Resistance Standards and Decades

STANDARD RESISTORS

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

AC CONSIDERATIONS

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

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

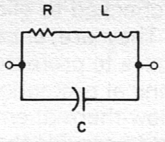


Figure 1.

It is necessary to differentiate clearly between the concepts of equivalent series and equivalent parallel circuits. The two-terminal circuit of Figure 1 can be described as an impedance $R_s + jX_s$ or as an admittance $G + jB = \frac{1}{R_p} + \frac{1}{jX_p}$, wherein the parameters are a function of frequency. This distinction between series and parallel components is more than a mathematical exercise — the use to which the resistor is 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:

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

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 inductive 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.

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

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

DECADE BOXES

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

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

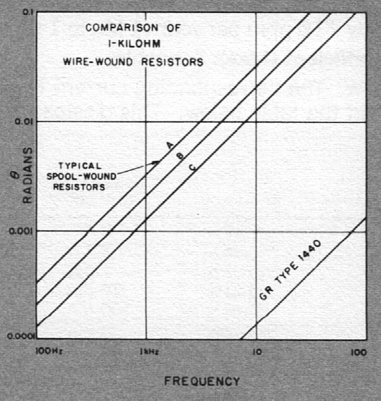
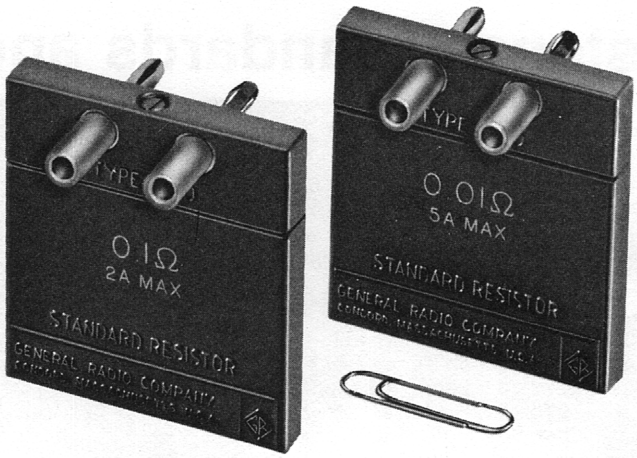


Figure 2.



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).

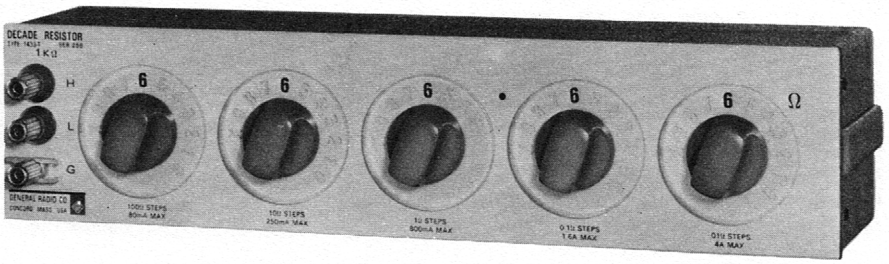
Net Weight (approx): 2 oz (57 g).

Resistance	Accuracy	Max Current	Inductance Typical	Approx Frequency for 0.1% Resistance Change		Temperature Coefficient	Catalog Number
				Series R	Parallel R		
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 at the back of the catalog.

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.

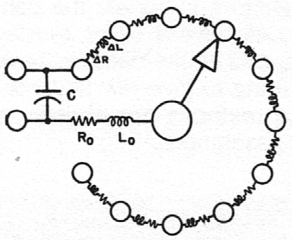
Typical Values of R_o, L_o, and C for the Decade Resistors:

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.

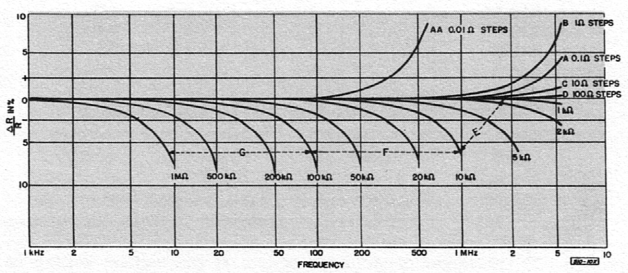
Zero Inductance (L_o): 0.1 μH per dial + 0.2 μH.

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.

National stock numbers are listed at the back of the catalog.

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.

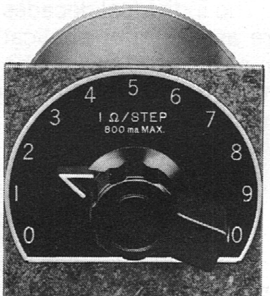
** Add approx 1 lb (0.5 kg) for rack-mount hardware.

Type	Total Ohms	Ohms per Step	No. of Dials	Type 510 Decades Used	Catalog Number	
					Bench	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 at the back of the catalog.

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.

National stock numbers are listed at the back of the catalog.

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.

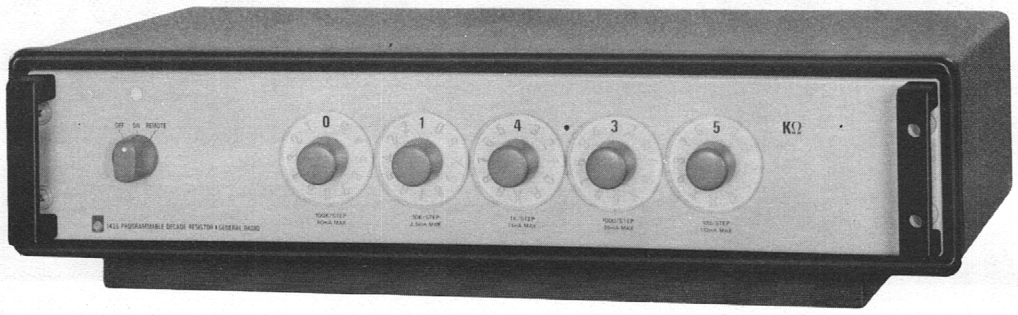
Terminals: Jack-top binding posts on standard ¾-in. spacing. A shield terminal is also provided. The 1434-G has lug connections accessible from the rear.

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)	17 5/16	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**



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.

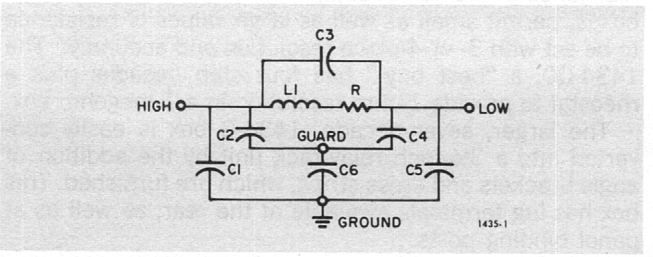
* Registered trademark of the Wilbur B. Driver Co.

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	Decade Resistance 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.).

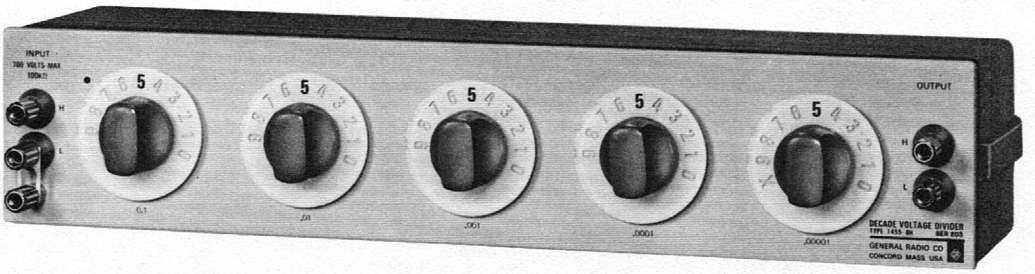
Supplied: Power cord and board-edge connector, for programming input.

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, 19x3.47x10.8 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**

National stock numbers are listed at the back of the catalog.



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.

National stock numbers are listed at the back of the catalog.

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**