Portable, 12.75×12.5×7.75 in. (324×318×197 mm); rack, 19×12.25×5 in. (483×312 ×127 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.

ORDERING INFORMATION

Description	Order No.
1644-A Megohm Bridge	
115-V Portable Model	**1644-9701**
230-V Portable Model	**1644-9711**

TO ORDER CALL TOLL-FREE 1-800-772-2220,
IN MASSACHUSETTS 1-617-369-4400 ext.3129

1863 AND 1864 MEGOHMMETERS

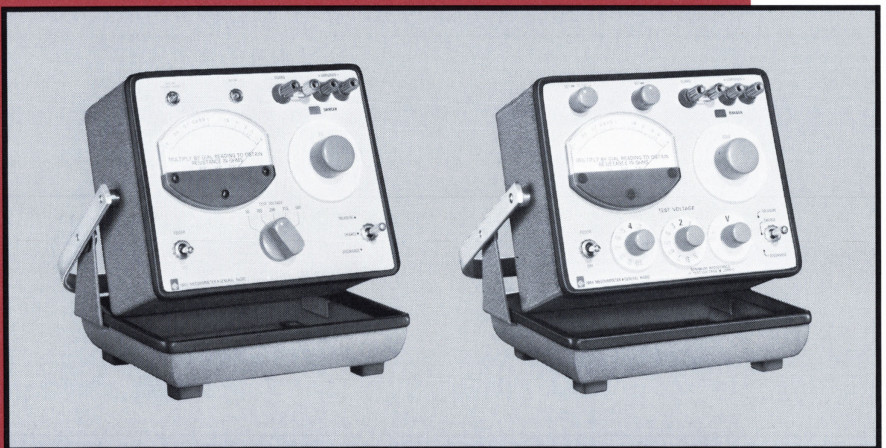
A Choice of Meters to Meet Your Exact Needs

GENRAD 1863

- ☐ 5 test voltages: 50 to 500 V
- ☐ 50 kΩ to 20 TΩ (2 x 10^{13}Ω)
- ☐ Economical, simple operation
- ☐ Direct reading, safe, stable

GENRAD 1864

- ☐ 200 test voltages: 10 to 1090 V
- ☐ 50 kΩ to 200 TΩ (2 x 10^{14}Ω)
- ☐ Direct reading, safe, stable
- ☐ Simple operation



GenRad 1863 and 1864 Megohmmeters

GenRad offers a choice of two accurate, reliable instruments to fit your precise high-resistance measurement applications.

Both the GenRad 1863 and 1864 Megohmmeters are easy to use, with direct-reading meters, lighted range switches, and panel lights that warn when voltage is present. Both minimize drift and time-consuming manual adjustments with stable power supplies and feedback voltmeter circuits. Both can measure grounded or ungrounded two- or three-terminal resistors, using the guard and ground terminals. They can also be used in a convenient, portable flip-tilt case that acts as a stand while also protecting the instrument during travel and storage.

Each is designed to be an economical solution to specific measurement needs.

Ideal for Production

The 1863 Megohmmeter measures resistance at any one of five common test voltages from 50 to 500 volts. Easier to use than the 1864, it is also the lower-priced model. So it's the best selection when multiple units are needed on a production floor, when your operators are inexperienced, or when specifications call for standard insulation-testing voltages.

Ideal for the Laboratory

With the more flexible 1864 Megohmmeter, you can set test voltages ranging from 10 to 109 volts in 1-volt increments, and up to 1090 volts in 10-volt increments. That means 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 easily measured with the 1864, and an additional range allows measurements up to 2 x 10^{14}Ω (200 TΩ).

SPECIFICATIONS

VOLTAGE AND RESISTANCE RANGES:

Voltage	R_{min} Full Scale	R_{max}† 10% of Scale	R_{max}† 2½% of Scale	Useful Ranges
		Type 1863		
50, 100 V	50 kΩ	500 GΩ	2 TΩ	7
200, 250, 500 V	500 kΩ	5 TΩ	20 TΩ	7
		Type 1864		
10 to 50 V	50 kΩ	500 GΩ	2 TΩ*	7*
50 to 100 V	200 kΩ	5 TΩ	20 TΩ	8
100 to 500 V	500 kΩ	5 TΩ	20 TΩ*	7*
500 to 1090 V	5 MΩ	50 TΩ	200 TΩ	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 ±2%, ±4%, –, for the 1863; ±2%, ±3%, ±5%, for the 1864.

VOLTAGE ACCURACY (across unknown): ±2%.

SHORT-CIRCUIT CURRENT: 5 mA approx.

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

MECHANICAL: Flip-Tilt case. DIMENSIONS (w×h×d): 6.63×10×6.75 in. (245×254×172 mm). WEIGHT: 9.5 lb (4.4 kg) net, 14 lb (7 kg) shipping.

ORDERING INFORMATION

Description	Order No.
1863 Megohmmeter	1863-9700
1864 Megohmmeter	1864-9700

1633-A INCREMENTAL-INDUCTANCE BRIDGE

Accurate Measurements at High Levels and Multiple Frequencies

- ☐ Frequency range from 20 Hz to 20 kHz for versatility
- ☐ Accuracy of ±1%
- ☐ Direct readings at nine frequencies, in series L and R or Q
- ☐ Impressed voltage can be as high as 1250 V and 7 A, ac and dc (up to 50 A with the 1633-P1)
- ☐ Range of 0.2 μH to 1000 H

The GenRad 1633-A Incremental-Inductance Bridge is designed for measuring inductance and loss of transformers, chokes, and similar components at very high levels of ac and dc excitation. It functions over a wide frequency range from 20 Hz to 20 kHz. Other nonlinear elements such as rectifiers and lamps can also be measured.

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.

Accuracy That's Consistent

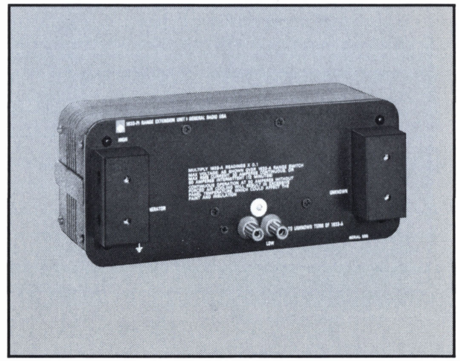
The 1633-A uses active elements in the bridge circuit that keep signals small. This minimizes corrections and eliminates sliding balance, even when large signal and bias levels are applied to the unknown inductor. Since current and voltage in the unknown inductor are nearly identical in magnitude and waveform to those applied at the generator terminals, measurements can be made on the inductor while it is actually operating.

Up to seven amperes rms (ac and dc combined) can be passed through the inductor during measurement; up to 50 amperes when you use the GenRad 1633-P1 Range-Extension Unit. Two power supplies are available, a dc supply and a variable-frequency oscillator, both designed specifically for use with the bridge. Most conventional power supplies are not suitable.

This unit can also be ordered with high-power ac and dc supplies, as the self-contained 1630-AV Inductance-Measuring Assembly (see page 18). The assembly is ideal for measuring inductance and loss of coils with ferromagnetic cores.

1633-P1 Range-Extension Unit

The GenRad 1633-P1 Range-Extension Unit 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.



1633-P1 Range Extension Unit

Continued on the next page.

SPECIFICATIONS

Ranges and Accuracy:

Measurement	Frequency	Full-Scale Ranges a	b	c	d	e	f	Lowest Scale Division	Accuracy
Inductance	50, 60, 100, 120 Hz	10 mH	100 mH	1 H	10 H	100 H	1000 H	20 µH	±(1% of reading or 0.1% of full scale) ±($2\pi f_{kHz}/100\ Q_x$) %*, ±2% above 10 kHz or ±3% above 15.75 kHz
	400, 800, 1000 Hz	1 mH	10 mH	100 mH	1 H	10 H	100 H	2 µH	
	10, 15.75 kHz	100 µH	1 mH	10 mH	100 mH	1 H	10 H	0.2 µH	
Resistance	All	10 Ω	100 Ω	1 kΩ	10 kΩ	100 kΩ	1 MΩ	10 mΩ	±(2% of reading or 0.1% of full scale) ± $\frac{4\pi f_{kHz} Q_x}{100}$ %*
Q		∞ to 1, direct reading at above frequencies. Largest scale reading: 1000						0.9	1/Q accuracy = ±2% ±0.001 ±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 = $\sqrt{I^2_{dc} = I^2_{ac}}$

†1633-P1 Range-Extension Unit contains a 0.1-Ω resistor, which you connect externally to shunt R_B (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 ±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 (w×h×d): Bench, 19×12.75×10.25 in. (483×324×260 mm); rack, 19×12.25×8.75 in. (483×311×222 mm). WEIGHT: 31 lb (14kg) net, 48 lb (22 kg) shipping.

1633 P-1

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 ≤ 120 Hz, 10 mH for f ≤ 1 kHz.

ACCURACY: Additional ±1% error for f ≤ 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 (w×h×d): 10.5×4.25×5 in. (267×108×127 mm). WEIGHT: 5.3 lb (2.4 kg) net, 7 lb (3.2 kg) shipping.

ORDERING INFORMATION

Description	Order No.
1633-A Incremental-Inductance Bridge	
115-V Bench Model	1633-9801
115-V Rack Model	1633-9811
230-V Bench Model	1633-9802
230-V Rack Model	1633-9812

Accessories	Order No.
1633-P1 Range Extension Unit	1633-9601

1630-AV INDUCTANCE-MEASURING ASSEMBLY

Complete System for the Measurement of Inductance

- ☐ Test levels from millivolts to 400 V
- ☐ Continuous coverage from 20 Hz to 20 kHz with external detector
- ☐ Capable of 200-voltampere outputs into wide range of inductors under test
- ☐ L accuracy 1% (R and Q, 2%)

Designed to measure the inductance and loss of coils with ferromagnetic cores, the GenRad 1630-AV Inductance-Measuring Assembly consists of a 1633-A Incremental-Inductance Bridge, 1265-A Adjustable DC Power Supply, and 1308-A Audio Oscillator/Power Amplifier in a self-contained cabinet-type rack that includes all necessary cables.

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

When you need measurements at frequencies not given for the internal detector, you can use the 1232-A Tuned Amplifier and Null Detector.

SPECIFICATIONS

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

MECHANICAL: Pedestal cabinet. DIMENSIONS (w×h×d): 22.5×43×20 in. (572×1092×508 mm). WEIGHT: 310 lb (145 kg) net, 460 lb (215 kg) shipping.

ORDERING INFORMATION

Description	Order No.
1630-AV Inductance-Measuring Assembly	
115 V, 60 Hz	1630-9827
230 V, 50 Hz	1630-9857

DIGIBRIDGE® AUTOMATIC RLC TESTERS

Digital electronics provide an easy and reliable means for making accurate impedance measurements. That's why GenRad has engineered its complete family of microprocessor-based Digibridge® Automatic RLC Testers for precise, digital impedance measurements.

Our five Digibridge Automatic RLC and LC Testers offer high accuracy, flexibility, and ease of use in measuring resistors, capacitors, and inductors.

GenRad's Digibridges are:

1657 Automatic RLC Digibridge
1658 Automatic RLC Digibridge
1687-B 1-Megahertz LC Digibridge
1689 Precision RLC Digibridge
1689M Precision RLC Digibridge

1657 AUTOMATIC RLC DIGIBRIDGE

Full Performance at Surprisingly Low Cost

- ☐ Accuracy of 0.2% for R, L, and C measurements
- ☐ 5- and 4-digit readouts
- ☐ 1 kHz and either 120 Hz or 100 Hz test frequencies
- ☐ Built-in Kelvin test fixture for fast setup and high throughput

Ideal for engineering labs and small incoming inspection departments, the GenRad 1657 Automatic RLC Digibridge is the lowest cost member of our Digibridge family.

The 1657 automatically measures R, L, C, D, and Q at better than three measurements per second, with a basic accuracy of 0.2% for R, L, and C.

This Digibridge gives you precision measurements with guarded Kelvin measurement techniques, two sinusoidal test frequencies, series or parallel measurement modes, and proven reliability.

Like all GenRad Digibridges, the 1657 features displays and controls that are so easy to read and adjust that the unit can be easily run by operators with little or no technical training.

Continued on the next page.

SPECIFICATIONS

MEASUREMENT MODES: 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.

DISPLAYS: Two LED numerical displays with automatically positioned decimal points and illumination of units. For RLC, five digits (99999) and simultaneously for DQ, four digits (9999).

APPLIED VOLTAGE: 0.3 V rms maximum.

RANGES: The basic ranges for each parameter (see RLC Range Table) consist of three instrument ranges at two decades each. Limits of range extensions are also tabulated.

RLC RANGE

Parameter	Minimum Low Extension	Basic Ranges	Maximum High Extension
R:120 Hz*	00.001Ω	2Ω to 2 MΩ	99.999 MΩ
R:1 kHz	00.001Ω	2Ω to 2 MΩ	9.9999 MΩ
L:1 kHz	0.0001 mH	0.2 mH to 200 H	999.99 H
L:120 Hz*	00.001 mH	2 mH to 2000 H	9999.9 H
C:1 kHz	0.0001 nF	0.2 nF to 200 μF	999.99μF
C:120 Hz*	00.001 nF	2 nF to 2000 μF	99999 μF
D (with C)		.0001 to 9.999	
Q (with L)		00.01 to 999.9	

*120 Hz or 100 Hz depending on the instrument.

DETAILED ACCURACY SPECIFICATIONS:

Accuracy: For R, L, and C, ±0.2% of reading in basic ranges, if quadrature component is small (D<0.1, Q>10)

D accuracy: ±.001 in basic ranges, for D<0.1

Q accuracy: ±.01 in basic ranges, for Q<1

Parameter	Low Extension	Basic Ranges	High Extension	Cross-Term Factor
R:either frequency	±[4 mΩ	0.2% of rdg,	(R/10 MΩ)% of rdg]	(1+Q)
L:1 kHz	±[0.4 μH	0.2% of rdg,	(L/1000 H)% of rdg]	(1+1/Q)
L:120 Hz*	±[4 μH	0.2% of rdg,	(L/10 kH)% of rdg]	(1+1/Q)
C:1 kHz	±[0.4 pF**	0.2% of rdg,	(C/1000 μF)% of rdg]	(1+D)
C:120 Hz*	±[4 pF**	0.2% of rdg,	(C/.01 F)% of rdg.]	(1+D)
D (with C)	±[	0.001+0.002(1+D) D	]	K†
Q (with L)	±[	0.01+0.002(1+Q) Q	]	K†

*120 Hz or 100 Hz **Fixed offset "zero" capacitance is 1.5 pF.

†K=(LC basic accuracy as % of rdg)/0.2%. Therefore K=1 on basic ranges.

SUPPLIED: Power cord, axial-lead adaptors, instruction manual.

POWER: 90 to 125, or 180 to 250 V, 48 to 62 Hz. Voltage selected by rear-panel switch. 25 W max.

MECHANICAL: DIMENSIONS: (w × h × d) 14.78 × 4.4 × 13.5 in. (37.5 × 11.2 × 34.2 cm). WEIGHT: 12.5 lb (5.7 kg) net; 22 lb (10 kg) shipping.

ENVIRONMENT: TEMPERATURE: 0° to 50°C, operating; −40° to +75°C, storage. HUMIDITY: 0 to 85% R.H., operating.

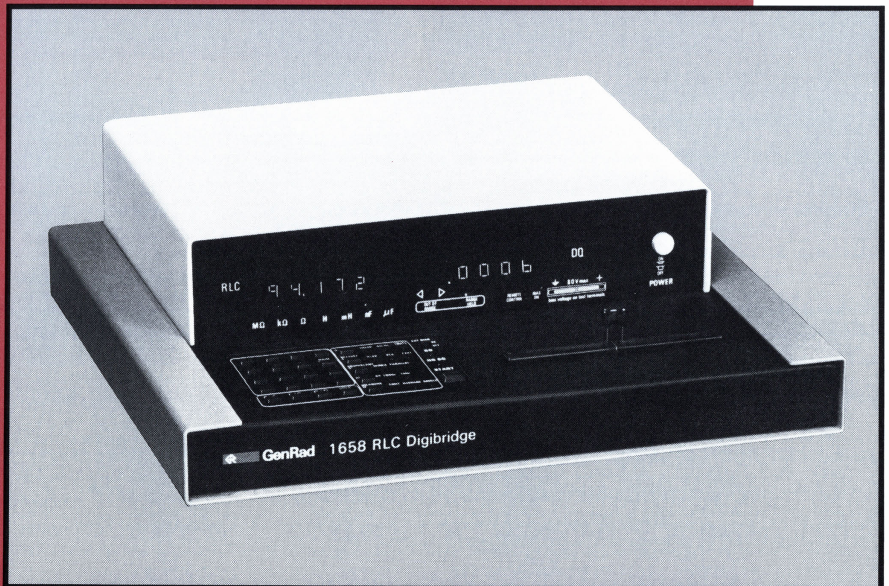
ORDERING INFORMATION

Description	Order No.
1657 Automatic RLC Digibridge	
120 Hz & 1 kHz Test Freq.	1657-9700
100 Hz & 1 kHz Test. Freq.	1657-9800
(See pages 30-35 for information on Digibridge accessories.)	

1658 AUTOMATIC RLC DIGIBRIDGE

Unmatched Flexibility at Incoming Inspection

- ☐ Accuracy of 0.1% for R, L, and C measurements
- ☐ Two test frequencies of 1 kHz and either 120 Hz or 100 Hz
- ☐ Automatic limit comparison and binning
- ☐ IEEE-488 Bus and Component Handler Option



The GenRad 1658 Automatic RLC Digibridge gives you a level of flexibility and ease of use that make it ideal at incoming inspection, where you need to test a wide range of components quickly.

Instrument features include a simple but sophisticated programming keyboard for setting component test limits, enabling the operator to perform high throughput testing, sorting, and evaluation; a choice of continuous, average, or triggered measurement modes to meet all measurement applications; and simple GO/NO GO indicators, plus an easy readout of value or bin number results at the touch of a button.

Available Options

The standard 1658 provides two test frequencies – 1 kHz and either 120 or 100 Hz. On special order, you can get test frequencies of 50 Hz, 60 Hz, 400 Hz, or 800 Hz to meet your specific needs.

For increased throughput or hard-copy results, the IEEE-488 Bus/Handler Option connects the 1658 to peripherals such as handlers, printers, or computer-based systems.

SPECIFICATIONS

MEASUREMENT PARAMETERS AND MODES: Series or parallel R and Q, series or parallel L and Q, series or parallel C and D. Continuous-repetitive, single, or averaged (set of 10) measurements; start button initiates single or averaged measurements. Keyboard selection of these and all measurement conditions.

MAIN DISPLAYS (3 selections): Value display is LED-type numerical readout with automatically positioned decimal points and illumination of units; five digits for RLC (99999) and, simultaneously, four digits for DQ (9999). Limits display shows comparator bin limits and nominal values. Bin No. display shows the bin assignment of the measured device.

MEASUREMENT RATES: Approximately 2, 3, and 7 measurements/second. Keyboard selections are "slow, medium, fast."

TEST FREQUENCIES: Keyboard selection between 2. Accuracy re panel legends is +2%, −.01%. Actual frequencies: for 1658-9700, 120.00 Hz ±.01% and 1020.0 Hz ±.01% (panel legend "1 kHz"); for 1658-9800, 100.00 and 1000.0 Hz ±.01%.

RANGES: The basic ranges for each parameter (see RLC Range Table) consist of three instrument ranges at two decades each. Limits of range extensions are also tabulated.

RLC RANGE

Parameter	Minimum Low Extension	Basic Ranges	Maximum High Extension
R:1 kHz	0.0001Ω	2Ω to 2 MΩ	9.9999 MΩ
R:120 Hz*	0.0001Ω	2Ω to 2 MΩ	99.999 MΩ
L:1 kHz	.00001 mH	0.2 mH to 200 H	999.99 H
L:120 Hz*	0.0001 mH	2 mH to 2000 H	9999.9 H
C:1 kHz	.00001 nF	0.2 nF to 200 μF	999.99 μF
C:120 Hz*	0.0001 nF	2 nF to 2000 μF	99999 μF
Q (with R)		.0001 to 9.999	
Q (with L)		00.01 to 999.9	
D (with C)		.0001 to 9.999	

*120 Hz or 100 Hz, depending on the instrument.

ACCURACY: For R, L, and C, ±0.1% of reading in basic ranges, if quadrature component is small (<10% of principal measurement) for slow measurement rate. More details given in table. Accuracy of Q (with R), ±.001; of Q (with L), ±.01; of D (with C), ±.0005; in basic ranges, for D or Q <<1; (otherwise, see table).

BIAS: Connector for external voltage source, on-off switch, and indicator light. Limit, 60 V (max). External source requirements: ripple <1 mV pk-pk, dynamic Z <<1Ω with currents of ±50 mA pk (source and sink); external discharge circuit recommended.

SUPPLEMENTARY DISPLAYS: Parameters, modes, overrange and underrange conditions, range held, bias on, and remote control.

SORTING: Limit comparator sorts vs a DQ limit and up to 8 pairs of RLC limits into 10 bins, conveniently defined by keyboard entries. GO/NO GO is indicated, whether bin number or measured value is selected as main display.

INTERFACE OPTION: 2 ports; a 24-pin connector for each port. IEEE-488 INTERFACE PORT: Functions are SH1, AH1, T5, L4, SR1, RL2, PP0, DC0, DT1, C0. Refer to IEEE Standard 488-1978. Switch selection between 2 modes as follows. TALKER-LISTENER MODE: Input commands from system controller can disable keyboard and program all functions (except setting limits for sorting); any or all measurement results are available as outputs. TALKER-ONLY MODE: Measured results are always output, for use in systems without controllers. HANDLER INTERFACE PORT: 1 input (start signal), 2 output (status signals), and set of 10 output lines (sorting data); active-low logic; for input, logic low is 0.0 to +0.4 V (current is 0.4 mA max) and logic high is +2.4 to +5.0 V; for outputs, open-collector drivers rated at +30 V max, 40 mA max (sink), each, this port only. (External power supply and pull-up resistors are required.)

ENVIRONMENT: TEMPERATURE: 0 to 40°C, operating; −40 to +75°C, storage. HUMIDITY: 0 to 85% RH, operating.

SUPPLIED: Power cord, axial-lead adaptors, bias cable, instruction manual.

LINE VOLTAGE AND POWER: 90 to 125 V, or 180 to 250 V, 50 to 60 Hz. Either of these ranges selected by rear-panel switch. 30 W max.

MECHANICAL: Bench mounting. DIMENSIONS (w × h × d): 14.8 × 4.4 × 13.5 in. (375 × 112 × 343 mm). WEIGHT: 13.5 lb (6 kg) net; 22 lb (10 kg) shipping.

ACCURACY

Parameter	Low Extension	Basic Ranges	High Extension	Cross-Term Factor
R:either frequency	±M [2 mΩ,	0.1% of rdg,	(R/20 MΩ)% of rdg]	(1 + Q)
L:1 kHz	±M [0.2 μH,	0.1% of rdg,	(L/2000 H)% of rdg]	(1 + 1/Q)
L:120 Hz*	±M [2 μH	0.1% of rdg,	(L/20 kH)% of rdg]	(1 + 1/Q)
C:1 kHz	±M [0.2 pF**	0.1% of rdg,	(C/2000 μF)% of rdg]	(1 + D)
C:120 Hz*	±M [2 pF**	0.1% of rdg,	(C/.02 F)% of rdg]	(1 + D)
Q (with R)	±KM [	.001 + .001 Q (1 + Q)	]	
Q (with L)	±K [	.01 + .001 MQ (1 + Q)	]	
D (with C)	±KM [	.0005 + .001 D (1 + D)	]	

Factors: M is 1, 2, or 5 for SLOW, MEDIUM, or FAST measurement, respectively. K is the quotient (RLC basic accuracy) / (RLC basic accuracy in basic range). Therefore, K = 1 in basic ranges.

*120 Hz or 100 Hz.

**Fixed offset "zero" capacitance is <2.0 pF.

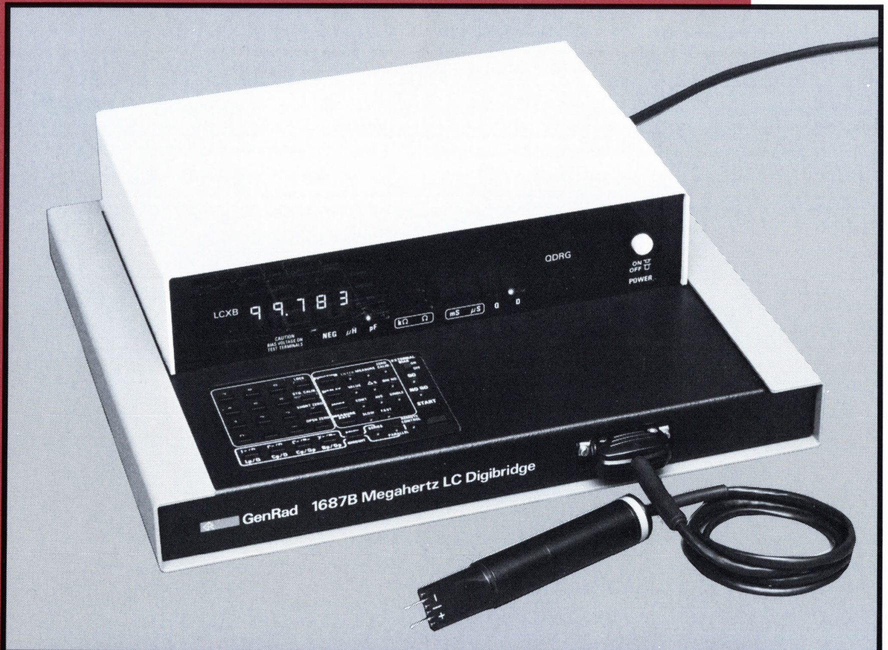
ORDERING INFORMATION

Description	Order No.
1658 Automatic RLC Digibridge	
120 Hz & 1 kHz Test Freq.	**1658-9700**
100 Hz & 1 kHz Test Freq.	**1658-9800**
RLC Production Test Packages	
120 Hz, 1 kHz, and 1 MHz Package consisting of 1658-9700 and 1687-9702	**1687-9800**
100 Hz, 1 kHz, and 1 MHz Package consisting of 1658-9800 and 1687-9702	**1687-9801**
(See pages 30-35 for information on Digibridge accessories.)	

1687-B 1-MEGAHERTZ LC DIGIBRIDGE

High-Frequency Component Testing That's Fast and Easy

- ☐ 0.1% accuracy for C, 0.2% for L
- ☐ 1 MHz test frequency for high-frequency component tests
- ☐ 3 test voltages, automatic binning, and automatic contols for ease of use
- ☐ Remote programmability for easy offline program preparation



High-frequency component testing with the accuracy, flexibility, ease of use, and low cost that are characteristic of the GenRad Digibridge family: that's the performance you get with the GenRad 1687-B 1-Megahertz LC Digibridge.

Designed for incoming and production test applications, the 1687-B tests components calling for a 1 MHz frequency with a 0.1% basic accuracy for C, X, or B and a 0.2% basic accuracy for L.

In addition to full digit display, automatic binning, and GO/NO GO indicators, features include a coded keyboard lock that prevents tampering with pre-set limits; total remote programmability for fast offline program preparation and storage; three test voltages; a wide choice of measurement parameters; a self-check diagnostic system; and test speeds from 3 to 5 measurements per second for achieving the optimum balance between accuracy and throughput.

Easy-to-Add Options

For higher throughput and flexibility, an IEEE-488 Bus/Handler Option lets you connect your 1687-B to peripheral equipment such as handlers, printers, and controllers. The specially designed probe and cable help eliminate the measurement errors typically encountered when megahertz bridges are interfaced to special fixtures and automatic component handlers.

Continued on the next page.

SPECIFICATIONS

MEASUREMENT PARAMETERS: Measures C and D series or parallel; L and Q series or parallel; C and R or X and R series; and C and G or B and G parallel. All measurement parameters are key-selectable.

MEASUREMENT SPEED: Slow (3/s typical), fast (5/s typical). Key-selectable.

TEST FREQUENCY: 1.000 MHz±.01%.

MEASUREMENT RANGES:
C–00.001 to 99999 pF
L–00.001 to 99999 μH
Q–.0001 to 999.9
D–.0001 to 999.9
R–0.01 Ω to 999.9 kΩ
X–0.01 Ω to 999.99 kΩ
B–0.01 μs to 999.99 ms
G–0.01 μs to 999.9 ms

DISPLAY: Key-selectable. Value: Ls/Q, Lp/Q, Cs/D, Cp/D, Cs/Rs, Cp/Gp, Xs/Rs, or Bp/Gp. Five full digits (99999) for L, C, X, or B and four full digits (9999) for Q, D, R, or G. Completely autoranging. Bin number: identifies bin for tested component based on programmed limits. Limits: programmed limits for any bin. △%: percentage deviation of selected L, C, X, or B from entered nominal value.

MEASUREMENT MODE: Continuous, average (average of 10 measurements), or single. Key-selectable.

EXTERNAL BIAS: Up to 60 V can be applied to capacitors. On-off switch on keyboard. Indicator lights when bias is applied.

APPLIED VOLTAGE: 0.1 V rms nominal with 1687-9603 probe (supplied). 0.01 V rms with 1687-9607 probe or 1.0 V rms with 1687-9604 probe (available). Actual voltage is ±20% for high impedance DUT (i.e. C<100 pF) and rolls off on low impedance DUT (to 1/10 of nominal for C of 1600 pF).

ACCURACY:

Capacitance and Dissipation Factor

C Value		Accuracy	
Min.	Max.	C	D
25 pF	400 pF	±0.1%	±.001[1+(1+D)D]
6 pF	1850 pF	±0.2%	±.002[1+(1+D)D]
1.8 pF	6000 pF	±0.5%	±.005[1+(1+D)D]
0.8 pF	13000 pF	±1.0%	±.01[1+(1+D)D]
0.4 pF	27500 pF	±2.0%	±.02[1+(1+D)D]

Inductance and Quality Factor

L Value		Accuracy	
Min.	Max.	L	Q
40 μH	1700 μH	±0.2%	±.001[1+(1+Q)Q]
6 μH	10000 μH	±0.5%	±.0025[1+(1+Q)Q]
2.5 μH	24000 μH	±1.0%	±.005[1+(1+Q)Q]
1.2 μH	53000 μH	±2.0%	±.02[1+(1+Q)Q]

Reactance and Resistance

X or R Value		Accuracy
Min.	Max.	X or R
520 Ω	4.6 kΩ	±0.1%
110 Ω	22 kΩ	±0.2%
33 Ω	73 kΩ	±0.5%
16 Ω	158 kΩ	±1.0%
7.5 Ω	330 kΩ	±2.0%

Susceptance and Conductance

B or G Value		Accuracy
Min.	Max.	B or G
220 μs	1.9 ms	±0.1%
45 μs	9 ms	±0.2%
14 μs	30 ms	±0.5%
6.3 μs	66 ms	±1.0%
3.1 μs	137 ms	±2.0%

The above specifications apply for measurements made with either the 10 mV or 100 mV measurement probes, with measurement rate set to "slow." For the optional 1.0 V probe (1687-9604), multiply accuracy values by a factor of 2. For fast measurement rate, multiply by an additional factor of 2. For values outside of these ranges, or for high dissipation or low-quality factor components, contact GenRad's Digibridge Support Group.

ENVIRONMENTAL: TEMPERATURE: 0° to +50°C operating, −40° to +75°C, storage; HUMIDITY: 0 to 85% RH, operating.

SUPPLIED: 0.1 V measurement probe and cable (1687-9603), test fixture (1687-9600), bias cable, and power cord.

POWER: 90 to 125 V, or 180 to 250 V, 48 to 62 Hz. Voltage selected by rear-panel switch. 30 W max.

MECHANICAL: Bench model. DIMENSIONS (w×h×d): 14.8×4.4×13.5 in. (37.5×11.2×34.3 cm). WEIGHT: 13.5 lb (6.14 kg) net; 18 lb (8.20 kg) shipping.

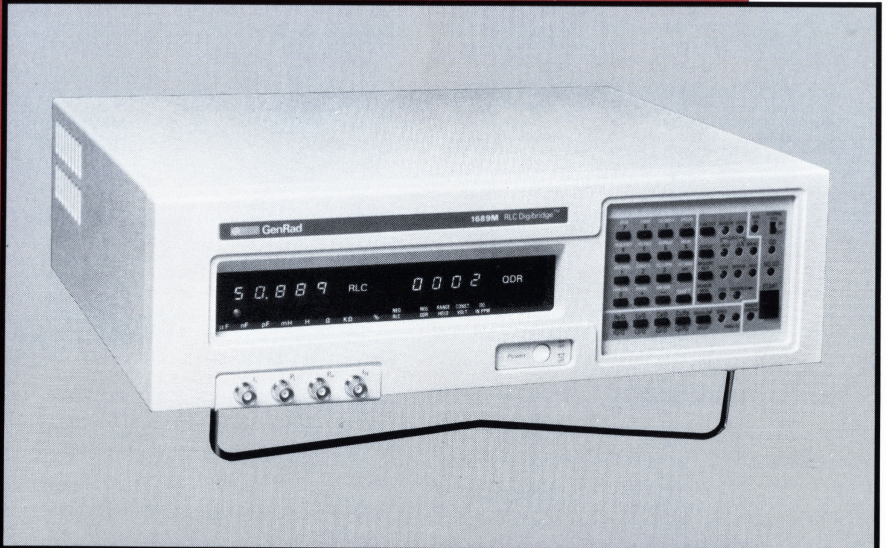
ORDERING INFORMATION

Description	Order No.
1687-B 1-Megahertz LC Digibridge	**1687-9702**
RLC Production Test Packages	
120 Hz, 1 kHz, and 1 MHz Package consisting of 1658-9700 and 1687-9702	**1687-9800**
100 Hz, 1 kHz, and 1 MHz Package consisting of 1658-9800 and 1687-9702	**1687-9801**
(See pages 30-35 for information on Digibridge accessories.)	

1689 AND 1689M PRECISION RLC DIGIBRIDGES

Top-of-the-Line Performance at a Price That Can't Be Beat

- ☐ 0.02% accuracy for R, L, and C
- ☐ Programmable test frequencies from 12 Hz to 100 kHz
- ☐ Programmable test voltages from 5 mV to 1.275 V
- ☐ Up to 30 or 50 measurements per second respectively, with high-speed option



GenRad 1689M Precision RLC Digibridge

When you consider price and performance, there are only two high-speed RLC testers that can meet your most demanding requirements: the GenRad 1689 and 1689M Precision RLC Digibridges. In production test, incoming inspection, component design and evaluation, process monitoring, and dielectric measurement applications, these test instruments offer a high level of performance at a low cost.

In addition to all the automatic, easy-to-use GenRad Digibridge features you've come to expect, the 1689 and 1689M provide programmable test frequencies from 12 Hz to 100 kHz; programmable test voltages from 5 mV to 1.275 V; and a basic accuracy of ±.0001 for D, and 0.02 for R, L, and C.

With the high-speed option, the 1689 can deliver up to 30 measurements per second, while the 1689M can deliver as high as 50 measurements per second.

A Variety of Special Features

You also get automatic limit comparison, range extension capability, automatic parameter selection, remote programmability, bin sorting summary data, automatic zeroing, self-check diagnostics, keyboard lock, and more.

That's a lot of performance for the price. And it's backed by the GenRad reputation for reliability.

1689M Rack-Mountable Instrument

When you choose your model, remember that the 1689M is not only faster with the high-speed option, but it can be easily mounted in a standard 19-inch electronics rack using the GenRad 1689-9611 Rack-Mount Kit. The BNC connectors can be moved to the rear panel of the 1689M, if desired.

SPECIFICATIONS

DISPLAYS: Measurement results may be displayed in four ways as selected by the keyboard: VALUE, % difference, RLC difference, and BIN NO. The VALUE display can be one of four pairs of measured quantities: L and Q, C and D, C and R, or R and Q. The primary display (L, C, or R) has five digits of resolution and the secondary display (D, Q, or R with C) has four digits of resolution. The % difference display indicates the percent deviation of the measured L, C, or R value from a stored NOMINAL VALUE. The sign of this deviation is indicated. The RLC difference is similar to the % difference except that the deviation is displayed in appropriate units (ohms, henries, etc.) The BIN NO. display is the number of the bin (0 through 14) into which the component should be sorted. The testing limits for these bins are set up by the user in the ENTER mode. These test limits may be symmetrical or non-symmetrical about the NOMINAL VALUE. One bin is used for D or Q rejects and one is used for RLC rejects (outside all limits). The sum of the number of components sorted into each bin may be displayed (99999 max). Also displayed during entry or upon interrogation are: test frequency, test voltage, number of measurements averaged, delay time, nominal value, bin limits and bin sum, and codes for SPECIAL FUNCTIONS. GO/NO-GO lights are also provided and these are active with all modes of measurement display as long as test limits have been set.

RANGES:
Primary Display:*
C: .00001 pF to 99999 µF
R: .00001 Ω to 99999 kΩ
L: .00001 mH to 99999 H
% difference (C, R, or L), .0001% to 99999%; RLC difference, same as R, L, or C. If any of these quantities is negative, the NEG RLC indicator light is lit.

*These ranges may be extended by a factor of more than 10,000 larger or smaller by using the special ratio mode.

Secondary Display:
D (with C) or Q (with L or R), .0001 to 9999; D (with C) or Q (with R) in ppm, 1 ppm to 9999 ppm; R (with C), .0001 Ω to 9999 kΩ. If any of these quantities is negative, the NEG QDR indicator is lit.

EQUIVALENT CIRCUIT: Either the equivalent SERIES or the equivalent PARALLEL circuit representation of L, R, or C may be selected by keyboard control.

TEST FREQUENCIES: Over five hundred test frequencies between 12 Hz and 100 kHz may be selected using the keyboard. These are:

$$f = \frac{200\ \text{kHz}}{n} \text{ where } 2 \leq n \leq 13$$

$$f = \frac{60\ \text{kHz}}{n} \text{ where } 4 \leq n \leq 256$$

$$f = \frac{3\ \text{kHz}}{n} \text{ where } 13 \leq n \leq 250$$

If the exact frequency entered is not available, the nearest available frequency will be used. Frequency tolerance is .01%.

MEASUREMENT TIME: Measurement rate is selected via the keyboard. The time required for a complete measurement is typically less than indicated in the following table.

1689

Measurement Rate	Test Frequency 12 Hz	100 Hz	120 Hz	1 kHz	10 kHz	100 kHz
Slow	875 ms	940ms	940 ms	970 ms	930 ms	930 ms
Medium	670 ms	130 ms	185 ms	200 ms	190 ms	190 ms
Fast	670 ms	125 ms	110 ms	80 ms	75 ms	70 ms
Maximum	670 ms	110 ms*	100 ms*	40 ms	34 ms	33 ms

1689M

Measurement Rate	Test Frequency 12 Hz	100 Hz	120 Hz	1 kHz	10 kHz	100 kHz
Slow	875 ms	920ms	920 ms	950 ms	920 ms	920 ms
Medium	670 ms	120 ms	170 ms	180 ms	170 ms	170 ms
Fast	670 ms	105 ms	90 ms	65 ms	55 ms	55 ms
Maximum	660 ms	101 ms*	86 ms*	32 ms	22 ms	22 ms

*These times can be shortened by 14 ms with reduced accuracy using the quick acquisition routine.

Notes: The following notes apply to the 1689 and 1689M. Values without parentheses are for the 1689M. Values inside parentheses are for the 1689.
1. If the high-speed measurement option is not used, add 12 ms (19 ms) for MAXIMUM, or 24 ms (38 ms) for SLOW, MEDIUM, or FAST measurement.
2. If the display is Value, Δ%, or ΔRLC, add 3 to 5 ms (6 to 10 ms).
3. If data is output via the IEEE Bus, add 3 to 6 ms (6 to 12 ms).
4. For ACQ, subtract 11 ms (22 ms) for SLOW, MEDIUM, or FAST and 6 ms (12 ms) for MAXIMUM.

The measurement times (see charts) are obtained with use of the high-speed measurement option, continuous measurement mode, bin number display/handler output, and without IEEE-Bus data output. For other conditions, refer to the table notes. If the measurement mode is triggered, programmed delay (settling time), if any, should be added. Normal power-up conditions include a programmed delay of 7/f to 12/f ms, depending upon measurement rate. This delay can be programmed to zero or to any value up to 100 sec. Test connections can be broken (handler indexing can begin) as soon as data acquisition is complete (ACQ line low on handler interface). See Note 4 in tables.

MEASUREMENT MODES: Two test modes are available. The CONTINUOUS mode makes successive measurements continuously, updating the display after each measurement. TRIGGERED measurements are initiated by the Start button, or remotely from the IEEE bus or from the Handler Interface, and the measurement result is displayed until the next measurement is started.

AVERAGE: The average of any number of measurements from 1 to 255 may be made as desired in either of the two measurement modes. In the TRIGGERED mode, the running average is displayed and the final value held until the Start button is again depressed. In the CONTINUOUS mode, only the final value is displayed.

TEST VOLTAGE: The RMS test voltage is selectable from 5 mV to 1.275V in 5 mV steps. The accuracy is (5% + 2mV) (1 + .001f²) where f is in kHz. This voltage may be applied behind a source impedance (which depends on the range) in which case the selected voltage is the maximum that will be applied and the voltage will be less at the low-impedance end of each range. The voltage may also be applied behind 25 ohms using the CONSTANT VOLTAGE function, in which case the applied voltage will be constant except when low impedances are measured.

DELAY: A delay of from 1 to 99999 ms may be added to allow for settling of external switches and to permit a wider selection of measurement rates.

DC BIAS: An internal bias of 2 V may be applied to capacitors under test by means of the INT BIAS key. An external bias of up to 60 V dc may be applied to capacitors under test using a panel switch. The applied current should be limited to 200 mA. The instrument is protected from damage from charged capacitors with a stored energy up to 1 joule at 60 V or less. Protection from higher voltages may be provided by external components.

ZEROING: A simple OPEN operation removes the effects of stray capacitance and conductance of the internal test fixture or any other test fixture or cable. A similar SHORT zeroing operation removes the effects of series resistance and inductance.

DUT CONNECTIONS: The 1689 has a built-in test fixture that will accept radial or axial components. The 1689M has BNC connectors for attachment to a wide variety of measurement accessories. Four-terminal (Kelvin) connections are made to the device under test. The instrument ground is guard for three-terminal measurements.

KEYBOARD LOCK: A combination of keyboard entries makes the keyboard inactive.

SPECIAL FUNCTIONS: Several special features may be selected. These include: Direct range setting; range extension; choice of integration time; blanking of lesser digits; signal reversal to reduce hum pickup effects; selection of the median value of three measurements; a routine that reduces transient delays when bias is applied; automatic parameter selection; and quick acquisition routine.

IEEE-488 BUS/HANDLER INTERFACE CARD (1658-9620): IEEE-488 Bus (J2 on rear panel with option). All front-panel functions are programmable from the bus. All RLC, DQ, and bin data are available as output to the bus. Output data format, ASCII or Binary. The following functions, per IEEE-488, have been implemented:
AH1 Acceptor Handshake (Listener)
SH1 Source Handshake (Talker)
T5 Talker with normal and talk-only modes (for systems without a controller), switch selectable or rear panel
L4 Listener

1689 AND 1689M PRECISION RLC DIGIBRIDGES (Cont'd)

IEEE-488 BUS-HANDLER INTERFACE CARD (Cont'd):

SR1 Service Request (to request service when measurement is complete and the instrument is not addressed to talk)
RL2 Remote/Local (no local lockout, no return-to-local switch)
PP0 No parallel poll
DC0 No device clear
DT1 Device Trigger (to start measurement)
C0 No controller functions

HANDLER CONNECTIONS (J1 rear panel with option):
1. Outputs, Active low: (Open collector drivers rated at 30 V max. Each will sink 16 mA at 0.4 V. External power and pull-up resistors required). Bin 0 through bin 9 (10 lines) – Sorting outputs. ACQ OVER (1 line) – indicates end of data acquisition. Component may be removed (see TEST TIME). EOT (1 line) – indicates end of test. Bin No. is valid.
2. Input, Active low: ($0V \leq V_1 \leq 0.4$ V, $+2.5$ V $\leq Vh \leq +5$ V). Start (1 line) – Initiates new measurement.

HIGH-SPEED MEASUREMENT/INTERFACE OPTION (1689-9620): Same as above option but also with high-speed capability to increase measurement rate and five more sorting bins (15 lines, open collector drives rated at 15 V max. Each will sink 24 mA at 0.5 V). See Measurement Rate specification, above.

LIMIT OF ERROR (ACCURACY):

PRIMARY READOUT C, R, OR L:

$$C: .01\% \left[(1+Kcv) \text{ or } \frac{Cx}{Cmax} \text{ or } \frac{Cmin}{Cx}\right] (1+|D|)\quad(1+Ks+Kfv)+.01\%$$

$$R: .01\% \left[(1+Kcv) \text{ or } \frac{Rx}{Rmax} \text{ or } \frac{Rmin}{Rx}\right] (1+|Q|)\quad(1+Ks+Kfv)+.01\%$$

$$L: .01\% \left[(1+Kcv) \text{ or } \frac{Lx}{Lmax} \text{ or } \frac{Lmin}{Lx}\right] \left(1+\frac{1}{|Q|}\right)\quad(1+Ks+Kfv)+.01\%$$

NOTES:
1. The limit of error is a percent of the reading and may be positive or negative.
2. The largest term of the first bracketed factor should be used.
3. Cx, Rx, and Lx are the values of the components being tested, and Cmax, Cmin, Rmax, etc., are range constants given in Table I below.
4. The values of Ks, Kfv, and Kcv are all zero for measurements made at 1 kHz, with the SLOW measurement rate and using a non-CONSTANT 1-V signal.

For other test conditions, these constants may be evaluated using Tables II through V below.

5. These specifications assume proper OPEN and SHORT zeroing calibrations made at 1 kHz. Much better accuracy is possible at extreme impedance values if these zeroing calibrations are recent and made at the test frequency to be used. For example, the SLOW measurement rate typically will give 1% accuracy when measuring 100 MΩ at 30 Hz, 0.1F at 120 Hz, 0.1 pF at 10 kHz or 0.1μH at 100 kHz. Even better accuracy is possible if several measurements are averaged.
6. Although L measurements on the 1689 and 1689M should be capable of the accuracy stated above, calibrations by the National Bureau of Standards are specified to .02% so that this amount should be added to the 1689 and 1689M specification for inductance measurements if they are to be used in any manner involving legal certification.

LIMIT OF ERROR (ACCURACY) (Cont'd):

SECONDARY READOUT R WITH C:

R (with C); D ≥ 1:

$$1\text{ count} + .01\% \left[(1+Kcv) \text{ or } \frac{Rx}{Rmax} \text{ or } \frac{Rmin}{Rx}\right] \left(1+\frac{1}{|D|}\right)\quad(1+Ks+Kfv)+.01\%$$

R (with C); D < 1:

$$1\text{ count} + .01\% \left[(1+Kcv) \text{ or } \frac{Cx}{Cmax} \text{ or } \frac{Cmin}{Cx}\right] \left(1+\frac{1}{|D|}\right)\quad(1+Ks+Kfv)+.01\%$$

This is a percent of reading specification plus (or minus) 1 count because of resolution. Otherwise, the notes for the primary readout apply.

SECONDARY READOUT D AND Q:

D (with C):

$$.0001 \left[(1+Kcv) \text{ or } \frac{Cx}{Cmax} \text{ or } \frac{Cmin}{Cx}\right] (1+|D|+D^2)\quad(1+Ks+Kfv)+.0001$$

Q (with R):

$$.0001 \left[(1+Kcv) \text{ or } \frac{Rx}{Rmax} \text{ or } \frac{Rmin}{Rx}\right] (1+|Q|+Q^2)\quad(1+Ks+Kfv)+.0001$$

Q (with L):

$$.0001 \left[(1+Kcv) \text{ or } \frac{Lx}{Lmax} \text{ or } \frac{Lmin}{Lx}\right] (1+|Q|+Q^2)\quad(1+Ks+Kfv)+.0001$$

NOTES:
This is not a percent error but rather the amount, positive or negative, by which the D or Q reading may be in error. Otherwise, the notes for the primary readout apply. When using DQ in PPM, the final term of .0001 should be removed.

TABLE I:
Range Constants

	Auto Range	Range Held			
		Range 1*	Range 2	Range 3	Range 4
Cmax	25μF/f	6400 pF/f	100 nF/f	1600 nF/f	25μF/f
Cmin	400 pF/f**	400 pF/f	6.4 nF/f	100 nF/f	1.6μF/f
Rmax	410 kΩ	410 kΩ	25.6 kΩ	1.6 kΩ	100Ω
Rmin	6.25 Ω	25.6 kΩ	1.6 kΩ	0.1 kΩ	6.25 Ω
Lmax	65 H/f**	65 H/f	4100 mH/f	256 mH/f	16 mH/f
Lmin	1 mH/f	4.1 H/f	256 mH/f	16 mH/f	1 mH/f

Where f = test frequency in kHz.
*This range is not used above 20 kHz.
**Above 20 kHz, Cmin = 6.4 nF/f and Lmax = 4100 mH/F.

TABLE II:
Kcv as a Function of Voltage Mode (Constant Voltage)

Voltage Mode	Non-Constant	Constant Voltage
Kcv	0	2

TABLE III:
Ks as a Function of Measurement Rate

Measurement Rate	Slow	Medium	Fast	Maximum*
Ks	0	3	10	23

*Fast measurement with minimum integration time programmed.

TABLE IV:
Kfv as a Function of Frequency and RMS Voltage for Range I

Frequency / Voltage	12 to <30 Hz	30 to <100 Hz	100 to <250 Hz	250 to <1000 Hz	1 kHz	>1 to 3 kHz	>3 to 6 kHz	>6 to 10 kHz	>10 to 20 kHz	>20 to 50 kHz	>50 to 100 kHz
1 to 1.26 V	7	3	2	1	0	2	6	15	50	This range is not used above 20 kHz	
.25 to <1 V	10	6	4	2	1	3	10	20	65		
.1 to <.25 V	20	13	9	6	4	6	15	30	100		
.03 to <.1 V	70	50	35	25	15	17	25	60	*		
.01 to <.03 V	*	*	100	70	50	50	70	*	*		

*Not specified.

TABLE V:
Kfv as a Function of Frequency and RMS Voltage for Range 2, 3, and 4

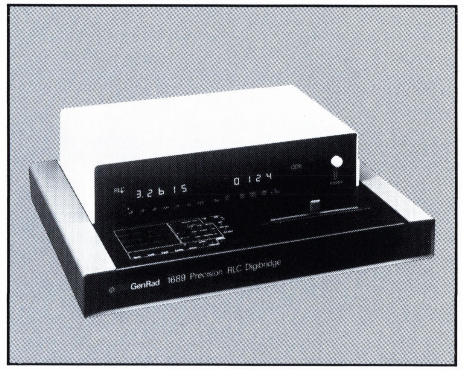
Frequency / Voltage	12 to <30 Hz	30 to <100 Hz	100 to <250 Hz	250 to <1000 Hz	1 kHz	>1 to 3 kHz	>3 to 6 kHz	>6 to 10 kHz	>10 to 20 kHz	>20 to 50 kHz	>50 to 100 kHz
1 to 1.26 V	7	3	2	1	0	1	2	3	5	15	30
.25 to <1 V	9	5	3	2	1	2	3	5	6	18	35
.1 to <.25 V	12	8	6	5	4	5	6	8	10	22	40
.03 to <.1 V	35	30	25	20	14	15	15	15	20	30	50
.01 to <.03 V	90	80	70	60	50	50	50	50	60	70	90

ENVIRONMENT: TEMPERATURE: 0° to 50°C, operating; −40° to 74°C, storage. HUMIDITY: 0 to 85% RH, operating. When the high-speed option is used, the operating temperature range is 0° to 40°C.

TEMPERATURE EFFECTS (TYPICAL): R, L, or C, ±5 ppm/°C; Q or D, ±[2 ppm/°C +(3 ppm/°C)×(frequency in kHz)]. All specifications refer to 23°C (calibration temperature).

POWER: 90 to 125 V, or 180 to 250 V ac, 50 to 60 Hz. Voltage selected by rear panel switch; 50 W max, 40 W typical. When the high-speed option is used, the max power is 60 W.

MECHANICAL: DIMENSIONS (w×h×d): For *1689,* 14.781×4.40×13.50 in. (375.4×111.8×342.9 mm). WEIGHT: 13 lbs (5.9 kg). For *1689M,* 17.25×5.625×15.160 in. (438.15×142.87×385.06 mm). WEIGHT: 17 lbs (7.71 kg).



1689 Precision RLC Digibridge

ORDERING INFORMATION

Description	Order No.
1689 Precision RLC Digibridge	1689-9700
1689M Precision RLC Digibridge	1689-9750
(See pages 30-35 for information on Digibridge accessories.)	

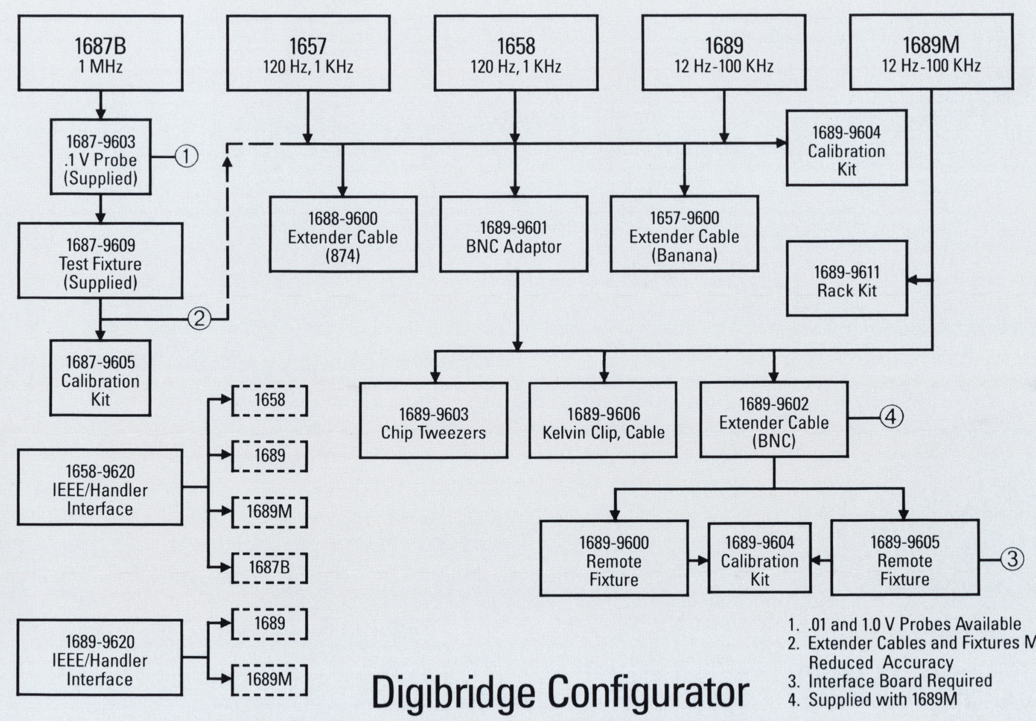
Accessories	Order No.
1689M Rack Mount Kit	1689-9611

DIGIBRIDGE® ACCESSORIES

When you buy GenRad Digibridge® Automatic RLC Testers, you're choosing a family of products that lets you configure a tester for your exact applications.

Use the Digibridge "Configurator" diagram below to configure the system and accessories you need.

These accessories include cables, adaptors, and fixtures for expanding your applications; handler interfaces for volume testing; computer and printer interfaces for hard-copy test results and data manipulation; component tweezers for easy device handling; and calibration kits for fast in-house recalibration.



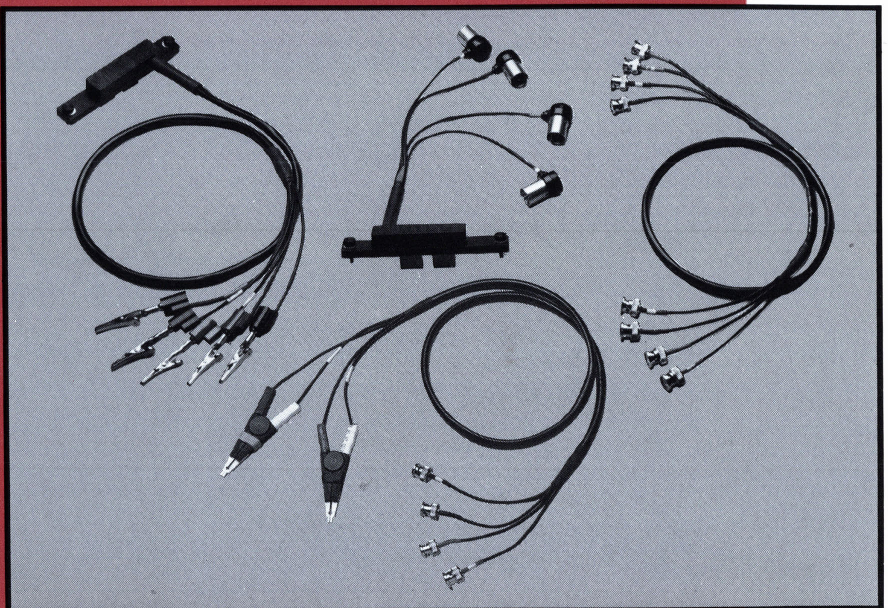
Digibridge Configurator

1. .01 and 1.0 V Probes Available
2. Extender Cables and Fixtures May Be Used with Reduced Accuracy
3. Interface Board Required
4. Supplied with 1689M

DIGIBRIDGE EXTENDER CABLES

Cables for Greater Flexibility and Ease of Testing

- ☐ 1657-9600 Extender Cable
- ☐ 1688-9600 Extender Cable
- ☐ 1689-9602 Extender Cable
- ☐ 1689-9606 Extender Cable



Left to right: 1657-9600 Extender Cable, 1688-9600 Extender Cable, 1689-9602 Extender Cable, and 1689-9606 Extender Cable.

For added flexibility and ease of testing, three GenRad extender cables are available for use with your GenRad Digibridge Automatic RLC Testers. All three cables are designed to maintain four-terminal Kelvin connections to the device under test, and to minimize stray impedances.

1657-9600 Extender Cable. This general-purpose extender cable is three feet long and is terminated in five banana plugs, allowing for four-terminal Kelvin connections and a guard.

Alligator clips are supplied for ease of connection to odd-size components. The cable can also be used for connection to many handlers and custom fixtures.

1688-9600 Extender Cable. This cable is terminated in four shielded GenRad 874 Coaxial Cables and is used to connect to custom fixtures and precision standards.

1689-9602 Extender Cable. This cable consists of four BNC-to-BNC cables. It can be used in conjunction with the 1689-9601 BNC adaptor to make connections to external fixtures or one of the GenRad Digibridge remote fixtures. (The 1689-9602 cable is supplied with the 1689M.)

1689-9606 Extender Cable. (Kelvin Clips) This cable consists of four BNC connectors on one end and Kelvin clips on the other. Kelvin clips provide a means for easily making four terminal connections to passive components.

ORDERING INFORMATION

Description	Order No.
1657 Extender Cable (for use with 1657, 58, 88 & 89)	1657-9600
1688 Extender Cable	1688-9600
1689 Extender Cable	1689-9602
1689 Extender Cable	1689-9606

TO ORDER CALL TOLL-FREE 1-800-772-2220,
IN MASSACHUSETTS 1-617-369-4400 ext.3129

Fixtures for Expanding Your Test Capabilities

- ☐ 1689-9600 Remote Test Fixture
- ☐ 1689-9605 Remote Test Fixture
- ☐ 1687-9609 Remote Test Fixture

GenRad 1689-9600 Remote Test Fixture (above) and 1689-9605 Remote Test Fixture.

To help you get the most from your Digibridge Automatic RLC Testers, three GenRad remote test fixtures are available for use in a variety of applications.

These fixtures will make four-terminal connections directly on most axial or radial-leaded components; can be used to accept GenRad extender cables; and will accept components with wire diameters from .25 mm (AWG 30) to 1 mm (AWG 18), spaced 4 to 98 mm apart.

Each radial lead wire must be 4 mm long. The axial lead adaptors that are supplied with the tester may be used with the remote fixtures and will accept components up to 80 mm long and with a diameter of 44 mm.

GenRad fixtures are guarded, and the tapped holes on each end of the fixtures are grounded to connect to the shields of extender cables.

1689-9600 Remote Test Fixture. Used with all members of the GenRad Digibridge family, this fixture provides added testing flexibility.

Tester-to-fixture interconnection is via a 1689-9601 BNC Adaptor and a 1689-9602 BNC Extender Cable for 1657, 1658, and 1689 testers. No additional cable or adaptor is required with the 1689M.

1689-9605 Remote Test Fixture. For a level of test flexibility and ease of use beyond that of the 1689-9600, select the 1689-9605 Remote Fixture.

This fixture offers all of the remote testing capabilities of the former, plus several additional features that make operation even faster and easier. A START bar quickly and easily initiates measurements, and GO/NO GO indicators facilitate rapid sorting of components.

The tester-to-fixture interconnections are the same as with the 1689-9600, with the additional requirement that the Digibridge Automatic RLC Tester must have an IEEE-488/Handler Interface for operation of the START bar and GO/NO GO indicators.

1687-9609 Remote Test Fixture. This fixture (not shown) allows a variety of Digibridge accessories to be used with a 1687-B, 1-Megahertz LC Digibridge, such as GenRad Extender Cables, BNC Adaptor, and the BNC Adaptor/Chip Component Tweezer combination.

(The 1687-9609 Remote Test Fixture is supplied with the 1687-B.)

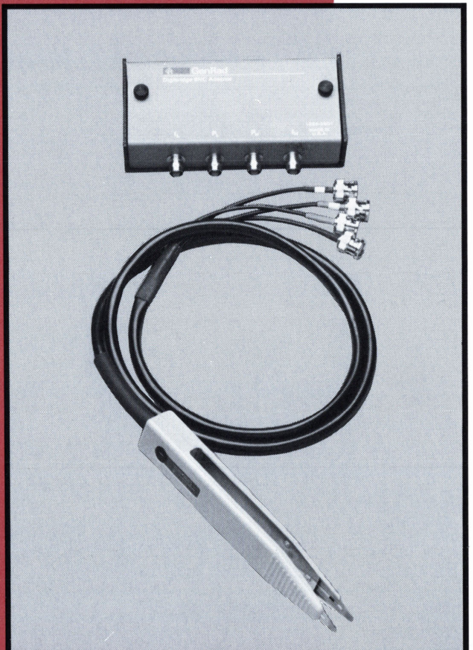
ORDERING INFORMATION

Description	Order No.
1689 Remote Test Fixture	**1689-9600**
1689 Remote Test Fixture	**1689-9605**
1687 Remote Test Fixture (included with 1687-B)	**1687-9609**
Replacement Axial-Lead Test Clips (pkg. of 4)	**1657-5995**

BNC ADAPTOR AND CHIP COMPONENT TWEEZERS

Adaptor and Tweezers for Fast, Easy Testing

- ☐ 1689-9603 Chip Component Tweezers
- ☐ 1689-9601 BNC Adaptor



GenRad 1689-9601 BNC Adaptor (above) and 1689-9603 Chip Component Tweezers

GenRad 1689-9603 Chip Component Tweezers let your operators easily handle a wide variety of devices, including SMDs, helping to keep test time and labor at a minimum.

With the GenRad 1689-9601 BNC Adaptor, you can use the wide range of GenRad Digibridge accessories to expand test capabilities, increase your flexibility, and keep throughput high.

1689-9603 Chip Component Tweezers. Our durable, reliable Chip Component Tweezers let you efficiently handle small, unleaded "chip" components while using your GenRad Digibridges.

The tweezers are used for handling chip components and surface mount devices (SMDs) and for making electrical connections to the components. Connection between the tweezers and the 1689M is direct via the attached BNC cable. Connection to the 1657, 1658, 1687-B, and 1689 requires a 1689-9601 BNC Adaptor.

Four-terminal Kelvin connections are maintained to the tweezer tips, where the measurement becomes two-terminal. The tweezers are shielded down to the tips to minimize capacitance between terminals, and the gold-plated tips are easily removed for cleaning or replacement.

The tweezers weigh 6 ounces and the tweezer body is 6 inches in length. The attached cable is 4 feet long. Capacitance between the tips is typically less than 1 pF at .1 inch spacing, and the maximum spacing between the tips is one-half inch.

1689-9601 BNC Adaptor. The BNC Adaptor converts the built-in test fixture of the 1657, 1658, 1689, and remote Digibridge fixtures into four BNC connectors for connection to various adaptors and fixtures.

The adaptor is necessary to support most Digibridge options, such as remote fixtures and the chip tweezers.

ORDERING INFORMATION

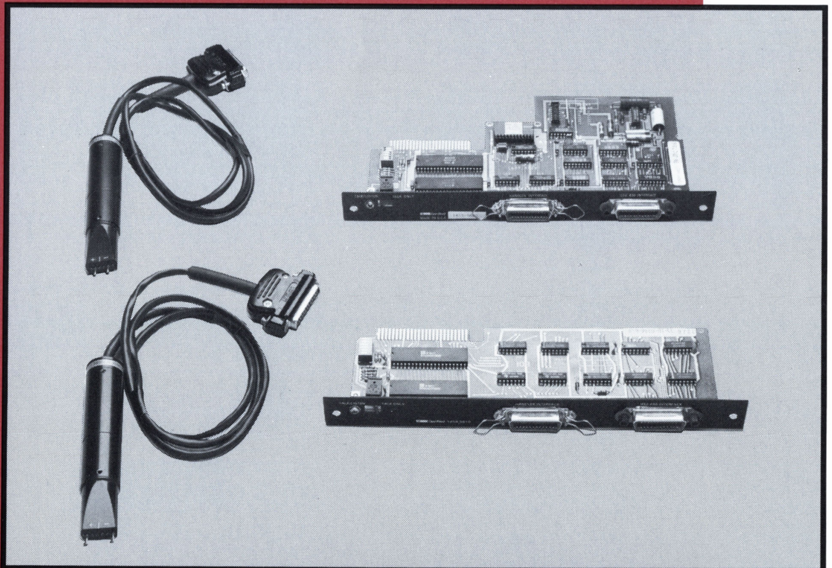
Description	Order No.
BNC Adaptor	1689-9601
Chip Component Tweezers	1689-9603
Replacement Tweezer Tips (pkg. of 4)	1689-9503

TO ORDER CALL TOLL-FREE 1-800-772-2220,
IN MASSACHUSETTS 1-617-369-4400 ext.3129

MEASUREMENT PROBES AND IEEE-488/HANDLER INTERFACES

Versatility That's Easy to Add

- ☐ 1689-9620 High-Speed Interface
- ☐ 1658-9620 Interface
- ☐ 1687 Measurement Probes



Clockwise from upper left: 1.0 V Measurement Probe, 1689-9620 High-Speed Interface, 1658-9620 Interface, and the 0.01 V Measurement Probe.

Two GenRad IEEE-488/Handler Interfaces and three measurement probes are available for GenRad Digibridge Automatic RLC Testers. Adding these accessories is fast, easy, and inexpensive.

The IEEE-488/Handler Interfaces provide IEEE-488 interfacing for remote control and data output to computers and printers, and handler interfacing with automatic component handlers and sorters. An interface board is easily installed through the rear panel of a GenRad Digibridge Automatic RLC Tester (not applicable to the 1657).

1689-9620 High-Speed Interface. This interface is used with the 1689 and the 1689M Precision RLC Digibridges to provide an IEEE-488/Handler interface, and to provide for the high-speed measurement capabilities of the instrument.

With this option, the 1689M is capable of making up to 50 measurements per second. The 1689-9620 also allows for the sorting of components into 15 bins.

1658-9620 Interface. Used with the 1658, 1687-B, 1689, and the 1689M, this interface supports the IEEE-488 interfacing to automatic handlers or component sorters, and allows for sorting into 10 bins.

Measurement Probes. Three GenRad probes are available for the 1687-B: the 1687-9607 0.01 V Measurement Probe, the 1687-9603 0.1 V Measurement Probe, and the 1687-9604 1.0 V Measurement Probe.

The 0.1 V probe (not shown) is supplied with the 1687-B while 1 V and 0.01 V probes are available if these voltages are required. These probes connect directly to the 1687-B via the attached cable.

ORDERING INFORMATION

Description	Order No.
High-Speed Measurement & IEEE/ Handler Interface	1689-9620
IEEE/Handler Interface	1658-9620
.01 Volt Measurement Probe	1687-9607
0.1 Volt Measurement Probe	1687-9603
1.0 Volt Measurement Probe	1687-9604

TO ORDER CALL TOLL-FREE 1-800-772-2220,
IN MASSACHUSETTS 1-617-369-4400 ext.3129

DIGIBRIDGE CALIBRATION KITS

Calibration Kits for Maintaining Your Instrument Accuracy

- ☐ 1687-9605 Calibration Kit
- ☐ 1689-9604 Calibration Kit

GenRad 1687-9605 and 1689-9604 Calibration Kits

Two self-contained GenRad calibration kits are offered for the GenRad Digibridge family of automatic RLC testers. With them, accuracy and reliability of testers can be maintained with minimum effort.

These kits provide complete, reliable, accurate recalibration for the 1689, 1689M, and the 1687-B. With these kits, total instrument recalibration is accomplished within minutes. The standards used in these kits are NBS traceable.

1687-9605 Calibration Kit. The 1687-9605 Calibration Kit is used to recalibrate the 1687-B 1-Megahertz LC Digibridge.

The kit consists of a GenRad 900 Reference Standard Adaptor, a precision open circuit termination, a precision short circuit termination, a GenRad 1406 100 pF Coaxial Capacitance Standard, and a certificate of calibration.

A sturdy, convenient GenRad carrying case protects the kit in storage and travel.

1689-9604 Calibration Kit. The 1689-9604 Calibration Kit is used to recalibrate the 1689 and 1689M.

The kit consists of four resistors, a precision open circuit, and a precision short circuit. A calibration chart is provided with the recorded R and Q of each resistor.

A sturdy, convenient carrying case protects the kit in storage and travel.

SPECIFICATIONS

NOMINAL VALUES: R1, 95.3 kΩ; R2, 5.97 kΩ; R3, 374 Ω; R4, 24.9 Ω.

ACCURACY: 0.1% of nominal value.

STABILITY: Better than 25 ppm per year.

TEMPERATURE COEFFICIENT: 2ppm/°C.

CALIBRATION ACCURACY: These resistors are compared with a precision of 5 ppm to working standards whose absolute values are known to 10 ppm, as determined from reference standards periodically measured by the National Bureau of Standards. The 1 kHz Q values are in parts-per-million and are based on the D values of GenRad 1404 capacitors, which have been shown to be less than 5 ppm, and the assumption that the difference between the inductance of a low-valued composition resistor and a wire of the same geometry is negligible. These Q values should be within 25 ppm at 1 kHz. All calibrations are made at 23° ±2°C. The standards plug directly into the internal fixture of the 1689. The 1689M requires a 1689-9600 or a 1689-9605 remote fixture.

ORDERING INFORMATION

Description	Order No.
1687 Calibration Kit	1687-9605
1689 Calibration Kit	1689-9604

CAPACITANCE STANDARDS AND DECADES

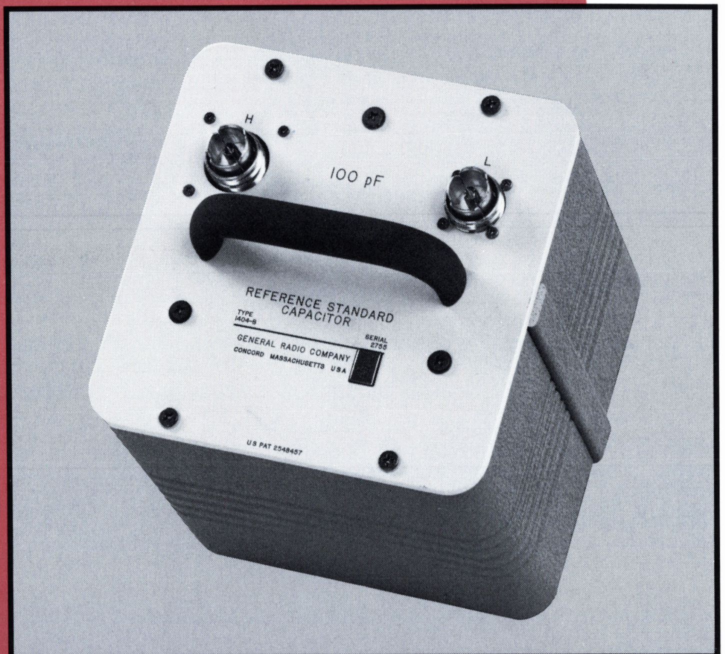
GenRad's capacitance standards and decades employ a variety of time-tested materials and technologies that are tailored to specific applications and environments. The capacitance standards and decades are:

1404 Reference Standard Capacitor
1409 Standard Capacitors
1422 Precision Capacitors
1412-BC Decade Capacitor
1413 Precision Decade Capacitor
1423-A Precision Decade Capacitor
1417 Four-Terminal Capacitance Standard

1404 REFERENCE STANDARD CAPACITOR

A Primary Reference Standard of Capacitance

- ☐ Hermetically sealed in dry nitrogen for long-term stability – drift less than 20 ppm/year
- ☐ Values of 10, 100, 1000 pF
- ☐ 3-terminal, coaxial connections



The GenRad 1404 Reference Standard Capacitor is the primary reference standard of capacitance with which working standards can be accurately compared.

The 1615-A Capacitance Bridge is particularly well suited for this purpose and can be conveniently used to calibrate accurately a wide range of working standards in terms of the 1404 Reference Standard Capacitor. A single 1000- or 100-picofarad standard is also the only standard necessary to calibrate the bridge itself.

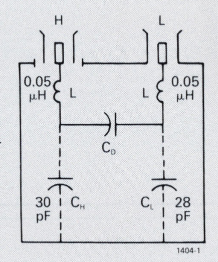
In combination with an accurately known external resistor, this capacitor becomes a standard of dissipation factor.

Stability

To ensure stability and low-temperature coefficient, all critical plate-assembly components are made of Invar. The assembly is mounted in a heavy brass container, filled with dry nitrogen under pressure slightly above atmospheric, and sealed. Each capacitor is subjected to a series of temperature cycles to determine hysteresis and temperature coefficient and to stabilize the capacitance.

Two locking GenRad 874 Coaxial Connectors are used as terminals. The outer shell of one is connected to the case, but the outer shell of the other is left unconnected to permit the capacitor to be used with an external resistor as a dissipation-factor standard.

Equivalent circuit showing direct capacitance, C_D, and average values of residual inductance, L, and terminal capacitances, C_H and C_L. C_D = 1000 pF for 1404-A, 100 pF for 1404-B, and 10 pF for 1404-C.



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1404 REFERENCE STANDARD CAPACITOR (Cont'd)

SPECIFICATIONS

CALIBRATION: A certificate of calibration is supplied with each capacitor, giving the measured direct capacitance at 1 kHz and at 23° ±1°C. The measured value is obtained by a comparison to a precision better than ±1 ppm with working standards whose absolute values are known to an accuracy of ±5 ppm, determined and maintained in terms of reference standards periodically measured by the National Bureau of Standards.

ADJUSTMENT ACCURACY: The capacitance is adjusted before calibration, with an accuracy of ±5 ppm, to a capacitance about 5 ppm above the nominal value relative to the capacitance unit maintained by the General Radio reference standards.

STABILITY: Long-term drift is less than 20 ppm per year. Maximum change with orientation is 10 ppm and is completely reversible.

TEMPERATURE COEFFICIENT OF CAPACITANCE: 2 ±2 ppm/°C for 1404-A and -B, 5 ±2 ppm/°C for 1404-C, from −20°C to +65°C. A measured value with an accuracy of ±1 ppm/°C is given on the certificate.

TEMPERATURE CYCLING: For temperature cycling over range from −20°C to +65°C, hysteresis (retraceable) is less than 20 ppm at 23°C.

DISSIPATION FACTOR: Less than 10^{-5} at 1 kHz.

RESIDUAL IMPEDANCES: See equivalent circuit for typical values of internal series inductances and terminal capacitances.

MAX VOLTAGE: 750 V.

TERMINALS: Two locking GenRad 874 Coaxial Connectors; easily convertible to other types of connectors by attachment of locking adaptors. Outer shell of one connector is ungrounded to permit capacitor to be used with external resistor as a dissipation-factor standard.

MECHANICAL: Lab-bench cabinet. DIMENSIONS (w×h×d): 6.75×6.63×8 in. (172×169×204 mm). WEIGHT: 8.5 lb (3.9 kg) net, 14 lb (6.4 kg) shipping.

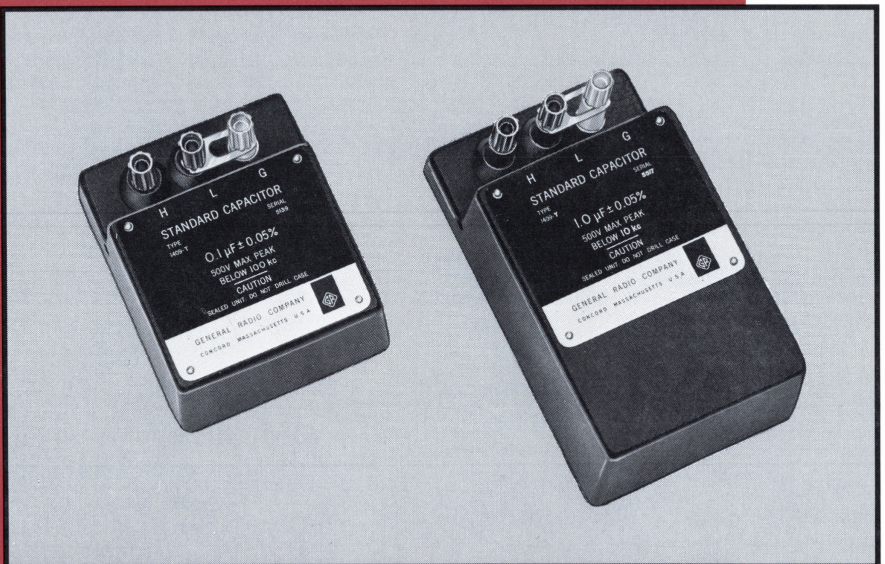
ORDERING INFORMATION

Description	Order No.
Reference Standard Capacitor	
1404-A, 1000 pF	**1404-9701**
1404-B, 100 pF	**1404-9702**
1404-C, 10 pF	**1404-9703**

1409 STANDARD CAPACITORS

Reference or Working Standards with Long-Term Stability

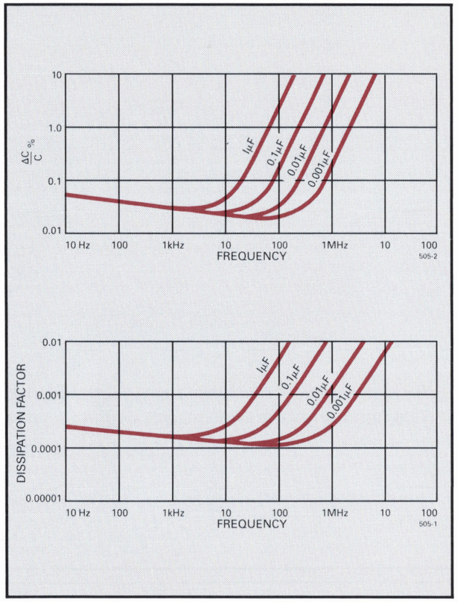
☐ Stability at ±.01%/year
☐ Calibration accuracy of ±0.02%
☐ Values of 0.001 to 1 μF



GenRad 1409-T and 1409-Y Standard Capacitors

The GenRad 1409 Standard Capacitors are fixed mica capacitors of very high stability for use as two- or three-terminal reference or working standards in the laboratory.

Typical capacitors, observed over more than fifteen years, have shown random fluctuations of less than ±0.01% in measured capacitance with no evidence of systematic drift.



(Above) Change in capacitance as a function of frequency for typical 1409 Capacitors. The 1-kHz value on the plot should be used as a basis of reference in estimating frequency errors. (Below) Dissipation factor as a function of frequency.

A Precision Design

The capacitors consist of a silvered-mica and foil pile, spring-held in a heavy metal clamping structure for mechanical stability. The units are heat cycled for stability, placed in a cast aluminum case with silica gel for continuous desiccation, and sealed with high-temperature potting compound.

A well is provided in the wall of the case for inserting a dial-type thermometer. Three jack-top binding posts are provided on the top of the case, with removable plugs on the bottom, for convenient parallel connection without error.

Continued on the next page.

1409 STANDARD CAPACITORS (Cont'd)

SPECIFICATIONS

ADJUSTMENT ACCURACY: Within ±0.05% of the nominal capacitance value (two-terminal) marked on the case.

CALIBRATION: A certificate of calibration is supplied with each unit, giving both two- and three-terminal measured capacitances at 1 kHz and at a specified temperature. The measured value is the capacitance added when the standard is plugged directly into General Radio binding posts. This value is obtained by comparison, to a precision better than ±0.01%, with working standards whose absolute values are known to an accuracy typically ±0.01%, determined and maintained in terms of reference standards periodically calibrated by the National Bureau of Standards.

STABILITY: Capacitance change is less than 0.01% per year.

TEMPERATURE COEFFICIENT OF CAPACITANCE: +35 ± 10 ppm/°C between 10° and 70°C.

DISSIPATION FACTOR: Less than 0.0003 at 1 kHz and 23°C (see curves). Measured dissipation factor at 1 kHz is stated in the certificate to an accuracy of ±0.00005.

SERIES INDUCTANCE: Typically 0.050 μH for 1409-F and -L, 0.055 μH for -T and -Y.

SERIES RESISTANCE AT 1 MHz: 0.02 Ω, except for 1409-Y, which is 0.03 Ω.

FREQUENCY CHARACTERISTICS: See curves. Series resistance varies as the square root of the frequency, for frequencies above 100 kHz.

APPROX TERMINAL CAPACITANCE: From H terminal to case (G), 12 to 50 pF. From L terminal (outside foils of capacitor) to case, 300 to 1300 pF.

LEAKAGE RESISTANCE: 5000 ohm-farads or 100 GΩ, whichever is the lesser.

MAX VOLTAGE: 500 V pk up to 10 kHz.

MECHANICAL: Sealed case. DIMENSIONS (w × h × d): 1409-Y, 3.25 × 5.63 × 2.69 in. (83 × 143 × 69 mm); others, 3.25 × 4 × 2 in. (83 × 102 × 51 mm). WEIGHT: 1.25 lb (0.6 kg) net, 4 lb (1.9 kg) shipping; the 1409-Y is heavier by approx 1 lb (0.5 kg).

1409 Standard Capacitor

Type	Nominal Capacitance μF
1409-F	0.001
1409-L	0.01
1409-T	0.1
1409-Y	1.0

ORDERING INFORMATION

Description	Order No.
Standard Capacitor	
1409-F	1409-9706
1409-L	1409-9712
1409-T	1409-9720
1409-Y	1409-9725

1422 PRECISION CAPACITORS

Low-loss Variable Air Capacitors

- ☐ Better than .02% stability, full scale per year
- ☐ Wide range of models to meet your exact needs
- ☐ Settable to 40 ppm

The GenRad 1422 Precision Capacitor is a stable, precise, variable-air capacitor designed as a continuously adjustable standard of capacitance.

One of its most important applications is in ac bridge measurements, either as a built-in standard or as an external standard for substitution measurements. It is available in a variety of ranges, terminal configurations, and scale arrangements to permit selection of precisely the required characteristics.

Range of Models

With a range of models and scale arrangements to choose from, the 1422 is available in the configuration and at the performance level you need.

The 1422-D is a dual-range, two-terminal capacitor with direct readings in total capacitance at the terminals.

The 1422-CB and CL are three-terminal capacitors with shielded coaxial terminals for use in three-terminal measurements. The 1422-CL has particularly low, constant terminal capacitances, making it suitable for measurement circuits in which high capacitance to guard cannot be tolerated.

Calibrated Accuracy

The errors tabulated in the specifications are possible errors, i.e., the sum of error contributions from setting, adjustment, calibration, interpolation, and standards. When the capacitor is in normal position with the panel horizontal, the actual errors are almost always smaller. The accuracy is improved when the readings are corrected using the 12 calibrated values of capacitance given on the correction chart on the capacitor panel and interpolating linearly between calibrated points. Even better accuracy can be obtained from a precision calibration of approximately 100 points on the capacitor dial, which permits correction for slight residual eccentricities of the worm drive and requires interpolation over only short intervals. This precision calibration is available, at an extra charge, for models listed with the additional suffix letter P, in the type number.

Continued on the next page.

1422 PRECISION CAPACITORS (Cont'd)

SPECIFICATIONS

ACCURACY: See table.

STABILITY: Capacitance change with time <1 scale division (0.02% of full scale) per year. Long-term accuracy can be estimated from the stability and the initial accuracy.

CALIBRATION: Measured values (supplied) are obtained by comparision at 1 kHz, with working standards whose absolute values are known to an accuracy of ±(0.01% + 0.0001 pF). Each comparison is made to a precision better than ±0.01%. The values of the working standards are determined and maintained in terms of reference standards periodically calibrated by the National Bureau of Standards.

RESOLUTION: Dial can be read and set to 1/5 of a small division, i.e., to 0.004% of full scale. BACKLASH: Negligible for any setting reached consistently from lower scale readings; <0.004% of full scale, for settings reached from alternate directions.

TEMPERATURE COEFFICIENT: Approx +20 ppm/°C, for small temperature changes.

RESIDUAL PARAMETERS: See table. Series resistance varies as $\sqrt{f}$, for f> 100 kHz; negligible for f< 100 kHz.

FREQUENCY CHARACTERISTICS: Two-terminal model, see curve. Three-terminal models: 20, 40, and 60 MHz (approx) resonant frequency for 1422-CB and -CL.

DISSIPATION FACTOR: Two-terminal, loss primarily in stator supports of low-loss polystyrene (the product DC≈10^{-14}). Three-terminal, estimated D<20×10^{-6}. INSULATION RESISTANCE: >$10^{12}\Omega$, under standard conditions (23°C, RH<50%).

MAX VOLTAGE: 1000 V pk (all models).

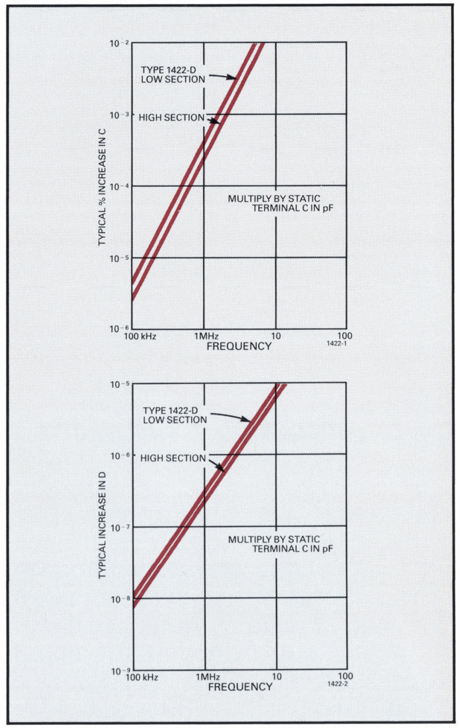
TERMINALS: 2-terminal model, jack-top binding posts at standard (0.75-in.) spacing. Rotor terminal connected to panel and shield. 3-terminal model, locking 874 type connection.

MECHANICAL: Lab-bench cabinet. DIMENSIONS (w × h × d): 9.5 × 7 × 8.5 in. (242 × 178 × 216 mm). WEIGHT (depending on model): 10.5 to 12.5 lb (4.8 to 5.7 kg) net, 15 lb (7 kg) shipping.

1422 Precision Capacitors

		Two-Terminal		Three-Terminal	
Type 1422		-D		-CB	-CL
Capacitance Range, pF	Min	100	35	50	10
	Max	1150	115	1100	110
Scale, pF/Division:		0.2	0.02	0.2	0.02
Initial Accuracy: ± Picofarads Direct-Reading (Adjustment): Total Capacitance		1.5*	0.3*	1.5*	0.1
With Corrections from Calibration Chart (supplied): Total Capacitance		N/A	N/A	N/A	0.04
With Corrections from Precision Calibration (extra charge): Total Capacitance		N/A	N/A	N/A	0.01
Residuals (typical values): Series Inductance, μH		0.06	0.10	0.14	0.13
Series Resistance, ohms at 1 MHz		0.04	0.05	0.1	0.1
Terminal Capacitance, pF, typical:	high terminal to case	min scale		36	34
		max scale		35	33
	low terminal to case	min scale		58	58
		max scale		53	55

* Total capacitance is the capacitance added when the capacitor is plugged into a 777-Q3 Adaptor.



Variation with frequency of effective capacitance and dissipation factor per pF of capacitance for two-terminal 1422 Precision Capacitors.

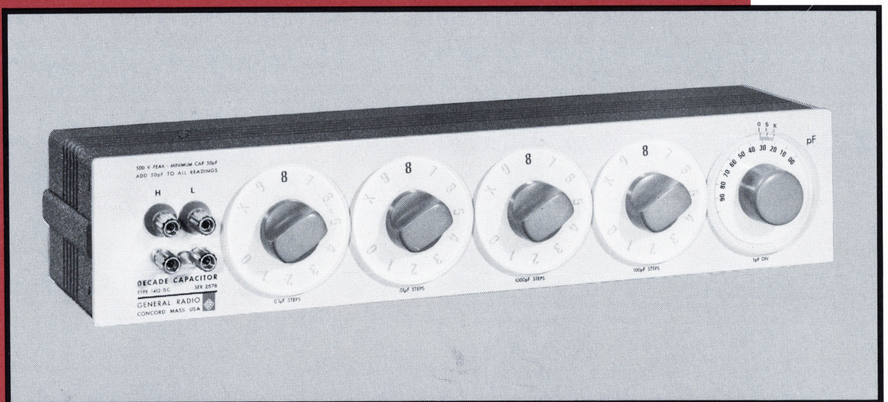
ORDERING INFORMATION

Description	Order No.
Precision Capacitors	
with precision calibration (≈ 100 points)	
1422-CLP	**1422-9508**
with standard calibration (12 points)	
1422-D	**1422-9704**
1422-CB	**1422-9916**
1422-CL	**1422-9933**

1412-BC DECADE CAPACITOR

A Stable Polystyrene Decade Capacitor

- ☐ Accuracy ±(0.5% plus 5 pF) for total capacitance
- ☐ Low loss, low leakage, and low dielectric absorption for accurate measurements
- ☐ Better than 1-pF resolution with continuous adjustment dial



The wide capacitance range and high resolution of the GenRad 1412-BC Decade Capacitor make it exceptionally useful in both laboratory and test shop. Owing to its fine adjustment of capacitance, it is a convenient variable capacitor to use with the 1654 Impedance Comparator. The polystyrene dielectric used in the decade steps is necessary for applications requiring low dielectric absorption and constancy of both capacitance and dissipation factor with frequency.

Four decades of polystyrene capacitors and a variable air capacitor are used, mounted in a double-shield box. The double-shielding provides two-terminal and three-terminal capacitances that are the same except for the capacitance between the terminals. The variable air capacitor with a linear ΔC of 100 pF and a resolution of better than 1 pF provides continuous adjustment between the 100-pF steps of the smallest decade.

Continued on the next page.

TO ORDER CALL TOLL-FREE 1-800-772-2220,
IN MASSACHUSETTS 1-617-369-4400 ext.3129

1412 DECADE CAPACITOR (Cont'd)

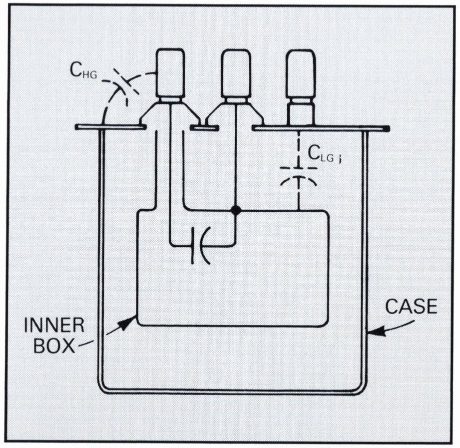
SPECIFICATIONS

CAPACITANCE: 50 pF to 1.11115 μF in steps of 100 pF, with a 0- to 100-pF variable air capacitor providing continuous adjustment with divisions of 1 pF. Capacitances for 2- and 3-terminal connections differ by about 1 pF (C_{HG} in the drawing). C_{LG} is approx 125 pF.

MIN CAPACITANCE: 50 pF with all controls set at zero.

DIELECTRIC: Polystyrene for decade steps.

ACCURACY: ±(0.5% + 5 pF) at 1 kHz for total capacitance including 50-pF minimum for the 3-terminal connection.



The double shielding used in the 1412-BC Decade Capacitor keeps C_{HG} very small. This capacitance is the difference between the 3-terminal and 2-terminal capacitance of the box; C_{LG} is approx 125 pF.

TEMPERATURE COEFFICIENT: −140 ppm/°C (nominal).

FREQUENCY CHARACTERISTICS: DC Cap/ 1-kHz Cap <1.001. At higher frequencies, the increase is approx $\Delta C/C = (f/f_r)^2$. The resonant frequency, f_r, varies from over 400 kHz for a capacitance of 1 μF to about 27 MHz for a capacitance of 150 pF when connections are made to the front terminals. f_r is about 300 kHz and 70 MHz for rear connections and the same capacitances.

MAX OPERATING TEMPERATURE: 65°C.

DIELECTRIC ABSORPTION (Voltage Recovery): 0.1% max.

DISSIPATION FACTOR: 150 to 1000 pF, 0.001 max, at 1 kHz; over 1000 pF, 0.0002 max, at 1 kHz.

INSULATION RESISTANCE: 10^{12} ohms min.

MAX VOLTAGE: 500 V peak, up to 35 kHz.

TERMINALS: Four 938 Binding Posts with grounding link are provided on the panel. Two of the binding posts are connected to the case and located for convenient use with patch cords in 3-terminal applications. Access is also provided to rear terminals for relay-rack applications.

MECHANICAL: Lab-bench cabinet; brackets provided for rack mounting. DIMENSIONS (w × h × d): 17.25 × 3.5 × 6 in. (439 × 89 × 153 mm). WEIGHT: 8.5 lb (3.9 kg) net, 10 lb (4.6 kg) shipping.

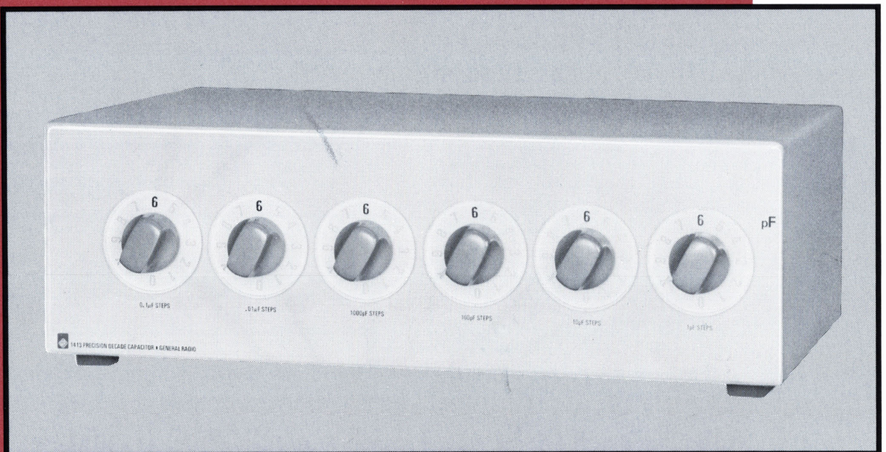
ORDERING INFORMATION

Description	Order No.
1412-BC Decade Capacitor	1412-9410

1413 PRECISION DECADE CAPACITOR

Flexibility as a Self-Contained Decade Calibrator or Systems Component

- ☐ Basic accuracy of ±(0.05% plus 0.5 pF)
- ☐ 6-digit resolution for accurate measurements
- ☐ 3-terminal connections for accuracy
- ☐ BCD output capability for connection to other instruments



We've designed special flexibility into the GenRad 1413 Precision Decade Capacitor, giving you not only a precision standard, but a systems component as well. It is ideally suited for use with the GenRad 1654 Impedance Comparator. Each decade also provides contact closures for 1-2-4-8 BCD output.

Six precision decades provide a range of 0 to 1.11111 μF in increments as small as 1 pF. Air capacitors are used for the two lower decades, and precision silvered-mica capacitors are used for the remaining four.

The lower four decades contain adjustments that are factory-set but accessible for readjustment later if desired.

The shielding is divided into two parts, arranged to provide low terminal-to-guard capacitances and low detector input capacitance in order to reduce errors with the 1654. When the two shields are connected together, the 1413 becomes a well-shielded, three-terminal capacitor with an extremely low zero capacitance, suitable for a variety of applications.

Continued on the next page.

1413 PRECISION DECADE CAPACITOR (Cont'd)

SPECIFICATIONS

RANGE: 0 to 1.11111 μF, controlled by six in-line readout dials.

ACCURACY: ±(0.05% + 0.5 pF) at 1 kHz.

STABILITY: ±(0.01% +0.1 pF) per year. TEMPERATURE COEFFICIENT: ≈20 ppm/°C from 10° to 50°C.

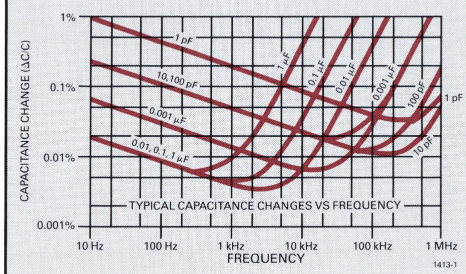
ZERO CAPACITANCE: ≤0.1 pF.

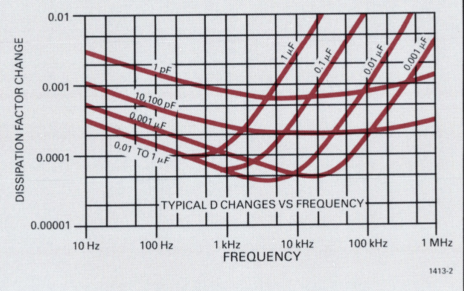
VOLTAGE RATING: 500 V pk max up to 10 kHz.

FREQUENCY: See curves.

	1 pF to 100 pF	101 pF to 1000 pF	1001 pF to 2000 pF	2001 pF to 0.1 μF	0.1 μF to 1.11111 μF
Dissipation Factor, max at 1kHz	0.002	0.001	0.0005	0.0003	0.0004
Insulation Resistance, 3 term., after 2 min at 500 V dc	≥5 × 10^{10}Ω				≥5 × 10^{9}Ω
Terminal Capacitance, max high to case high to guard low to guard	4 pF 85 pF 45 pF	8 pF 110 pF 70 pF	10 pF 125 pF 80 pF	30 pF 165 pF 110 pF	60 pF 200 pF 120 pF

1413 Precision Decade Capacitor





INTERFACE: CONNECTIONS: 2 rear-mounted GenRad 874 Locking Connectors. DATA OUTPUT: 36-pin Amphenol Type 57 Connector provides connections to 1-2-4-8 weighted BCD contacts rated at 28 V, 1 A, on each decade switch.

AVAILABLE: 4220-3036 Connector to mate with Data Output Connector.

MECHANICAL: Convertible-bench cabinet. DIMENSIONS (w × h × d): Bench, 17 × 5.59 × 11.96 in. (432 × 142 × 304 mm); rack, 19 × 5.22 × 10.9 in. (483 × 133 × 277 mm). WEIGHT: Bench, 23 lb (11 kg) net, 29 lb (14 kg) shipping; rack, 24 lb (11 kg) net, 30 lb (14 kg) shipping.

ORDERING INFORMATION

Description	Order No.
1413 Precision Decade Capacitor	
Bench Model	1413-9700
Rack Model	1413-9701

1423-A PRECISION DECADE CAPACITOR

Ideal for Both Laboratory Calibrations and Production Test

- ☐ Accuracy ±(0.05% plus 0.05 pF)
- ☐ 2- or 3-terminal connections
- ☐ Double-shielded construction

With the GenRad 1423-A Precision Decade Capacitor, a bridge can be standardized to an accuracy that's exceeded only by the highest quality, individually certified laboratory standards, such as the GenRad 1404 Reference Standard Capacitor.

When used with a limit bridge, such as the GenRad 1654 Impedance Comparator, the 1423 provides accurate production-line measurements of arbitrary capacitance values. And its setup time is minimal.

Any value of capacitance from 100 pF to 1.111 μF, in steps of 100 pF, can be set on the four decades and will be known to an accuracy of 0.05%. The terminal capacitance values are set precisely to the nominal value and can be readjusted later at calibration intervals, if necessary, without disturbance of the main capacitors.

The 1423 consists of four decades of silvered-mica capacitors, similar to the GenRad 1409 Standard Capacitor. Double-shielded construction ensures that capacitance at the terminals is virtually the same for both two-terminal and three-terminal connections.

Continued on the next page.

1423-A PRECISION DECADE CAPACITOR (Cont'd)

SPECIFICATIONS

NOMINAL VALUES: 100 pF to 1.111 μF in steps of 100 pF.

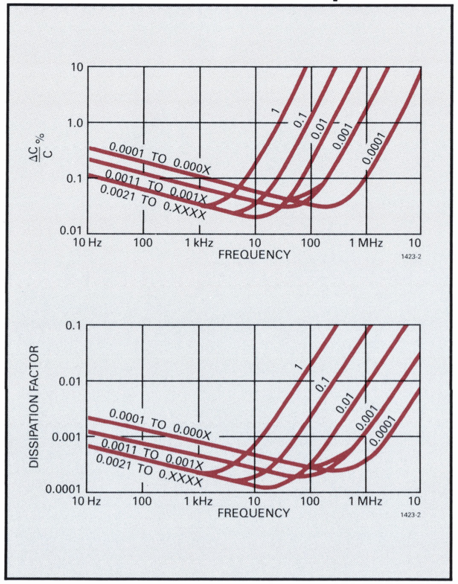
ACCURACY: ±(0.05%+0.05pF) at 1 kHz, calibrated in the three-terminal connection. Two-terminal connection adds about 1.3 pF.

STABILITY: ±(0.01% + 0.05pF) per year.

CERTIFICATE: A certificate is supplied certifying that each component capacitor was adjusted by comparison, to a precision better than ±0.01%, with working standards, whose absolute values are known to an accuracy typically ±0.01%, determined and maintained in terms of reference standards periodically calibrated by the National Bureau of Standards.

FREQUENCY: See curves for typical variation of capacitance and dissipation factor with frequency.

1423-A Precision Decade Capacitor



(Top) Change in capacitance as a function of frequency. These changes are referred to the values that the capacitors would have if there were neither interfacial polarization nor series inductance. The 1-kHz value on the plot should be used as a basis of reference in estimating frequency errors. (Bottom) Dissipation factor as a function of frequency.

DISSIPATION FACTOR: Not greater than 0.001, 0.0005, and 0.0003 for capacitances of 100 to 1000 pF, 1100 to 2000 pF, and 2100 pF to 1.1110 μF, respectively.

TEMPERATURE COEFFICIENT OF CAPACITANCE: Approx +20 ppm/°C between 10° and 50°C.

INSULATION RESISTANCE: >5×10[10] Ω to 0.1 μF and >5×10[9] Ω from 0.1 μF to 1.111 μF.

MAXIMUM VOLTAGE: 500 V peak, up to 10 kHz.

MECHANICAL: Rack-bench cabinet. DIMENSIONS (w×h×d): Bench, 19×7.25×10.5 in. (483×184×267 mm); rack, 19×7×8.5 in. (483×178×216 mm). WEIGHT: 26 lb (12 kg) net, 39 lb (18 kg) shipping.

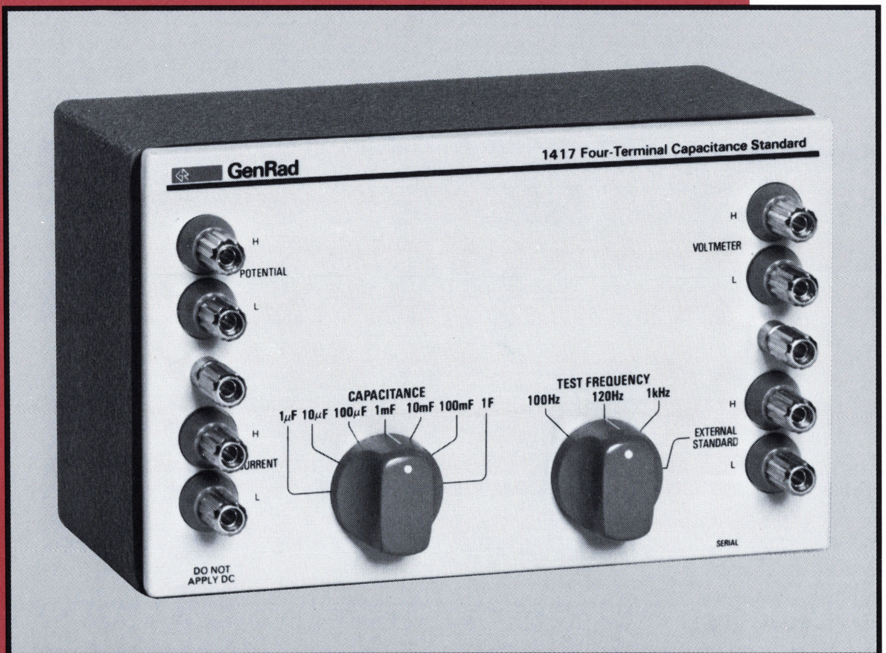
ORDERING INFORMATION

Description	Order No.
1423-A Precision Decade Capacitor	
Bench Model	1423-9801
Rack Model	1423-9811

1417 FOUR-TERMINAL CAPACITANCE STANDARD

Provides a Wide Range of Capacitance

- ☐ Basic capacitance accuracy of 0.25%
- ☐ Range from 1 μF to 1 F in decade steps, to meet your exact needs
- ☐ Can be used as a standard of dissipation factor
- ☐ Can calibrate popular universal or RLC bridges for even greater versatility



The GenRad 1417 Four-Terminal Capacitance Standard consists of a 1 μF standard capacitor and two precise inductive voltage dividers, which scale the value of the capacitor up to 1 F in decade steps.

This unique design accounts for the 1417's unmatched accuracy and stability, a level of performance you simply can't find in any comparably priced standard, including high-value true capacitors.

By using external capacitors, an infinite number of intermediate or high capacitance values can be obtained in addition to the 1417's seven direct-reading capacitance values.

Accuracy and Versatility

The direct-reading accuracy of the instrument is ±0.25% plus the associated ratio accuracy at test frequencies of 100 Hz, 120 Hz, or 1000 Hz. Since the 1417 scaling ratios are precise and repeatable, better accuracy can be obtained by measuring the actual value of the internal 1 μF standard or of an external standard before scaling.

The 1417 also serves as a standard of dissipation factor (D). The dissipation factor of the 1417 is intentionally set to 0.01 at test frequencies of 100, 120, and 1000 Hz. Basic D accuracy is ±0.001.

The 1417 may also be used as a two-terminal capacitance standard when higher D values can be tolerated. In a two-terminal configuration, D is less than 1 for capacitance values up to 1000 μF at frequencies below 150 Hz. This feature allows the 1417 to be used in calibrating the higher capacitance ranges of popular universal or RLC bridges.

Continued on the next page.

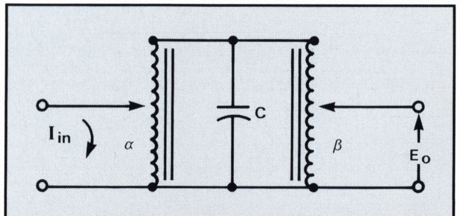
1417 FOUR-TERMINAL CAPACITANCE STANDARD (Cont'd)

SPECIFICATIONS

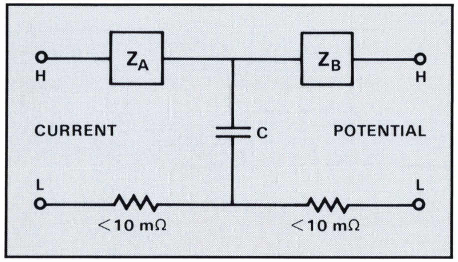
Capacitance Value (Internal Standard)	Ratio Accuracy		D Accuracy		Approximate Terminal Impedance		E Max* AC (V)
	100 & 120 Hz	1 kHz	100 & 120 Hz	1 kHz	ZA (Ω)	ZB (Ω)	
1 μF	–	–	±.001	±.001	0.03	0.03	20
10 μF	0.02%	0.04%	±.001	±.001	7.0	15.5	6
100 μF	0.02%	0.04%	±.001	±.001	3.1	6.4	2
1 mF	0.02%	0.06%	±.001	±.002	1.1	2.2	0.8
10 mF	0.03%	0.2%	±.001	±.005	0.37	0.72	0.5
100 mF	0.1%	**	±.003	**	0.13	0.23	0.25
1 F	0.25%	**	±.01	**	0.04	0.05	0.06

*DC voltage cannot be applied.

**Not specified.



Basic circuit diagram



CAPACITANCE: Internal Standard: 1 μF to 1 F in 7 switch-selected decade values. External Standard: Indicated capacitance, multiplied by C ext/1 μF.

CAPACITANCE ACCURACY (direct-reading): 0.25% plus ratio accuracy at 100 Hz, 120 Hz, and 1 kHz, 20° to 25°C, with low applied voltage (<1/4 E max) using internal standard and a proper four-terminal measurement. (May also be used as a two-terminal standard, with a D <1 and a capacitance change from the four-terminal value of <1/2% up to 1mF at 120 Hz or less.)

CAPACITANCE RATIO ACCURACY: See table.

DISSIPATION FACTOR: 0.01 at 100 Hz, 120 Hz and 1 kHz. For D accuracy, see table.

TERMINAL IMPEDANCES: See figure and table (approx values given).

TEMPERATURE COEFFICIENT: Approximately −140 ppm/°C.

VOLTAGE CHARACTERISTIC: Approximately +0.3% change from O to E max (see table) at 100 Hz. Less at higher frequencies.

MECHANICAL: DIMENSIONS (w×h×d): 8.5×5.9×5.25 in. (21.5×14.7×13.2 cm). WEIGHT: 6 lb (2.7 kg) net, 11 lb (5 kg) shipping.

ORDERING INFORMATION

Description	Order No.
1417 Four-Terminal Capacitance Standard	1417-9700

RESISTANCE DECADES

GenRad's resistance decades are configured for flexibility. The 1433 Decade Resistor, comprised of 510 Decade Resistance Units and available in more than a dozen models, ensures precision and stability while, in many cases, providing measurement capability into the radio-frequency range.

The GenRad 510 Decade-Resistance Unit can function as a single-decade component in "local" settings such as experimental environments or commercial instruments.

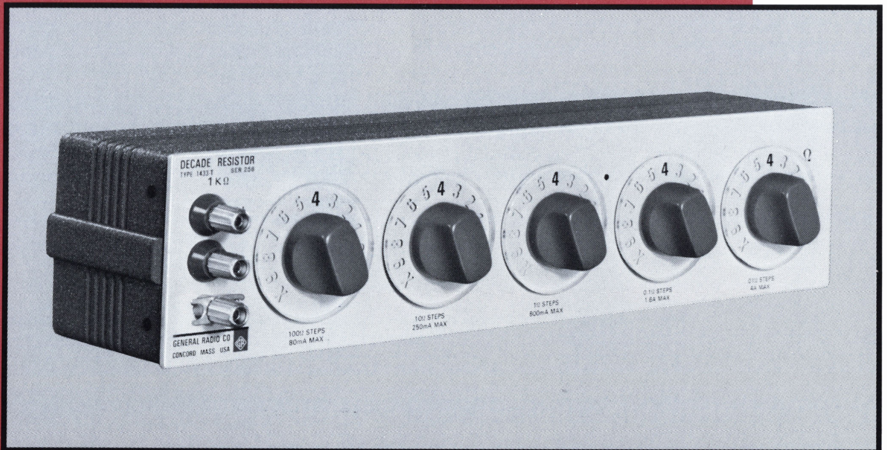
The GenRad resistance decades are:

1433 Decade Resistor
510 Decade-Resistance Unit

1433 DECADE RESISTOR

Precision Decade Resistors with Excellent Accuracy, Stability, and Low Zero Resistance

- ☐ Accuracy of ±0.01%
- ☐ Low zero resistance and excellent stability
- ☐ Low temperature coefficient for repeatability



The GenRad 1433 Decade Resistors are primarily intended for precision measurement applications that take full advantage of the instrument's accuracy, stability, and low zero resistance.

They are convenient resistance standards for checking the accuracy of resistance-measuring devices and are used as components in dc and audio-frequency impedance bridges. Many of the models can be used up into the radio-frequency range.

Each 1433 Decade Resistor is an assembly of GenRad 510 Decade-Resistance Units in a single cabinet. Mechanical as well as electrical shielding of the units and switch contacts is provided by the attractive aluminum cabinet and panel. The resistance elements have no electrical connection to the cabinet and panel, for which a separate shield terminal is provided.

SPECIFICATIONS

ACCURACY: The specified tolerances apply for low-current measurement at dc, or low-frequency ac (see below).

OVER-ALL ACCURACY: The difference between the resistances at any setting and at the zero setting is equal to the indicated value ±(0.01%+2mΩ).

INCREMENTAL ACCURACY: See table. This is the accuracy of the change in resistance between any two settings on the same dial.

MAX CURRENT: The max current for each decade is given in the table below and also appears on the panel of each decade box and on the dial plate of each decade resistance unit.

FREQUENCY CHARACTERISTIC: The accompanying plot shows the max percentage change in effective series resistance, as a function of frequency for the individual decade units. For low-resistance decades, the error is due almost entirely to skin effect and is independent of switch setting. For the high-resistance units, the error is due almost entirely to the shunt capacitance and its losses and is approx proportional to the square of the resistance setting.

The high-resistance decades (510-E, -F, -G, and -H) are very commonly used as parallel resistance elements in resonant circuits, in which the shunt capacitance of the decades becomes part of the tuning capacitance. The parallel resistance changes by only a fraction (between a tenth and a hundredth) of the series-resistance change, depending on frequency and the insulating material in the switch.

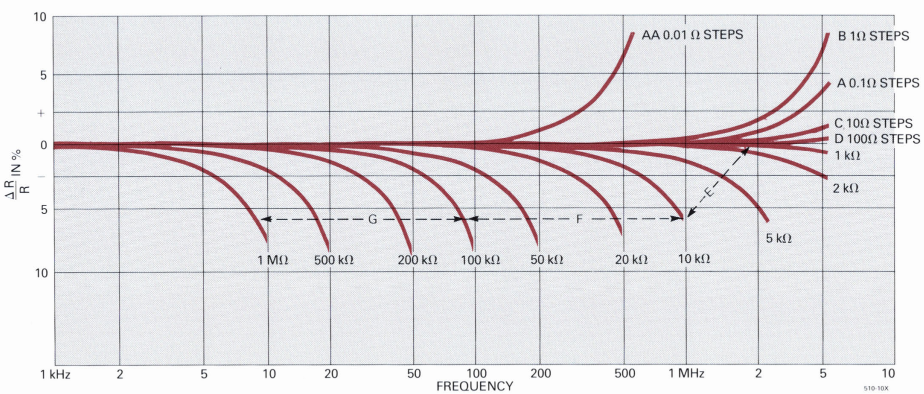
Characteristics of the 1433s are similar to those of the individual 510s, modified by the increased series inductance, L_o, and shunt capacitance, C, due to the wiring and the presence of more than one decade in the assembly. At total resistance settings of approx. 1000 Ω or less, the frequency characteristics of any of these decade resistors are substantially the same as those shown for the 510s. At higher settings, shunt capacitance becomes the controlling factor, and the effective value of this capacitance depends upon the settings of the individual decades.

TYPICAL VALUES OF R_o, L_o, AND C FOR THE DECADE RESISTORS: ZERO RESISTANCE (R_o): 0.001 Ω per dial at dc; 0.04 Ω per dial at 1 MHz; proportional to square root of frequency at all frequencies above 100 kHz. ZERO INDUCTANCE (L_o): 0.1 μH per dial + 0.2 μH. EFFECTIVE SHUNT CAPACITANCE (C): This value is determined largely by the highest decade in use. With the low terminal connected to the shield, a value of 15 to 10 pF per decade may be assumed, counting decades down from the highest. Thus, if the third decade from the top is the highest resistance decade in circuit (i.e., not set at zero), the shunting terminal capacitance is 45 to 30 pF. If the highest decade in the assembly is in use, the effective capacitance is 15 to 10 pF, regardless of the settings of the lower-resistance decades.

TEMPERATURE COEFFICIENT OF RESISTANCE: Less than ±10 ppm/°C for values above 100 Ω, and ±20 ppm/°C for 100 Ω and below, at room temperatures. For the 1433s the box wiring will increase the over-all temperature coefficient of the .01- and 0.01-Ω decades.

SWITCHES: Quadruple-leaf brushes bear on lubricated contact studs of 3/8-in. diameter in such a manner as to avoid cutting, yet give a good wiping action. A ball-on-cam detent is provided. There are eleven contact points (0 to 10 inclusive). The switch resistance is less than 0.0005 Ω. The effective capacitance is of the order of 5 pF, with a dissipation factor of 0.06 at 1 kHz for the standard cellulose-filled molded phenolic switch form and 0.01 for the mica-filled phenolic form used in the 510-G and 510-H units.

Change in Series Resistance



Max percentage change in series resistance as a function of frequency.

MAX VOLTAGE TO CASE: 2000 V pk.

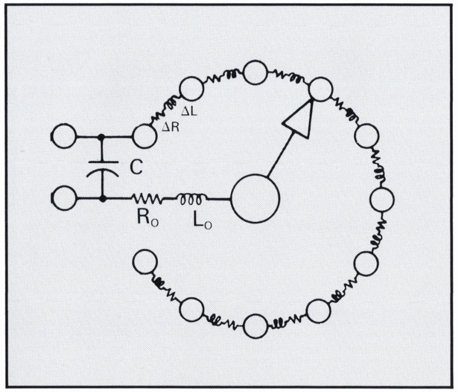
TERMINALS: Low-thermal-emf jack-top binding posts on standard 3/4-in. spacing; also provisions for rear-panel connections. Shield terminal is provided.

MECHANICAL: Lab-bench cabinet; rack models include mounting hardware. DIMENSIONS and WEIGHTS: in. (mm), lb (kg):

	4-dial U, K, J, L, Q	5-dial T, N, M, P, Y	6-dial W, X, B, Z	7-dial F, G, H
Width*	12.3 (312)	14.8 (375)	17.3 (439)	
Height	3.5 (89)			5.3 (135)
Depth	5 in. over-all, 4 in. behind panel (127, 102)			
Net Wt**	4.8 (2.2)	5.8 (2.7)	7 (3.2)	8.8 (4.0)
Ship Wt**	5.5 (2.5)	6.5 (3.0)	8.5 (3.9)	10.3 (4.7)

*Data given for bench models. All rack models same except 19 in. (483 mm) wide.

**Add approx 1 lb (0.5 kg) for rack-mount hardware.



Equivalent circuit of a resistance decade, showing residual impedances.

1433 Decade Resistor

Type	Total Ohms	Ohms per Step	No. of Dials	Type 510 Decades Used
1433-U	111.1	0.01	4	AA, A, B, C
1433-K	1,111	0.1	4	A, B, C, D
1433-J	11,110	1	4	B, C, D, E
1433-L	111,100	10	4	C, D, E, F
1433-Q	1,111,000	100	4	D, E, F, G
1433-T	1,111.1	0.01	5	AA, A, B, C, D
1433-N	11,111	0.1	5	A, B, C, D, E
1433-M	111,110	1	5	B, C, D, E, F
1433-P	1,111,100	10	5	C, D, E, F, G
1433-Y	11,111,000	100	5	D, E, F, G, H
1433-W	11,111.1	0.01	6	AA, A, B, C, D, E
1433-X	111,111	0.1	6	A, B, C, D, E, F
1433-B	1,111,110	1	6	B, C, D, E, F, G
1433-Z	11,111,100	10	6	C, D, E, F, G, H
1433-F	111,111.1	0.01	7	AA, A, B, C, D, E, F
1433-G	1,111,111	0.1	7	A, B, C, D, E, F, G
1433-H	11,111,110	1	7	B, C, D, E, F, G, H

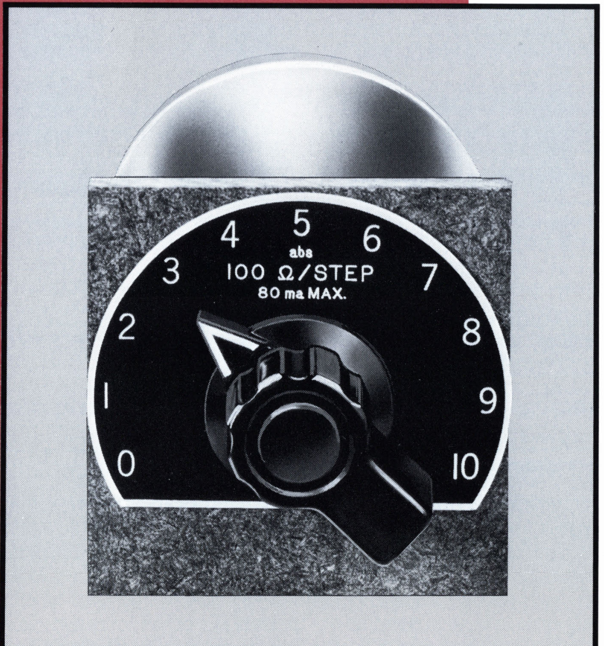
ORDERING INFORMATION

Description	Order No. Bench	Rack
1433 Decade Resistor		
1433-U	**1433-9700**	**1433-9701**
1433-K	**1433-9702**	**1433-9703**
1433-J	**1433-9704**	**1433-9705**
1433-L	**1433-9706**	**1433-9707**
1433-Q	**1433-9708**	**1433-9709**
1433-T	**1433-9710**	**1433-9711**
1433-N	**1433-9712**	**1433-9713**
1433-M	**1433-9714**	**1433-9715**
1433-P	**1433-9716**	**1433-9717**
1433-Y	**1433-9718**	**1433-9719**
1433-W	**1433-9720**	**1433-9721**
1433-X	**1433-9722**	**1433-9723**
1433-B	**1433-9724**	**1433-9725**
1433-Z	**1433-9726**	**1433-9728**
1433-F	**1433-9729**	**1433-9730**
1433-G	**1433-9731**	**1433-9732**
1433-H	**1433-9733**	**1433-9734**

510 DECADE-RESISTANCE UNIT

A Single Decade Resistance Unit

- ☐ Decade steps as low as .01 Ω/step; as high as 1M Ω/step
- ☐ Panel-mountable for systems use



The GenRad 510 Decade-Resistance Units that essentially make up the 1433 are also available separately for applications requiring a single decade or as components for experimental setups, production test equipment, or commercial instruments.

Each unit is enclosed in an aluminum shield. A knob and etched-metal dial plate are supplied. Each decade has ten resistors in series. The contacts in the lower-valued decades have a silver overlay to ensure stability of resistance, and all the decades have a silver contact on the zero setting to give low and constant zero resistance. Winding methods are chosen to reduce the effects of residual reactances.

SPECIFICATIONS

ELECTRICAL: See table.

TERMINALS: Soldering lugs.

SUPPLIED: Dial plate, knob, template, and mounting screws.

MECHANICAL: Panel mounting, in shield can. DIMENSIONS: Dia. 3.06 in. (78 mm), depth 3.31 in. (85 mm) behind panel. WEIGHT: 11 oz (312 g) net.

ORDERING INFORMATION

Description	Order No.
510 Decade Resistance Unit	
510-AA	0510-9806
510-A	0510-9701
510-B	0510-9702
510-C	0510-9703
510-D	0510-9704
510-E	0510-9705
510-F	0510-9706
510-G	0510-9707
510-H	0510-9708

510 Decade Resistance Unit

Type	Total Resistance Ohms	Resistance Per Step (ΔR) Ohms	Accuracy of Resistance Increments	Max Current 40° C Rise	Power Per Step Watts	ΔL μH	C** pF	L_o μH
510-AA	0.1	0.01	±2%	4 A	0.16	0.01	7.7-4.5	0.023
510-A	1	0.1	±0.4%	1.6 A	0.25	0.014	7.7-4.5	0.023
510-B	10	1	±0.1%	800 mA	0.6	0.056	7.7-4.5	0.023
510-C	100	10	±0.04%	250 mA	0.6	0.11	7.7-4.5	0.023
510-D	1000	100	±0.01%	80 mA	0.6	5	7.7-4.5	0.023
510-E	10,000	1000	±0.01%	23 mA	0.5	13	7.7-4.5	0.023
510-F	100,000	10,000	±0.01%	7 mA	0.5	70	7.7-4.5	0.023
510-G	1,000,000	100,000	±0.01%	2.3 mA	0.5	–	7.7-4.5	0.023
510-H	10,000,000	1,000,000	±0.01%	0.7* mA	0.5	–	7.5-4.5	0.023

*Or a max of 4000 V, pk.

**The larger capacitance occurs at the highest setting of the decade. The values given are for units without the shield cans in place. With the shield cans in place, the shunt capacitance is from 0 to 20 pF greater than indicated here, depending on whether the shield is tied to the switch or to the zero end of the decade.

TO ORDER CALL TOLL-FREE 1-800-772-2220,
IN MASSACHUSETTS 1-617-369-4400 ext.3129

INDUCTANCE STANDARDS AND DECADES

GenRad's inductance standards and decades combine stability and durability. The GenRad 1482 Standard Inductor is a stable and reliable device that has shown low predictable drift over many years of use. The GenRad 1491 Decade Inductor is an all-purpose unit suitable for design and development of oscillators, analyzers, and similar equipment.

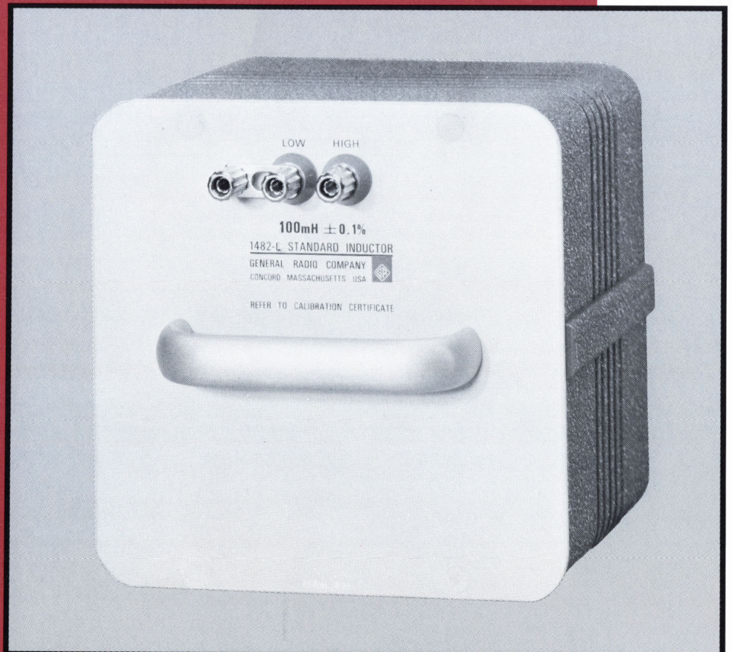
GenRad's inductance standards and decades are:

1482 Standard Inductor
1491 Decade Inductor

1482 STANDARD INDUCTOR

A Primary Inductance Standard

- ☐ Stable within ±0.01% per year
- ☐ Toroidal design to minimize effects from external fields
- ☐ Low, known temperature coefficient



When you need an accurate standard of self-inductance that can be used as a low-frequency reference or as a working standard in the laboratory, the GenRad 1482 Standard Inductor will more than meet your needs.

Records extending over 16 years, including those for inductors that traveled to national laboratories in several countries for calibration, show long-term stabilities well within ±0.01%.

Designed for High Stability

Each of our six 1482 inductors is a uniformly wound toroid on a ceramic core with a negligible external magnetic field and, therefore, essentially no pickup from external fields. The inductor is resiliently supported in a mixture of ground cork and silica gel, and the whole assembly is cast with a potting compound into a cubical aluminum case.

Sizes of 1 mH and above have three terminals, two for the inductor leads and a third connected to the case, to provide either a two- or three-terminal standard. The 100 μH size has three additional terminals for the switching used to minimize connection errors.

Continued on the next page.

SPECIFICATIONS

INDUCTANCE RANGE: See table.

ACCURACY OF ADJUSTMENT: See table.

CALIBRATION: A certificate of calibration is provided with each unit, giving measured values of inductance at 100, 200, 400, and 1000 Hz, with temperature and method of measurement specified. These values are obtained by comparison, to a precision, typically, of better than ±0.005%, with working standards whose absolute values, determined and maintained in terms of reference standards periodically certified by the National Bureau of Standards, are known to an accuracy typically ±(0.02% + 0.1 μH) at 100 Hz.

STABILITY: Inductance change is less than ±0.01% per year.

DC RESISTANCE: See table for representative values. A measured value of resistance at a specified temperature is given on the certificate of calibration.

LOW-FREQUENCY STORAGE FACTOR Q: See table for representative values of Q at 100 Hz (essentially from dc resistance). An individual value of Q, calculated from the measured dc resistance, is given on each certificate of calibration.

TEMPERATURE COEFFICIENT OF INDUCTANCE: Approx 30 ppm per °C. Minute temperature corrections may be computed from dc resistance changes. A 1% increase in resistance, produced by a temperature increase of 2.54°C., corresponds to 0.0076% increase in inductance.

RESONANT FREQUENCY: See table for representative values. A measured value is given on the certificate of calibration.

MAX INPUT POWER: For a rise of 20°C, 3 W; for precise work, a rise of 1.5°C, 200 mW. See table for corresponding current limits.

TERMINALS: Jack-top binding posts on 3/4-in. spacing with removable ground strap.

MECHANICAL: Lab-bench cabinet. DIMENSIONS (w × h × d): 6.5 × 6.5 × 8 in. (166 × 166 × 204 mm). WEIGHT: 11.5 lb (5.3 kg) net, 13 lb (6 kg) shipping.

1482 Standard Inductor

Type	Nominal Induct-ance	Adjustment Accuracy (Percent)	*Resonant Frequency (kHz)	*DC Resistance (Ohms)	*Q at 100 Hz	Milliamperes, rms for, 200 mW	3W
1482-B	100 μH	±0.25	800	0.083	0.76	1550	6010
1482-E	1 mH	±0.1	800	0.84	0.75	490	1890
1482-H	10 mH	±0.1	220	8.2	0.77	156	600
1482-L	100 mH	±0.1	71	81	0.78	50	192
1482-P	1 H	±0.1	14.6	616	1.02	18	70
1482-T	10 H	±0.1	4.9	6400	0.98	5.6	22

*Representative values. Actual values given on certificate.

ORDERING INFORMATION

Description	Order No.
1482 Standard Inductor	
1482-B	1482-9702
1482-E	1482-9705
1482-H	1482-9708
1482-L	1482-9712
1482-P	1482-9716
1482-T	1482-9720

1491 DECADE INDUCTOR

All-Purpose Inductor Used for Design and Measurement

- ☐ Shielded toroidal cores for small mutual inductance and minimal effect from external fields
- ☐ Sealed against moisture for long-term stability
- ☐ Excellent as a moderately precise standard of inductance
- ☐ High-Q, 200 and above

The GenRad 1491 Decade Inductor – an assembly of several GenRad decade-inductor units into a single metal cabinet – is a convenient element for use in filters, equalizers, and tuned circuits throughout the range of audio and low radio frequencies.

When you're conducting preliminary design measurements, GenRad 1491 Inductors are useful as components in oscillators, analyzers, and similar equipment. With the 1491, you can quickly vary circuit elements over relatively wide ranges to determine optimum operating values.

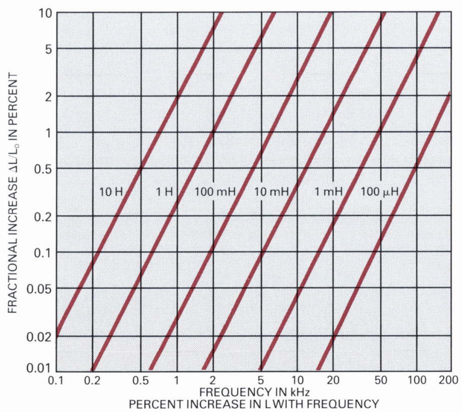
Sealed against moisture for long-term stability, the inductance decades can act as moderately precise standards of inductance, with values of low-frequency storage factor (Q) that are much higher than those of air-core coils.

SPECIFICATIONS

FREQUENCY CHARACTERISTICS: Percentage increase in effective series inductance (above the zero-frequency value, L_0) may be obtained by interpolation in accompanying graph for any setting of the highest-value decade used, when LOW terminal is grounded to cabinet.

ZERO INDUCTANCE: Approx 1 μH.

MAX VOLTAGE: 500 V rms. Switch will break circuit at 500 V if turned rapidly, but voltages above 150 V may cause destructive arcing with switch between detent positions.



Variation of inductance with frequency for the 1491 Decade Inductors.

TERMINALS: Binding posts on 3/4-in. centers; separate ground terminal provided.

MECHANICAL: Lab-bench cabinet. DIMENSIONS (w × h × d): Bench, 17 × 8.75 × 6.5 in. (432 × 223 × 166 mm). WEIGHT: 1491-D bench model, 23 lb (11 kg) net, 30 lb (14 kg) shipping; 1491-G bench model, 27 lb (12 kg) net, 34 lb (16 kg) shipping.

1491 Decade Inductor

Type	Total	Steps
1491-D Bench	11.11 H	0.001 H
1491-G Bench	11.111 H	0.0001 H

Accuracy

	Inductance Per Step				
	100μH	1mH	10mH	100 mH	1H
1491-9704	N/A	±2%	±1.6%	±.8%	±.8%
1491-9707	±2%	±2%	±1.6%	±.8%	±.8%

ORDERING INFORMATION

Description	Order No.
1491 Decade Inductor	
1491-D Bench	**1491-9704**
1491-G Bench	**1491-9707**

LOW-FREQUENCY OSCILLATORS, POWER SUPPLIES, AND DETECTORS

GenRad's family of low-frequency oscillators, power supplies, and detectors lets you configure a measurement system that provides the level of precision, flexibility, and speed your application requires.

The related products are:

1311-A Audio Oscillator
1308-A Audio Oscillator and Power Amplifier
1316 Oscillator
1265-A Adjustable DC Power Supply
1232-A Tuned Amplifier and Null Detector
1232-P2 Preamplifier
1240 Bridge Oscillator-Detector
1238 Detector

1311-A AUDIO OSCILLATOR

Useful for Driving Bridges, Transducers, and Other Equipment

- ☐ 11 fixed frequencies from 50 Hz to 10 kHz for various applications
- ☐ Accuracy at ±1%
- ☐ 1 W, 100 V, or 4 A output
- ☐ Transformer output for bridge applications

With high-power output and load-matching – through a multitap output transformer that ensures at least one-half watt into any load from 0.08 to 8,000 ohms – the GenRad 1311-A Audio Oscillator is ideal for driving impedance bridges where high sensitivity is required at extreme measurement limits.

Directly driving low-impedance devices like acoustic transducers is also convenient with this instrument.

The instrument's shielded output transformer secondary minimizes circulating ground currents, making it ideal for bridge measurements.

A Range of Uses

The 1311-A can be ordered with the 1232-A Tuned Amplifier and Null Detector in the easy-to-use, self-contained GenRad 1240 Bridge Oscillator-Detector Assembly.

The instrument is also a standard component in several GenRad impedance-measuring systems.

SPECIFICATIONS

FREQUENCY RANGE: 50 Hz to 10 kHz. Eleven fixed frequencies, 50, 60, 100, 120, 200, 400, and 500 Hz, 1, 2, 5, and 10 kHz. One other frequency can be added at an unused switch position. A Δf control provides ±2% continuous adjustment.

ACCURACY: ±1% of setting with Δf control at zero.

STABILITY (typical at 1 kHz): Warmup drift, 0.3%. After warmup, 0.008% short-term (10 min), 0.02% long-term (12 h).

SYNCHRONIZATION: INPUT: Frequency can be locked to external signal. Lock range, ±3% per volt rms up to 10 V. The Δf control functions as a phase adjustment. OUTPUT: Constant amplitude (1 V) to drive counter or oscilloscope. Source impedance 4.7 kΩ.

OUTPUT LEVEL: VOLTAGE: Continuously adjustable from 0 to 1, 3, 10, 30, or 100 V open circuit (E_{oc}), dependent on setting of 5-position output switch. CURRENT: Continuously adjustable from 0 to 40, 130, 400, 1300, or 4000 mA, into approx short circuit (I_{sc}). POWER: >1.0 W into matched load, >0.5 W into any resistive load between 80 mΩ and 8 kΩ.

OUTPUT IMPEDANCE: One to three times $\frac{E_{oc}}{I_{sc}}$, depending on output amplitude. Output ungrounded.

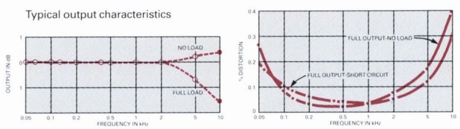
DISTORTION: <0.5% with any linear load. Oscillator will drive a short circuit without clipping.

HUM: <0.01%, independent of output setting.

TERMINALS: Output, GenRad 938 Binding Posts and ground terminal with shorting link; sync, telephone jack on side panel.

POWER: 105 to 125, or 210 to 250 V, 50 to 400 Hz, 22 W.

MECHANICAL: Convertible-bench cabinet. DIMENSIONS (w × h × d): 8 × 6 × 7.75 in. (204 × 153 × 197 mm). WEIGHT: 6 lb (2.8 kg) net, 9 lb (4.1 kg) shipping.



ORDERING INFORMATION

Description	Order No.
1311-A Audio Oscillator	
115-V Model	1311-9701
230-V Model	1311-9702

1308-A AUDIO OSCILLATOR AND POWER AMPLIFIER

High AC Power Source Covering the Audio Range

- ☐ Frequencies from 20 Hz to 20 kHz in three ranges
- ☐ Output power at 200 VA, up to 400 V or 5 A
- ☐ Low dynamic output impedance
- ☐ Overload circuit for added safety

The GenRad 1308-A Audio Oscillator and Power Amplifier is a reliable ac power source with the low dynamic output impedance to meet a variety of measurement applications:

- ☐ An excellent power source for the GenRad 1633-A Incremental-Inductance Bridge
- ☐ A low-distortion signal, without clipping, for nonlinear loads such as capacitor-input rectifier systems
- ☐ An audio frequency power amplifier that, when used with a tone-burst generator, provides high-power tone bursts for testing sonar projectors and amplifiers
- ☐ An instrument for driving small shake tables or to isolate equipment from power-line transients.

The 1308-A gives you these capabilities and more.

A Quality Design

The 1308-A combines a capacitor-tuned Wienbridge oscillator, a low-distortion power amplifier, and a tapped output transformer. For safety, the output is monitored by an overload circuit, which turns off the output when it begins to exceed safe limits.

Continued on the next page.

1308-A AUDIO OSCILLATOR AND POWER AMPLIFIER (Cont'd)

SPECIFICATIONS

FREQUENCY RANGE: 20 Hz to 20 kHz in 3 ranges. CONTROLS: Continuously adjustable main dial covers decade range in 157.5°, vernier in 2 turns.

ACCURACY: ±3% of setting or ±1 Hz, whichever is greater.

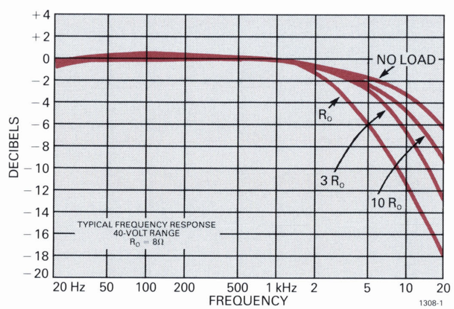
FREQUENCY STABILITY (typical at 1 kHz): Warmup drift at full load, 0.3%. After warmup: 0.003% short-term (10 min), 0.03% long-term (12 h), 0.04% from no load to full load.

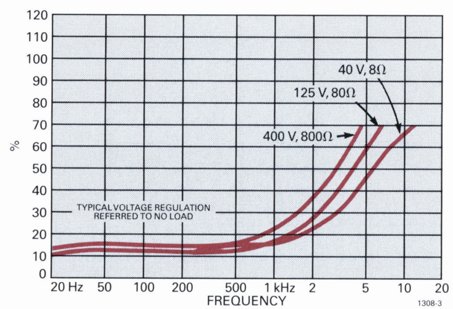
OUTPUT VOLTAGE RANGES: Max of 4, 12.5, 40, 125, and 400 V open circuit, continuously adjustable from 0 to max.

OUTPUT POWER: 200 VA max, 50 Hz to 1 kHz. CURRENT RANGES: Max of 0.016, 0.05, 0.16, 0.5, 1.6, and 5.0 A.

REGULATION: <20%, no load to full load, 20 Hz to 1 kHz. Output impedance is typically 0.3, 0.8, 1.6, 19, and 220 Ω, depending on voltage range, 20 Hz to 1 kHz. Output transformer can pass dc current equal to max of ac current range. Output isolated from ground.

LOAD IMPEDANCES: Short circuit or non-linear loads can be driven. Load impedances of 0.8, 2.5, 8, 80, or 800 Ω, depending on voltage range, are optimum for max available power. LOAD POWER FACTOR: Continuous operation at max VA for any power factor 0 to 1 with ambient up to 25°C. Power factor of 0.7 to 1.0 for continuous operation to 40°C ambient. Intermittent operation to 50°C.

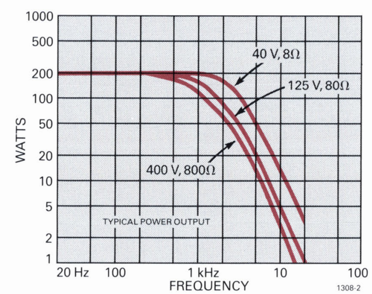


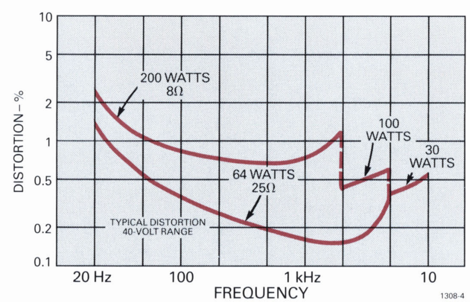


DISTORTION (linear load): <1%, 100 Hz to 10 kHz; <2%, 50 Hz to 100 Hz at max power and 115-V supply.

HUM: <0.3% of max output.

METERS: Indicate output terminal voltage and current. VOLTMETER: 5, 15, 50, 150, and 500 V ±3% full scale. AMMETER: 0.016, 0.05, 0.16, 0.5, 1.6, and 5 A ±3% f s.





OVERLOAD PROTECTION: Electronic overload trips at approx 1.5 × max of current range (manual reset), thermal cut-out on transistor heat sink (automatic reset).

AMPLIFIER SENSITIVITY: ≤2.0 V for full output.

INPUT IMPEDANCE: 10 kΩ.

TERMINALS: Output, GenRad 938 Binding Posts and four-terminal socket on rear panel; input, GenRad 938 Binding Posts on rear panel.

SUPPLIED: Four-terminal plug, power cord.

POWER: 105 to 125, or 210 to 250 V, 50 to 60 Hz, 70 to 500 W, depending on load.

MECHANICAL: Rack-bench cabinet. DIMENSIONS (w × h × d): Bench, 19 × 7 × 16.25 in. (438 × 178 × 413 mm); rack, 19 × 7 × 15 in. (483 × 178 × 381 mm). WEIGHT: 91 lb (42 kg) net, 145 lb (66 kg) shipping.

ORDERING INFORMATION

Description	Order No.
1308-A Audio Oscillator and Power Amplifier	
115-V Bench Model	**1308-9801**
115-V Rack Model	**1308-9811**
230-V Bench Model	**1308-9802**
230-V Rack Model	**1308-9812**

1316 OSCILLATOR

A High-Performance, All-Purpose Oscillator

- ☐ Frequencies from 10 Hz to 100 kHz in four decade ranges
- ☐ Output power at 1.6 VA up to 125 V or 5 A
- ☐ Output levels are adjustable and metered
- ☐ In-line readout dials for ease of use

Convenience and high performance are two of the strongest reasons why you should choose the GenRad 1316 Oscillator.

Simply set four controls and the 1316 provides any frequency from 10 Hz to 100 kHz with 1% accuracy and little chance of an improper setting (the dials provide in-line readout). Set two more controls and the 1316 provides up to 1.6 watts of output power, low distortion, and accurate metering for even greater measuring performance.

The capabilities of this GenRad oscillator continue: Output constant within ±2%, excellent stability with a 0.005% drift over a 12-hour period, and a synchronizing capability allowing the oscillator to be locked to an external standard for even greater accuracy and stability.

An Accurate Bridge Oscillator

As a high-performance bridge oscillator for use with the GenRad 1238 Detector, the 1316 supplies two references (in quadrature) for the 2-phase phase-sensitive detector. This 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 Wienbridge oscillator, isolated from the load by a low-distortion transformer-coupled power amplifier. The oscillator produces a synchronizing signal for phase locking or extracting a signal independent of the output setting, to let you quickly operate a counter or synchronize an oscilloscope.

Continued on the next page.

1316 OSCILLATOR (Cont'd)

SPECIFICATIONS

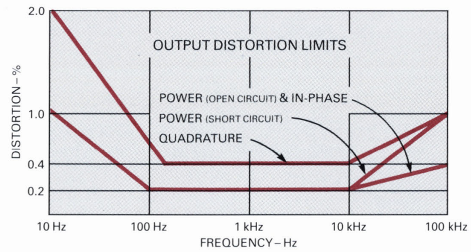
FREQUENCY: 10 Hz to 100 kHz in 4 decade ranges. Controlled by one 11-position and one 10-position switch for the most-significant digits and a continuously adjustable dial with detented zero position for the third digit; in-line readout with decimal point and frequency units.

ACCURACY: ±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%. RESETTABILITY: Within 0.005%.

POWER OUTPUT: CONTROLLED by 5-position switch and uncalibrated vernier. MONITORED by meter with ±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 ±2% from 10 Hz to 50 kHz, ±5% for frequencies >50 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 kΩ
Power	1.6 W max into matched load				

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	±2%	
	10 kHz to 100 kHz	±4%	
Minimum Load		47 kΩ	

SYNCHRONIZATION: INPUT: Frequency can be locked to external signal; lock range, ±1%/V rms input up to 10 V; frequency controls function as phase adjustment. OUTPUT: ≥0.3 V rms behind 27 kΩ; 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 (w × h × d): Bench, 19.75 × 5 × 13.06 in. (502 × 127 × 332 mm); rack, 19 × 3.47 × 11.44 in. (483 × 88 × 291 mm). WEIGHT: Bench, 26 lb (12 kg) net, 32 lb (15 kg) shipping; rack, 21 lb (10 kg) net, 27 lb (12 kg) shipping.

ORDERING INFORMATION

Description	Order No.
1316 Oscillator	
Bench Model	**1316-9700**
Rack Model	**1316-9701**

1265-A ADJUSTABLE DC POWER SUPPLY

A Versatile DC Power Supply

- ☐ Voltage range of 0 to 400 V
- ☐ Maximum rated power of 200 W to 8, 80, or 800 Ω
- ☐ Safety features prevent damage from overload

The GenRad 1265-A Adjustable DC Power Supply 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, an electronic monitoring 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.

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

OVERLOAD PROTECTION: Overload circuit trips at approx 1½ 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 (w × h × d): Bench, 19 × 7.5 × 17.25 in. (483 × 190 × 438 mm); rack, 19 × 7 × 15 in. (483 × 178 × 381 mm). WEIGHT: 70 lb (32 kg) net, 124 lb (57 kg) shipping.

ORDERING INFORMATION

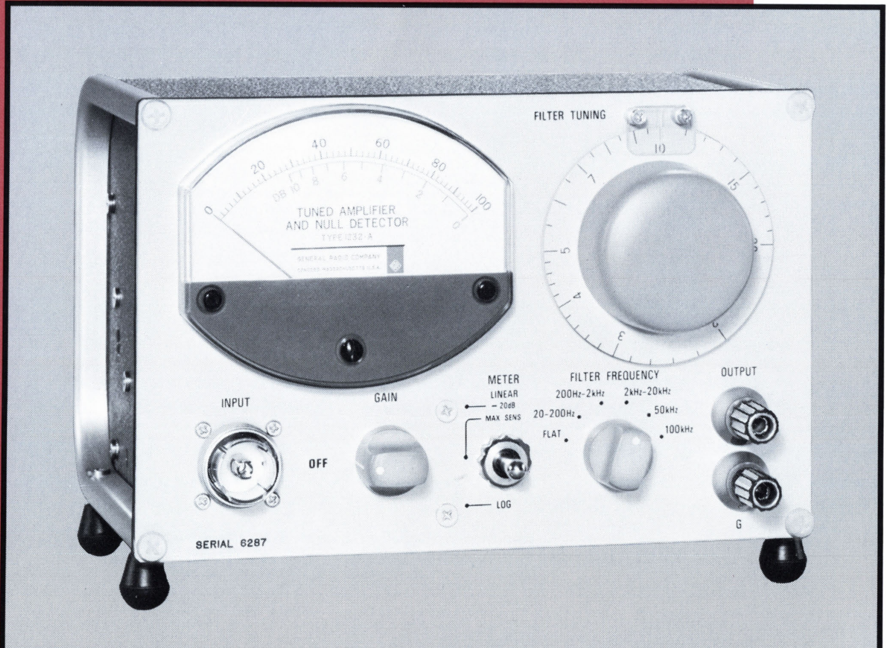
Description	Order No.
1265-A Adjustable DC Power Supply	
115-V Models	
60-Hz, Bench	**1265-9801**
60-Hz, Rack	**1265-9811**
50-Hz, Bench	**1265-9803**
50-Hz, Rack	**1265-9813**
230-V Models	
60-Hz, Bench	**1265-9802**
60-Hz, Rack	**1265-9812**
50-Hz, Bench	**1265-9804**
50-Hz, Rack	**1265-9814**

TO ORDER CALL TOLL-FREE 1-800-772-2220,
IN MASSACHUSETTS 1-617-369-4400 ext.3129

1232-A TUNED AMPLIFIER AND NULL DETECTOR

All-Purpose Detector for Accurate Frequency Measurements

- ☐ Tunable, bandwidth of approximately 5%
- ☐ 0.1 μ V sensitivity with 120-dB gain
- ☐ Frequencies from 20 Hz to 20 kHz, 50 and 100 kHz
- ☐ Battery power for low noise and portability



Low noise and high gain up to 120 dB give the GenRad 1232-A Tuned Amplifier and Null Detector the sensitivity you need to make difficult bridge measurements.

The instrument is ideal as a bridge detector at audio frequencies. With the GenRad 1232-P2 Preamplifier, it is equally sensitive for extremely high impedance sources. The 1232 also makes an excellent audio preamplifier; a general-purpose, tunable, or broadband audio amplifier; and a sensitive audio-wave analyzer for approximate measurements.

Easily tuned with a choice of bandwith, the 1232-A enables you to reject broadband noise as well as the harmonics that can impair accurate measurements.

Battery operation frees the 1232-A from power-line noise and makes it highly portable.

Continued on the next page.

SPECIFICATIONS

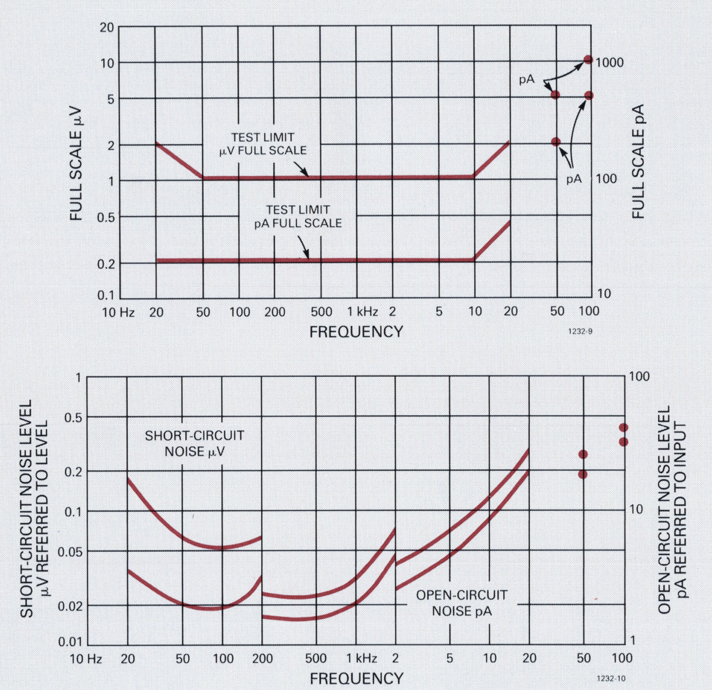
FREQUENCY RESPONSE: TUNABLE FILTERS: 20 Hz to 20 kHz in 3 ranges; between 2% and 6% bandwidth to 15 kHz; 2nd harmonic at least 34 dB down from peak, 3rd at least 40 dB down; rejection filter on two highest ranges reduces 60-Hz level to at least 60 dB below peak response (50-Hz level is down >50 dB). Dial accuracy is ±3%. FIXED-TUNED FILTERS: 50 kHz, 2nd harmonic is 44 dB down; 100 kHz, 2nd harmonic is 53 dB down. FLAT RESPONSE: ±3 dB from 20 Hz to 100 kHz.

SENSITIVITY: See plot. Typically better than 0.1 μV over most of the frequency range.

NOISE LEVEL: REFERRED TO INPUT: See plot. Noise figure at 1 kHz < 2 dB at an optimum source impedance of 27 kΩ. REFERRED TO OUTPUT: < 5 mV on FLAT filter-frequency position, min gain setting, and −20-dB switch position; < 50 mV in MAX SENS position.

INPUT: IMPEDANCE: Approx 50 kΩ at max gain; varies inversely with gain to 1 MΩ at min gain. MAX SAFE VOLTAGE: 200 V ac or 400 V dc.

OUTPUT: VOLTAGE GAIN: Approx 120 dB on the tunable ranges; 100 dB, flat range; 106 dB at 50 kHz; 100 dB at 100-kHz position. LEVEL: 1 V into 10 kΩ when meter indication is full scale. INTERNAL IMPEDANCE: 3 kΩ. METER LINEARITY: dB differences are accurate to ±5% ±0.1 division for inputs of less than 0.3 V. COMPRESSION (meter switched to LOG): Reduces full-scale sensitivity by 40 dB. Does not affect bottom 20% of scale. ATTENUATION (meter switched to −20 dB): Linear response with 20-dB less gain than MAX SENS.



Performance. *Upper:* Specified sensitivity as input level for full scale indication, max gain, tuned. *Lower:* Typical noise level in terms of equivalent current and voltage sources.

DISTORTION (filter switch in FLAT position): <5% (due to meter rectifiers).

TERMINALS: Input, GenRad 874 Coaxial Connector. Output, binding posts.

AVAILABLE: 1232-P2 Preamplifier to maintain sensitivity of 1232-A at low frequencies when operating from a source impedance above 100 kΩ; rack-adaptor sets (see below) convert 1232-A alone, or with companion instruments, to 19-in. rack-mount width.

POWER: 12 V dc, from 9 mercury (M72) cells in series. Est battery life 1500 hours. Optionally, a rechargeable battery (non-mercury) can be supplied on special order.

MECHANICAL: Convertible bench cabinet. DIMENSIONS (w × h × d): Bench, 8 × 6 × 7.5 in. (203 × 152 × 190 mm). WEIGHT: 5.75 lb (2.6 kg) net, 8 lb (3.7 kg) shipping.

ORDERING INFORMATION

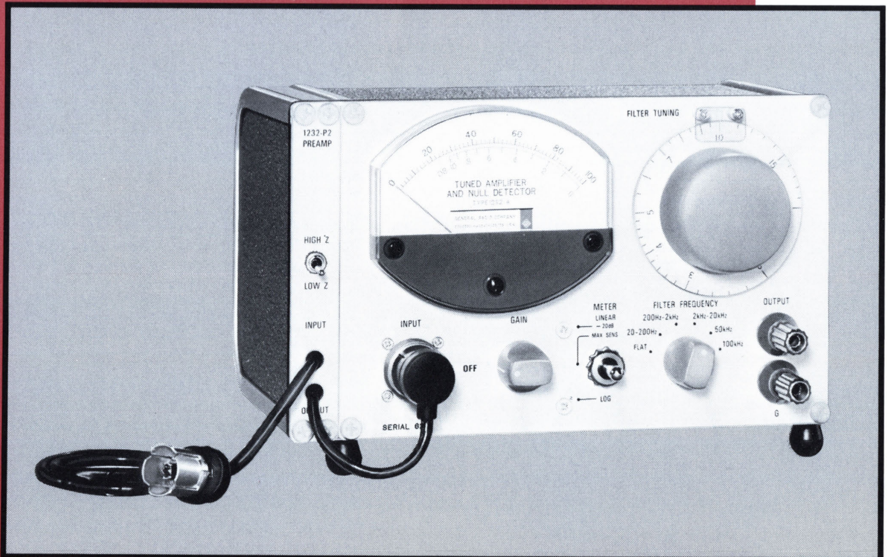
Description	Order No.
1232-A Tuned Amplifier and Null Detector	**1232-9701**
1232-AP Tuned Amplifier and Null Detector, with preamplifier	**1232-9829**

Accessories	Order No.
Replacement Battery (9 req'd)	**8410-1372**

1232-P2 PREAMPLIFIER

Preamplifier for Low-Frequency Measurements

- ☐ Increases sensitivity for measurements at frequencies below 1000 Hz
- ☐ Ideal for use with 1615-A Capacitance Bridge



GenRad 1232-P2 Preamplifier attached to the left side of the 1232-A Tuned Amplifier and Null Detector.

The GenRad 1232-P2 has particular application to measurements with the 1615-A Capacitance Bridge. It increases sensitivity for measurements made at frequencies well below 1000 Hz if the bridge is set to both its lowest C and D (not G) ranges simultaneously.

Low-frequency measurement of small samples of dielectric materials can be made more accurately with the addition of this preamplifier.

SPECIFICATIONS

VOLTAGE GAIN: Approx 0.7.

NOISE (REFERRED TO INPUT): Open-circuit equivalent 0.1 pA; short-circuit equivalent, 0.3 μV (when used with Type 1232-A tuned to 100 Hz).

IMPEDANCES: INPUT: >100 mΩ in parallel with 70 pF. OPTIMUM SOURCE: 3 MΩ. OUTPUT: 10 kΩ.

CONNECTORS: GenRad 874 on cables, input and output.

POWER: 12 V, 200 μA, supplied by 1232-A.

MECHANICAL: Special cabinet. DIMENSIONS (w × h × d): 0.75 × 6 × 7.5 in. (19 × 152 × 190 mm). WEIGHT: 0.94 lb (0.43 kg) net, 4 lb (1.9 kg) shipping.

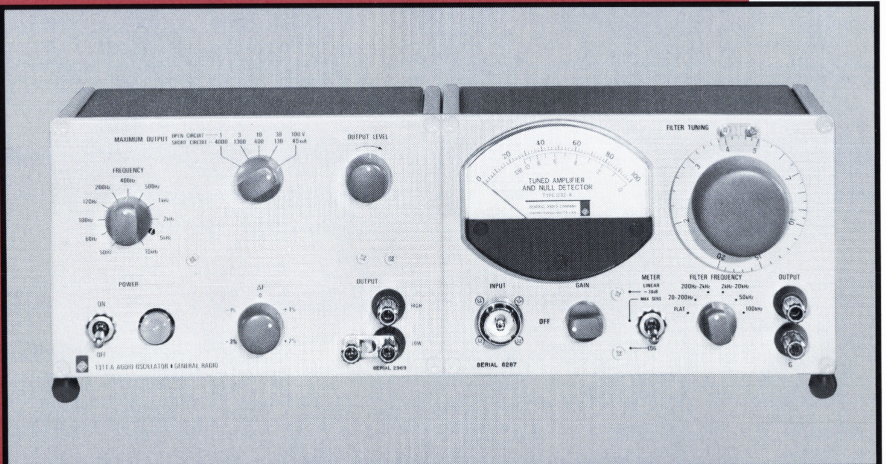
ORDERING INFORMATION

Description	Order No.
1232-P2 Preamplifier	1232-9602

1240 BRIDGE OSCILLATOR-DETECTOR

Oscillator and Detector in a Single, Versatile Package

- ☐ 11 fixed frequencies from 50 Hz to 10 kHz
- ☐ Accurate low-frequency measurements when used with 1232-P2 Preamplifier



We've combined the GenRad 1232-A Tuned Amplifier and Null Detector with the 1311-A Audio Oscillator for use with audio-frequency bridges and other null-balance devices to give you a compact instrument that delivers high performance in a minimum of space.

The GenRad 1240 Bridge Oscillator-Detector provides 11 fixed frequencies from 50 Hz to 10 kHz, and the detector can be tuned continuously from 20 Hz to 20 kHz, with additional spot frequencies of 50 kHz and 100 kHz.

When you need accurate low-frequency measurements, you can easily combine the assembly with the GenRad 1232-P2 Preamplifier.

Removable panel extensions are available for rack mounting.

SPECIFICATIONS

POWER: Null detector, internal battery; oscillator, 105 to 125, or 210 to 250 V, 50 to 400 Hz, 22 W max.

MECHANICAL: Cabinets bolted together. DIMENSIONS (w × h × d): 19 × 6 × 7.75 in. (483 × 153 × 197 mm), including panel extensions for rack mounting. WEIGHT: 13.5 lb (7 kg) net, 28 lb (13 kg) shipping.

ORDERING INFORMATION

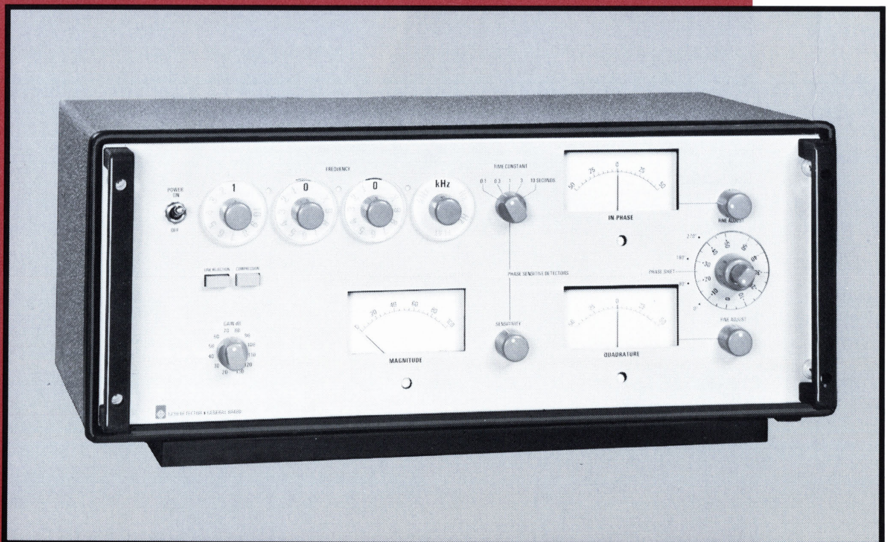
Description	Order No.
1240-A Bridge Oscillator-Detector,	
115-V Model	1240-9701
230-V Model	1240-9711
1240-AP Bridge Oscillator-Detector,	
with preamplifier, 115 V	1240-9829
with preamplifier, 230 V	1240-9839

Accessories	Order No.
ASA type M72 Replacement Battery (for 1232, 9 req'd)	8410-1372

1238 DETECTOR

A High-Performance Detector For Your Most Difficult Measurements

- ☐ Frequency range from 10 Hz to 100 kHz
- ☐ Magnitude, in-phase, and quadrature meters for rapid bridge balances
- ☐ High precision bridge detector performance
- ☐ 100 nV full-scale sensitivity



If you've ever had to extract a small signal from noise or resolve a signal into its in-phase and quadrature components, you can appreciate the advantages of the Genrad 1238 Detector. 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 to the most exacting applications.

Fast Accurate Measurements

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 the 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.

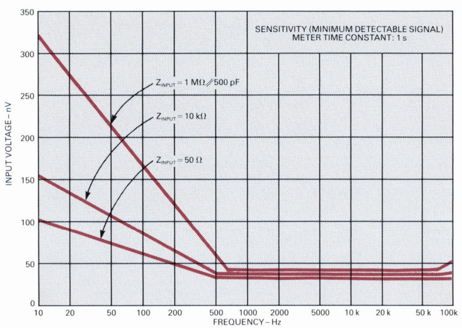
The 1238 includes 1-GΩ input impedance for minimum loading, overload protection for signals as high as 200 volts, and flat or tuned frequency response to tailor the detector to your specific signal, no matter how "tainted" that signal may be.

In combination with the GenRad 1316 Oscillator, which supplies the necessary quadrature reference channels, this detector is superb for sensitive audio-frequency detection.

Continued on the next page.

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 ±5% of reading accuracy, 2 to 4% bandwidth, and second harmonic ≥30 dB down from peak. LINE-REJECTION FILTER: Reduced 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 GΩ∕∕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: <30 nV × $\sqrt{\text{bandwidth}_{Hz}}$ at 1 kHz with input impedance of 70 MΩ∕∕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 ≈10°.

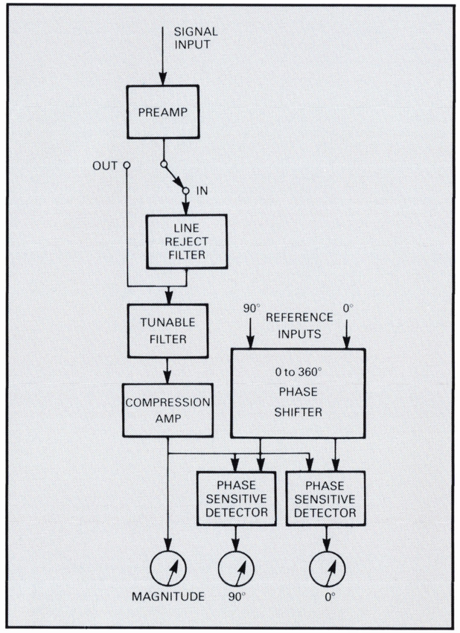
OUTPUTS: MAIN AMPLIFIER: 4 V rms (approx 2.3 V for full scale on Magnitude meter) available at rear BNC connector. MAGNITUDE: 6 V dc for full-scale deflection; PHASE DETECTORS: Up to 1 V dc each for full-scale deflection (depending on Sensitivity setting); available at rear 5-pin type 126 jack.

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 (w × h × d): Bench, 19.56 × 6.66 × 12.94 in. (497 × 169 × 329 mm); rack, 19 × 5.22 × 13.06 in. (483 × 133 × 332 mm). WEIGHT: Bench, 27 lb (13 kg) net, 40 lb (19 kg) shipping; rack, 21 lb (10 kg) net, 34 lb (16 kg) shipping.



ORDERING INFORMATION

Description	Order No.
1238 Detector	
60-Hz Bench Model	1238-9700
60-Hz Rack Model	1238-9701
50-Hz Bench Model	1238-9703
50-Hz Rack Model	1238-9704

PRECISION RLC MEASUREMENTS – REFERENCE MATERIALS

GenRad makes a wide line of impedance-measuring instruments, which cover a variety of applications in research and development laboratories, incoming inspection, quality control, production testing, and service repair.

Application notes are available upon request.

IMPEDANCE MEASUREMENT

The following discussion defines some of the terms used in the specifications of impedance-measuring instruments and outlines some of the measurement methods used.

DEFINITIONS

OHM'S LAW: For dc, Ohm's law defines resistance, R, as the ratio of the voltage across a device to the current through it.

$$R = \frac{E}{I} \qquad (1)$$

The reciprocal of resistance is conductance, G.

For ac, this ratio is complex because the voltage and current have relative phase as well as magnitude. This complex quantity is impedance, Z.

$$Z = \frac{E}{I} = R + jX \qquad (2)$$

where R is (ac) resistance and X is reactance.

The reciprocal of impedance is admittance, Y.

$$Y = \frac{1}{Z} = \frac{I}{E} = G + jB \qquad (3)$$

where G is (ac) conductance and B is susceptance.

EQUIVALENT SERIES AND PARALLEL COMPONENTS, D AND Q: Any impedance, regardless of its actual physical configuration, can be expressed, at any given frequency, as either a series or a parallel combination of resistance and reactance, as shown in Figure 1. The relationship between these elements is:

$$Z = R_s + jX_s = \frac{1}{Y} = \frac{1}{G_p + jB_p} = \frac{G_p}{G_p^2 + B_p^2} - j\frac{B_p}{G_p^2 + B_p^2} \qquad (4)$$

or:

$$Y = G_p + jB_p = \frac{1}{Z} = \frac{1}{R_s + jX_s} = \frac{R_s}{R_s^2 + X_s^2} - j\frac{X_s}{R_s^2 + X_s^2} \qquad (5)$$

where the subscripts s and p denote series and parallel values.

We could also use parallel resistance instead of parallel conductance, $R_p = 1/G_p$, and parallel reactance instead of parallel susceptance, $X_p = 1/B_p$; but $R_p \neq R_s$ and $X_p \neq X_s$. See Equation 5.

The dissipation factor, D, is defined as

$$D = \frac{R_s}{X_s} = \frac{X_p}{R_p} = \frac{G_p}{B_p} \qquad (6)$$

and the storage (or quality) factor, Q, is defined as

$$Q = \frac{1}{D} = \frac{X_s}{R_s} = \frac{R_p}{X_p} = \frac{B_p}{G_p} \qquad (7)$$

Using these quantities, we get

$$R_p = \frac{1}{G_p} = R_s(1 + Q^2) \qquad (8)$$

and

$$X_p = \frac{1}{B_p} = X_s(1 + D^2) \qquad (9)$$

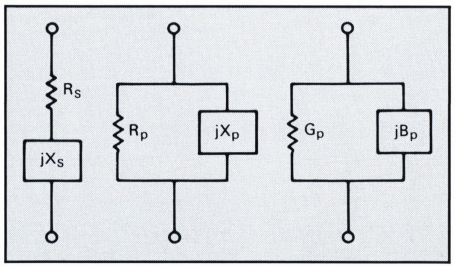


Figure 1. Series and parallel components of impedance.

The reactances of Figure 1 are either capacitive or inductive so that, at any given frequency, an impedance acts like a combination of equivalent resistance and inductance, L, or equivalent resistance and capacitance, C, and these quantities have different values depending upon whether they are in series or in parallel. The relationships between these quantities are:

$$C_p = C_s\left(\frac{1}{1 + D^2}\right) \qquad (10)$$

or

$$C_s = C_p(1 + D^2), \qquad (11)$$

$$L_p = L_s\left(1 + \frac{1}{Q^2}\right) \qquad (12)$$

or

$$L_s = L_p\frac{Q^2}{1 + Q^2}, \qquad (13)$$

$$\text{and D of a capacitor} = \omega R_s C_s = \frac{1}{\omega C_p R_p} \qquad (14)$$

$$\text{and Q of an inductor} = \frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p}. \qquad (15)$$

Many GenRad bridges allow the measurement of either the series or parallel values of C and L. Generally, components are specified in terms of their series values. Note that if $D < 0.1$ (or $Q > 10$) the difference between series and parallel values is less than 1%. Most ac bridges measure D of capacitance and Q of inductance; sometimes the Q of resistors can also be measured. In some countries, D is referred to as tan δ, the tangent of the angle δ in the vector (phasor) representation of impedance or admittance of Figure 2. This figure also defines the power factor, PF.

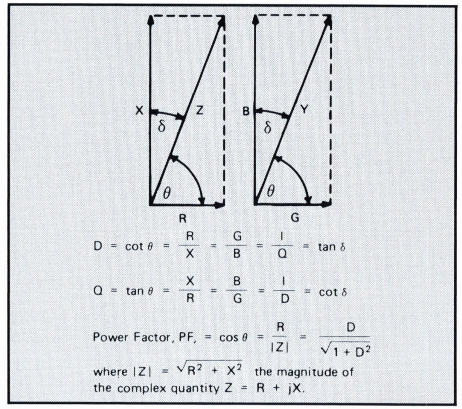


Figure 2. Vector diagram showing the relations between factors D and Q and angles θ and δ.

THREE- AND FOUR-TERMINAL MEASUREMENTS Many GenRad instruments are capable of making measurements that are quite immune to errors caused by either shunt admittance or series impedance. This means that they make good guarded, three-terminal measurements or four-terminal "Kelvin" measurements, respectively.

In order to measure the direct capacitance C_{HL} in the circuit of Figure 3, the guard terminal, G, must not be left floating because, if it is, C_{HL} is shunted by the series combination of C_{HG} and C_{LG}. A three-terminal connection must be made, and the instrument used must not be affected by these two shunting capacitances. This situation is very common, particularly when measuring shielded, three-terminal capacitance or any high impedance connected with shielded cables. The shunting impedances are not always just capacitive; they could be

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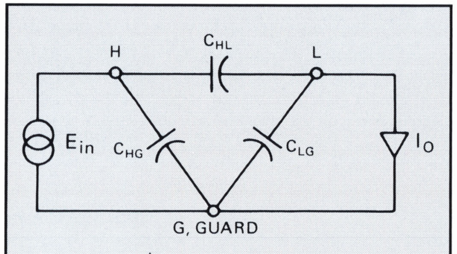
IMPEDANCE MEASUREMENT (Cont'd)



$$\frac{I_O}{E_{in}} = j\omega C_{HL}$$

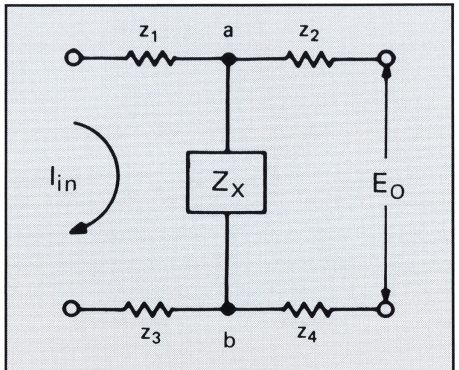
Figure 3. Three-terminal capacitance and an ideal 3-terminal measurement.

THREE- AND FOUR-TERMINAL MEASUREMENTS (Cont'd)

leakage resistances in a dc measurement or even actual circuit components, as would be the case if a component must be measured while it is connected in a circuit. Almost all of GenRad's bridges and meters are capable of making such three-terminal, or guarded, measurements, but the amount of shunt admittance they can tolerate without error depends on the type of circuit used. The best in this respect is the precise transformer-type bridge, the 1615-A (see **Measurement Methods**).

When low impedances are measured, a two-terminal connection has errors caused by the addition of the series impedance of the connecting leads to the impedance to be measured. One way to correct for this error is to short-circuit the test leads at the far end, measure the lead impedance, and subtract it from later measurements of the unknown. A better way is to make a four-terminal measurement. The four-terminal impedance value of the network of Figure 4 is E_0 / I_{in}, and this value is independent of the "lead" impedances, z_1, z_2, z_3 and z_4. Any instrument that makes a four-terminal connection and is immune to lead impedances of reasonable value makes a good four-terminal measurement. This four-terminal connection is also called a Kelvin connection, named for Lord Kelvin whose famous bridge design (still used in the GenRad 1666) makes good four-terminal resistance measurements. Many low-impedance standards have four terminals and require this type of measurement, as does the accurate measurement of any low-valued impedance.

The terminals carrying the current (Figure 4) are called the current terminals and those used to make the voltage measurement are called the potential terminals. In theory, and in many cases, these pairs of terminals can be interchanged and yet give the same result. Most instruments, however, can tolerate more series impedance in some of their connections than in others so that consideration should be given to how they are connected. Also, when very high currents are used, they should be applied to the current terminals, which are designed to carry them; the potential terminals could be damaged.



$$\frac{E_O}{I_{in}} = Z_X$$

Figure 4. 4-terminal impedance and an ideal 4-terminal measurement.

In many cases, four-terminal measurements are made on low-valued components that have only two lead wires, in order to avoid errors caused by the connections to the bridge. Two connections are made to each lead, and it is the position of the inner connections that determines how much of the component's lead impedance is included in the measurement. In Figure 4, the effective four-terminal value includes all the impedance between the junctions a and b and, in the two-lead case, these points are where the inner connection is made.

Several GenRad instruments make good four-terminal measurements. Many of these also make good three-terminal measurements at the same time and sometimes this combination is called a "five-terminal" measurement.

MEASUREMENT METHODS

BRIDGES AND METERS: Historically, impedance-measuring instruments were divided into meter types, which measured voltage or current on meters calibrated in impedance quantities, and bridge or null types, which required an adjustment and indicated impedance on a scale or dial associated with a variable component of some kind. A meter was faster and easier to use, while a bridge was generally more accurate.

Many applications require both accuracy and speed. Some years ago, GenRad developed bridges that made fast balances automatically and impedance meters that used precise circuitry and digital readouts to obtain good accuracy. The distinction between bridge and meter became less meaningful. More recently, the GenRad Digibridge® has all but eliminated this distinction because while it uses a meter method, it has many properties of a bridge.

GenRad makes many types of impedance-measuring instruments. The various measurement techniques used are discussed below.

DC BRIDGES: The Wheatstone bridge measures an unknown resistance, R_x, in terms of calibrated standards of resistance connected, as shown in Figure 5. A dc source (GEN) must be applied and a dc null detector (DET) used to detect output voltage. When this output voltage is zero, the bridge is balanced or nulled and the relationship between the resistors is

$$R_x = \frac{R_N R_B}{R_A} = R_N R_B G_A \qquad (16)$$

Generally, one of the standard resistors is adjustable and has a calibrated readout proportional to its value. Another standard (or the other two) is changed to

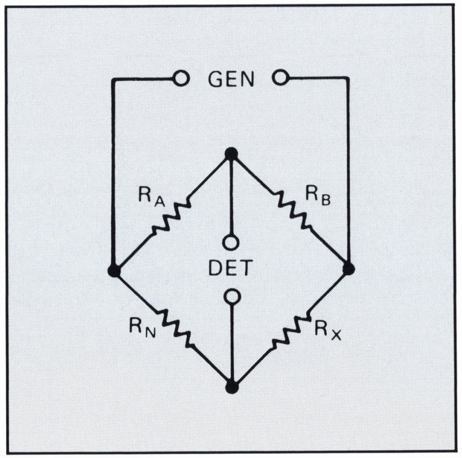


Figure 5. The general Wheatstone Bridge circuit.

extend the bridge range. The GenRad 1644 Megohm Bridge is a Wheatstone bridge designed for measuring high-value resistors at high voltages. A guarded Wheatstone circuit is used in the GenRad 1666 Resistance Bridge, which also uses the Kelvin Double Bridge circuit to make four-terminal measurements.

AC BRIDGES: This Wheatstone bridge circuit is adaptable to ac measurements but, with complex ac impedance, two balances are necessary to balance both the real (resistive) and imaginary (reactive) parts in order to obtain a null. At balance

$$Z_x = R_x + jX_x = Z_N Y_A Z_B \quad (17)$$

or

$$Y_x = G_x + jB_x = Y_N Z_A Y_B \quad (18)$$

The first of these equations expresses the unknown in terms of impedance, and the second expresses it in terms of admittance. To satisfy these equations, at least one of the three arms, N, A, or B, must be complex.

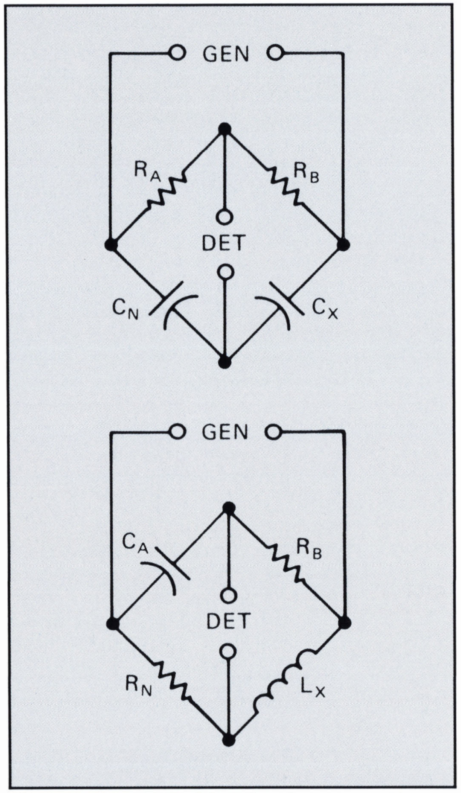
A reactance, X_x, can be measured in terms of a similar reactance in an adjacent arm (Figure 6) or an unlike reactance in the opposite arm (Figure 7). Bridges rarely use standard inductors.

The complex arm required to satisfy balance conditions of Equation (17) or (18) may be a resistance and reactance either in series or parallel. The bridge will indicate equivalent series components if this complex arm is a series connection in an adjacent arm or a parallel connection in the opposite arm. The converse is also true.

If both components in 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 this combination is adjustable, this component will be proportional to D or Q of the unknown. In this case, when D is very high or Q very low, the two bridge adjustments will interact, causing a slow balance convergence.

GenRad's general-purpose impedance bridge, the 1656, uses the basic circuits of Figures 5, 6, and 7 to measure R, C, and L. It has additional D or Q adjustments connected to allow both series and parallel equivalent values. Adjustable resistors (pots or decades) and resistance ratio arms are used to extend the range.

TRANSFORMER-RATIO-ARM BRIDGES: While inductance standards are rarely used in bridges because they are generally larger, less stable, and less pure than resistors or capacitors, a transformer can form an inductively coupled voltage divider whose ratio is more precise and stable than one made with resistors or capacitors. Ratio accuracies of a few parts per million (ppm) are possible even for ratios as high as 1000 to 1, and these ratios are virtually unaffected by age, temperature, humidity, or voltage. Such a divider can be used as two adjacent arms of a bridge, giving the bridge extremely precise ratio accuracy.



Figures 6 and 7. Circuits for capacitance bridges in which like reactances (top) or unlike reactances (bottom) are compared.

The GenRad 1654 Impedance Comparator uses a fixed, unity-ratio transformer, and GenRad's precise capacitance bridge, the 1615, uses a multiple-tapped transformer to allow decade adjustment, as shown in simplified form in Figure 8. The balance equation for this circuit is

$$G_x + j\omega C_x = \frac{N_1}{N_2}\Big[\beta_1 G_1 + \beta_2 G_2 + \ldots + j\omega(\alpha_1 C_1 + \alpha_2 C_2 + \ldots)\Big] \quad (19)$$

where α and β are the decade ratio values adjusted by the panel lever controls. (Actually, there are many more than two of each.)

Transformer-ratio-arm bridges have a second, equally important characteristic in that they can make very good three-terminal measurements. Their tolerance to loading capacitances is illustrated in Figure 8. Here, C_B shunts the detector, causing no error directly, only a reduction in sensitivity if C_B is very large. The other capacitance, C_A, shunts the transformer winding and thus tends to reduce the voltage across the unknown.

However, because of the tight coupling between the two windings (N_1 and N_2), the voltage on the standard capacitors will be reduced in very nearly the same proportion as the unknown voltage, leaving the balance condition almost unchanged. A 1-μF load at 1 kHz makes an almost negligible error. This high immunity allows remote measurements with long cables with guarded shields and even many measurements of capacitors connected in networks.

ACTIVE AND AUTOMATIC BRIDGES: In the transformer-type bridge of Figure 8, fixed standards are used and voltages are varied to give a null. A potentiometer could also be used to vary the voltage on a fixed standard, but its output resistance would add to the impedance of the standard. A multistage, unity-gain amplifier can have a very low output impedance so that, when used with a potentiometer, it makes good adjustable voltage to drive fixed standards. This scheme is used on the GenRad 1633 Incremental Inductance Bridge, allowing it to make direct-reading measurements at many different frequencies.

IMPEDANCE COMPARATOR: The GenRad 1654 Impedance Comparator is both a bridge and a meter. It measures the difference between two similar, externally connected impedances which, together with two precision inductively coupled arms, form a bridge circuit. This bridge is not balanced. Instead, the phase components of the bridge unbalance voltage are displayed on meters as percent-magnitude difference and phase-angle difference. If these impedances are relatively pure resistance, capacitance, or inductance, then the magnitude difference is very nearly the percent difference in R, C, or L and the phase-angle difference is $\triangle Q$, $\triangle D$, and $\triangle D$, respectively. *(Cont'd)*

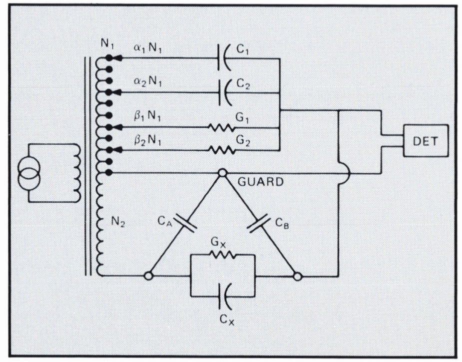


Figure 8. Transformer-ratio-arm bridge.

IMPEDANCE MEASUREMENT (Cont'd)

IMPEDANCE COMPARATOR (Cont'd)
This comparator can indicate very small differences, down to .003%, if the two external impedances are close in value. It can also resolve D differences of .00003. Moreover, it makes measurements at 100 Hz, 1 kHz, 10 kHz, and 100 kHz. This combination of sensitivity and wide frequency range is valuable for many difficult measurements. Impedance comparators can be combined with analog limit comparators and decade standards to make inexpensive test systems for rapid sorting (see the 1654-Z systems).

ANALOG METERS: The two GenRad megohmmeters (1863 and 1864) use the simple analog meter method outlined in Figure 9. Here, a high dc voltage is applied to the unknown, R_x, and the subsequent current is measured as a voltage across a standard resistor, R_s (one of a set selected by a range switch). The value of the applied voltage is selected by panel switches that also change the meter sensitivity so that the meter deflection is a function of R_x, not I_x. These megohmmeters have wide range, going up to over 100 TΩ. They are commonly used for testing insulation resistance of electrical machinery and leakage resistance of capacitors.

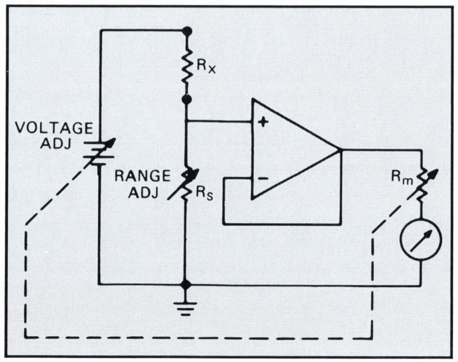


Figure 9. Basic megohmmeter.

DIGIBRIDGE® METERS: Impedance is defined as a ratio or division, and the best way to make an accurate division is with a digital computer. The GenRad Digibridge models (1657, 1658, 1687-B, and 1689) use small, inexpensive microprocessors for precise digital division and for many other functions as well.

The Digibridge impedance-measurement instruments are not really bridges because there is no null. They successively measure the voltage across the unknown and the voltage across a standard resistor carrying the same current, and divide the digital results. The quotient is independent of the scale factor of the converter because it cancels in the division. The Digibridge instruments measure complex ac quantities so the measuring circuit must include a phase-sensitive detector; two measurements must be made on each signal; and the division is that of two complex numbers. To express the results in terms of capacitance or inductance requires a multiplication or division by the angular frequency, which is precisely known because a quartz-crystal oscillator is used.

Because the result is independent of the detector-converter gain, the only precise components, besides the crystal oscillator, are the standard resistors used. In this respect, the Digibridge instrument is more like a bridge than a meter. It has an advantage over a bridge in that no adjustable components are necessary (adjustable components are a main source of the phase shifts that cause D or Q errors, as well as being a source of magnitude error.)

The GenRad 1658, 1687-B, and 1689 Digibridge models have a keyboard with which to enter test limits for fast, multiple-limit sorting of components.

RESISTANCE STANDARDS AND DECADES

STANDARD RESISTORS

Because of its accuracy of adjustment, long-term stability, low and uniform temperature coefficient, and relative immunity to ambient humidity conditions, the wire-wound resistor is the most suitable type for use as a laboratory standard at audio and low radio frequencies, as well as at dc.

AC CONSIDERATIONS: Resistors designed for ac use differ from those intended for use only at dc in that low series reactance and constancy of resistance as frequency is varied are important design objectives. The residual capacitance and inductance become increasingly important as the frequency is raised, acting to change the terminal resistance from its low-frequency value.

For frequencies where the resistance and its associated residual reactances behave as lumped parameters, the equivalent circuit of a resistor can be represented as shown in Figure 1. L is the equivalent inductance in series with the resistance, and C is the equivalent capacitance across the terminals of the resistor.

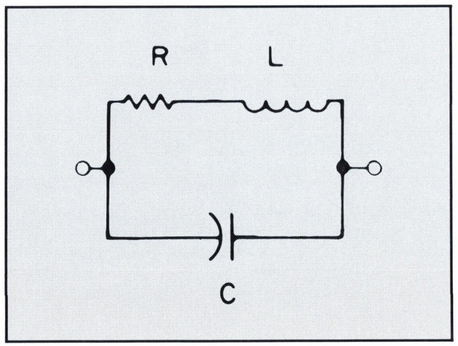


Figure 1.

It is necessary to differentiate clearly between the concepts of equivalent series and equivalent parallel circuits. The two-terminal circuit of Figure 1 can be described as an impedance

$R_s + jX_s$

or as an admittance

$G + jB = \frac{1}{R_p} + \frac{1}{jX_p}$,

wherein the parameters are a function of frequency. This distinction between series and parallel components is more than a mathematical exercise; the use to which the resistor is put will frequently determine which component is of principal interest.

The expression for the effective series impedance is

$$Z_s = R_s + jX_s = \frac{R + j\omega\left[L\left(1 - \frac{\omega^2}{\omega_r^2}\right) - R^2C\right]}{\left(1 - \frac{\omega^2}{\omega_r^2}\right)^2 + (\omega RC)^2}$$

where $\omega_r = \frac{1}{\sqrt{LC}}$ and $\frac{\omega^2}{\omega_r^2} = \omega^2 LC$.

The expression of the effective parallel admittance is

$$Y = G + jB = \frac{1}{R_p} + \frac{1}{jX_p} \frac{\frac{1}{R} + j\omega\left[C - \frac{L}{R^2}\left(1 - \frac{\omega^2}{\omega_r^2}\right)\right]}{1 + \left(\frac{\omega L}{R}\right)^2}$$

At low frequencies, where terms in ω^2 are negligible, the resistor may be represented by a two-element network consisting of the dc resistance, R, in series with an inductance equal to $L - R^2C$ or in parallel with a capacitance equal to $C - L/R^2$. Because of the presence of the R^2 term in the equivalent reactive parameters, shunt capacitance is the dominating residual for high values of resistance, while for low values the series inductance invariably predominates. Generally, individual wire-wound resistors above a few kilohms are capacitive, while decades, at somewhat lower values are inductive.

RESISTANCE STANDARDS AND DECADES (Cont'd)

In the simplified circuit of Figure 1, the effective parallel resistance of a high-valued resistor in which capacitance dominates would be independent of frequency. Actually, other effects may cause the parallel resistance to decrease with frequency. For example, dielectric losses in the shunt capacitance, C, are equivalent to a resistance

$$R^d = \frac{1}{D\omega C}$$

(where D is the dissipation factor of the distributed capacitance), which decreases with frequency and causes the effective parallel resistance to decrease rapidly beyond a certain frequency. In addition, distributed capacitance along the winding causes a similar rapid decrease in resistance even if its dielectric loss is negligible. The equations above indicate that the effective series resistance of low-valued resistors would be independent of frequency up to quite high frequencies. In practice, if the residual inductance and capacitance are kept small, skin effect becomes the main cause for departure from the low-frequency values of these resistors.

GenRad wire-wound resistance elements are designed to minimize inductance in low-resistance values and to minimize capacitance for high values of resistance. All units up through 200 ohms utilize an Ayrton-Perry winding. For very low-valued units, the residual inductance of such a winding is about 1% of that of a corresponding single winding.

Elements of resistance from 500 ohms to 100 kilohms are unifilar wound on flat cards to provide low inductance and capacitance. Separate resistors of higher values are also wound on flat cards for optimum ac performance but spools are used in decade boxes (see Figure 2). This is because the effect of inductors is negligible at these high frequencies and the effect of capacitance between resistors, which is more important than capacitance across a single resistor, is minimized.

DECADE BOXES

In decade boxes, the residual impedances of the switches, wiring, and cabinet are added to those of the resistors themselves. For multiple-decade boxes, the series inductances are additive, but the capacitance is approximately that across the highest valued decade used (see specifications for each type).

The effect of the residual reactance depends greatly upon the way the resistor is connected in the circuit. For example, parallel capacitance can often be compensated for when the resistor is connected in parallel with a capacitor. For high-valued resistors, the upper frequency limit for a given error is some ten times higher in the effective parallel resistance than it is for the series connection.

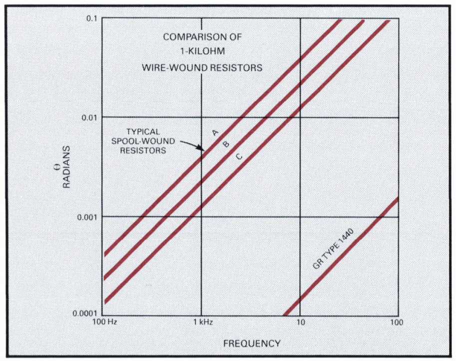


Figure 2.

INDUCTANCE STANDARDS AND DECADES

CONSTRUCTION: An inductor with a non-magnetic core (called an "air core") will have higher stability and negligible non-linearity compared to one wound on a core made of a high-permeability alloy (referred to as an "iron core" even if the alloy contains little or no iron). However, an air-core coil will have a relatively low Q. Because stability is the prime requirement of a laboratory standard, the GenRad 1482 Standard Inductors are wound on ceramic forms that magnetically act like air.

For circuit design and other experimental work, a higher Q is preferable, even at the expense of stability and linearity. Therefore, the GenRad 1491 Decade Inductors use iron cores. A good balance between these opposing characteristics is possible, however, with cores made from certain powdered alloys so that these decades can maintain good accuracy through time and over a reasonable current range. All GenRad inductors use cores of toroidal shape, which generate a very low external field and are relatively immune to pickup from external fields. Coils of this shape can be placed close together with negligible mutual inductance. The symmetry of the toroidal shape also contributes to stability and a constant temperature coefficient.

INDUCTANCE CHANGES: The inductance depends not only upon the geometry of the winding and the permeability of the core but also upon the residual impedances that are shown in the equivalent circuit of Figure 1. The largest changes of inductance with frequency are produced by the effective shunt capacitance, C_0, of the winding and the terminals. Any capacitance increases the effective inductance value as the resonant frequency is approached, expressed as

$$L = \frac{L_0}{1 - \omega^2 L_0 C_0} \qquad (1)$$

where L_0 is the zero-frequency inductance. The inductor will appear capacitive above resonance. When the frequency is well below the resonant frequency,

$$f_r = \frac{1}{2\pi\sqrt{L_0 C_0}}$$

the fractional increase in inductance is

$$L \simeq L_0\left[1 + (f/f_r)^2\right] \qquad (2)$$

The resistances shown in Figure 1 also affect the inductance value and make the effective series and parallel inductance values somewhat different, particularly when the Q is low. This is expressed as

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

Air-core inductors change very little with current, but the permeability of ferromagnetic materials depends upon the ampere turns of magnetizing force applied. The inductance rises linearly over a small region near zero current, then more rapidly to a maximum, followed by a sudden decrease as saturation is approached. To make these curves independent of inductance value, the current has been normalized to a value I_1, which is the current that produces a specified fractional increase in inductance.

Q VS FREQUENCY: The storage (or quality) factor, Q, is the ratio of reactance to resistance and is infinite for a pure inductance. If the resistance is all true

Continued on the next page.

INDUCTANCE STANDARDS AND DECADES (Cont'd)

Q VS FREQUENCY (Cont'd): series resistance (R_c in Figure 1) and the inductance is constant, then the Q is proportional to frequency expressed as

$$Q = \omega L/R_c.$$

But, as noted above, L changes with frequency, and there are other sources of loss. The components of loss can best be described in terms of the dissipation factor, D = 1/Q, because the total D is the sum of the component D's, and these can be plotted as straight lines in logarithmic coordinates, as shown in Figure 2. For an air-core coil, the other sources of loss besides the ohmic or "copper" loss are eddy current loss, in any nearby conductors (such as a case) and in the wire itself, and dielectric loss, in the stray shunting capacitance (shown lumped as C_0).

$$D \simeq \underbrace{\frac{1}{1-(f/f_r)^2}}_{\text{Resonance Factor}} \left[\underbrace{\frac{R_c}{\omega L_0}}_{\text{Ohmic Loss } D_c} + \underbrace{G_e \omega L_0}_{\text{Eddy Current Loss, } D_e} + \underbrace{(f/f_r)^2 D_0}_{\text{Dielectric Loss, } D_d} \right] \quad (3)$$

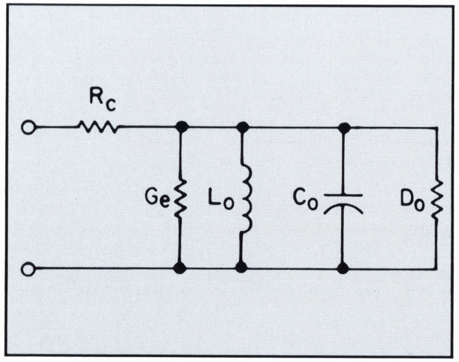


Figure 1. Equivalent circuit of an air-core inductor. R_c is the series resistance. G_e is the conductance due to eddy-current loss, and D_0 is the dissipation factor of the distributed capacitance.

The higher permeability obtained by using an iron core allows fewer turns for a given inductance, reducing R_c and C_0 and increasing f_r. The core adds two more components to the dissipation factor: one from eddy current loss in the core, which increases D_e, and another from hysteresis loss in the core, which depends on flux density.

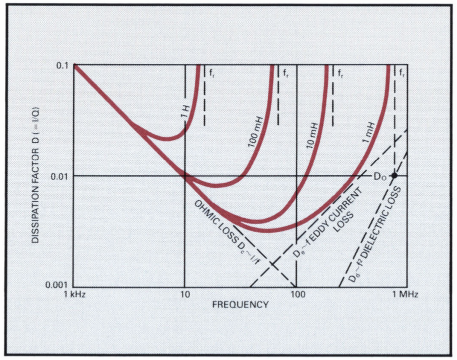


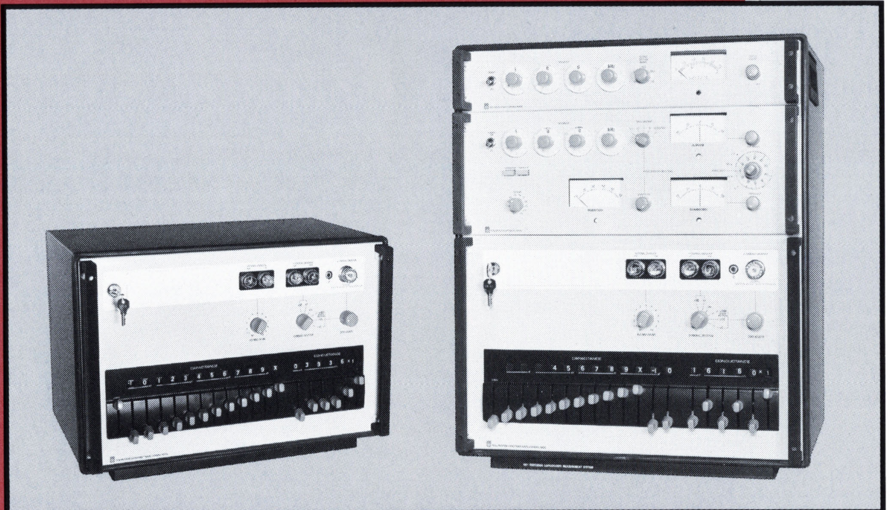
Figure 2. Dissipation-factor variation with frequency in typical air-core. Standard inductors.

CALIBRATION: The calibrated inductance of a standard inductor is the change in the measured inductance of a circuit when a portion of that circuit is removed and replaced by the inductor. This measured inductance includes small and variable mutual inductances between the inductor and the rest of the circuit, which are negligible when the calibrated inductance is larger than, say, 100 microhenrys, but which can introduce accuracy-limiting uncertainties into the calibration of smaller inductances. These uncertainties can be reduced to less than one nanohenry to permit accurate calibrations down to one microhenry, if the mutual components are made a definite part of the calibrated inductance. One method of achieving this, used in the 1482 Standard Inductors of 200 microhenrys and less, is to provide on the inductor a switching link, which connects either the inductor coil or a short circuit through internal leads to the external connection terminals. The calibrated inductance, which is the measured difference of the connection terminals, when the switch is moved from coil to short, is, to a high degree, independent of the external connections or environment.

Since the inductance usually varies with frequency, an accurate calibration requires that the frequency be specified. When, as in inductors with iron cores, the inductance also varies with current, the calibration must also specify a corresponding current or voltage. Since the frequency or current at which the inductor will be used is not usually known, a convenient reference level is zero frequency and zero current (initial permeability). Measurements made at two currents within the linear range and at well below resonant frequency are extrapolated to obtain inductance at zero current and initial permeability of the core material.

1616 PRECISION CAPACITANCE BRIDGE

- ☐ 10^{-7} pF to 10 μF—12-digit readout
- ☐ 10^{-10} μS to 1000 μS—5-digit readout
- ☐ 10 Hz to 100 kHz
- ☐ Up to 150-V input from oscillator
- ☐ 3-terminal measurements with 2- or 3-terminal connection
- ☐ Coaxial measurements
- ☐ Comparison measurements
- ☐ Simple lever balance with in-line readout



GenRad 1616 Precision Capacitance Bridge (left) and 1621 Precision Capacitance-Measurement System (right)

1621 PRECISION CAPACITANCE-MEASUREMENT SYSTEM

The Heart of Precision

The 1616 is the heart of the 1621 Capacitance-Measuring Assembly. The 1616 employs a transformer ratio-arm bridge with which unbalances as small as 0.1 aF (10^{-7} pF) and 100 aS (10^{-10} μS) 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.

The Whole of Precision

The 1621 is an assembly of three integrated instruments: A precision ratio-arm bridge (the GR1616), a highly stable oscillator (the GR1316), and an extremely sensitive detector (the GR1238). 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 aS (10^{-10} μS; equivalent to a shunt resistance of 10^{10} MΩ). 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.

continued on the next page

1616 PRECISION CAPACITANCE BRIDGE (cont.)

1616 SPECIFICATIONS

CAPACITANCE MEASUREMENT, 3-TERMINAL: DECADES: 12. RANGE: 0.1 aF to 1 μF (10^{-19} to 10^{-6} F). ACCURACY: * ±10 ppm, when most-significant decade is 1, 10, or 100 pF per step; otherwise, and at other frequencies, accuracy is ±[50 ppm + (0.5 + 20 $C_{\mu F}$) $(f_{kHz})^2$ ppm + (f_{kHz}) aF].

CAPACITANCE, 2-TERMINAL: Same as above, except as follows. RANGE: One additional decade, to 10 μF (10^{-19} to 10^{-5} F).

CONDUCTANCE MEASUREMENT, 3-TERMINAL: DECADES: 5 (virtually extended to 11 by G multiplier). RANGE: 100 aS to 100 μS (10^{-16} to 10^{-4}S). ACCURACY: * ±(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): ±(<0.03 pF).

CONDUCTANCE, 2-TERMINAL: Same as above, except as follows: RANGE: One additional decade, to 1000 μS (10^{-16} to 10^{-3} S).

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±1 ppm/°C and D <10 ppm for 3 middle decades; mica dielectric with TC of 20 ±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.

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: **G900® locking coaxial connector on panel to connect 2-terminal unknowns, 2 gold-plated **G874® 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, 1238 DETECTOR, and a broad line of capacitance 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.

*Accuracy stated as fraction of measured value, for these conditions: frequency, 1 kHz, except as noted; temperature, 23°±1°C; humidity, <50% RH.
†Registered trademark of the Carpenter Steel Co.
**G874/900—Gilbert Engineering, Glendale, Arizona.

1621 PRECISION CAPACITANCE-MEASUREMENT SYSTEM (cont.)

1621 SPECIFICATIONS (See 1616 for performance specifications)

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

AVAILABLE: 1404 REFERENCE STANDARD CAPACITORS (10 pF, 100 and 1000 pF) for calibration.

POWER: 100 to 125 and 250 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.

ORDERING INFORMATION

Description	Order No.
1616 Precision Capacitance Bridge	
Bench Model	1616-9700
Rack Model	1616-9701
1621 Precision Capacitance -Measurement System	
Bench Model, 60-Hz	1621-9701
Rack Model, 60-Hz	1621-9702
Bench Model, 50-Hz	1621-9703
Rack Model, 50-Hz	1621-9704

INDEX

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RESISTANCE DECADES

INDUCTANCE STANDARDS AND DECADES

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