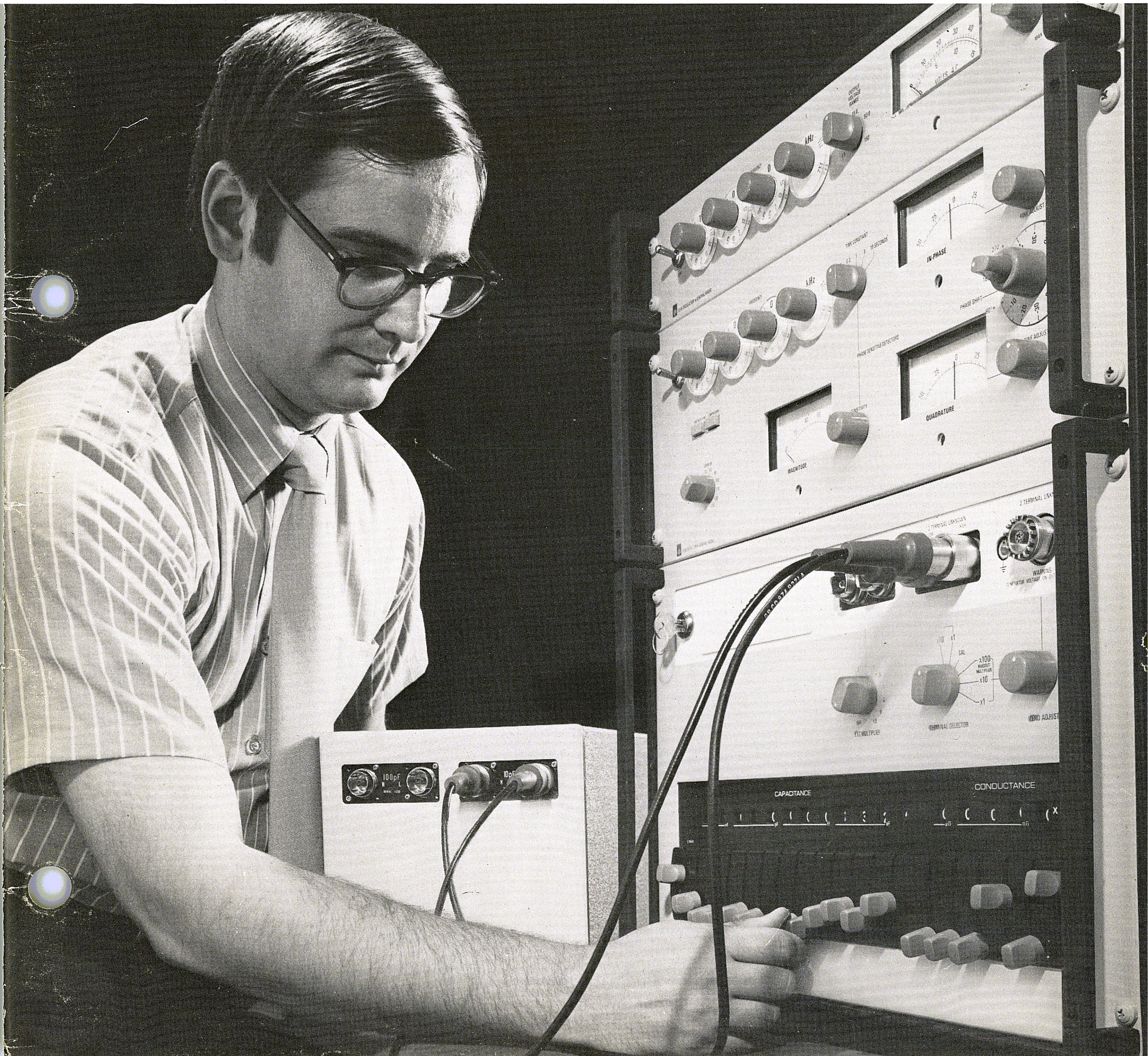
GenRad

impedance standards and precision bridges



CONTENTS

INTRODUCTION

This brochure contains complete information about GenRad's extensive line of impedance standards and precision bridges. These products enjoy worldwide acceptance for quality and precision and perform significant functions in a variety of measurement applications. These products represent but one facet of GenRad's total capability.

In addition to the products listed in this pamphlet, GenRad manufactures a broad line of state-of-the-art instrumentation, ranging from basic test instruments to elaborate computer-controlled systems. Among these products are manual and automatic impedance bridges, frequency synthesizers, manual and automatic rf-network analysis systems, coaxial components and accessories, rf bridges, general-purpose and precision slotted lines, precision directional couplers, low-frequency oscillators, Variac® adjustable autotransformers and automatic line-voltage regulators, sound and vibration and signal-processing equipment, including fast-Fourier and other real-time analyzers, stroboscopes and automatic test systems, plus instruments for digital, analog, and hybrid components and boards. For additional information on any of these products, simply contact your nearest GenRad sales office.

Capacitance Standards

CHOOSING A STANDARD CAPACITOR

A properly designed air capacitor approaches the ideal standard reactance in that it has very low loss and very small changes with time, frequency, and environment. Capacitance changes with changes in atmospheric pressure (about 18 ppm per inch Hg) and in relative humidity (about 2 ppm per % RH) can be eliminated by hermetic sealing of the capacitor. Changes with temperature can be reduced to a few ppm per °C by the use of low-temperature-coefficient materials in the capacitor. The maximum capacitance of an air-dielectric unit of practical size is of the order of 1000 pF.

For higher capacitance, solid dielectrics are used. The preferred dielectric for standard capacitors is high-quality mica, because of its dimensional stability, low loss, and high dielectric strength. The temperature coefficient of a mica capacitor is of the order of +35 ppm per °C. At dc or extremely low frequencies the mica dielectric has the disadvantage of relatively large change of capacitance with frequency.

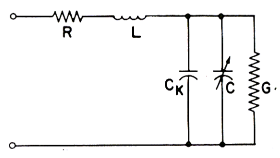
Polystyrene has a dielectric constant and dissipation factor very nearly constant with frequency, so that the capacitance change from dc to 1 kHz is a small fraction of a percent. The temperature coefficient of a polystyrene capacitor is, however, of the order of −140 ppm per °C.

FREQUENCY CHARACTERISTICS

Although the characteristics of the high-quality capacitors used as standards closely approach those of the ideal capacitor, to obtain high accuracy the small deviations from ideal performance must be examined and evaluated. The residual parameters that cause such deviations are shown in the lumped-constant, two-terminal equivalent circuit of Figure 1. R represents the metallic resistance in the leads, supports, and plates; L, the series inductance of the leads and plates; C, the capacitance between the plates; C_k, the capacitance of the supporting structure. The conductance, G, represents the dielectric losses in the supporting insulators, the losses in the air or solid, dielectric between capacitor plates, and the dc leakage conductance.

The effective terminal capacitance C_e of the capacitor becomes greater than the electrostatic or zero-frequency

Figure 1.



capacitance C_o as the frequency increases because of the inductance L. When the frequency, f, is well below the resonance frequency f_r (defined by $\omega_r^2 LC_o = 1$), the fractional increase in capacitance is approximately

$$\frac{\Delta C}{C_o} \approx \omega^2 LC_o = \left(\frac{f}{f_r}\right)^2 \qquad (1)$$

This change in capacitance with frequency for the capacitors described on the following pages is given either as a plot on logarithmic co-ordinates of the percent increase, $\Delta C/C_o$, versus frequency or as a tabulation of the values of L or f_r. Since the inductance is largely concentrated in the leads and supports, it is nearly independent of the setting of a variable capacitor. With this information, the increase in capacitance at, for example, a frequency of 1 MHz can be computed from the calibrated value at 1 kHz with high accuracy. For small increases, the accuracy may be greater than that of a measurement at 1 MHz because of the difficulties in determining the measurement errors produced by residuals in the connecting leads outside the capacitor.

The three-terminal capacitor has a similar increase in capacitance produced by inductance. The lowest resonance is determined not solely by the calibrated direct capacitance but also by the terminal capacitances, which may be much larger than the direct capacitances.

When the capacitor has a solid dielectric, such as mica, there is another source of capacitance change with frequency. The capacitance increases at low frequencies as the result of dielectric absorption caused by interfacial polarization in the dielectric. The change in capacitance with frequency of a 1000-pF capacitor with mica dielectric is shown in Figure 2. The dotted line slanting downward to the right represents the change in the dielectric constant of mica resulting from interfacial polarization; that slanting upward to the right shows the change in effective capacitance resulting from series inductance. The magnitude of the change at low frequencies depends upon the dielectric material and is, for example, much smaller for polystyrene than for mica.

DISSIPATION FACTOR

The dissipation factor of a capacitor is determined by the losses represented in Figure 1 by R and G. The resistance R is not usually significant until the frequency is high enough for the skin effect to be essentially complete. At such frequencies the resistance varies as the square root of frequency and may be expressed as $R_1\sqrt{f}$, where R_1 is the resistance at 1 MHz and f is the frequency in MHz. The total dissipation factor at high frequencies is then

$$D = \frac{G}{\omega C} + R_1\sqrt{f}\,\omega C \qquad (2)$$

At low frequencies only the dielectric losses represented by G are important. The leakage conductance component is negligible at frequencies above a few hertz and is important only when the capacitor is used at dc for charge storage. The dominant components at audio frequencies are the dielectric losses in the insulating structure and in the dielectric material between the plates.

In the air capacitor the losses in the air dielectric and on the plate surfaces are negligible under conditions of moderate humidity and temperature. The loss is, therefore, largely in the insulating supports. When good-quality, low-loss materials, such as quartz, ceramics, and polystyrene, are used for insulation, the conductance varies approximately linearly with frequency and the dissipation factor, D_k, of the supports is nearly constant with frequency. The total low-frequency dissipation factor of an air capacitor whose equivalent circuit is that of Figure 1 may be expressed as

$$D = \frac{G}{\omega(C + C_k)} = \frac{D_k C_k}{C + C_k} \qquad (3)$$

When the capacitance C is variable, this D is then inversely proportional to the total capacitance. Since the quantity $D_k C_k$ is nearly independent of both frequency and capacitance setting, it is a convenient figure of merit for a variable capacitor.

In a capacitor with a solid dielectric the dominant component of the conductance G is the loss in the dielectric, which varies with frequency The resulting variation of D with frequency, shown for a mica capacitor in Figure 2, is the sum of three principal components: a constant dissipation factor caused by residual polarizations; a loss produced by interfacial polarizations, which decreases with frequency; and an ohmic loss in the leads and plates, which results in a D proportional to the 3/2 power of frequency. The total dissipation factor has a minimum value at a frequency that varies inversely with capacitance and which ranges from 1 kHz to 1 MHz for capacitance values from 1 μF to 100 pF.

The capacitors described in these pages include air-dielectric reference standards, both fixed and variable, both fixed and decade mica-dielectric, and other decades with polystyrene, mica, and paper dielectric.

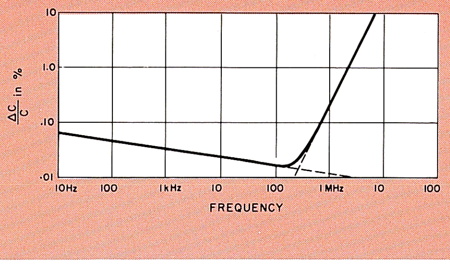
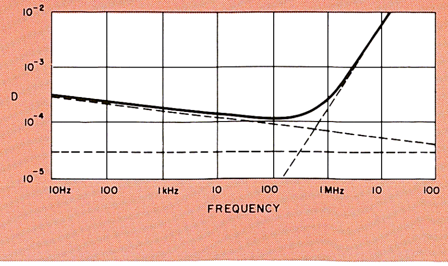
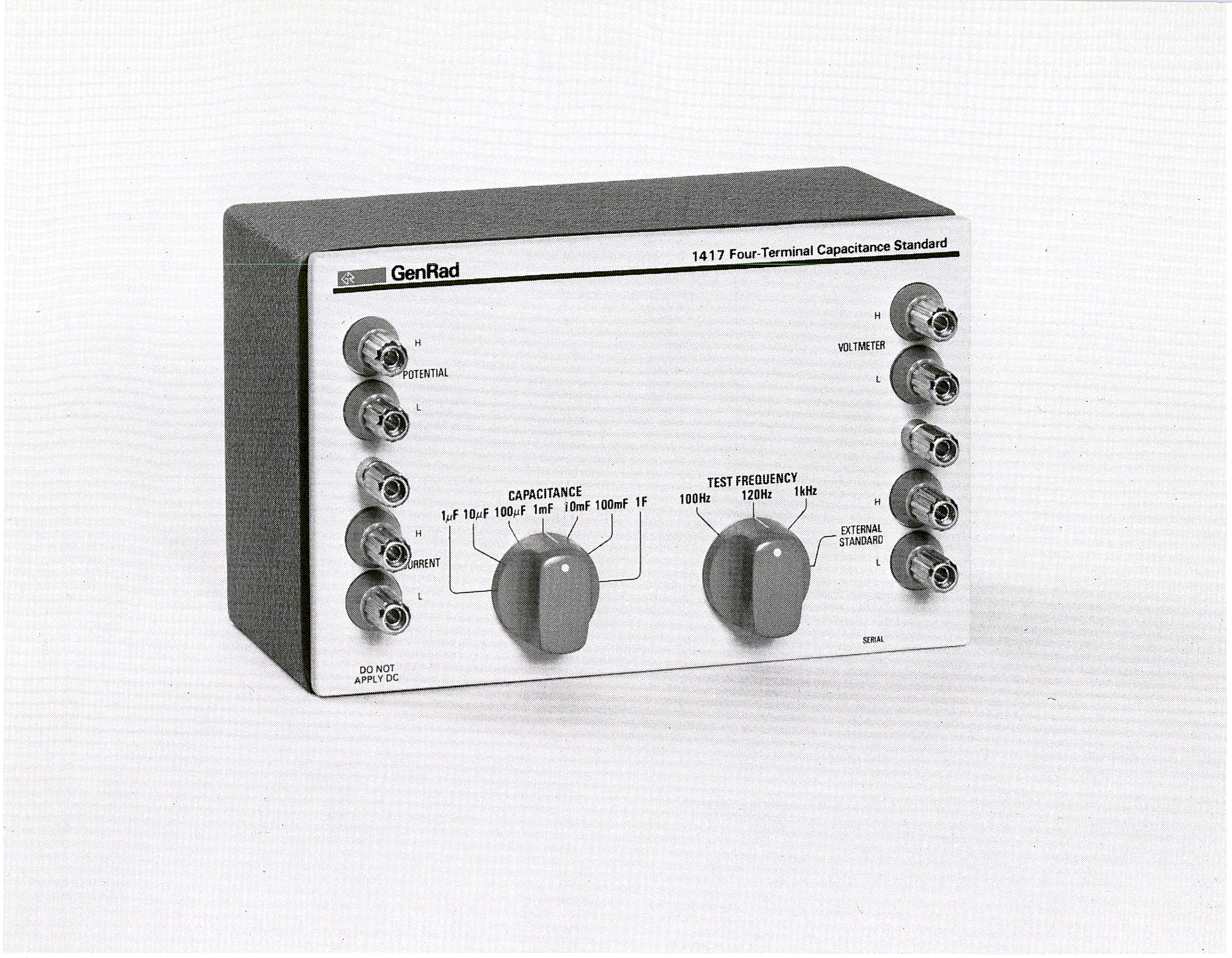


Figure 2. Variation with frequency of capacitance and dissipation factor for a 1000-pF mica capacitor, Type 1409.





GR 1417 Four-Terminal Capacitance Standard

- **1 μF to 1 F in decade steps**
- **0.25% basic capacitance accuracy**
- **0.02 to 0.25% ratio accuracy**
- **Dissipation-factor standard**

The GR 1417 Four-Terminal Capacitance Standard consists of a 1-μF standard capacitor and two precise inductive voltage dividers used to scale the value of the 1-μF capacitor up to 1 F in decade steps. This arrangement provides accuracy and stability unattainable with very high-value true capacitors.

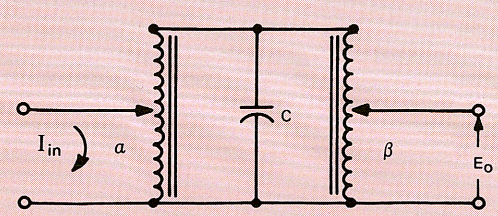
In addition to the seven direct-reading capacitance values, an infinite number of intermediate or higher capacitance values can be obtained by using external capacitors. An external capacitor is simply connected to the 1417's external standard terminals, either directly or in parallel with the 1-μF internal standard, and the resulting capacitance is scaled in value by the 1417's inductive voltage dividers.

The direct-reading accuracy of the 1417 is ±0.25% plus the associated ratio accuracy at test frequencies of 100, 120, 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.

One additional feature of importance is that all the 1417's parameters are measurable (without disassembly) so, in effect, its ultimate accuracy depends on the accuracy of the external measurement equipment.



Basic Circuit Diagram

Capacitance Value (Internal Standard)	Ratio Accuracy		D Accuracy		Approximate Terminal Impedance		E Max (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

*Not specified

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

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.

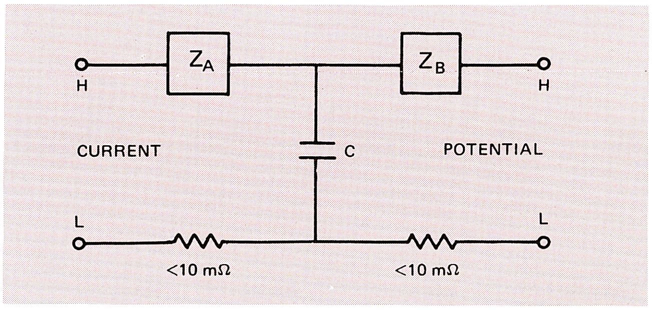
Dissipation Factor: 0.01 at 100 Hz, 120 Hz and 1 kHz. For D accuracy, see table.

Terminal Impedances: See figure and table (approx values given).

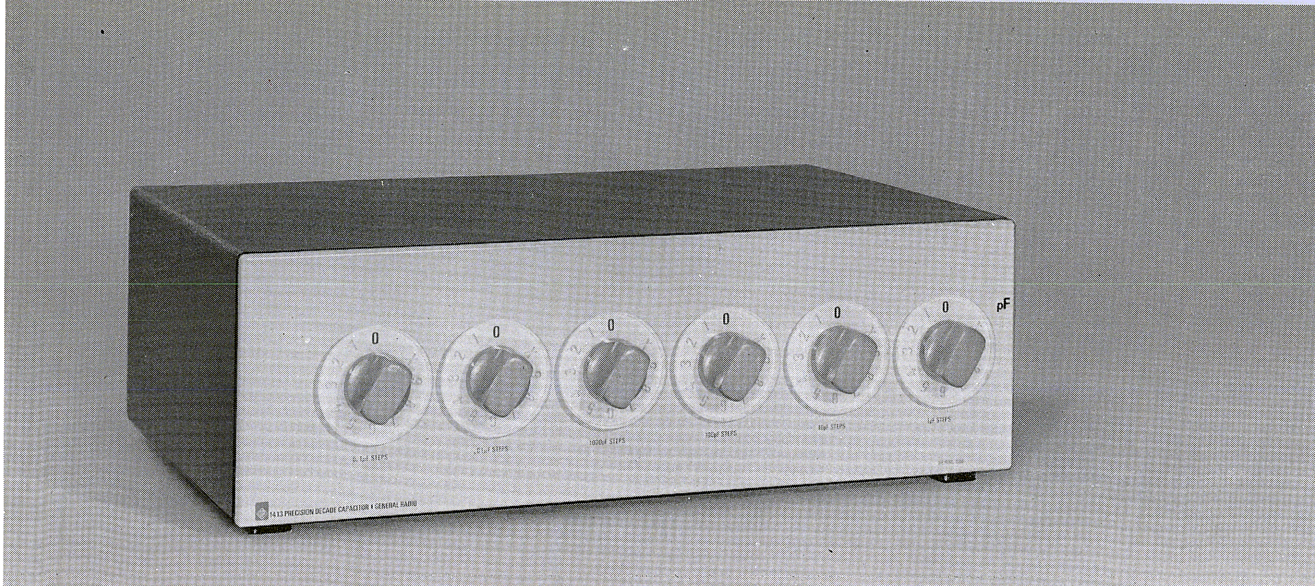
Temperature Coefficient: Approximately −140 ppm/°C.

Voltage Characteristic: Approximately +0.3% change from 0_V to E max (see table) at 100 Hz. Less at higher frequencies.

Mechanical: DIMENSIONS: (wxhxd): 8.5x5.9x5.25 in. (21.5x14.7x 13.2 cm). WEIGHT: 6 lb (2.7 kg) net, 11 lb (5 kg) shipping.



Description	Catalog Number
1417 Four-Terminal Capacitance Standard	**1417-9700**



1413 Precision Decade Capacitor

- **0 to >1 μF**
- **0.05% basic accuracy**
- **6-digit resolution**
- **3-terminal connections**
- **provision for BCD output**

The 1413 is not only a precision standard, it is a systems component as well — connections are made at the rear and each decade provides contact closures for 1-2-4-8 BCD output. It is an excellent companion to the 1654 Impedance Comparator, with which it is combined in 1654-Z Sorting Systems.

Six precision decades are employed to provide a range of 0 to 1.11111 μF in increments as small as 1 pF and with an accuracy of 0.05% + 0.5 pF. Air capacitors are used for the two lower decades and precision silvered-mica capacitors are used for the remainder. 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.

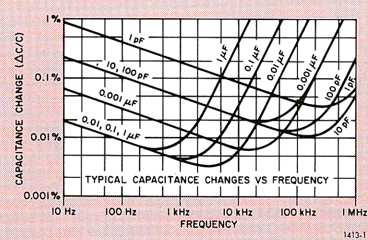
SPECIFICATIONS

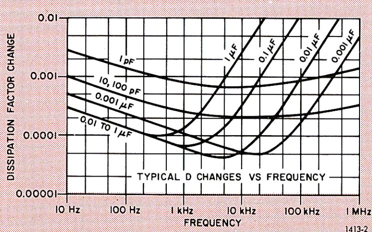
Range: 0 to 1.11111 μF, controlled by six in-line-readout dials.
Accuracy: ±(0.05% + 0.5 pF) at 1 kHz.
Stability: ±(0.01% + 0.1 pF) per year. TEMPERATURE COEFFICIENT: ≈20 ppm/°C from 10 to 50°C.
Zero Capacitance: ≤0.1 pF.
Voltage Rating: 500 V pk max up to 10 kHz.
Frequency: See curves.

	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 1 kHz	0.002	0.001	0.0005	0.0003	0.0004
Insulation Resistance, 3 term., after 2 min at 500 V dc	≥5 x 10^{10} Ω				≥5 x 10^{9} Ω
Terminal Capacitance, max high to case	4 pF	8 pF	10 pF	30 pF	60 pF
high to guard	85 pF	110 pF	125 pF	165 pF	200 pF
low to guard	45 pF	70 pF	80 pF	110 pF	120 pF

Interface: CONNECTIONS: 2 rear-mounted GR874® 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.

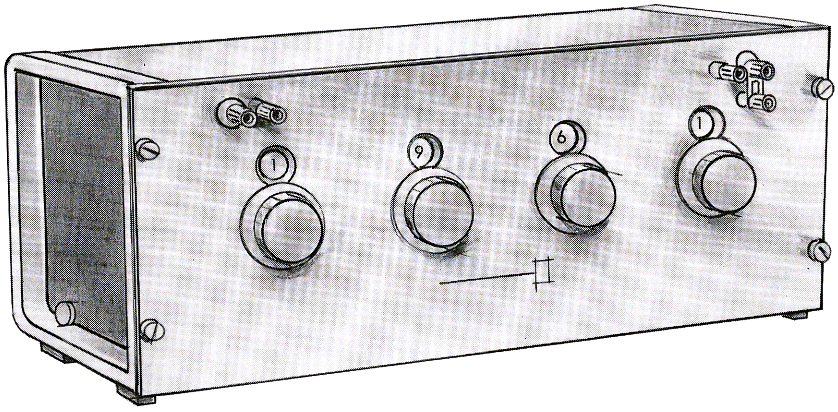
Available: 0480-9703 RACK-ADAPTOR SET to convert bench models to rack models, 874-Q2 ADAPTOR to convert GR874 connector to binding posts (2 req'd), 938-L SHORTING LINK to connect shields together when 874-Q2 Adaptors are used, 4220-3036 CONNECTOR to mate with Data Output Connector.





Mechanical: Convertible-bench cabinet. DIMENSIONS (wxhxd): Bench, 17x5.59x11.96 in. (432x142x304 mm); rack, 19x5.22x10.9 in. (483x133x277 mm). WEIGHT: Bench, 23 lb (11 kg) net, 29 lb (14 kg) shipping; rack, 24 lb (11 kg) net, 30 lb (14 kg) shipping.

Description	Catalog Number
1413 Precision Decade Capacitor	
Bench Model	**1413-9700**
Rack Model	**1413-9701**
Rack-Adaptor Set	**0480-9703**



1423-A Precision Decade Capacitor

- **100 pF to > 1 μF**
- **±0.05% accuracy**
- **two- or three-terminal connection**

This capacitor is a versatile tool for calibration laboratories and production-line testing. With it a bridge can be standardized to an accuracy exceeded only by that of the highest quality, individually certified laboratory standards such as the GR 1404 and 1408 Reference Standard Capacitors. Used with a limit bridge, such as the GR 1654 Impedance Comparator, the 1423 facilitates fast and accurate production-line measurements of arbitrary capacitance values with minimum setup time.

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 high-quality silvered-mica capacitors similar to those used in the GR 1409 Standard Capacitors. The capacitors and associated switches are mounted in an insulated metal compartment, which in turn is mounted in a complete metal cabinet. This double-shielded construction ensures that capacitance at the terminals is the same for either the three-terminal or the two-terminal method of connection (except for a constant difference of about one picofarad). This external capacitance can be included in the two-terminal calibration by the adjustment of a single trimmer.

SPECIFICATIONS

Nominal Values: 100 pF to 1.111 μF in steps of 100 pF.

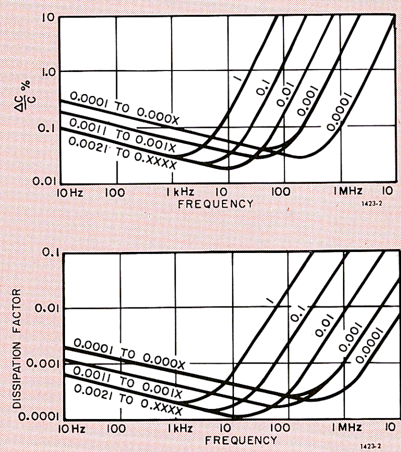
Accuracy: ±(0.05% + 0.05pF) at 1 kHz, calibrated in the three-terminal connection. Two-terminal connection (capacitor inserted into Type 777-Q3 Adaptor) adds about 1.3 pF.

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.

(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 per degree between 10° and 50°C.

Insulation Resistance: $>5 \times 10^{10}$ Ω to 0.1 μF and $>5 \times 10^{9}$ Ω from 0.1 μF to 1.111 μF.

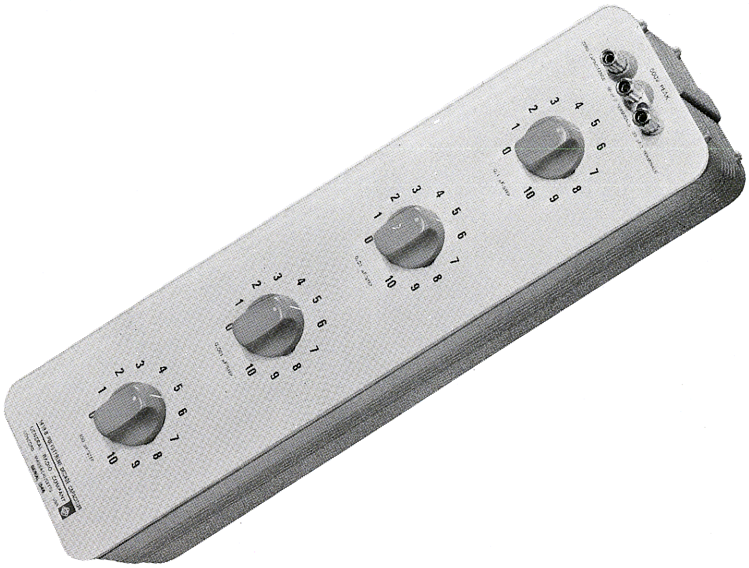
Maximum Voltage: 500 V peak, up to 10 kHz.

Supplied: Two Type 777-Q3 Adaptors.

Mechanical: Rack-bench cabinet. DIMENSIONS (wxhxd): Bench, 19x7.25x10.5 in. (483x184x267 mm); rack, 19x7x8.5 in. (483x178x216 mm). WEIGHT: 26 lb (12 kg) net, 39 lb (18 kg) shipping.

Description	Catalog Number
1423-A Precision Decade Capacitor	
Bench Model	**1423-9801**
Rack Model	**1423-9811**

National Stock Numbers are listed on the back cover.



1419 Decade Capacitors

- **100 pF to 1.1 μF**
- **choice of models**
- **two- or three-terminal connection**

Type 1419 Decade Capacitors are offered in three models using two different dielectric materials to satisfy a variety of needs.

Types 1419-A and -B (Polystyrene) Capacitance and dissipation factor constant with frequency, essentially noninductive, very low dielectric absorption. The dielectric is specially prepared of purified high-molecular-weight polystyrene, having very high resistance and freedom from interfacial polarization. Moisture sealing with Teflon* feed-through insulators assures high performance under adverse humidity conditions.

Type 1419-K (Silvered Mica) Higher accuracy, low dissipation factor, and +35 ±10 ppm/°C temperature coefficient (10-50°C) for use in higher ambient temperatures.

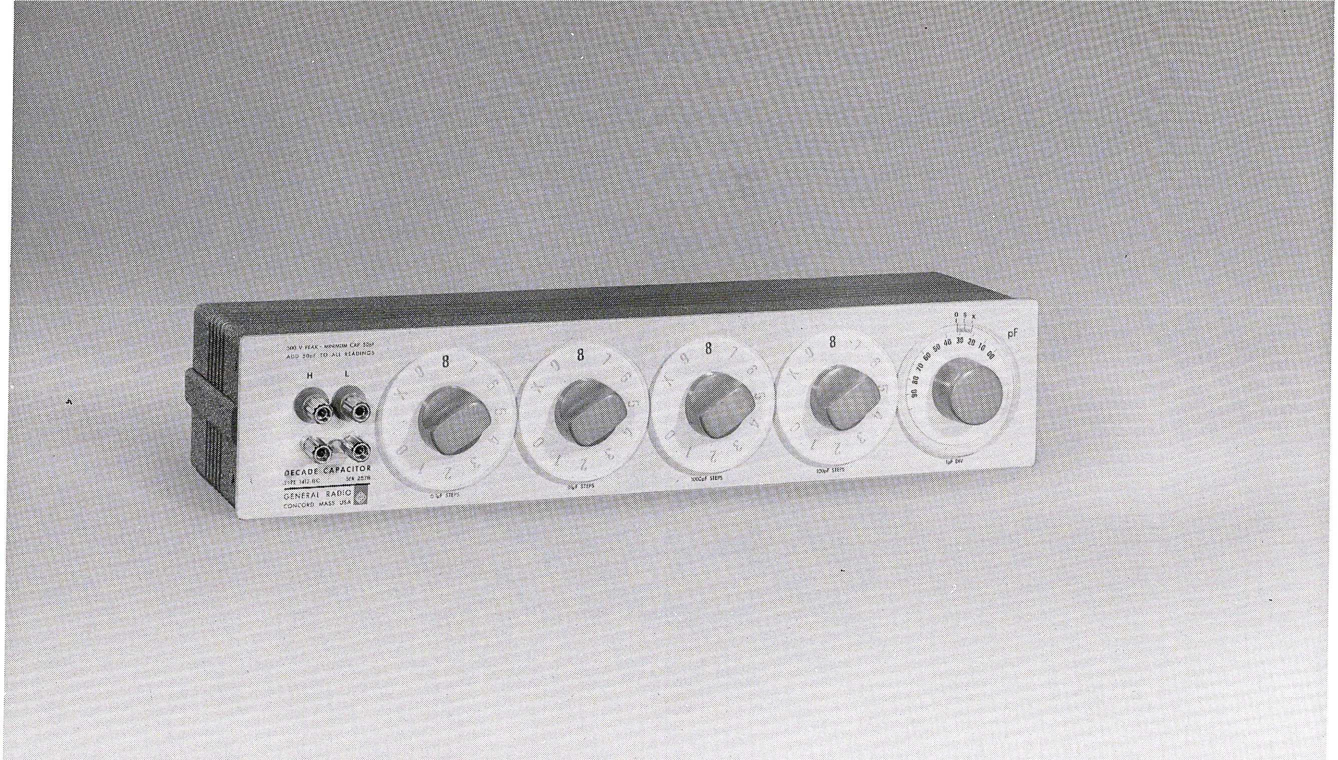
* Registered trademark of E. I. duPont de Nemours and Company.

SPECIFICATIONS

Type Number	1419-A	1419-B	1419-K
Dielectric	Polystyrene	Polystyrene	Silvered Mica
Maximum Capacitance of Box (μF)	1.110	1.1110	1.110
In Steps of (μF)	0.001	0.0001	0.001
Dials	3	4	3
Zero Capacitance, typical			
2-terminal connection	37 pF	50 pF	41 pF
3-terminal connection	15 pF	20 pF	13 pF
Accuracy[1]			
2-terminal connection[2]	±1%	±(1% + 2 pF)	±0.5%
3-terminal connection	±1% except ±1.5% on smallest decade	±1% except +1% to −(2% + 4 pF) on smallest decade	±0.5% except ±1% on smallest decade
Dissipation Factor at 1 kHz	<0.0002		<0.0003
Insulation Resistance at 100 V, 25°C 50% RH, typical	$>10^{12}$ Ω		$>5 \times 10^{9}$ Ω
Max Voltage[3] (dc or peak)	500 V up to 35 kHz		500 V up to 10 kHz
Max Operating Temperature (C)	65°		75°
Voltage Recovery[4]	<0.1%		<3%
Resonant Frequencies (typical)	1 μF—400 kHz; 0.1 μF—1MHz; 0.01 μF—2.7 MHz; 0.001 μF—7.8 MHz; 0.0001 μF—23 MHz		
Dc Cap/1-kHz Cap	<1.001		Typically 1.03
Cabinet: Lab-bench			
Over-all Dimensions — in. (mm)	13 x 4.31 x 5 (330 x 110 x 127)	16.3 x 4.31 x 5 (415 x 110 x 127)	14.13 x 5.5 x 6 (359 x 140 x 153)
Net Weight — lb (kg)	8.38 (3.8)	10.5 (4.8)	11.25 (5.5)
Shipping Weight — lb (kg)	10 (4.6)	11 (5)	18 (8.5)
Catalog Number	**1419-9701**	**1419-9702**	**1419-9711**

[1] Capacitance increments from zero position are within this percentage of the indicated value for any setting at 1 kHz.
[2] Units are checked with switch mechanism high, electrically, and the common lead and case grounded.
[3] At frequencies above the indicated max, the allowable voltage decreases and is (approx) inversely proportional to frequency. These limits correspond to a temperature of 40°C at max setting of each decade in box.
[4] Final % of soaking voltage V measured after holding terminal voltage at V for 1 h, then discharging for 10 s through a resistance of V ohms.

National Stock Numbers are listed on the back cover.



1412-BC Decade Capacitor

- **50 pF to >1 μF**
- **better than 1-pF resolution**
- **accuracy ±(0.5% + 5 pF)**
- **low loss, leakage, dielectric absorption**

The wide capacitance range and high resolution of this decade capacitance box 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 2-terminal and 3-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.

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.

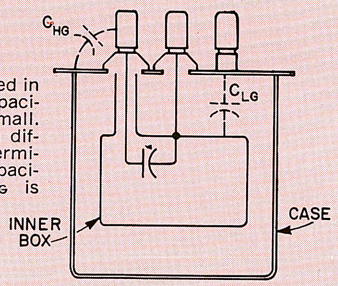
Min Capacitance: 50 pF with all controls set at zero.

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.

Temperature Coefficient: −140 ppm/°C (nominal).

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.



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.

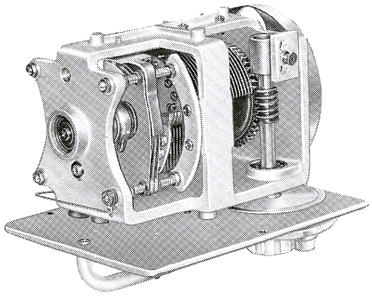
Max Voltage: 500 V peak, up to 35 kHz.

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.

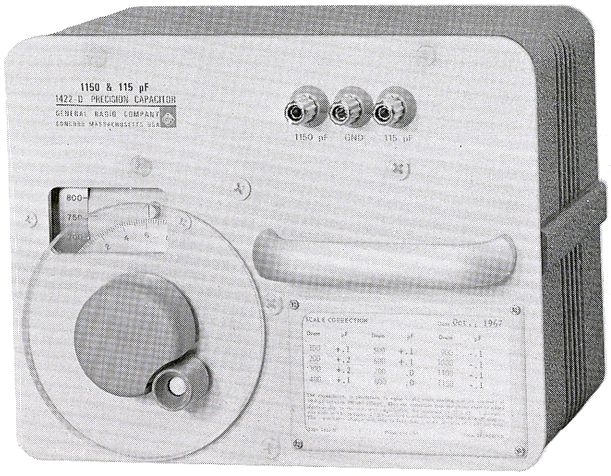
Mechanical: Lab-bench cabinet; brackets provided for rack mounting. DIMENSIONS (wxhxd): 17.25x3.5x6 in. (439x89x153 mm). WEIGHT: 8.5 lb (3.9 kg) net, 10 lb (4.6 kg) shipping.

Description	Catalog Number
1412-BC Decade Capacitor	**1412-9410**

National Stock Numbers are listed on the back cover.



Interior of 1422-D



1422 Precision Capacitors

- **variable air capacitors**
- **stability: better than 0.02% full scale per year**
- **settable to 40 ppm**
- **low temperature coefficient, low losses**
- **wide selection to suit needs**

The 1422 is a stable and precise variable air capacitor intended for use as a continuously adjustable standard of capacitance.

One of the 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.

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

Three-terminal The 1422-CB, -CL, and -CD are three-terminal capacitors with shielded coaxial terminals for use in three-terminal measurements. The calibrated direct capacitance is independent of terminal capacitances to ground, and losses are very low. The 1422-CL has particularly low, constant terminal capacitances, making it suitable for measurement circuits in which high capacitance to guard cannot be tolerated.

Construction The capacitor assembly is mounted in a cast frame for rigidity. This frame and other critical parts are made of aluminum alloys selected to give the strength of brass with the lightness of aluminum. The plates of most models are also aluminum, so that all parts have the same temperature coefficient of linear expansion.

A worm drive is used to obtain high precision of setting. To avoid eccentricity, the shaft and the worm are accurately machined as one piece. The worm and worm wheel are also lapped into each other to improve smoothness. The dial end of the worm shaft runs in a self-aligning ball bearing, while the other end is supported by an adjustable spring mounting, which gives positive longitudinal anchoring to the worm shaft through the use of a pair of sealed, self-lubricating, preloaded ball bearings. Similar pairs of preloaded ball bearings provide positive and invariant axial location for the main or rotor shaft. Electrical connection to the rotor is made by means of a silver-alloy brush bearing on a silver-overlay drum to assure a low-noise electrical contact.

Stator insulation in all models is a cross-linked thermosetting modified polystyrene having low dielectric losses and very high insulation resistance. Rotor insulation, where used (Types 1422-CB and -CL), is grade L-4 steatite, silicone treated.

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 its 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 for all models at an extra charge. Models so calibrated are listed with the additional suffix letter, P, in the type number. A plastic-enclosed certificate of calibration is supplied, giving corrections to one more figure than the tabulated accuracy.

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 comparison 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%.

		Two-Terminal		Three-Terminal			
Type 1422		**-D**		**-CB**	**-CL**	**-CD**	
CAPACITANCE RANGE, pF	Min	100	35	50	10	0.5	0.05
	Max	1150	115	1100	110	11	1.1
SCALE, pF/Division:		0.2	0.02	0.2	0.02	0.002	0.0002
INITIAL ACCURACY: ± Picofarads Direct-Reading (Adjustment): Total Capacitance		0.6*	0.1*	0.6	0.1	0.04	0.008
Capacitance Difference		1.2	0.2	1.2	0.2	0.08	0.016
With Corrections from Calibration Chart (supplied): Total Capacitance		0.3*	0.04*	0.3	0.04	0.01	0.002
Capacitance Difference†		0.6	0.08	0.6	0.08	0.02	0.004
With Corrections from Precision Calibration (extra charge): Total Capacitance		0.1*	0.01*	0.1	0.01	0.001	0.0002
Capacitance Difference†		0.2	0.02	0.2	0.02	0.002	0.0004
RESIDUALS (typical values): Series Inductance, μH		0.06	0.10	0.14	0.13	0.17	0.17
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	98	25
		max scale		35	33	74	23
	low terminal to case	min scale		58	58	117	115
		max scale		53	55	92	93

* Total capacitance is the capacitance added when the capacitor is plugged into a 777-Q3 Adaptor.
† Divide error by 2 when one setting is made at a calibrated point.

The values of the working standards are determined and maintained in terms of reference standards periodically calibrated by the National Bureau of Standards.

The indicated value of total capacitance of a two-terminal capacitor is the capacitance added when the 1422 Capacitor is plugged into a 777-Q3 Adaptor. The uncertainty of this method of connection is approx ±0.03 pF.[1]

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 f s, 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 Characteristic: 2-terminal model, see curve. 3-terminal models: 20, 40, and 60 MHz (approx) resonant frequency for 1422-CB, -CL, and -CD (each section), respectively.

Dissipation Factor: 2-terminal, loss primarily in stator supports of low-loss polystyrene (the product DC ≈ 10^{-14}). 3-terminal, estimated D < 20 x 10^{-6}; except, for 1422-CD, < 10 x 10^{-6}. INSULATION RESISTANCE: > 10^{12} Ω, under standard conditions (23°C, RH < 50%).

Max Voltage: 1000 V pk (all models).

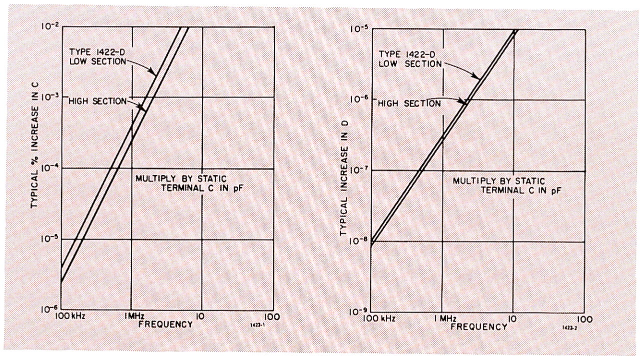
Terminals: 2-TERMINAL MODEL: Jack-top binding posts at standard (0.75-in.) spacing. Rotor terminal connected to panel and shield. 3-TERMINAL MODELS: Locking GR874® coaxial connectors.

Required: For 3-terminal models, two GR874 Patch Cords, or equivalent.

Available: For 2-terminal model, 777-Q3 Adaptor. (See "Calibration," above.)

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

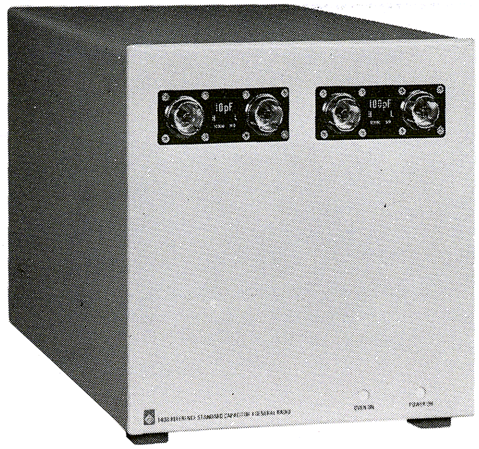
Mechanical: Lab-bench cabinet. DIMENSIONS (wxhxd): 9.5x7x8.5 in. (242x178x216 mm). WEIGHT (depending on model): 10.5 to 12.5 lb (4.8 to 5.7 kg) net, 15 lb (7 kg) shipping.



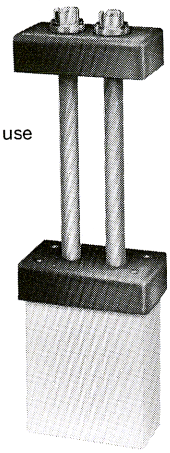
Variation with frequency of effective capacitance and dissipation factor per pF of capacitance for two-terminal 1422 Precision Capacitors.

Description	Catalog Number
Precision Capacitors	
with precision calibration (≈ 100 points)	
1422-DP	**1422-9904**
1422-CBP	**1422-9902**
1422-CLP	**1422-9508**
1422-CDP	**1422-9925**
with standard calibration (12 points)	
1422-D	**1422-9704**
1422-CB	**1422-9916**
1422-CL	**1422-9933**
1422-CD	**1422-9823**

National Stock Numbers are listed on the back cover.



1408 standard, with temperature-controlled air bath.



1408 standard; for use with an oil bath.

1408 Reference Standard Capacitors

- **10 pF, 100 pF**
- **high stability**
- **low voltage coefficient**
- **fused-silica dielectric**

Ultra-high stability The continuously improving accuracy of capacitor calibrations by the National Bureau of Standards brings a better knowledge of capacitance to standards laboratories — provided, of course, the laboratories have adequate reference standards. The 1408 Reference Standard Capacitors, with their high stability, are suitable for calibration in parts in 10^7. The 1616 Precision Capacitance Bridge is highly recommended for accurate calibration of a wide range of working standards from such a reference.

More extensively equipped laboratories are offered the economy of a unit designed for use in a temperature-controlled oil bath. Laboratories that lack a facility can take advantage of the built-in, temperature-controlled air bath of a second version. Two capacitance values are available, 10 pF and 100 pF, and either or both can be ordered in the air-bath version.

Fused-silica dielectric The active elements of the capacitors are gold, deposited on a substrate of fused silica — noted for exceptional stability, low loss, and relative independence of frequency. The plated substrate is mounted in a brass cell which is then sealed in a stainless-steel case containing dry nitrogen.

Air-Bath Version This unit includes one or two standards, as desired, plus a self-contained air bath whose temperature is held constant to within 0.01°C per year to assure the utmost stability of the standards. Since it carries its own environment, it is well adapted for use in laboratories without an oil bath or closely-controlled ambient temperature or in portable laboratories and calibration centers. The air bath operates from 12 volts so that it is an easy matter to transport it under power at all times.

Oil-Bath Version This unit is for laboratories that want to use the standard in a temperature-controlled oil bath. Two values are available, 10 pF and 100 pF, and each offers the same high precision and stability.

SPECIFICATIONS

Nominal Values: 10 pF and 100 pF.

Calibration: A certificate of calibration is supplied with each capacitor, giving the measured direct capacitance at 1 kHz and at a specified temperature near 25°C for an oil-bath capacitor or near 30°C for an air-bath capacitor. The measured value is obtained by comparison to a precision better than 0.1 ppm with standards whose values are determined and maintained by periodic calibrations made by the National Bureau of Standards. The limit of uncertainty of these calibrations is ±0.5 ppm.

Adjustment Accuracy: ±100 ppm.

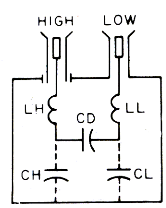
Stability: Estimated to be better than 0.3 ppm/yr.

Environment: TEMPERATURE COEFFICIENT, 12 ppm ± 2 ppm/°C. TEMPERATURE CYCLING, from 0 to 60°C, <1 ppm hysteresis at 30°C.

Air-Bath Characteristics: TEMPERATURE, 30°C nominal with stability of 0.01°C/year, <0.005°C/hour if ambient temperature is kept within 1°C. TEMPERATURE COEFFICIENT: 0 ± 0.05 ppm/°C from 17 to 29°C ambient temperature. Thermometer well provided for calibration.

Electrical: DISSIPATION FACTOR, $<10^{-5}$ at 1 kHz. VOLTAGE, 500 V max. RESIDUAL IMPEDANCES:

		LH, LL	CD	CH	CL
air	10 pF	0.6 µH	10 pF	88 pF	64 pF
	100 pF	0.6 µH	100 pF	120 pF	56 pF
oil	10 pF	0.2 µH	10 pF	55 pF	31 pF
	100 pF	0.2 µH	100 pF	87 pF	23 pF



Terminals: Two gold-plated GR874® locking connectors, easily adapted to other common connector types (on air-bath version, connectors can be moved to rear).

Available: GR874 ADAPTORS, 874-R22LA PATCH CORDS.

General: Fused-silica dielectric; plated substrate is hermetically sealed in a dry-nitrogen-filled stainless-steel case. Connections to the air-bath version can be made to the front or the rear as your application dictates. A 12-volt input is provided to maintain a constant air-bath temperature even while the unit is in transit.

Power (Air-bath version only): 100 to 120 or 200 to 240 V, 50 to 60 Hz, 5 W; 12 V at 0.4 A for dc operation, battery connectors provided on rear.

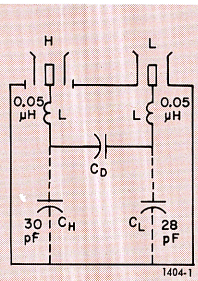
Mechanical: DIMENSIONS (wxhxd): Air-bath version 8.42x 8.72x16 in. (214x222x407 mm); oil-bath version, 3.5x11.1x 1.86 in. (89x283x48 mm). WEIGHT: Air-bath version (single value), 23 lb (11 kg) net, 32 lb (15 kg) shipping; (two values), 25 lb (12 kg) net, 34 lb (16 kg) shipping; oil-bath version, 3 lb (1.4 kg) net, 7 lb (3.2 kg) shipping.

Description	Catalog Number
Reference Standard Capacitor, air bath	
1408, 10 pF	**1408-9700**
1408, 10/10 pF	**1408-9702**
1408, 100 pF	**1408-9703**
1408, 100/100 pF	**1408-9705**
1408, 10/100 pF	**1408-9706**
Reference Standard Capacitor, oil bath	
1408-A, 10 pF	**1408-9701**
1408-B, 100 pF	**1408-9704**

1404 Reference Standard Capacitor

- **10, 100, 1000 pF**
- **20 ppm/year stability**
- **3-terminal, coaxial connections**
- **hermetically sealed in dry nitrogen**

These capacitors have been designed as primary reference standards of capacitance with which working standards can be 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 a 1404 Reference Standard Capacitor. A single 1000- or 100-picofarad standard is also the only standard necessary to calibrate the bridge itself.



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.

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

All critical parts of the plate assembly are made of Invar for stability and low temperature coefficient. After heat cycling and adjustment, the assembly is mounted in a heavy brass container, which, after evacuation, is filled with dry nitrogen under pressure slightly above atmospheric and sealed. The container is mounted on an aluminum panel and protected by an outer aluminum case. Each capacitor is subjected to a series of temperature cycles to determine hysteresis and temperature coefficients and to stabilize the capacitance.

Two locking GR874® 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.

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 parts per million 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.

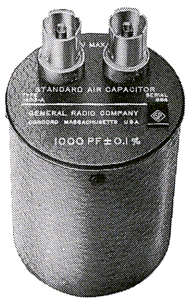
Terminals: Two locking GR874 coaxial connectors; easily convertible to other types of connectors by attachment of locking adaptors. Outer shell of one connector is ungrounded to permit capacitor to be used with external resistor as a dissipation-factor standard.

Required: For connection to 1615-A Capacitance Bridge, 2 Type 874-R20A or 874-R22LA Patch Cords.

Mechanical: Lab-bench cabinet. DIMENSIONS (wxhxd): 6.75x 6.63x8 in. (172x169x204 mm). WEIGHT: 8.5 lb (3.9 kg) net, 14 lb (6.4 kg) shipping.

Description	Catalog Number
Reference Standard Capacitor	
1404-A, 1000 pF	**1404-9701**
1404-B, 100 pF	**1404-9702**
1404-C, 10 pF	**1404-9703**

1403 Standard Air Capacitor



- **1000 pF to 1 pF**
- **calibration accuracy: ±0.02% ±0.01 pF**

The 1403 Standard Air Capacitors are stable, three-terminal standards in decimal values from 1 to 1000 pF. Their terminals are arranged to plug directly into the External Standard and Unknown terminals of the 1615 and 1616 capacitance bridges.

SPECIFICATIONS

Calibration: A certificate of calibration is supplied with each unit giving the measured capacitance at 1 kHz and at a specified temperature. The measured value is the direct capacitance between shielded terminals when the capacitor has at least one lead completely shielded and its case connected to a guard point. This value is obtained by comparison, to a precision better than ±(0.01% + 0.00001 pF), 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 0.05% per year.

Residual Impedances: See curve for effect of frequency. Capacitance from either terminal to case is ≈ 30 pF.

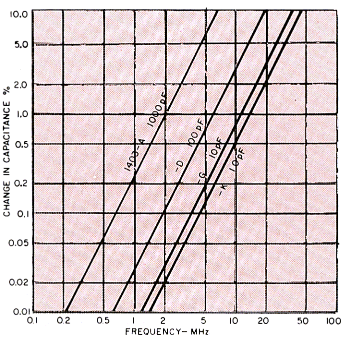
Dissipation Factor: $< 20 \times 10^{-6}$ max at 1 kHz and 50% or less relative humidity.

Peak Voltage: 1500 V, except 700 V for 1403-A.

Temperature Coefficient of Direct Capacitance: Typically 20 to 40 ppm per degree between 20° and 70°C. The larger coefficients apply to the smaller capacitance values.

Terminals: GR874® coaxial connectors, for complete shielding of the leads. SPACING: 1.13 in (28.6 mm).

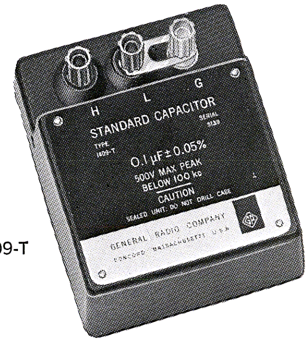
Mechanical: Cylindrical case. DIMENSIONS (dia x h): 3.06x 5.25 in. (77x133 mm). WEIGHT: 1 lb (0.5 kg) net, 4 lb (1.9 kg) shipping.



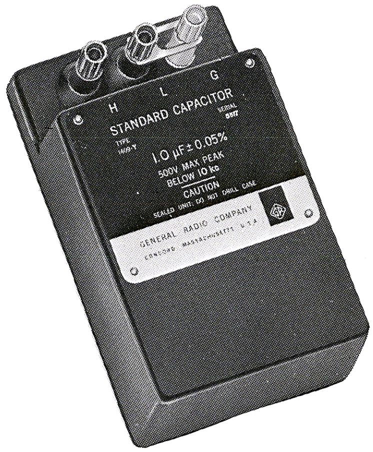
Typical increase (percent) in effective direct capacitance, with frequency produced by residual inductance.

Description	Nominal Capacitance	Adjustment Accuracy	Catalog Number
Standard Air Capacitor			
1403-A	1000 pF	0.1%	**1403-9701**
1403-D	100	0.1	**1403-9704**
1403-G	10	0.1	**1403-9707**
1403-K	1.0	0.1	**1403-9711**

National Stock Numbers are listed on the back cover.



GR 1409-T



GR 1409-Y

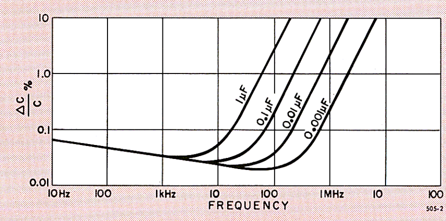
1409 Standard Capacitors

- **0.001 to 1 μF**
- **±0.01%/year stability**
- **calibration accuracy ±0.02%**
- **two- and three-terminal calibration provided**

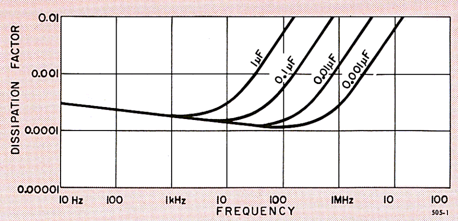
The 1409 Standard Capacitors are fixed mica capacitors of very high stability for use as two- or three-terminal reference or working standards in the laboratory.

Typical capacitors, observed over more than 15 years, have shown random fluctuations of less than ±0.01% in measured capacitance with no evidence of systematic drift.

These capacitor units consist of a silvered-mica and foil pile, spring-held in a heavy metal clamping structure for mechanical stability. The units are selected for low dissipation factor and are stabilized by heat cycling. They are housed, with silica gel to provide continuous desiccation, in cast aluminum cases, sealed with high-temperature potting wax. A well is provided in the wall of the case for the insertion of a dial-type thermometer. Three jack-top binding posts are provided on the top of the case and removable plugs on the bottom, for convenient parallel connection without error.



(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.



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 per degree 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 ohm, except for 1409-Y, which is 0.03 ohm.

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 (wxhxd): 1409-Y, 3.25x5.63x2.69 in. (83x143x69 mm); others, 3.25x4x2 in. (83x102x51 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).

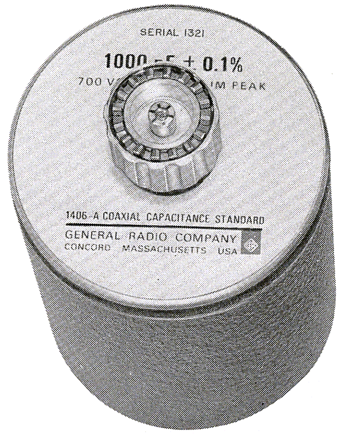
Description	Nominal Capacitance μF	Catalog Number
1409 Standard Capacitor		
1409-F	0.001	**1409-9706**
1409-L	0.01	**1409-9712**
1409-T	0.1	**1409-9720**
1409-Y	1.0	**1409-9725**

National Stock Numbers are listed on the back cover.

1406 Coaxial Capacitance Standards

- **stable to 0.05% per year**
- **for rf impedance calibrations**

100 pF and 1000 pF

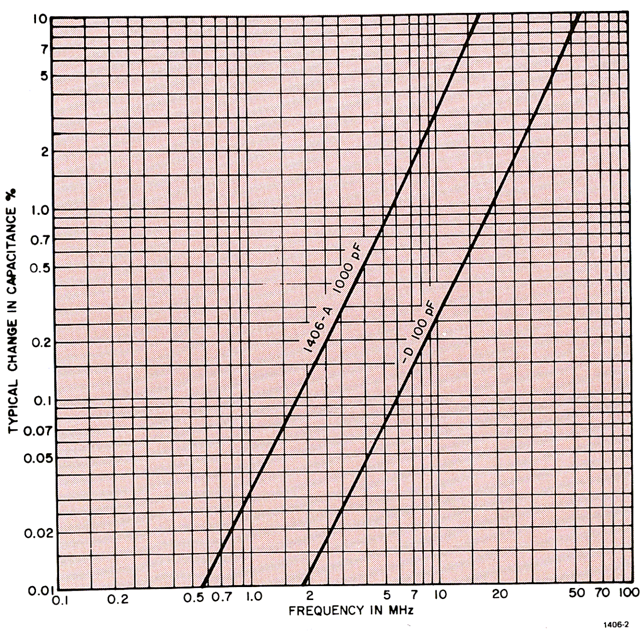


The 1406 Coaxial Capacitance Standards are stable, low-loss air capacitors with small, stable and known series inductance. Use them for the accurate, traceable calibration of high-frequency bridges and other impedance-measuring instruments.

Instrument calibration The 1406 standards can be connected directly to instruments, such as the 1616 Precision Capacitance Bridge, equipped with GR900® precision connectors and to others through appropriate adaptors. Series inductance and resistance have been kept to a minimum in the 900-Q9 Adaptor. When other adaptors are used, these quantities should be known to permit correcting for their effects at high frequencies.

These standards can be calibrated at audio frequencies with the 1616 bridge or with the 1615 Capacitance Bridge and the 1615-P2 Coaxial Adaptor. Each has an adjustment for compensating for terminal capacitance, to permit direct-reading measurements.

Repeatable coaxial connection GR900 precision coaxial connectors are used, for stability and repeatable performance that have been proven in use at frequencies as high as 9 GHz. The use of coaxial connectors also meets high-frequency calibration requirements of the National Bureau of Standards.



Typical percent increase in capacitance with frequency of 1406 Coaxial Capacitance Standards.

SPECIFICATIONS

Calibration: A certificate of calibration is supplied with each unit, giving the measured capacitance at 1 kHz and at a specified temperature and relative humidity. The measured capacitance is the capacitance at the reference plane of the GR900 connector. 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.

Typical Parameters

Nominal Capacitance	Peak Volts	Dissipation Factor 1 kHz (40% RH)	Dissipation Factor 1 MHz	Inductance
1000 pF	700	3×10^{-6}	50×10^{-6}	8.6 nH
100 pF	1500	30×10^{-6}	20×10^{-6}	7.6 nH

Accuracy: Capacitance adjusted by GR to nominal value ±0.1%. STABILITY: Capacitance change <0.05% per year. TEMPERATURE COEFFICIENT of capacitance: Typically 10 to 20 ppm/°C, between 20 and 70°C.

Residual Impedances: See table. Dissipation factor varies as the 3/2 power of frequency above about 100 kHz. Insulation resistance $>10^{12}\ \Omega$, at 23°C and relative humidity <50%.

Terminal: GR900 precision coaxial connector.

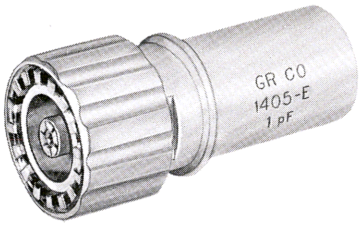
Available: 1615-P2 Adaptor for convenience in calibrating with 1615-A Capacitance Bridge. 900-Q9 Adaptor for connecting the 1406 to 0.25-in. x 28 threaded studs, tapped holes, or GR 938 Binding Posts spaced 0.75 to 1 in. apart.

Mechanical: Cylindrical case. DIMENSIONS (dia x h): 3.06x 5.25 in. (78x134 mm). WEIGHT: 1.5 lb (0.7 kg) net, 4 lb (1.9 kg) shipping.

Description	Catalog Number
Coaxial Capacitance Standard	
1406-A, 1000 pF	**1406-9701**
1406-D, 100 pF	**1406-9704**
1615-P2 Coaxial Adaptor, GR900 to 1615 Bridge	**1615-9602**
900-Q9 Adaptor, GR900 to binding posts	**0900-9874**

1405 Coaxial Capacitance Standards

- **1 and 10 pF**
- **rf standards**
- **GR900® connectors**



Extending the available values of rf capacitance downward, the 1405 standards permit impedance-measuring instruments to be calibrated at even higher frequencies accurately and with traceability to the National Bureau of Standards.

Accuracy is stated two ways. The first refers to nominal capacitance and includes initial adjustment, aging, and other effects. The second refers to the individual calibration and certificate.

SPECIFICATIONS

Calibration: A certificate of calibration is supplied with each unit, giving the measured capacitance at 1 kHz and at a specified temperature and relative humidity. The measured capacitance is the capacitance at the reference plane of the GR900 connector. This value is obtained by comparison, to a precision better than ±0.002 pF, with working standards whose absolute values are known to an accuracy typically ±0.02%, determined and maintained in terms of reference standards periodically calibrated by the National Bureau of Standards.

		1405-B, 10 pF	1405-E, 1 pF
Accuracy at 23°C		±0.2% (0.02 pF)	±0.5% (0.005 pF)
Calibration Accuracy		±0.04%	±0.2%
Stability	vs temperature, 10-70°C	−0.004%/°C	−0.01%/°C
	vs humidity, <90% RH	——	+0.005%/% RH
	vs aging	<0.1%/yr	<0.3%/yr
Frequency	0.1% C increase	40 MHz	120 MHz
	10% C increase	0.4 GHz	1.7 GHz
Residuals	D at 1 kHz, <50% RH	$<150 \times 10^{-6}$	$<100 \times 10^{-6}$
	insulation R	$>10^{12}\ \Omega$ at 23°C and <50% RH	
	equivalent L	1.6 nH at <250 MHz	1.8 nH at <500 MHz
Peak Volts		1 kV	3 kV

Available: ADAPTORS 1615-P2 for calibrating with GR 1615 bridge and 900-Q9 for connecting standard to ¼-inch x 28 threaded stud (GR 938 Binding Post) or tapped hole.

Terminal: GR900 precision coaxial connector.

Mechanical: DIMENSIONS (dia x h): 1.06x2.32 in. (27x59 mm). WEIGHT: 4 oz (103 g) net, 5 oz (142 g) shipping.

Description	Catalog Number
Coaxial Capacitance Standards	
1405-B, 10 pF	**1405-9703**
1405-E, 1 pF	**1405-9700**

Resistance Standards

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.

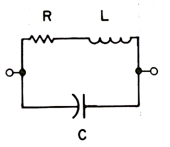


Figure 1.

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 to be 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 effective parallel admittance is given by:

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

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 are capacitive at somewhat lower values.

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.

General Radio 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.

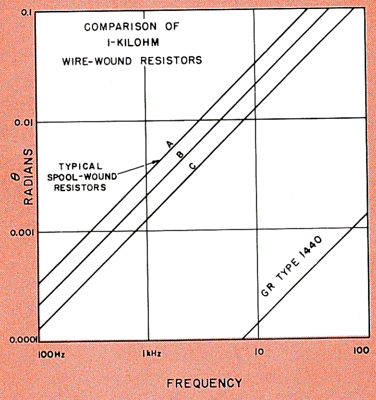
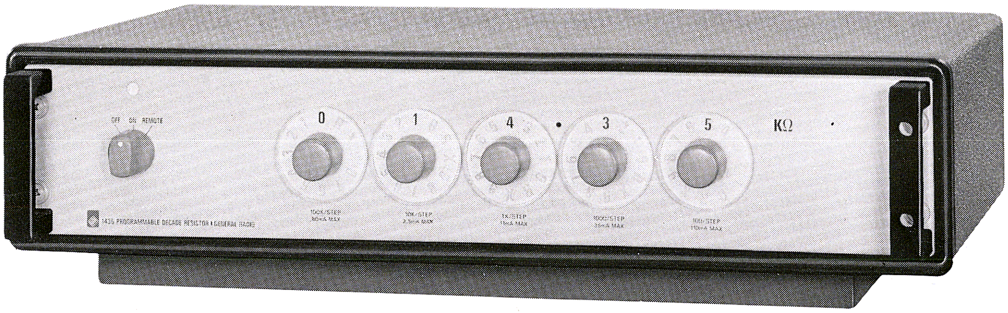


Figure 2.



1435 Programmable Decade Resistor

- **1.11 MΩ**
- **0.02% basic accuracy**
- **completely programmable**

The 1435 is a completely-programmable five-decade resistor (expandable to six or seven decades on special order) particularly adaptable to automatic test equipment for the control of load, time constant, gain, etc.

Each decade is controlled by a 12-position front-panel switch that displays 0 through X (10) and R (remote). This allows any decade or decades to be manually set while those remaining are remotely controlled. Another switch transfers total control of all the decades to the exernal control signal, regardless of the setting of the individual decade controls, and this transfer itself is externally programmable.

Four high-quality wire-wound resistors of low-temperature-coefficient Evanohm* wire are used in each decade. All are straight wound except the 10-Ω/step decade which is Ayrton-Perry wound to reduce inductance. Due to discontinuities that may exist when the settings are changed (manually or remotely), two logic lines are provided to short or open the decade-output terminals during the switching interval.

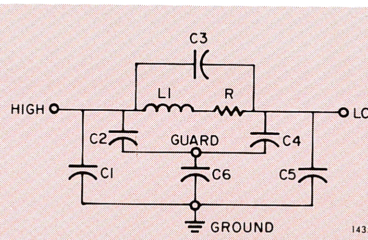
* Registered trademark of the Wilbur B. Driver Co.

SPECIFICATIONS

Range: 1,111,100 Ω total resistance; 10 Ω smallest step. Each decade can be individually controlled: manually by in-line-readout dials or remotely to digital techniques.

Programming: Control by negative true logic, 8-4-2-1 binary-coded decimal, at standard DTL or TTL levels (i.e., logic 0 ≈ ground, logic 1 > +3.5 V) or closures to ground applied to rear-panel etched-board (36 pins.) SWITCHING SPEED: < 4 ms per change. Switches are mercury-wetted reed relays for low, stable, and repeatable zero resistance and are used for both manual and remote control.

Resistance Characteristics: ACCURACY: The difference between the resistances at any setting and at the zero setting is equal to the indicated value ±(0.02% + 10 mΩ) for all decades except, for 10-Ω/step decade, the tolerance is ±(0.05% + 10 mΩ); all at low currents and low or zero frequency. ZERO RESISTANCE; Typically 700 mΩ total (all decades set to zero). TEMPERATURE COEFFICIENT: ±(10 ppm + 3 mΩ)/°C. FREQUENCY DEPENDENCE: At high resistance values, frequency characteristics depend mainly on capacitances and on the type of connections used (2- or 3-terminal, grounded or guarded). At low resistance values, they depend mainly on the inductance. Calculations based on the values tabulated should give a good approximation to the series-resistance error. (Parameters are defined by diagram.)



Parameter	Decade Resistance R = 100 kΩ	R = 1 MΩ
C1	19 pF	11 pF
C2	76 pF	23 pF
C3	19 pF	16 pF
C4	247 pF	276 pF
C5	46 pF	51 pF
C6	1606 pF	1606 pF
L1	23 μH	23 μH

Signal Power Ratings: 0.125 W per step of the most-significant non-zero digit (1.25 W max) for specified accuracy; 0.25 W/step (2.5 W max) without damage. Each decade labeled with rated current. GUARD VOLTAGE LIMIT: 100 V max with respect to ground.

Terminals: 5 (High, Low, Ground, Guard, Guard) nickel-plated brass binding posts on rear panel; standard spacing (0.75 in.).

Supplied: Power cord and board-edge connector, for programming input.

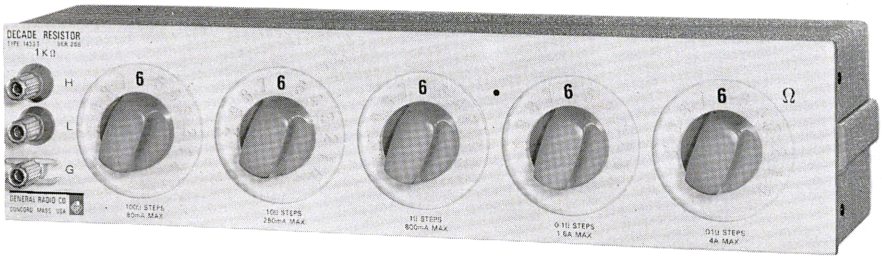
Power: 100 to 125 V or 200 to 250 V, 50 to 60 Hz, 7 W.

Mechanical: Bench or rack models. DIMENSIONS (wxhxd): Bench, 19.75x4.22x12.88 in. (502x107x327 mm); rack, 19x 3.47x10.8 in. (483x88x275 mm). WEIGHT: Bench, 18 lb (8.5 kg) net, 23 lb (11 kg) shipping; rack, 13 lb (6 kg) net, 18 lb (8.5 kg) shipping.

Description	Catalog Number
1435 Programmable Decade Resistor	
Bench Model	**1435-9700**
Rack Model	**1435-9701**

1433 Decade Resistor

- ±0.01% accuracy
- good frequency characteristics
- low temperature coefficient
- excellent stability
- low zero resistance



The 1433 Decade Resistors are primarily intended for precision measurement applications where their excellent accuracy, stability, and low zero resistance are important. 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. Although they are quite satisfactory as substitution boxes for optimizing electronic circuitry, the less expensive 1434 Decade Resistors are recommended for such less exacting applications.

Each 1433 Decade Resistor is an assembly of GR 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.

The individual decades (510 Decade-Resistance Units) are available for applications requiring only one decade or as components to be built into experimental equipment, production test equipment, or commercial instruments.

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% + 2 mΩ).

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 1433's are similar to those of the individual 510's 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 ohms or less, the frequency characteristics of any of these decade resistors are substantially the same as those shown for the 510's. At higher settings, shunt capacitance becomes the controlling factor, and the effective value of this capacitance depends upon the settings of the individual decades.

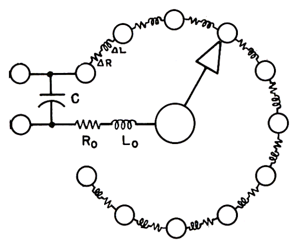
Typical Values of R_o, L_o, and C for the Decade Resistors:

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.

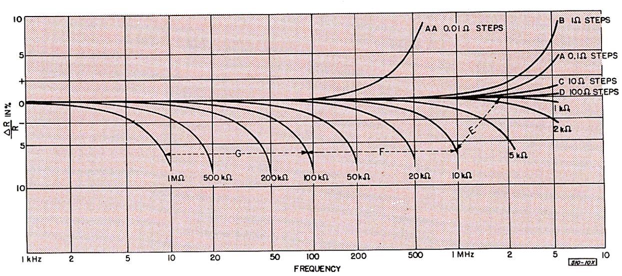
Zero Inductance (L_o): 0.1 μH per dial + 0.2 μH.

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 per degree C for values above 100 Ω and ±20 ppm per degree C for 100 Ω and below, at room temperatures. For the 1433's



Equivalent circuit of a resistance decade, showing residual impedances.



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

the box wiring will increase the over-all temperature coefficient of the 0.1- and 0.01-Ω decades.

Switches: Quadruple-leaf brushes bear on lubricated contact studs of ⅜-in. diameter in such a manner as to avoid cutting but 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.

Max Voltage to Case: 2000 V pk.

Terminals: Low-thermal-emf jack-top binding posts on standard ¾-in. spacing; also provisions for rear-panel connections. Shield terminal is provided.

Mounting: 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.

Type	Total Ohms	Ohms per Step	No. of Dials	Type 510 Decades Used	Catalog Number Bench	Catalog Number Rack
1433-U	111.1	0.01	4	AA, A, B, C	**1433-9700**	**1433-9701**
1433-K	1111	0.1	4	A, B, C, D	**1433-9702**	**1433-9703**
1433-J	11,110	1	4	B, C, D, E	**1433-9704**	**1433-9705**
1433-L	111,100	10	4	C, D, E, F	**1433-9706**	**1433-9707**
1433-Q	1,111,000	100	4	D, E, F, G	**1433-9708**	**1433-9709**
1433-T	1111.1	0.01	5	AA, A, B, C, D	**1433-9710**	**1433-9711**
1433-N	11,111	0.1	5	A, B, C, D, E	**1433-9712**	**1433-9713**
1433-M	111,110	1	5	B, C, D, E, F	**1433-9714**	**1433-9715**
1433-P	1,111,100	10	5	C, D, E, F, G	**1433-9716**	**1433-9717**
1433-Y	11,111,000	100	5	D, E, F, G, H	**1433-9718**	**1433-9719**
1433-W	11,111.1	0.01	6	AA, A, B, C, D, E	**1433-9720**	**1433-9721**
1433-X	111,111	0.1	6	A, B, C, D, E, F	**1433-9722**	**1433-9723**
1433-B	1,111,110	1	6	B, C, D, E, F, G	**1433-9724**	**1433-9725**
1433-Z	11,111,100	10	6	C, D, E, F, G, H	**1433-9726**	**1433-9728**
1433-F	111,111.1	0.01	7	AA, A, B, C, D, E, F	**1433-9729**	**1433-9730**
1433-G	1,111,111	0.1	7	A, B, C, D, E, F, G	**1433-9731**	**1433-9732**
1433-H	11,111,110	1	7	B, C, D, E, F, G, H	**1433-9733**	**1433-9734**

510 Decade-Resistance Unit

The 510 Decade 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 Decade-Resistance 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.

510-B mounted on a small panel.

SPECIFICATIONS

Electrical: See table.

Terminals: Soldering lugs.

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

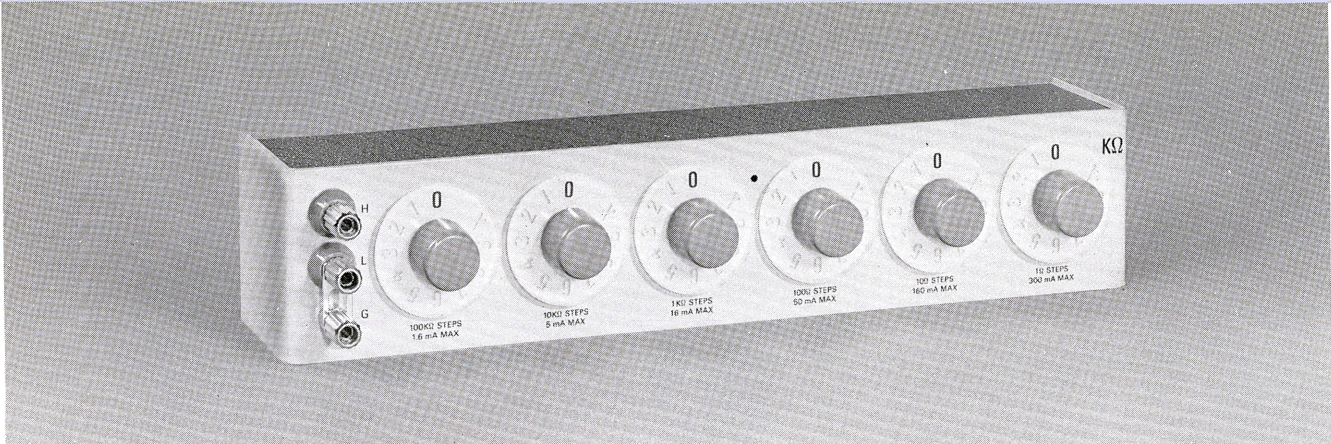
Mechanical: Panel mounting, in shield can. DIMENSIONS: Dia. 3.06 in. (78 mm), depth 3.31 in. (85 mm) behind panel. WEIGHT: 11 oz (312 g) net.

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	Catalog Number
510-AA	0.1	0.01	±2%	4 A	0.16	0.01	7.7–4.5	0.023	**0510-9806**
510-A	1	0.1	±0.4%	1.6 A	0.25	0.014	7.7–4.5	0.023	**0510-9701**
510-B	10	1	±0.1%	800 mA	0.6	0.056	7.7–4.5	0.023	**0510-9702**
510-C	100	10	±0.04%	250 mA	0.6	0.11	7.7–4.5	0.023	**0510-9703**
510-D	1000	100	±0.01%	80 mA	0.6	5	7.7–4.5	0.023	**0510-9704**
510-E	10,000	1000	±0.01%	23 mA	0.5	13	7.7–4.5	0.023	**0510-9705**
510-F	100,000	10,000	±0.01%	7 mA	0.5	70	7.7–4.5	0.023	**0510-9706**
510-G	1,000,000	100,000	±0.01%	2.3 mA	0.5	—	7.7–4.5	0.023	**0510-9707**
510-H	10,000,000	1,000,000	±0.01%	0.7* mA	0.5	—	7.5–4.5	0.023	**0510-9708**
510-P4	Switch only	(Black Phenolic Frame)							**0510-9604**
510-P4L	Switch only	(Low-Loss Phenolic Frame)							**0510-9511**

* 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.

National Stock Numbers are listed on the back cover.



1434 Decade Resistor

- **±0.02% accuracy**
- **5-, 6-, or 7-dial settability**
- **excellent stability, low cost**

These laboratory-quality, budget-priced decade boxes are designed for maximum usefulness and economy in laboratory measurement, testing, and development work. Their accuracy is adequate for all but the most exacting applications. Their small size and clear readout should be particularly useful in experimental setups using small, modern components.

The 1434-M, -N, and -P contain five step decades of resistance in a small cabinet. The 1434-B and -X, 6-dial boxes, permit small as well as large values of resistance to be set with 3- or 4-place resolution and accuracy. The 1434-QC, a "best buy," has four step decades plus a rheostat to provide 1-ohm resolution in a 1-megohm box.

The larger, seven-decade, 1434-G box is easily converted into a 3½-inch relay-rack unit by the addition of angle brackets and dress strips, which are furnished. This box has lug terminals available at the rear, as well as at panel binding posts.

DESCRIPTION

High-quality, wire-wound resistors are used in these decades. The low price is made possible by the use of only six resistors per decade instead of ten. These are combined by switching in such a way that there are no discontinuities; that is, the resistance increases stepwise just as though ten resistors were used. The switches have solid-silver-alloy contacts for low resistance and long life.

Resistors are of low-temperature-coefficient Evanohm* wire, except the 1-ohm/step and 0.1-ohm/step decades which use wire and ribbon (respectively) of another low-temperature coefficient alloy. The resistors of the 100-, 10-, and 1-ohm/step decades are Ayrton-Perry wound to minimize inductance.

* Registered trademark of the Wilbur B. Driver Company.

SPECIFICATIONS

Accuracy: Tolerances apply at low currents and at dc or low-frequency ac.

Over-all: The difference between the resistances at any setting and at the zero setting is equal to the indicated value ±(0.02% + 2 mΩ), except for the 1434-QC, which may have an additional error of ± 1 Ω when the rheostat is used.

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

Zero Resistance: Approx 3 mΩ per dial at low frequencies; except for the 1434-QC, approx 30 mΩ.

Max Current: See table; these values also appear on the panel of each decade box. When this max current is passed through a decade, the temporary change in value will be less than the accuracy specification. Currents appreciably higher than this will cause permanent damage.

Total Resistance of Decade	Resistance Per Step	Incremental Accuracy*	Max Current
1 Ω	0.1 Ω	±3.0%	1 A
10 Ω	1.0 Ω	±0.3%	0.3 A
100 Ω	10 Ω	±0.05%	160 mA
1 kΩ	100 Ω	±0.02%	50 mA
10 kΩ	1 kΩ	±0.02%	16 mA
100 kΩ	10 kΩ	±0.02%	5 mA
1 MΩ	100 kΩ	±0.02%	1.6 mA
100-Ω Rheostat**	1 Ω/div	±1 Ω	200 mA

* At low currents and low frequencies. ** Used in 1434-QC.

Temperature Coefficient: <±10 ppm/°C at room temperature, except for the low-valued units where the +0.4%/°C temperature coefficient of the zero resistance must be added.

Frequency Characteristics: Generally similar to those of the 1433 Decades.

Switches: Multiple wiper, solid-silver-alloy switches are used to obtain low and stable zero resistance.

Terminals: Jack-top binding posts on standard ¾-in. spacing. A shield terminal is also provided. The 1434-G has lug connections accessible from the rear.

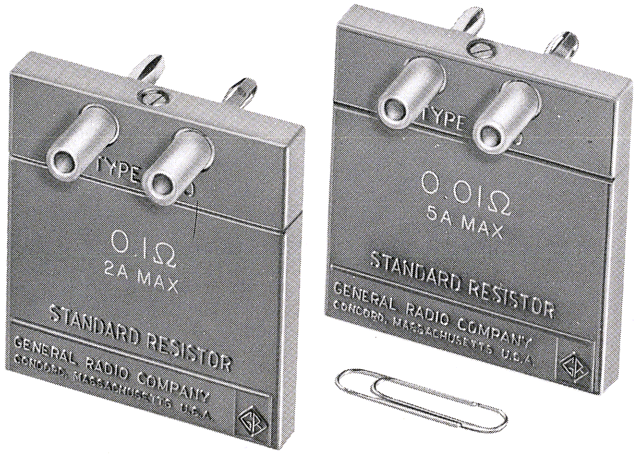
Mounting: All types except the 1434-G are in small cabinets for bench use. The 1434-G is also designed for bench use but, with the addition of mounting hardware, becomes 3½-in. high, 19-in. relay-rack unit.

Mechanical Data:

Models	Width		Height		Depth		Net Weight		Shipping Weight	
	in.	mm	in.	mm	in.	mm	lb	kg	lb	kg
M, N, P, QC	11¾	300	2¾	70	4¼	108	3	1.4	4	1.9
B, X	13¾	350	2¾	70	4¼	108	3¼	1.5	4	1.9
G (bench)	175⁄16	440	3½	89	5	127	6	2.8	7	3.2
G (rack)	19	483	3½	89	3½	89	6	2.8	7	3.2

Description	Total Resistance(Ω)	Resistance Per Step	Number of Decades	Catalog Number
Decade Resistor				
1434-N	11,111	0.1 Ω	5	**1434-9714**
1434-M	111,110	1.0 Ω	5	**1434-9713**
1434-P	1,111,100	10 Ω	5	**1434-9716**
1434-QC	1,111,105	1 Ω/div	4 + rheo	**1434-9576**
1434-B	1,111,110	1.0 Ω	6	**1434-9702**
1434-X	111,111	0.1 Ω	6	**1434-9724**
1434-G	1,111,111	0.1 Ω	7	**1434-9707**

National Stock Numbers are listed on the back cover.



1440 Standard Resistor

- **0.01Ω to 1 MΩ**
- **accuracy ±0.01%**
- **stability ±10 ppm per year**
- **low thermal emf to copper**

These extremely stable resistors are intended for use as laboratory or production standards for calibrating resistance bridges and for substitution measurements.

Units of 0.01 and 0.1 Ω are made of sheet metal with a low temperature coefficient of resistance, punched in a meander pattern to reduce inductance. Units of 1 Ω and above are card-type wire-wound resistors, carefully wound and adjusted. Low-temperature-coefficient wire is used for units of 1 Ω and 10 Ω; Evanohm * wire is used for units above 10 Ω. All units are heat cycled to reduce strains and are repeatedly checked to eliminate any that show abnormal behavior. They are encased in sealed, oil-filled, diallylphthalate boxes to promote long-term stability and to provide mechanical protection.

The 1440 resistors have low-thermal-emf binding posts and removable banana plugs to provide the four terminals necessary for accurate measurements at low values of resistance. A label on the reverse side lists initial calibration and date, serial number, and space for future calibration data.

* Registered trademark of the Wilbur B. Driver Company.

SPECIFICATIONS

Accuracy: See table. Measurements on the low-value units should be made with a four-terminal connection. All measurements at 23°C.

Calibration Accuracy: Resistors are calibrated by comparison, to a precision of ±20 ppm, with working standards whose absolute values are known typically to ±10 ppm as determined and measured in terms of reference standards periodically measured by the National Bureau of Standards. The measured deviation in % from nominal value, at 23°C and 0.01 watt, is entered on the label on the reverse side of the resistor.

Stability: Typically ±10 ppm per year (1 MΩ to 1 Ω).

Temperature Coefficient (Max): See table.

Power Rating: 1 W. The corresponding current is indicated on the resistor and in the table below. This dissipation will cause a temperature rise of approx 25°C and a resulting temporary resistance change due to the temperature. If this rating is exceeded, permanent changes may result.

Residual Impedances: Approx shunt capacitance (2-terminal measurement), 2.5 pF; less for 3-terminal measurement. Typical series inductance, see table.

Approx Frequency Characteristics: See table.

Terminals: Gold-plated jack-top copper binding posts (¾-in. spacing) with banana plugs that are removable and can be replaced by 6-32 screws for installation of soldering lugs.

Dimensions (less terminals): 2.25x2.47x0.34 in. (58x63x9 mm).

Net Weight (approx): 2 oz (57 g).

Resistance	Accuracy	Max Current	Inductance Typical	Approx Frequency for 0.1% Resistance Change Series R	Parallel R	Temperature Coefficient	Catalog Number
0.01 Ω	±0.10%	5 A	0.1 μH	3 kHz	1 kHz	+200 ppm	**1440-9671**
0.1 Ω	±0.05%	2 A	0.1 μH	20 kHz	10 kHz	+30 ppm	**1440-9681**
1 Ω	±0.02%	1.0 A	0.12 μH	300 kHz	30 kHz	±20 ppm	**1440-9601**
10 Ω	±0.01%	310 mA	0.13 μH	1 MHz	300 kHz	±20 ppm	**1440-9611**
100 Ω	±0.01%	100 mA	5. μH	3 MHz	1 MHz	±10 ppm	**1440-9621**
1 kΩ	±0.01%	30 mA	2.5 μH	2 MHz	1 MHz	±10 ppm	**1440-9631**
10 kΩ	±0.01%	10 mA		200 kHz	1 MHz	±10 ppm	**1440-9641**
100 kΩ	±0.01%	3 mA		20 kHz	100 kHz	±10 ppm	**1440-9651**
1 MΩ	±0.02%	1 mA		2 kHz	10 kHz	±10 ppm	**1440-9661**

National Stock Numbers are listed on the back cover.

Inductance Standards

CONSTRUCTION

For minimum generation of, or pickup from, external magnetic fields, the toroidal inductor is preferable to the solenoid. The symmetry of the toroid contributes both to stability and to a constant temperature coefficient.

An air core in the inductor results in the highest stability and a negligible variation of inductance with current, but at the expense of a relatively low Q. Because stability is the prime requirement in a laboratory standard, the Type 1482 Standard Inductors have air cores.

For a given volume, a larger inductance and Q can be obtained from a core of the high-permeability ferromagnetic materials, often termed "iron," although they usually are special alloys. Since the permeability of the material can change with age and particularly with current, the iron-core inductor is inherently less stable than the air-core type. Good stability can still be realized in iron-core inductors by proper design and choice of core materials, as in the Type 940 Decade Inductors and 1491 decade boxes.

INDUCTANCE CHANGES

The inductance depends not only upon the geometry and the permeability of the core but upon the residual impedances, which are shown in the equivalent circuit of Figure 1. The largest changes of inductance with frequency are produced by the effective shunt capacitance, C_o, of the winding and the terminals. When the frequency, f, is well below the resonance frequency, f_r, the fractional increase in inductance is approximately

$$\frac{\Delta L}{L_o} \approx \omega^2 L_o C_o = \left(\frac{f}{f_r}\right)^2, \qquad (1)$$

where L_o is the zero-frequency inductance.

There is practically no change in inductance with current when the core is air, but ferromagnetic core materials have a permeability that changes with magnetizing force, and the change is usually appreciable. The curves shown on page 24 for the Type 940 Inductors are typical. The inductance increases linearly over a small region near zero current, then rises rapidly to a maximum followed by a sudden decrease as saturation is approached. To make these curves independent of the inductance magnitude, the current has been normalized to a value, I_1, which is that current which produces a specified fractional increase in inductance at a specified permeability.

Q CHANGES

The storage factor, $Q = \omega L/R$, of an inductor is simply proportional to frequency when L and R are constant. But, as noted above, L can vary with frequency, and the losses are also functions of frequency. The components of loss are best described in terms of dissipation factor, $D = 1/Q$, since 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.

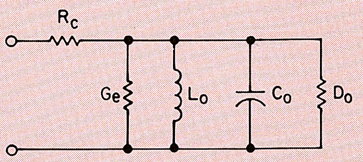


Figure 1. Equivalent circuit of an air-core inductor. R_c is the series resistance, G_e is the conductance due to eddy-current loss, and D_o is the dissipation factor of the distributed capacitance.

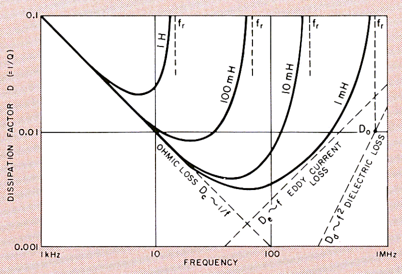


Figure 2. Dissipation-factor variation with frequency in typical air-core Type 1482 Standard Inductors.

$$D \simeq \frac{1}{1-\left(\frac{f}{f_r}\right)^2}\left[\frac{R_c}{\omega L_o} + G_e\omega L_o + \left(\frac{f}{f_r}\right)^2 D_o\right] \qquad (2)$$

Resonance Factor	Ohmic Loss, D_c	Eddy-Current Loss, D_e	Dielectric Loss, D_d

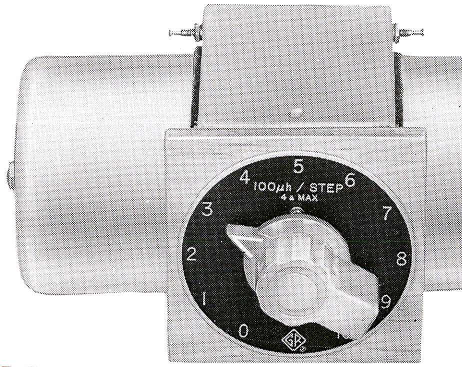
The higher permeability of an iron core makes possible lower values of D_c and D_e, while f_r is slightly reduced and D_o is not changed. The core adds three more components to the dissipation factor: one from eddy currents in the core, proportional to frequency, another from hysteresis loss in the core, independent of frequency, and a third from residual losses in the core, constant with frequency and relatively small. The effects of these losses are shown in the plots of Q versus frequency for Type 940 Decade 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 Type 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.

*John F. Hersh, "Connection Errors in Inductance Measurement," General Radio Experimenter, 34, 10, October, 1960.



940-DD

940 Decade-Inductor Unit

Each 940 Decade-Inductor Unit is an assembly of four inductors (relative values, 1, 2, 2, 5) wound on molybdenum-permalloy dust cores, which are combined by switching to give the eleven successive values from 0 to 10. The decade switch has high-quality ceramic stator-and-rotor members and well-defined ball-and-socket detents. All contacts are made of a silver alloy and have a positive wiping action.

SPECIFICATIONS

Accuracy: Each unit is adjusted so that its inductance at zero frequency and initial permeability will be the nominal value within the accuracy tolerance given in the following table:

Unit	940-DD	940-E	940-F	940-G	940-H
Inductance per step	100 μH	1 mH	10 mH	100 mH	1 H
Accuracy	±2%	±2%	±1%	±0.6%	±0.6%

Frequency Characteristics: For any specific operating frequency, Figure 2 shows the percentage increase in effective series inductance (above the value when f = 0), which is encountered with the extreme settings of each of the five decade-inductor units when the chassis is floating. Interpolation may be used for intermediate settings.

Change in Inductance with Current: Fractional change in initial inductance with ac current for each type of toroid is shown in the normal curves, Figure 1, in terms of the ratio of the operating current, I, to I_l, the current for 0.25% change, solid line (0.1%, broken line). For ratios below unity, inductance change is directly proportional to current. Values of I_l, listed below, are approximate and are based on the largest inductor in the circuit for each setting.

Incremental Inductance: Dc bias current I_b will reduce the initial inductance as shown in the incremental curves, Figure 1.

Switch Setting	RMS I_l (mA)				
	0.1% Increase	0.25% Increase			
	940-DD	940-E	940-F	940-G	940-H
1	141	17	5.4	1.7	0.54
2, 3, 4	100	12	3.8	1.2	0.38
5, 6, 7, 8, 9, 10	63	8	2.4	0.8	0.24

Storage Factor Q: See Figure 3:

Dc Resistance: Approx 45 Ω per henry.

Temperature Coefficient: Approx −25 ppm per degree C between 16° and 32°C.

Max Safe Current: Approx 200 times the pertinent I_l value (30 times for the 940-DD). Max current engraved on dial.

Terminals: Solder lugs. Circuit insulated from chaissis.

Mechanical: Panel-mounting (hardware, dial plate, and knob included). DIMENSIONS (wxhxd): 8x3.5x4.25 in. (204x89x108 mm). WEIGHT: 3.5 lb (1.6 kg) net, 6 lb (2.8 kg) shipping.

Description	Inductance Total	Inductance Steps	Catalog Number
Decade Inductor			
940-DD	1 mH	100 μH	**0940-9810**
940-E	0.01 H	0.001 H	**0940-9705**
940-F	0.1 H	0.01 H	**0940-9706**
940-G	1 H	0.1 H	**0940-9707**
940-H	10 H	1 H	**0940-9708**

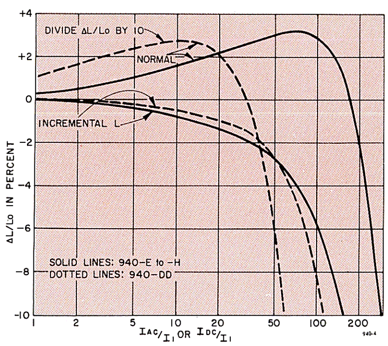


Figure 1. Percentage change in normal and incremental inductance with ac and bias current. Incremental curve is limited to an ac excitation less than I_l.

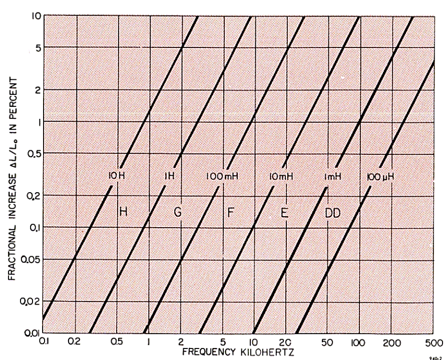


Figure 2. Change in effective inductance with frequency for the 940 Decade-Inductor Units.

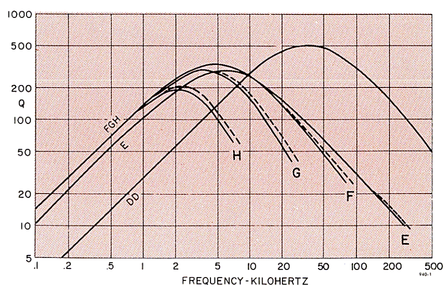
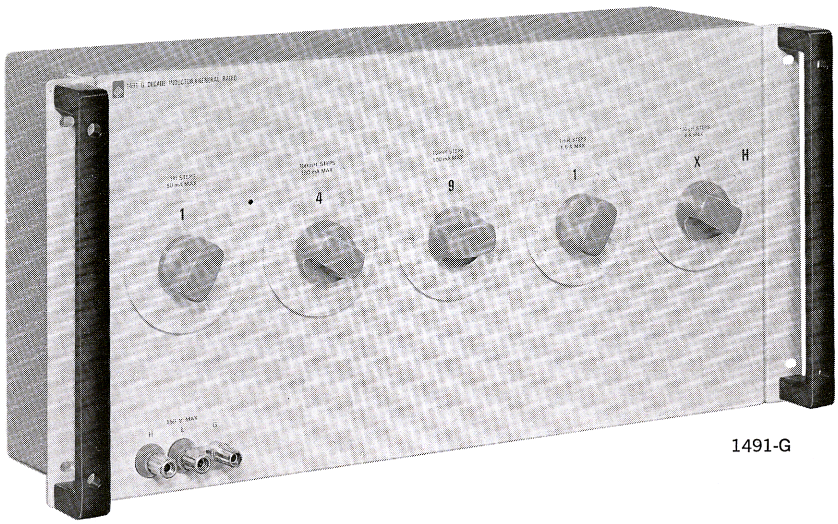


Figure 3. Variation of Q for the maximum inductance of each 940 Decade-Inductor Unit at low excitation levels. Dashed curves correspond to use with chassis floating.

National Stock Numbers are listed on the back cover.



1491-G

1491 Decade Inductor

- **high-Q, 200 and above**
- **shielded toroidal cores for small mutual inductance little effect from external fields**
- **sealed against moisture**

The 1491 Decade Inductor is an assembly of several 940 Decade-Inductor Units in a single metal cabinet. The units have no electrical connection to the panel, but a separate ground terminal is provided, which can be connected to the adjacent low terminal, leading to the smallest decade.

These inductance decades are convenient elements for use in wave filters, equalizers, and tuned circuits throughout the range of audio and low radio frequencies. As components in oscillators, analyzers, and similar equipment, they are especially useful during the preliminary design period, when you need to vary circuit elements over relatively wide ranges to determine optimum operating values. As moderately precise standards of inductance they have values of low-frequency storage factor, Q, that are much larger than those of air-core coils.

SPECIFICATIONS

Note: See also specifications for 940 Decade Inductor Units.

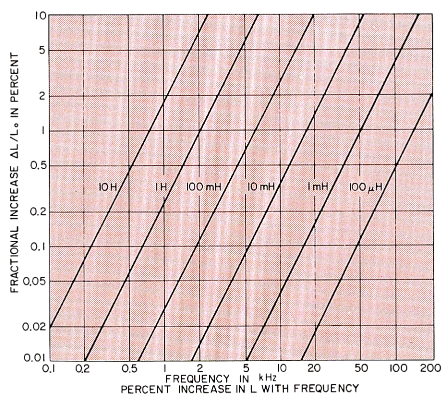
Frequency Characteristics: Percentage increase in effective series inductance (above the zero-frequency value, L_o) may be obtained by interpolation in accompanying graph for any setting of the highest-value decade used, when LOW terminal is grounded to cabinet.

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.

Terminals: Binding posts on ¾-in. centers; separate ground terminal provided.

Mechanical: Lab-bench cabinet. DIMENSIONS (wxhxd): Bench, 17x8.75x6.5 in. (432x223x166 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.



Variation of inductance with frequency for the 1491 Decade Inductors.

Description	Total	Steps	940's Included	Catalog Number
Decade Inductor				
1491-D Bench	11.11 H	0.001 H	E, F, G, H	**1491-9704**
1491-G Bench	11.111 H	0.0001 H	DD, E, F, G, H	**1491-9707**

National Stock Numbers are listed on the back cover.

1482-L

1482 Standard Inductor

- **stable within ±0.01% per year**
- **low, known temperature coefficient**
- **minimized connection errors**
- **toroidal — free from external fields**

The 1482 is an accurate, highly stable standard of self inductance for use as a low-frequency reference or working standard in the laboratory. Records extending over 16 years, including those of inductors that traveled to national laboratories in several countries for calibration, show long-term stabilities well within ±0.01%.

Each inductor is a uniformly wound toroid on a ceramic core. It has a negligible external magnetic field and hence essentially no pickup from external fields. The inductor is resiliently supported in a mixture of ground cork and silica gel, after which 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 the 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.

For comparing other inductors with these standards, the 1632-A Inductance Bridge is recommended.

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 Nationl 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 ¾-in. spacing with removable ground strap.

Mechanical: Lab-bench cabinet. DIMENSIONS (wxhxd): 6.5x 6.5x8 in. (166x166x204 mm). WEIGHT: 11.5 lb (5.3 kg) net, 13 lb (6 kg) shipping.

Description	Nominal Inductance	Adjustment Accuracy (Percent)	*Resonant Frequency (kHz)	*Dc Resistance (Ohms)	*Q at 100 Hz	Milliamperes, rms for, 200 mW	3 W	Catalog Number
Standard Inductor								
1482-B	100 μH	±0.25	800	0.083	0.76	1550	6010	**1482-9702**
1482-E	1 mH	±0.1	800	0.84	0.75	490	1890	**1482-9705**
1482-H	10 mH	±0.1	220	8.2	0.77	156	600	**1482-9708**
1482-L	100 mH	±0.1	71	81	0.78	50	192	**1482-9712**
1482-P	1 H	±0.1	14.6	616	1.02	18	70	**1482-9716**
1482-T	10 H	±0.1	4.9	6400	0.98	5.6	22	**1482-9720**

* Representative values. Actual values given on certificate.

National Stock Numbers are listed on the back cover.

GR900® Precision Coaxial Components

The first precision series For many years it was difficult to improve the design of highly accurate high-frequency measuring equipment since any improvements were obscured by connector difficulties. This fact spurred General Radio, with its long experience in coaxial-connector development, to design the first commercial coaxial connector that could honestly be called "precision" — the GR900® connector.

A versatile choice The successful development of the GR900® connector signaled the initiation of an entire line of precision coaxial components and instruments. These, together with connector kits and precision rod and tubing, can bring GR900 precision to every corner of your laboratory.

Electrical characteristics One of the most important characteristics of a connector is standing-wave ratio and in the GR 900-BT connector SWR $< (1.001 + 0.001\, f_{GHz})$. Of ever greater importance in many applications is connector repeatability because this sets the limit of measurement accuracy. The GR 900-BT connector offers repeatability of $\pm$ 0.002 dB in insertion loss, $\pm$ 0.008° in insertion phase, and 0.05% in SWR.

Leakage of the GR900 connector is better than 130 dB below signal level — lower than that of any other commonly used coaxial connector. This remarkable characteristic is due to the triple shielding action of the butt contact between outer conductors, the interlocking and overlapping of the centering gear rings, the threaded engagement of the outer locking nut, and the precise machining of the mating surfaces. Insertion loss is extremely small, due to the unique design of the contacts and the use of very low-loss materials — Teflon* for the bead and solid-silver alloys for both inner and outer conductors.

Electrical length of a connector pair is 3.50 cm and is virtually independent of frequency. Dc resistance is typically 0.4 mΩ for the inner conductors and 0.04 mΩ for the outer conductors of a mated pair.

The 900-BT connector meets all specifications contained in Part III, Section 1 of the IEEE Standard for Precision Coaxial Connectors, No. 287.

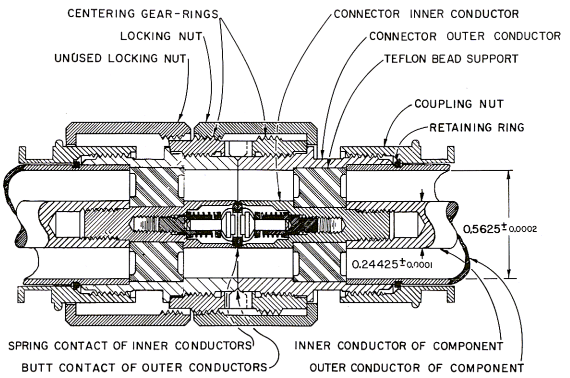
Mechanical characteristics The spring contact and inner conductor are made of gold-plated solid-silver alloy; the bead support, Teflon; the centering gear ring, stainless steel; the outer conductor, gold-plated coin silver; the retaining ring, phosphor bronze; and the coupling and locking nuts, chrome-plated brass.

When the parts are assembled onto an air line, the coupling nut and retaining ring attach the outer conductor of the connector to the outer conductor of the line. The inner conductor is threaded into the center conductor of the air line and is supported by the Teflon bead.

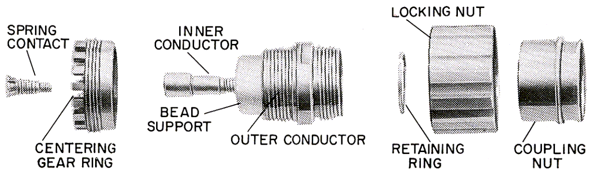
When two connectors are mated, the centering gear rings interlock and overlap to center the connectors with respect to each other. The interlocking also prevents the connectors from rotating against each other (with possible impairment of repeatability and reliability). The front surfaces of the outer conductors meet at a common reference plane, where they butt firmly together under the pressure of the locking nut.

The front surface of the inner conductor is recessed 0.001 inch with respect to the reference plane of the outer conductor, to ensure outer-conductor contact. Inner-conductor contact is made by a springy center contact assembly that projects slightly beyond the reference plane of the outer conductor until the connector is mated. The spring contact assembly consists of six independently sprung segments that are forced back and together upon mating, thereby making a wiping contact with both the inside of the inner conductor and the mating face of the other center contact. This connector structure is free from the reflections that would be caused by slots in the inner and outer conductors. It will give you exceptionally long life, with excellent repeatability, in part because micro-abrasion of the rubbing surfaces cannot affect the electrically critical conductor diameters.

* Registered trademark of the E. I. du Pont de Nemours and Company.



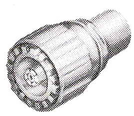
Cross-section view of mated 900-BT Precision Coaxial Connectors.



Exploded view of 900-BT Precision Coaxial Connector.

GR900® 50-Ohm Precision Terminations and Attenuators

Precision Resistive Terminations and Mismatches



Standard terminations are useful for calibration of bridges, slotted lines, admittance bridges, network analyzers, and reflectometers. The 50-ohm 900-W50 termination can also be used as a precision dummy load or as a termination in measurements of networks with more than one port. This termination, together with the 900-WNC Short Circuit and 900-LZ Air Lines, can form a calibration set for computer correction of measuring instruments. With an appropriate GR900 adaptor, it can be used as a low-SWR, precision type-N termination, or BNC, or C, etc.

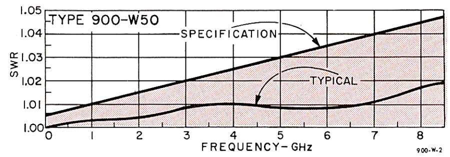
Standard mismatches introduce reflections of known SWR in a 50-ohm transmission line and are therefore useful in the calibration of reflectometers, network analyzers, and SWR-measuring instruments.

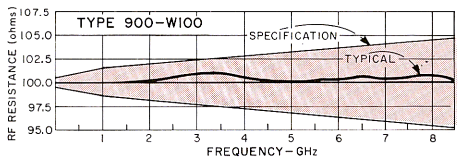
Frequency: Dc to 8.5 GHz.

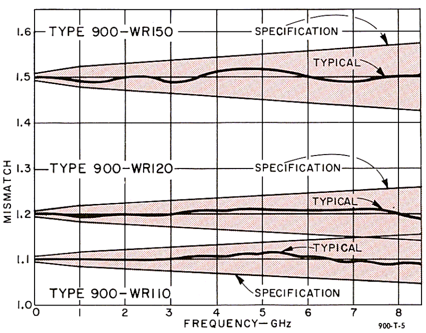
900	-W50	-W100	-W110	-W120	-W150
Dc Resistance:	50 Ω	100 Ω	45.45 Ω	41.67 Ω	33.33 Ω
Accuracy:	±0.3%	±0.5%	±0.5%	±0.5%	±0.5%
SWR, also see curves:	1.005 + 0.005 f_{GHz}	—	1.1 nom	1.2 nom	1.5 nom
Plane Position*:	—	4 cm nom	—	—	—

Electrical: INPUT POWER: <1 W with negligible change, <5 W without damage. TEMPERATURE COEFFICIENT: <150 ppm/°C.
Mechanical: DIMENSIONS: 2 in. (51 mm) long x 1.06 in. (27 mm) dia. WEIGHT: 0.2 lb (0.1 kg) net.

Description		Catalog Number
Precision Resistive Terminations		
900-W50	50-Ω Standard Termination	**0900-9953**
900-W100	100-Ω Standard Termination	**0900-9957**
Precision Mismatches:		
900-WR110	Standard Mismatch, SWR 1.1	**0900-9961**
900-WR120	Standard Mismatch, SWR 1.2	**0900-9963**
900-WR150	Standard Mismatch, SWR 1.5	**0900-9965**





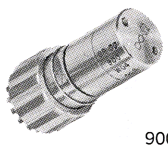


Open-Circuit Terminations

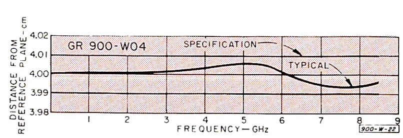
Open-circuit terminations are useful in establishing initial conditions of line length and signal phase, as shielding caps for open-circuited lines, and, at low frequencies, as capacitance standards.

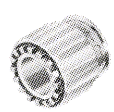
Frequency: Dc to 8.5 GHz.
Plane Position:* For 900-WO, typically 0.26 cm, but varies with frequency within ± 0.012 cm of value shown on graph. For -WO4, 4.00 ± 0.01 cm (corresponds to 4-cm offset in 900-W100 and -W200 Standard Terminations).
Electrical: CAPACITANCE: 0.172 ± 0.008 pF for -WO, at low frequencies; 2.670 pF ± 0.25% for -WO4, below 70 MHz.

Precision Open-Circuit Terminations	
900-WO, plane at 2.6 mm	**0900-9981**
900-WO4, plane at 4 cm	**0900-9985**

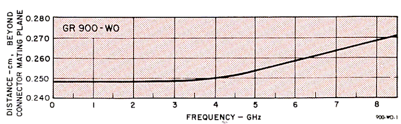


900-WO4





900-WO

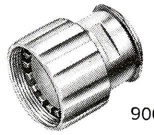


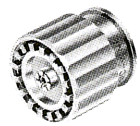
* Location of effective position of termination, measured toward "load", from reference plane of connector (where outer conductors butt together).

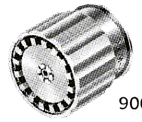
National Stock Numbers are listed on the back cover.

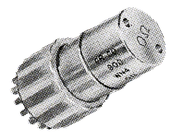
Precision Short-Circuit Terminations

Short-circuit terminations are useful in establishing initial conditions of line length and signal phase in, for example, impedance measurements. An s-c termination consists of a precision-machined, silver-plated disk, mounted in a centering gear ring and locking-nut assembly, to produce a fixed short circuit. The 900-WNC, -WNE, and -WN4 each includes a support for one end of the inner conductor of a 900-LZ Reference Air Line, which is beadless.


900-WN

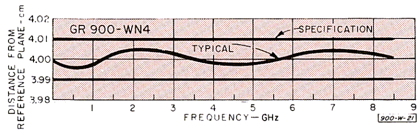

900-WNE


900-WNC


900-WN4

Frequency: Dc to 8.5 GHz.
Plane Position:* For 900-WN and -WNC, 0.00 cm; for 900-WNE, 0.26 ± 0.005 cm (corresponding open circuit is 900-WO); for 900-WN4, 4.00 ± 0.01 cm (corresponding resistive terminations are 900-W100 and -W200).
Reflection Coefficients: >0.999 for -WN and -WNC, >0.998 for -WNE, >0.996 for -WN4; all to 8.5 GHz.

Description	Catalog Number
50-Ω Precision Short-Circuit Terminations	
900-WN, without support, plane at 0.00 cm	**0900-9971**
900-WNC, with support, plane at 0.00 cm	**0900-9977**
900-WNE, with support, plane at 2.6 mm	**0900-9979**
900-WN4, with support, plane at 4 cm	**0900-9975**

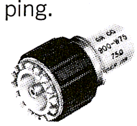


Precision 75-Ohm Termination

A fixed 75-Ω resistor mounted in a GR900 (75 Ω) connector for establishing reference conditions in coaxial lines, for impedance matching, for use as a termination, for the calibration of bridges, slotted lines, and reflectometers, and for use as a dummy load in network measurements.

Frequency: Dc to 1 GHz, usable to 9 GHz.
SWR: <(1.005 ± 0.005 f_{GHz}).
Electrical: IMPEDANCE: 75 Ω ± 0.3%, temperature coefficient < 150 ppm/°C. INPUT: 1 W with negligible change, 5 W without damage.

Mechanical: DIMENSIONS: 1.83 in. (47 mm) long x 1.06 in. (27 mm) dia. WEIGHT: 0.2 lb (0.1 kg) net, 1 lb (0.5 kg) shipping.



Description	Catalog Number
900-W75 (75-Ω) Precision Standard Termination	**0900-9733**

75- to 50-Ohm Precision Matching Pad

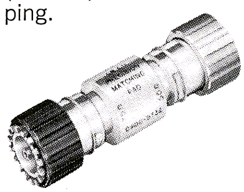
A two-port minimum-loss network to match 50-ohm GR900-equipped devices to similarly equipped 75-ohm devices. It features low SWR, low leakage, and the excellent repeatability inherent in GR900 connectors.

Frequency: Dc to 1 GHz, usable to 8.5 GHz.

SWR: Better than 1.003 + 0.003 f_{GHz} for 50-Ω side, 1.01 + 0.012 f_{GHz} for 75-Ω side.

Electrical: IMPEDANCE: 50 Ω and 75 Ω. INPUT: 1 W max continuous. INSERTION LOSS: 5.72 dB nominal. LEAKAGE: > 130 dB below signal.

Mechanical: DIMENSIONS: 3.75 in. (95 mm) long x 1.06 in. (27 mm) dia. WEIGHT: 0.6 lb (0.3 kg) net, 2 lb (1 kg) shipping.



900-MP 50 to 75-Ω Precision Matching Pad	**0900-9732**

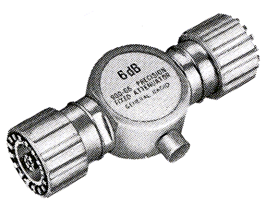
Precision Fixed Attenuators

GR900 attenuators permit greatly improved accuracy in the measurement of insertion loss, impedance, power, or phase, which requires precise impedance matching of the source and detector. In particular, they are ideal for swept measurements of these quantities. In point-by-point measurements, they reduce or eliminate the need to tune out residual reflections from source or detector.

The SWR characteristic of these attenuators is much lower than was previously available, and they exhibit uniform attenuation over a wide frequency range. They display a high degree of repeatability in SWR, contact resistance, and insertion loss, factors that contribute to their value in substitution measurements. The high repeatability and low SWR also permit them to be accurately calibrated for use as attenuation standards.

Frequency: Dc to 8.5 GHz.
Attenuation Accuracy: ±0.04 dB at dc, ±0.2 dB to 5 GHz, ±0.3 dB to 8.5 GHz. TEMPERATURE COEFFICIENT: <0.0001 dB/°C/dB.

SWR: <(1.005 + 0.005 f_{GHz}).
Electrical: IMPEDANCE: 50.0 Ω. INPUT POWER: <1 W continuous, or <500 W peak with <1 W average. DC RESISTANCE: 50.0 Ω±0.3% when terminated in 50.0 Ω.
Mechanical: DIMENSIONS: 3.75 in. (95 mm) long. WEIGHT: 0.7 lb (0.4 kg) net.



50-Ω Precision Fixed Attenuators:	
900-G6, 6 dB	**0900-9850**
900-G10, 10 dB	**0900-9851**

* Location of effective position of termination, measured toward "load", from reference plane of connector (where outer conductors butt together).

National Stock Numbers are listed on the back cover.

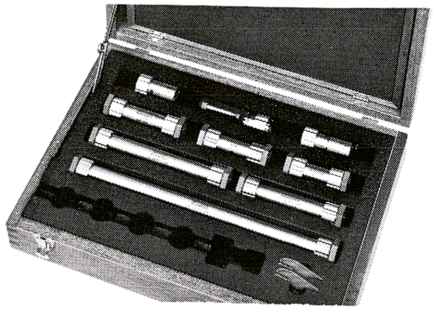
GR900® 50-Ohm Precision Air Lines

Reference-Air-Line Set

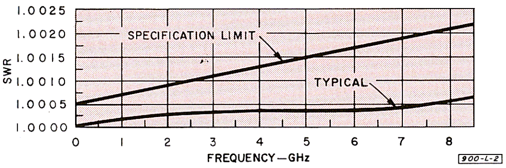
This set consists of one each of the seven lengths of 900-LZ Reference Air Lines, a 900-WN4 short circuit, and a 900-WO4 open circuit. All components are supplied in an attractive mahogany storage case, with recessed foam insets, which also can be supplied separately.

Mechanical: WEIGHT: 8 lb (3.7 kg) net, 13 lb (6 kg) shipping.

Description	Catalog Number
GR900 Reference-Air-Line Set	**0900-9452**
GR900 Storage Case	**0900-9450**



Reference Air Lines



For use in calibrations, especially in substitution measurements, as precision capacitance or time-delay standards, as well defined reactance standards, as dielectric sample holders for dielectric-constant and loss measurements with slotted lines and network analyzers, and as absolute impedance references in time-domain reflectometry. The 900-LZ series are beadless, virtually reflectionless coaxial air lines, with spring-loaded supporting tips on the ends of the inner conductor to mate with GR900 connectors; microfinished outer-conductor ends make butt contact with the mating connectors.

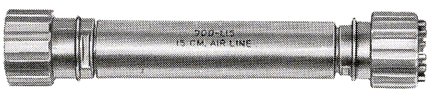
Frequency: Dc to 8.5 GHz.
SWR: <(1.0005 + 0.0002 f_{GHz}); calibration data supplied.
Repeatability: SWR: Within (0.010 + 0.003 f_{GHz})%.
Electrical: IMPEDANCE: 50 Ω ± 0.05% at 23°C and where skin depth is negligible. Additional skin-effect error is calculable.[1] INPUT VOLTAGE: Up to 3000 V pk. POWER, average into 50-Ω load: Up to 20 kW, dc to 1 MHz, decreasing as $1/\sqrt{f}$ at higher f. INSERTION LOSS: <(0.0008 $\sqrt{f_{GHz}}$) dB/cm. LEAKAGE: >130 dB below signal. DC CONTACT RESISTANCE each end, when mated with GR900 connector: <0.07 mΩ for outer conductor, <0.5 mΩ for inner conductor.

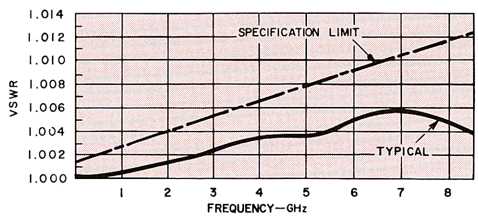
50-Ω Reference Air Lines

Type	Electrical Length (±0.002 cm) cm	Capacitance (±0.07%) pF	Time Delay (±0.1 ps) ps	Odd λ/4 Frequencies* GHz	Catalog Number
900-LZ3	2.998	2.0000	100.0	(2n+1) 2.50	**0900-9603**
900-LZ5	4.997	3.3333	166.7	(2n+1) 1.50	**0900-9600**
900-LZ6	5.996	4.0000	200.0	(2n+1) 1.25	**0900-9601**
900-LZ7H	7.495	5.0000	250.0	(2n+1) 1.00	**0900-9602**
900-LZ10	9.993	6.6667	333.3	(2n+1) 0.75	**0900-9604**
900-LZ15	14.990	10.0000	500.0	(2n+1) 0.50	**0900-9606**
900-LZ30	29.979	20.0000	1000.0	(2n+1) 0.25	**0900-9612**

* Frequencies at which air-line section is an odd multiple of a quarter wavelength, where n is zero or any integer).

Precision Air Lines





Useful as low-SWR line extenders, as 50-ohm impedance standards at frequencies at which the electrical length is an odd multiple of a quarter wavelength, as capacitance and time-delay standards, and as absolute impedance standards in time-domain reflectometry. Each line consists of a short section of precision 50-ohm air line with a GR900 connector at each end.

Frequency: Dc to 8.5 GHz.
SWR: <(1.0013 + 0.0013 f_{GHz}).
Electrical: IMPEDANCE: 50 Ω ± 0.065%. Additional skin-effect error is calculable.[1] INPUT VOLTAGE: Up to 3000 V pk. POWER, average into 50-Ω load: Up to 20 kW, dc to 1 MHz, decreasing as $1/\sqrt{f}$ at higher f. DC CONTACT RESISTANCE each end, when mated with GR900 connector: <0.07 mΩ for outer conductor, <0.5 mΩ for inner conductor.

50-Ω Precision Air Lines

Type	Electrical Length (±0.02 cm) cm	Capacitance pF	Time Delay (± 1 ps) ps	Insertion Loss dB	Catalog Number
900-L10	10	6.6667	333	< 0.012 $\sqrt{f_{GHz}}$	**0900-9605**
900-L30	30	20.000	1000	< 0.028 $\sqrt{f_{GHz}}$	**0900-9613**

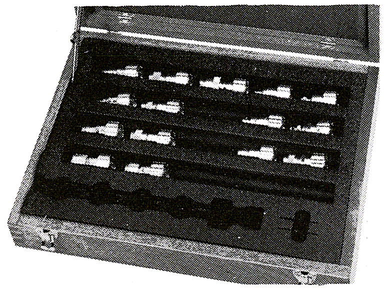
[1] J. Zorzy, "Skin-Effect Corrections in Standards," *IEEE Transactions on Instrumentation and Measurement,* Vol. IM-15 No. 4, December 1966, p. 358 (GR Reprint A-134).

GR900® 50-Ohm Precision Adaptors

Conversion plus precision The availability of precision adaptors from the GR900® connectors to other popular coaxial connectors means that the user of GR900 equipped instruments can convert to other series and still retain precision performance. For example, a 900-LB Precision Slotted Line equipped with a 900-QNJ or -QNP adaptor becomes a type N slotted line with an over-all residual SWR (line plus adaptor) of only 1.02 at 3 GHz. Conversely, users of instruments equipped with SMA, TNC, N, C, and GR874® connectors can, by means of adaptors, take advantage of the precision offered by GR900 tuners, airline standards, terminations, and other elements.

50-Ohm Precision Adaptor Kit

This set consists of the most commonly used GR900 precision adaptors including one each of the jack and plug versions of adaptors to BNC, C, N, SC, SMA, and TNC, as well as adaptors to Amphenol APC-7 and GR874® connectors. All components are supplied in an attractive mahogany storage case with recessed foam inserts.

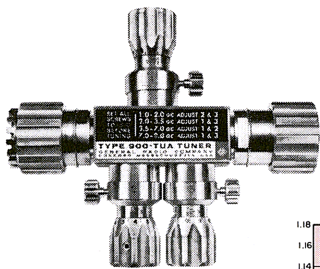


Mechanical: WEIGHT: 8 lb (3.7 kg) net, 12 lb (5.5 kg) shipping.

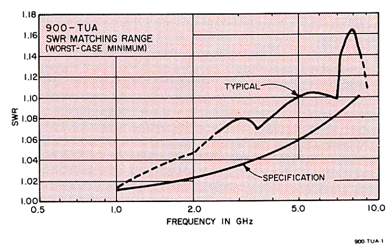
Description	Catalog Number
GR900 Precision Adaptor Set	**0900-9451**
GR900 Storage Case	**0900-9450**

Precision Tuner

Used to match out small residual reflections in low-SWR measuring instruments and devices. The tuner has three smoothly adjustable tuning screws that are used in pairs to tune out reflections of any phase throughout the tuner's frequency range. Each screw has a "neutral" setting, independent of frequency, at which it is effectively out of the circuit. Screws can be locked at any setting to enhance the excellent SWR resettability and to protect against accidental disturbance. They can be partially clamped for the desired friction.



Frequency: 1 to 8.5 GHz.
SWR Matching Range: 1.00 to 1.00 + 0.012 f_{GHz}, worst-case minimum. RESETTABILITY: <(1.0005 + 0.0003 f_{GHz}).
Repeatability: 0.05% (limited by connector).
Electrical: IMPEDANCE: 50 Ω nominal. INSERTION LOSS: <0.1 dB to 4 GHz, <0.3 dB to 8.5 GHz. ELECTRICAL LENGTH: 12.0 cm.
Mechanical: DIMENSIONS: 4.5x3.5x1 in. (114x89x25mm). WEIGHT: 1 lb (0.5 kg) net, 3 lb (1.4 kg) shipping.



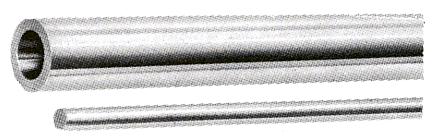
900-TUA Tuner	**0900-9635**

Precision Tube and Rod

Used to fabricate custom-length 14-mm air lines and components in conjunction with GR900 connectors and connector kits. Machining instructions are furnished.

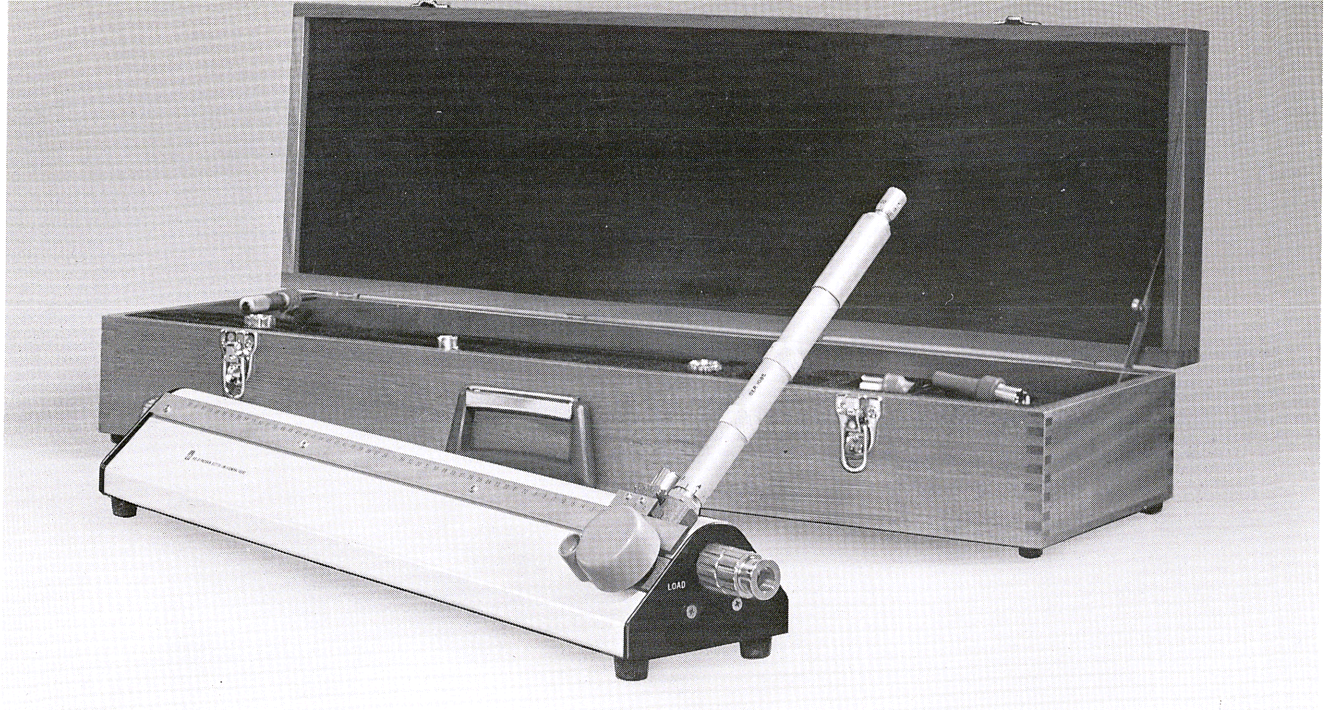
Precision Outer-Conductor Tube
Mechanical: Precision-forged, silver-lined brass; stress relieved to minimize dimensional changes during machining; for use with 890-BT, 900-BT and -BT (75Ω) connectors. DIMENSIONS (diameters specified at 23°C): 27 in. (690 mm) long, 0.830 in. nominal OD, 0.5625 in. ± 220 finish of 30 μin. max, 0.134 in. nominal wall thickness.

50-Ω Precision Inner-Conductor Rod
Electrical: IMPEDANCE: 50 ± 0.035 Ω (± 0.07%) when centered in 0900-9509 tube.
Mechanical: Supplied in pairs; centerless-ground, silver-layered brass rod; for use with 890-BT and 900-BT connectors. DIMENSIONS (diameters specified at 23°C): 13 ± 0.0312 in. (330 mm) long with straightness of 0.0015 in./ft; 0.24425 in. ± 65 μin. dia with uniformity of ±25 μin. and surface finish of 20 μin. max.



Description	Catalog Number
Precision Outer-Conductor Tube	**0900-9509**
50-Ω Precision Inner-Conductor Rod	**0900-9507**

National Stock Numbers are listed on the back cover.



900-LB Precision Slotted Line

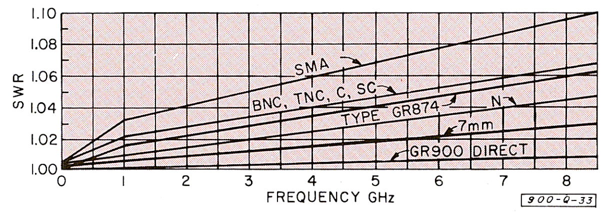
- **300 MHz to 8.5 GHz**
- **extremely low SWR**
- **impedance is 50 Ω ± 0.1%**
- **adaptable with precision to other connectors**

Unparalleled precision The most precise coaxial connector, the GR900, and a nearly perfect section of coaxial transmission line combine to give the 900-LB Precision Slotted Line unparalleled performance specifications. The residual SWR of the instrument is that of its GR900® connector: $1.001 + 0.001\ f_{GHz}$. For those whose applications demand the ultimate in accuracy, the 900-LB can be calibrated against a 900-LZ Reference Air Line, an impedance standard with a SWR under 1.0025 at 9 GHz.

In the field of microwave impedance measurement, the slotted line is **the** fundamental instrument, because of its inherent accuracy, broadband characteristics, and phase-measuring capabilities. Among the many transmission-line parameters that can be determined with the slotted line are SWR, reflection-coefficient magnitude and phase, attenuation or insertion loss, and wavelength. The admittance or impedance of source or termination can be measured; so also can transistor and diode characteristics and dielectric constant. It gives the design engineer all the information he needs to evaluate the over-all performance of devices and networks over a wide band.

The outstandingly low SWR of the 900-LB should save users the many hours required to calibrate less accurate instruments.

Equipped with the appropriate GR900 low-SWR adaptor, the 900-LB becomes a type-N slotted line (or BNC, or TNC, etc) whose specifications still exceed those of slotted lines originally equipped with that connector (see curve below).



Specified residual SWR of the 900-LB Precision Slotted Line in combination with various GR900® precision adaptors.

Included with the slotted line is a full set of accessories; no additional parts are needed for common measurements, except the generator and detector, which should be selected according to frequency range of interest.

SPECIFICATIONS

Frequency: 300 MHz to 8.5 GHz. Operates below 300 MHz (where probe travel equals ½ wavelength) if extended with lengths of GR900 air line or with another slotted line in series.

Probe: TRAVEL: 50 cm; scale in cm. SCALE ACCURACY: ±(0.1 mm + 0.05%). Attached vernier resolution is 0.1 mm and micrometer carriage-drive resolution is 0.002 mm. PICK-UP CONSTANCY (flatness): ±0.5%.

SWR: $<1.001 + 0.001\ f_{GHz}$ (unknown connector side), calibration data supplied.

Repeatability: Within 0.05% (0.0005 SWR).

Characteristic Impedance: 50 Ω ±0.1%. CONTACT RESISTANCE (900-BT connector): <0.57 mΩ.

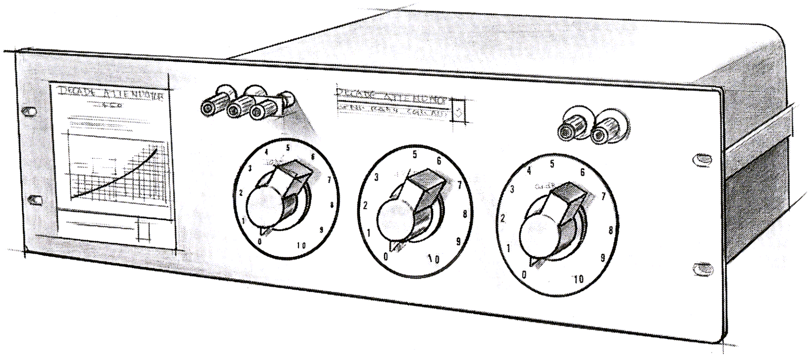
National Stock Numbers are listed on the back cover.

Supplied: Adjustable probe-tuner assembly, rf probe, micrometer carriage drive accurate to 0.01 mm, 900-WN Precision Short-Circuit Termination, 900-WO Precision Open-Circuit Termination, 874-R22A Patch Cord, 874-Q9000L adaptor, 1N21C and 1N23C detector diodes, Smith charts, storage case.

Required: Generator and detector.

Mechanical: DIMENSIONS (wxhxd): 27.5x10x4.75 in. (699x254x121 mm). WEIGHT: 11 lb (5 kg) net, 34 lb (16 kg) shipping.

Description	Catalog Number
900-LB Precision Slotted Line	**0900-9651**



1450 Decade Attenuator

- **0 to 111 dB in steps of 0.1 dB**
- **600-ohm input and output impedance**
- **accuracy: ±0.02 dB ±0.25%**
- **usable to 1 MHz**

Use the 1450 Decade Attenuator to provide accurate steps of attenuation for power-level measurements, transmission-efficiency tests, and gain or loss measurements on transistors, filters, amplifiers, and similar equipment. It can also serve as a power-level control in circuits not equipped with other volume controls.

Each decade consists of four individually shielded, series-connected T-pads. The switches have eleven positions, 0 to 10 inclusive, so the decades overlap. There are no stops on the 0.1- and 1-dB-per-step decades, thus facilitating quick return from full to zero attenuation.

SPECIFICATIONS

Attenuation Range: 111 dB in steps of 0.1 dB.

Terminal Impedance: 600 Ω nominal in either direction. An etched plate indicates the mismatch loss for other than 600-Ω circuits.

Accuracy: Each individual resistor is adjusted within ±0.25% of its correct value. The low-frequency error in attenuation is less than ±0.02 dB ±0.25% of indicated dB setting plus a switch-resistance error of 0.005 dB, when attenuator is terminated at both ends in a pure resistance of 600 Ω. For differences in attenuation between any two settings, switch-resistance error virtually disappears. To maintain accuracy at high attenuations, special wiring methods are employed to the "low" Input post.

Frequency Discrimination (with low terminal at panel potential): Less than 0.1 dB ±1% of the indicated value at frequencies below 200 kHz. For increments in attenuation, the 1% tolerance extends to approximately 1 MHz.

Maximum Input Power: 1 W.

Switches: Cam-type switches are used with twelve positions covering 360°. Dials are numbered from 0 to 10 inclusive, and the twelfth point is also connected to 0. Stops are provided in the switch mechanism for the 100-dB decade. No stops are provided initially to prevent complete rotation of the 10- and 1-dB decades, but spacers, which are provided, can be used under certain mounting screws to act as stops for the knob, if desired.

Characteristic Impedance: 600 Ω; if one end is terminated in 600 Ω, the input impedance at the opposite end is 600 Ω, for any attenuation setting.

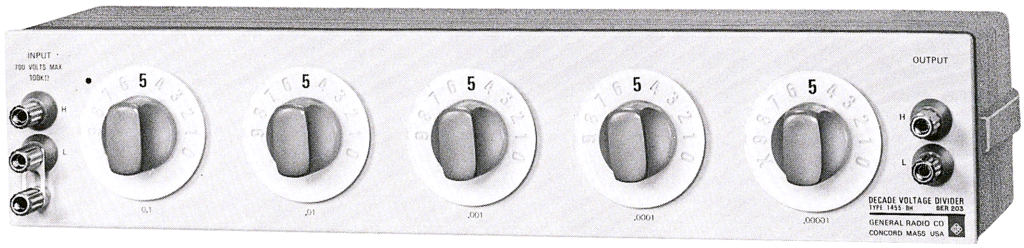
Terminals: Low-thermal-emf jack-top binding posts with ¾-in. spacing; ground ("G") terminal also provided, near Input.

Shielding: Each decade is individually shielded, and all shields are connected to the panel, to which the "G" post is also connected. The user is thus given free choice of grounding point for the "low" side, including connection to "G" by the link provided.

Mechanical: Lab-bench cabinet model. DIMENSIONS (wxhxd): Bench, 12x5.75x12.25 in. (305x146x311 mm); WEIGHT: 15 lb (7 kg) net, 20 lb (9.5 kg) shipping.

Description	Dials	Attenuation Total	Attenuation Steps	Catalog Number
Decade Attenuator **1450-TB,** Bench	3	111 dB	0.1 dB	**1450-9893**

National Stock Numbers are listed on the back cover.



1455 Decade Voltage Divider

- **linearity better than 20 ppm (5-dial model)**
- **input impedance: 10 or 100 kΩ**

The GR 1455 Decade Voltage Dividers provide accurately known voltage ratios from 0.00001 to 1.00000 for use in many common measurements:

- voltage gain or attenuation
- linearity of potentiometers and other controls
- frequency response of audio and rf networks
- transformer turns ratio
- voltmeter calibration

A resistive divider of the Kelvin-Varley type, the 1455 has precision resistors throughout (rather than in selected positions only) for over-all high accuracy. Linearity is as low as 0.02 ppm of input.

Match your needs exactly. Select input impedance, voltage rating, frequency range, 4- or 5-dial resolution, bench or rack mounting.

SPECIFICATIONS

Frequency Characteristic: Acts like simple RC circuit below f_o so that

$$\frac{E_o}{E_{in}} \approx \frac{\text{reading}}{\sqrt{1+\left(\frac{f}{f_o}\right)^2}}$$

Tabulated value of f_o is at setting that gives max output resistance so that f_o at all other settings is higher. At 0.044 f_o, response is down <0.1%.

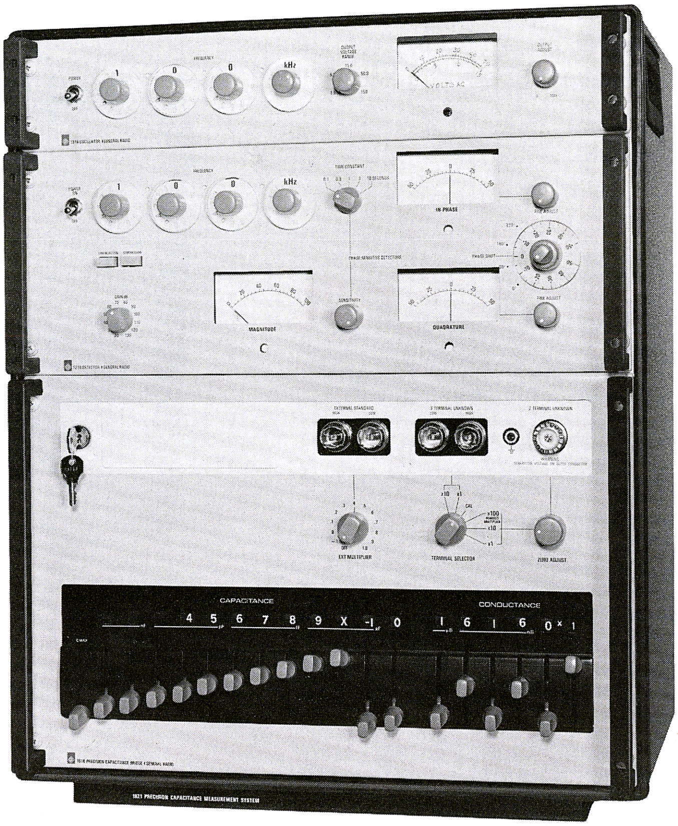
Temperature Coefficient: <20 ppm for each resistor. Since voltage ratios are determined by resistors of similar construction, net ambient temperature effects are very small.

Mechanical: Lab-bench cabinet. DIMENSIONS (wxhxd): Bench, 4-dial model, 14.75x3.5x6 in. (375x89x153 mm); 5-dial models, 17.31x3.5x6 in. (440x89x153 mm); rack, 19x3.5x4.63 in. (483x89x117 mm). WEIGHT: Bench, 4-dial model, 6.75 lb (3.1 kg) net, 8 lb (3.7 kg) shipping; 5-dial models, 7.75 lb (3.6 kg) net, 9 lb (4.1 kg) shipping; rack models are each 1 lb (0.5 kg) heavier than corresponding bench models.

Type	1455-A	-BH	-B
Number of Dials:	4	5	5
Input Resistance:	10 kΩ	100 kΩ	10 kΩ
Accuracy of Input R: (ppm)	+150	+150	+150
Input Voltage Rating[1]**:**	230 V	700 V	230 V
Frequency Response[2] **f_o:**	850 kHz	69 kHz	690 kHz
Resolution: (ppm of input)	100	10	10
Linearity (sum of A & B)			
A, **Absolute Linearity**[3]			
— Ratio —			
0.00001 to 0.00010	—	±0.02	±0.03
0.00010 to 0.00100	±0.3	±0.2	±0.3
0.00100 to 0.01000	±2	±2	±3
0.01000 to 0.10000	±15	±10	±10
0.10000 to 1.00000	±30	±20	±20
B, **Terminal Linearity** (in ppm of input).			
FOUR-TERMINAL (output with respect to low output terminal):	±0.04	±0.004	±0.04
THREE-TERMINAL[4]	±0.2	±0.02	±0.2
Max Output Resistance (input shorted):	2.79 kΩ	28.8 kΩ	2.88 kΩ
Effective Output Capacitance (typ, unloaded):	67 pF	80 pF	80 pF

[1] Safe operating limit, will not cause damage.
[2] Output-level change due to increasing frequency, with no load, with output resistance set to max, up to the tabulated frequency: <3 dB.
[3] Measured in ppm of input. Output is taken with respect to reference output measured when the indicated ratio is zero, with frequency in the low audio range, with input <0.5 of Input Voltage Rating. *Note:* Linearity change due to internal heating, for full rated input voltage, for ratios 0.1 to 1.0: <20 ppm; for ratios <0.1: negligible.
[4] Output measured with respect to low input terminal. Low output terminal may be floating or connected to the low input terminal.

Description	Catalog Number
1455 Decade Voltage Divider	
Bench Models	
1455-A, 4-dial, 10-kΩ	**1455-9700**
1455-B, 5-dial, 10-kΩ	**1455-9706**
1455-BH, 5-dial, 100-kΩ	**1455-9708**
Rack Models	
1455-A, 4-dial, 10-kΩ	**1455-9701**
1455-B, 5-dial, 10-kΩ	**1455-9707**
1455-BH, 5-dial, 100-kΩ	**1455-9709**



1621 Precision Capacitance-Measurement System

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

The whole of precision The 1621 represents the first major improvement in nearly a decade in ultra-precise laboratory capacitance intercomparisons and dielectric measurements. It is a completely self-contained system capable of capacitance measurements in increments as small as 0.1 aF (10^{-7} pF) and conductance measurements in increments as small as 100 a℧ (10^{-10} μ℧; 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.

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

Three integrated units The 1621 is an assembly of three integrated instruments: A precision ratio-arm bridge, a highly stable oscillator, and an extremely sensitive detector. Most of the bridge's internal standards are enclosed in an insulated housing to reduce the effects of ambient temperature changes; unused standards are disconnected to reduce shunt capacitance at the detector input. The oscillator provides up to 125 V or 5 A for sufficient signal to be detected even with unbalances as small as one part in 10^8 of 10 pF. The detector contains three meters to help you speed the balance: One displays the magnitude and the other two simultaneously display the in-phase and quadrature components of any unbalance.

SPECIFICATIONS

(See 1616 for performance specifications)

Frequency: 10 Hz to 100 kHz.

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

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

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

Mechanical: Bench or rack models. DIMENSIONS (wxhxd): Bench, 19.75x24.25x15 in. (502x616x381 mm); rack, 19x 20.91x11.44 in. (483x531x291 mm). WEIGHT: Bench, 105 lb (48 kg) net, 140 lb (64 kg) shipping; rack, 90 lb (41 kg) net, 125 lb (57 kg) shipping.

Description	Catalog Number
1621 Precision Capacitance-Measurement System	
Bench Model, 60-Hz	**1621-9701**
Rack Model, 60-Hz	**1621-9702**
Bench Model, 50-Hz	**1621-9703**
Rack Model, 50-Hz	**1621-9704**

1616 Precision Capacitance Bridge

- 10^{-7} pF to 10 μF — 12-digit readout
- 10^{-10} μ℧ to 1000 μ℧ — 5-digit readout
- 10 Hz to 100 kHz
- up to 150-V input from oscillator
- 3-terminal measurements
- coaxial measurements

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

The 1616 employs a transformer ratio-arm bridge with which unbalances as small as 0.1 aF (10^{-7} pF) and 100 a℧ (10^{-10} μ℧) 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.

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

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 $\pm[50 \text{ ppm} + (0.5 + 20\, C_{\mu F})\, (f_{kHz})^2 \text{ ppm} + (f_{kHz}) \text{ aF}]$.

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 a℧ to 100 μ℧ (10^{-16} to 10^{-4}℧). 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 μ℧ (10^{-16} to 10^{-3} ℧).

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.

*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.

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

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

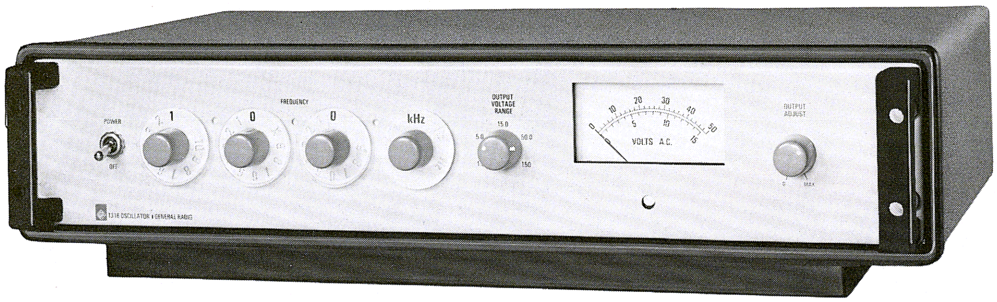
Interface: GR900® locking coaxial connector on panel to connect 2-terminal unknowns, 2 gold-plated GR874® locking coaxial connectors on panel to connect 3-terminal unknowns and 2 to connect external standard. DATA OUTPUT: 50-pin and 36-pin type 57 connectors on rear provide connection to 8-4-2-1 weighted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

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

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

Mechanical: Bench or rack model. DIMENSIONS (wxhxd): Bench, 19.75x13.81x12.88 in. (502x351x327 mm); rack, 19x 12.22x10.56 in. (483x310x268 mm). WEIGHT: Bench, 57 lb (26 kg) net, 69 lb (32 kg) shipping; rack, 49 lb (23 kg) net, 61 lb (28 kg) shipping.

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



1316 Oscillator

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

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

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

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

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

SPECIFICATIONS

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

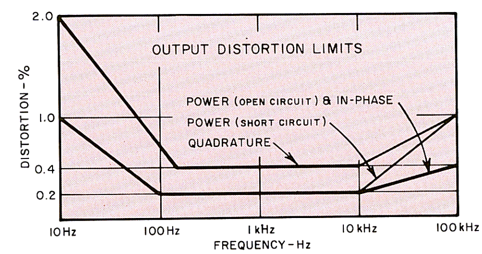
Accuracy: ±1% of setting with continuously adjustable dial at zero detent position. DRIFT (typical at 1 kHz): Warmup 0.1%, short-term (10 min) 0.001%, long-term (12 h) 0.005%. RESETTABILITY: Within 0.005%.

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 100 kHz*				
Short Circuit I	5 A	1.6 A	0.5 A	0.16 A	0.05 A
Distortion	<0.2% from 100 Hz to 10 kHz				
Impedance	0.25 Ω	2.5 Ω	25 Ω	250 Ω	2.5 kΩ
Power	1.6 W max into matched load				

*±5% for outputs >30 V rms at frequencies >50 kHz.

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



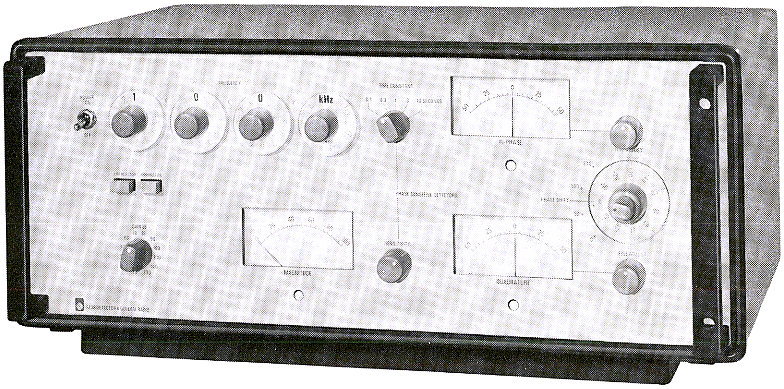
		In-Phase	Quadrature
Output, open-circuit		1.25 ± 0.25 V rms	
Distortion,	100 Hz to 10 kHz	<0.2%	<0.4%
Response,	10 Hz to 10 kHz	±2%	
	10 kHz to 100 kHz	±4%	
Minimum Load		47 kΩ	

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

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



1238 Detector

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

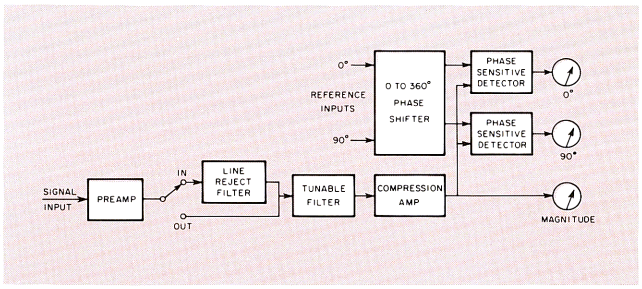
Designed for the difficult If you've ever had to extract a small signal from noise or to resolve a signal into its in-phase and quadrature components, you can appreciate the advantages of the 1238. With its high gain — 130 dB — and meters not only for magnitude of the input signal but for the in-phase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

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

Excellent bridge detector In combination with a special oscillator, GR 1316, that supplies the necessary quadrature reference channels, this detector is superb for sensitive audio-frequency detection. The combination is specifically intended for use with the 1616 Precision Capacitance Bridge, enabling resolutions of one part in 10^8 of 10 pF. Refer to the 1621 Precision Capacitance-Measurement System.

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

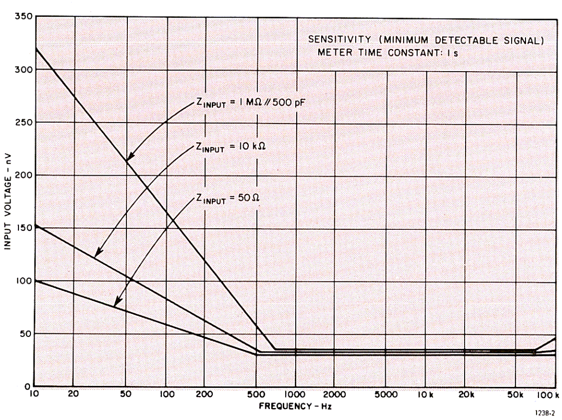
The effects of noise, hum, or any other input-signal contaminants are normally reduced or eliminated from your measurements by means of a tunable filter, line-rejection filter, and selectable time constants in the phase-sensitive detector circuits — all controlled from the front panel by the simple push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



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: Reduces line level by ≥40 dB while signal is down 6 to 10 dB at 10 Hz from line frequency; filter can be switched out.

Signal Input from bridge or other source: Applied to rear BNC connector. SENSITIVITY: Also see curve; 100 nV rms typical for full-scale deflection at most frequencies, compression can be switched in to reduce full-scale sensitivity by 20 dB. IMPEDANCE: 1 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.

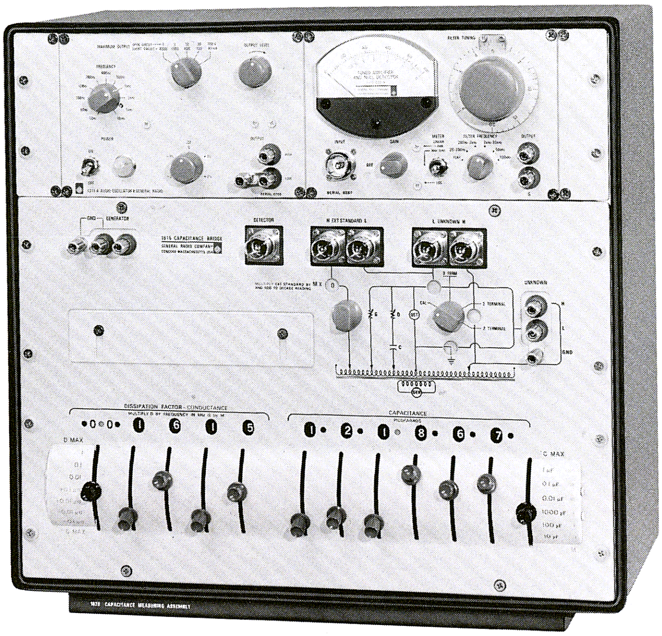
Environment: TEMPERATURE: 0 to +55°C operating, −40 to +75°C storage. BENCH HANDLING: 4 in. or 45° (MIL-810A-VI). SHOCK: 30 G, 11 ms (MIL-T-4807A-4.5-3A).

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 (wxhxd): Bench, 19.56x6.66x12.94 in. (497x169x329 mm); rack, 19x 5.22x13.06 in. (483x133x332 mm). WEIGHT: Bench, 27 lb (13 kg) net, 40 lb (19 kg) shipping; rack, 21 lb (10 kg) net, 34 lb (16 kg) shipping.

Description	Catalog Number
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**



1620-A Capacitance-Measuring Assembly

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

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

The 1620-A is intended for

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

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

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

Two- or Three-Terminal Connection Accurate three-terminal measurements can be made even in the presence of capacitances to ground as large as 1 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 both be made over the whole capacitance range.

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

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

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

SPECIFICATIONS

Performance: Refer to the 1615 Bridge.

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

Generator: 1311-A Oscillator.

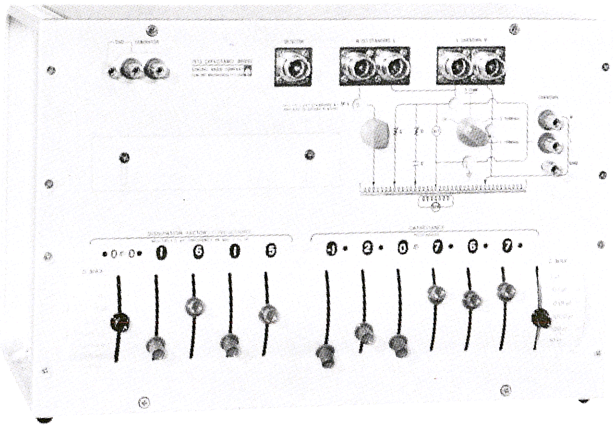
Detector: 1232-A Tuned Amplifier and Null Detector. 1232-P2 Preamplifier added in 1620-AP.

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

Mechanical: Bench cabinet. DIMENSIONS (wxhxd): 19.75x 19x11 in. (502x483x280 mm). WEIGHT: 59 lb (27 kg) net, 96 lb (44 kg) shipping.

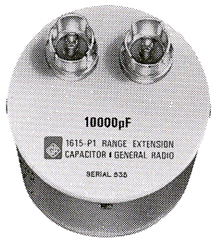
Description	Catalog Number
Capacitance-Measuring Assembly	
1620-A, 115 V	**1620-9701**
1620-A, 230 V	**1620-9702**
1620-AP, with 1232-P2, 115 V	**1620-9829**
1620-AP, with 1232-P2, 230 V	**1620-9830**
Replacement Battery (9 used)	**8410-1372**

National Stock Numbers are listed on the back cover.

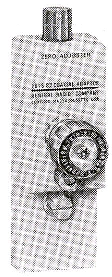


1615-A Capacitance Bridge

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



1615-P1



1615-P2

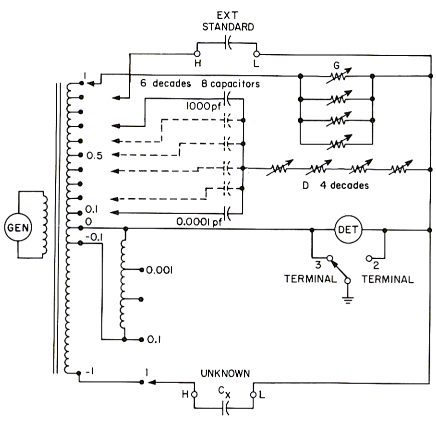
SPECIFICATIONS

RANGES	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 $[\pm 3 \times 10^{-5}\% + 2\,(C_{\mu F}) \times 10^{-3}\% \pm 3 \times 10^{-7}\text{ pF}] \times (f_{kHz})^2$. 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 $+ 10^{-5}\ \mu℧ + 6 \times 10^{-2}\, f_{kHz}\, C_{\mu F} \times (1 + f_{kHz} + 5\, f_{kHz}\, C_{\mu F})\ \mu℧]$

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: GR 1310 or 1311-A oscillator recommended. Max safe generator voltage ($30 \times f_{kHz}$) volts, 300 V max. If generator and detector connections are interchanged, 150 to 500 V can be applied, depending on switch settings.



Elementary schematic diagram.

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

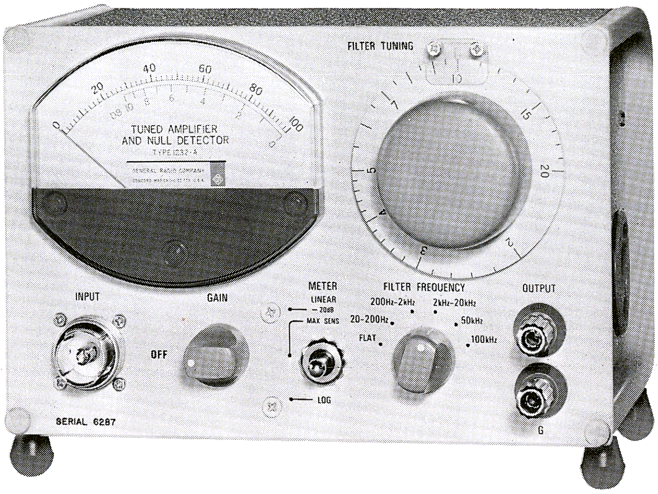
Supplied: 874-WO Open-Circuit Termination, 874-R22A Patch Cord, 274-NL Patch Cord.

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

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

Description	Catalog Number
1615-A Capacitance Bridge	
Bench Model	**1615-9801**
Rack Model	**1615-9811**
1615-P1 Range-Extension Capacitor	**1615-9601**
1615-P2 Coaxial Adaptor, GR900 to binding posts	**1615-9602**

National Stock Numbers are listed on the back cover.



1232-A Tuned Amplifier and Null Detector

- **20 Hz to 20 kHz, 50 and 100 kHz**
- **0.1-μV sensitivity**
- **bandwidth approx 5%**
- **120-dB gain**

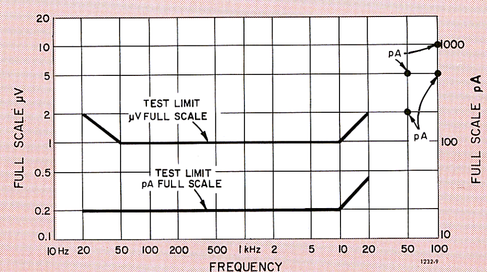
A sensitive null detector like this is the key to many a fussy bridge measurement. Battery operation frees the 1232 from power-line noise and makes it ultra portable. Low-noise solid-state circuitry and high gain make it very sensitive. Its tunability and choice of bandwidth enable you to reject broadband noise as well as the harmonics that might otherwise impair good measurements. Here are its prime uses:

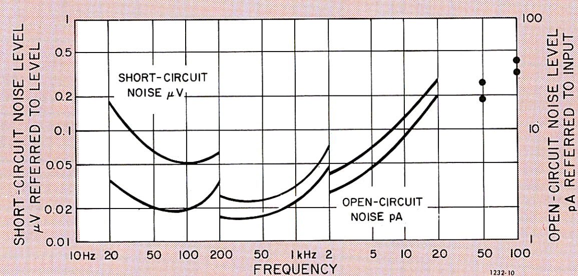
- bridge detector at audio frequencies; with the 1232-P2 Preamplifier it is equally sensitive for extremely high-impedance sources
- audio preamplifier and general-purpose, tunable, or broadband audio amplifier
- a-m detector for 0.5- to 500-MHz carrier frequencies, when used with an 874-VQ Voltmeter Detector
- sensitive audio wave analyzer for approximate measurements

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 . . . 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.





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.

Noise Level: REFERRED TO INPUT: See plot. Noise figure at 1 kHz is less than 2 dB at an optimum source impedance of 27 kΩ. REFERRED TO OUTPUT: Less than 5 mV on FLAT filter-frequency position, min gain setting, and −20-dB switch position; less than 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 fullscale 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.

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

Terminals: Input, GR874® cóaxial 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 alone, or with companion instruments, to 19-in. rack-mount width.

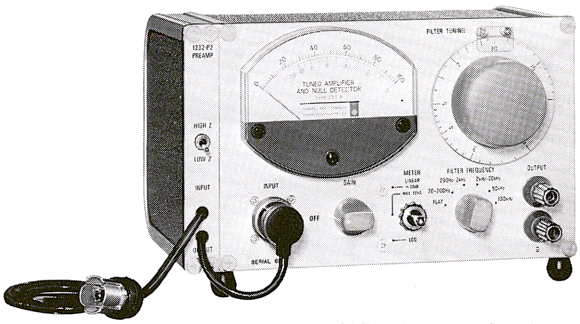
Power: 12 V dc, from 9 mercury (M72) cells in series. Est battery life 1500 hours. Optionally, a rechargeable battery (non-mercury) can be supplied on special order.

Mechanical: Convertible bench cabinet. DIMENSIONS (wxhxd): Bench, 8x6x7.5 in. (203x152x190 mm). WEIGHT: 5.75 lb (2.6 kg) net, 8 lb (3.7 kg) shipping.

Description	Catalog Number
1232-A Tuned Amplifier and Null Detector	**1232-9701**
1232-AP Tuned Amplifier and Null Detector, with preamplifier	**1232-9829**
Rack-Adaptor Sets	
480-P308, for 1232-A alone	**0480-9838**
480-P316, for 1232-A with 1310 or 1311 oscillator or similar 8-in. wide instrument with convertible-bench cabinet	**0480-9836**
480-P317, for 1232-AP (with preamp) and companion 8-in. instrument	**0480-9837**
Replacement Battery, 9 req'd	**8410-1372**

1232-P2 Preamplifier

The 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.



1232-P2 Preamplifier installed.

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.

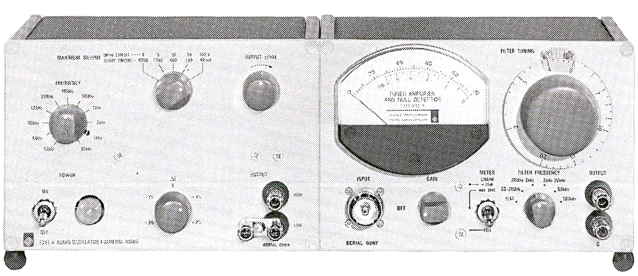
Connectors: GR874® on cables, input and output.

Power: 12 V, 200 μA, suppied by 1232-A.

Mechanical: Special cabinet. DIMENSIONS (wxhxd): 0.75x 6x7.5 in. (19x152x190 mm). WEIGHT: 0.94 lb (0.43 kg) net, 4 lb (1.9 kg) shipping.

Description	Catalog Number
1232-P2 Preamplifier	**1232-9602**

1240 Bridge Oscillator-Detector



The 1232-A Tuned Amplifier and Null Detector and the 1311-A Audio Oscillator have been combined for use with audio-frequency bridges and other null-balance devices. This assembly occupies a minimum of bench space and is supplied with removable panel extensions, which adapt it for rack mounting.

The oscillator supplies 11 fixed frequencies from 50 Hz to 10 kHz. The detector is tunable continuously from 20 Hz to 20 kHz, with additional spot frequencies of 50 kHz to 100 kHz. The assembly is also available with the 1232-P2 Preamplifier included.

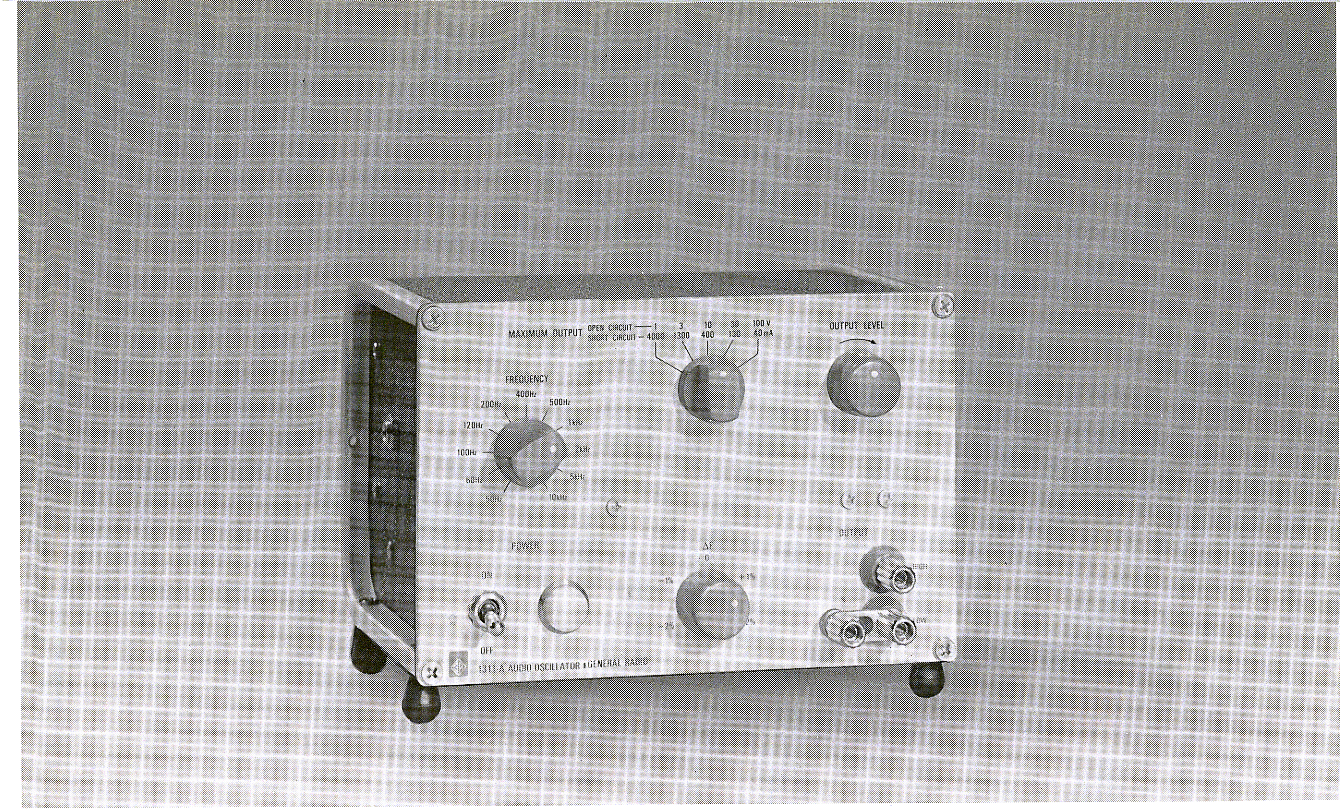
SPECIFICATIONS

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 (wxhxd): 19x6x7.75 in. (483x153x197 mm), including panel extensions for rack mounting. WEIGHT: 13.5 lb (7 kg) net, 28 lb (13 kg) shipping.

Description	Catalog Number
1240-A Bridge Oscillator-Detector, 115 V	**1240-9701**
1240-A Bridge Oscillator-Detector, 230 V	**1240-9711**
1240-AP Bridge Oscillator-Detector, with preamplifier, 115 V	**1240-9829**
1240-AP Bridge Oscillator-Detector, with preamplifier, 230 V	**1240-9839**
ASA type M72 Replacement battery (for 1232, 9 req'd)	**8410-1372**

National Stock Numbers are listed on the back cover.

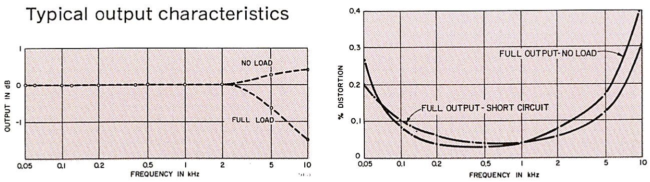


1311-A Audio Oscillator

- **50 Hz to 10 kHz, discrete frequencies**
- **1 W, 100-V or 4-A output**
- **transformer output**

The 1311 oscillator offers high-power output and load-matching through a multitap output transformer that ensures at least ½ watt into any load from 0.08 to 8000 ohms. Thus, it is ideal for driving impedance bridges where high sensitivity is required at extreme measurement limits and for driving directly such low-impedance devices as acoustic transducers. For bridge measurements, the shielded output-transformer secondary minimizes circulating ground currents. The 1311 is supplied in an assembly with the 1232 Tuned Amplifier and Null Detector as the 1240 Bridge Oscillator-Detector. The 1311 is also included in several GR impedance-measuring systems.

Typical output characteristics



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, GR 938 Binding Posts and ground terminal with shorting link; sync, telephone jack on side panel.

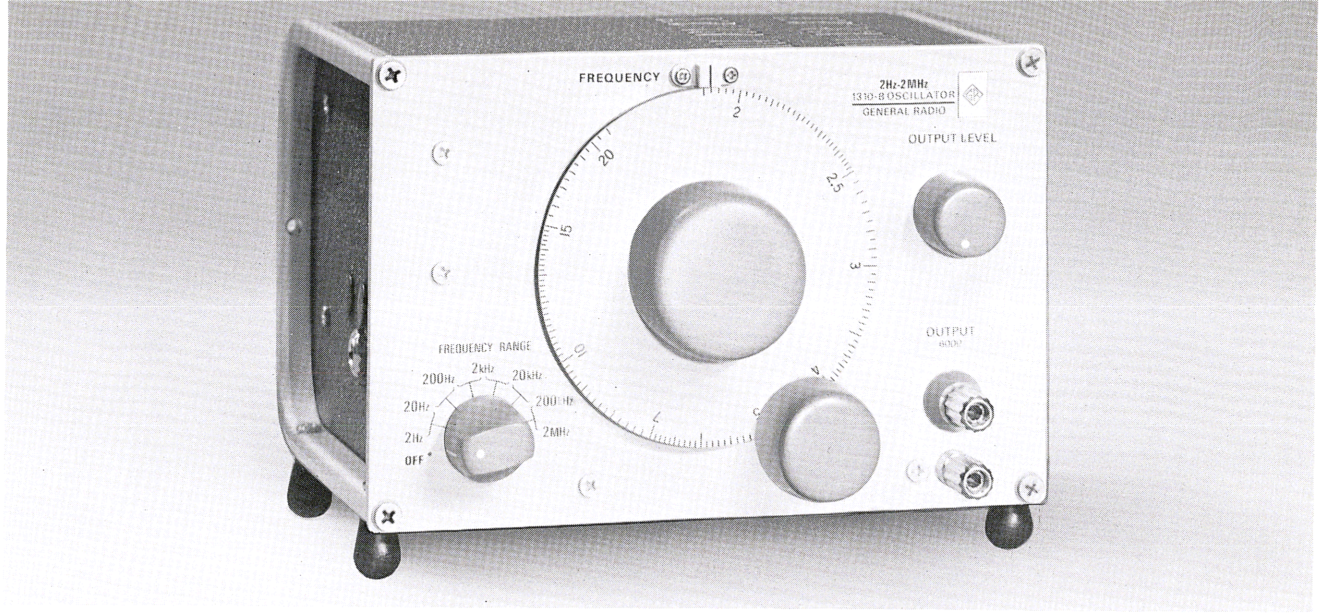
Available: ADAPTOR CABLE 1560-P95 (telephone plug to double plug), 0480-9838 SET to rackmount 1311-A alone, 0480-9880 SET to rackmount 1311-A side-by-side with same-size instrument such as 1310 Oscillator, 1396 Tone-Burst Generator, or 1232 Amplifier-Detector.

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

Mechanical: Convertible-bench cabinet. DIMENSIONS (wxhxd): 8x6x7.75 in. (204x153x197 mm). WEIGHT: 6 lb (2.8 kg) net, 9 lb (4.1 kg) shipping.

Description	Catalog Number
1311-A Audio Oscillator	
115-V Model	**1311-9701**
230-V Model	**1311-9702**
1560-P95 Adaptor Cable	**1560-9695**
480-P308 Rack-Adaptor Set	**0480-9838**
480 Rack-Adaptor Set	**0480-9880**

National Stock Numbers are listed on the back cover.



1310-B Oscillator

- **2 Hz to 2 MHz**
- **20-V, constant output, ±2%**
- **0.25% distortion**

The superior characteristics of this oscillator make it an exceptionally useful laboratory signal source.

Constant output over a very wide frequency range facilitates frequency-response measurements.

High-resolution dial and exceptional amplitude and frequency stability are important for measurements of filters and narrow-band devices.

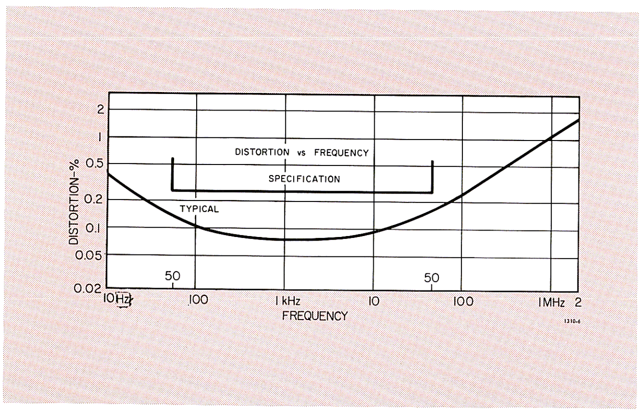
Equally useful in 600-ohm and 50-ohm circuits, since distortion is independent of load, even a short circuit.

When phase-locked to a frequency standard, the oscillator can deliver a high-level standard-frequency output with adjustable amplitude and low distortion.

Description A capacitance-tuned, RC Wien-bridge oscillator drives a low-distortion output amplifier, which isolates the oscillator from the load and delivers a constant voltage behind 600 ohms. All solid-state circuits ensure long, trouble-free life.

A jack is provided for introduction of a synchronizing signal for phase locking or to furnish a signal, independent of the output attenuator setting, to operate a counter, or to synchronize an oscilloscope or another oscillator.

Note: This product is manufactured also in Europe.



SPECIFICATIONS

Frequency Range: 2 Hz to 2 MHz in 6 decade ranges. Overlap between ranges, 5%.

Accuracy: ±3% of setting.

Stability (typical at 1 kHz): Warmup drift, 0.1%. After warmup: 0.003% short term (10 min), 0.03% long term (12 h).

Controls: Continuously adjustable main dial covers decade range in 305°, vernier in 4 turns.

Synchronization: Frequency can be locked to external signal. Lock range ±3% per volt rms input up to 10 V. Frequency dial functions as phase adjustment.

Output Voltage: 20 V open circuit, nominal.

Power: ≥160 mW into 600 Ω.

Output Impedance: 600 Ω. One terminal grounded.

Attenuation: Continuously adjustable attenuator with >46-dB range.

Distortion: <0.25%, 50 Hz to 50 kHz with any linear load. Oscillator will drive a short circuit without clipping.

Hum: <0.02%, independent of attenuator setting.

Amplitude vs Frequency: ±2%, 20 Hz to 200 kHz, into open circuit or 600-Ω load.

Synchronization: Constant-amplitude (0.8-V), high-impedance (27-kΩ) output to drive counter or oscilloscope.

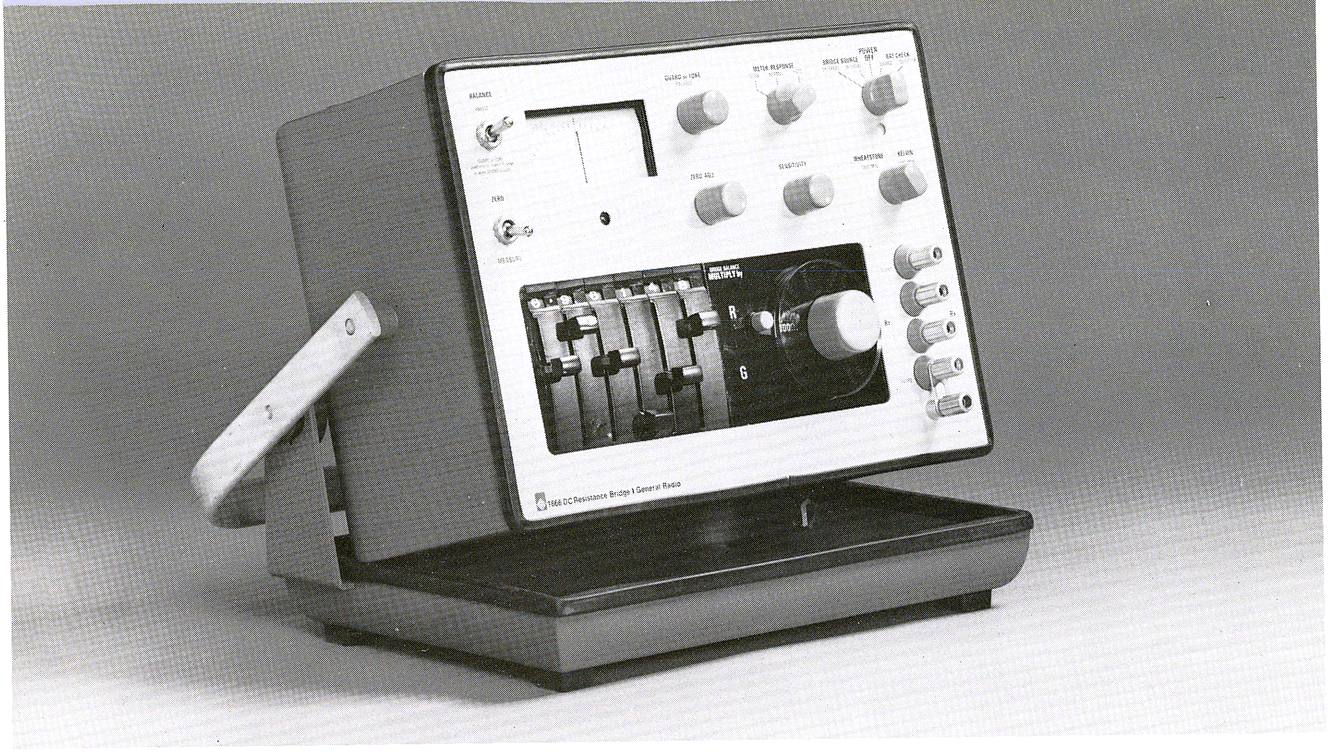
Terminals: Output, GR 938 Binding Posts; sync, side-panel telephone jack.

Available: ADAPTOR CABLE 1560-P95 (telephone plug to double plug); 0480-9838 SET to rackmount 1310 alone; 0480-9880 SET to rackmount 1310 side-by-side with same-size instrument such as the 1309 Oscillator, 1369 Tone-Burst Generator, or 1232 Amplifier-Detector.

Power: 105 to 125, 195 to 235, or 210 to 250 V, 50 to 400 Hz, 12 W.

Mechanical: Convertible-bench cabinet. DIMENSIONS (wxhxd): 8x6x8.13 in. (204x153x207 mm). WEIGHT: 7.75 lb (3.6 kg) net, 10 lb (4.6 kg) shipping.

Description	Catalog Number
1310-B Oscillator	
115-V Model	**1310-9702**
220-V Model	**1310-9703**
230-V Model	**1310-9704**
1560-P95 Adaptor Cable	**1560-9695**
480-P308 Rack-Adaptor Set	**0480-9838**
480 Rack-Adaptor Set	**0480-9880**



1666 DC Resistance Bridge

- **0.01% accuracy, direct reading**
- **six-digit resolution**
- **2-, 3-, or 4-terminal resistance or conductance**
- **1 μΩ to 1 TΩ range (1 p℧ to 1 M℧)**

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

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

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

SPECIFICATIONS

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

Ranges: TOTAL MEASUREMENT RANGE, 1 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 x (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 2 μΩ additional with ≤ 0.1Ω in any lead.

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

Available: 1440 Standard Resistors, for recalibration.

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

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

Description	Catalog Number
1666 DC Resistance Bridge, portable	**1666-9700**
Replacement Battery (8 req'd)	**8410-0200**

National Stock Numbers
for
Products in this Catalog

Catalog No.	National Stock Number
0510-9511	5930 00 499 1999
0510-9604	5930 00 499 2000
0510-9701	6625 00 553 8082
0510-9703	6625 00 993 1190
0510-9704	6625 00 864 6074
0510-9705	5905 00 561 4150
0510-9706	5905 00 561 4158
0510-9708	5905 00 561 4160
0900-9451	5985 00 004 0103
0900-9651	6625 00 498 0925
0900-9851	5985 00 456 0240
0900-9957	5985 00 472 3969
0900-9963	5985 00 472 3973
0940-9705	6625 00 462 7099
0940-9706	6625 00 455 8715
0940-9707	6625 00 455 8716
0940-9708	6625 00 486 7855
1232-9701	6625 00 873 6684
1311-9701	6625 00 930 3449
1403-9701	6625 00 730 8565
1403-9704	6625 00 804 7402
1403-9707	6625 00 804 7401
1403-9711	6625 00 804 9059
1404-9701	4931 00 916 5948

Catalog No.	National Stock Number
1409-9706	6625 00 629 1983
1409-9712	6625 00 585 4053
1409-9720	6625 00 585 4051
1409-9725	6625 00 629 1980
1412-9410	6625 00 465 6861
1419-9701	6625 00 953 7537
1419-9702	6625 00 124 9382
1419-9711	6625 00 585 1670
1422-9704	6625 00 987 9060
1422-9823	6625 00 881 8665
1422-9916	6625 00 891 5939
1423-9801	6625 00 775 1753
1433-9700	6625 00 892 4783
1433-9702	6625 00 437 9157
1433-9704	6625 00 148 8033
1433-9706	6625 00 235 6308
1433-9708	6625 00 098 3712
1433-9712	6625 00 495 0023
1433-9714	6625 00 466 0214
1433-9715	6625 00 463 4011
1433-9716	6625 00 229 9918
1433-9721	6625 00 038 4559
1433-9722	6625 00 947 7534
1433-9724	6625 00 031 3521

Catalog No.	National Stock Number
1433-9725	6625 00 106 7545
1433-9731	6625 00 440 0950
1434-9707	6625 00 004 8652
1434-9707	6625 00 067 9025
1434-9713	6625 00 229 6642
1434-9714	6625 00 935 1470
1434-9724	6625 00 204 0031
1440-9601	6625 00 133 7548
1440-9621	6625 00 421 1931
1440-9621	6625 00 169 5861
1440-9641	6625 00 855 4283
1440-9651	6625 00 169 5862
1450-9893	6625 00 612 1837
1455-9700	6625 00 123 7458
1455-9708	6625 00 420 3931
1482-9702	6625 00 583 0040
1482-9705	6625 00 567 2700
1482-9708	6625 00 583 0041
1482-9712	6625 00 556 8584
1482-9716	6625 00 583 0044
1482-9720	6625 00 583 0043
1491-9704	6625 00 251 1158
1615-9801	6625 00 470 8446
1615-9801	6625 00 005 7274
1620-9701	6625 00 076 6762

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