TYPE 1432 DECADE RESISTOR

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TYPE 510 DECADE-RESISTANCE UNIT

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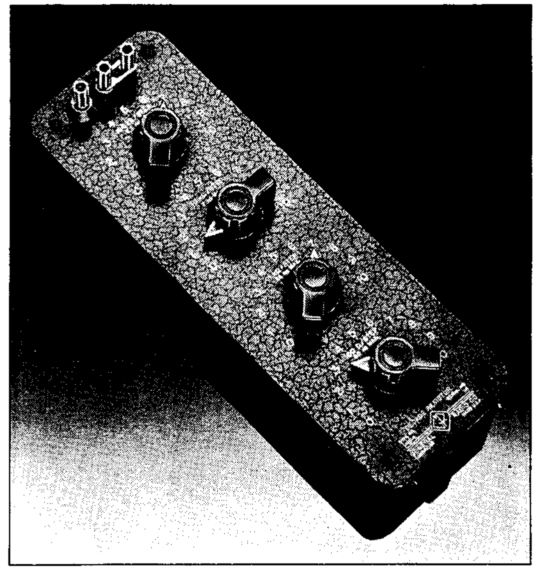


USES: Accurate decade resistors are extremely valuable wherever electrical measurements are made. They are constantly used in circuits where a wide range of resistance values is required or where variable dummy generator and load resistances are needed. The accuracy of TYPE 1432 Decade Resistors easily meets the requirements of these applications and also permits them to be used as laboratory standards and as ratio arms for direct- and alternating-current bridges.

Although designed primarily for direct-current and audio-frequency work, many of the models are useful well into the radio-frequency range.

DESCRIPTION: The TYPE 1432 Decade Resistor is an assembly of TYPE 510 Decade-Resistance Units in a single cabinet. Mechanical as well as electrical shielding of the units is provided by the rugged aluminum cabinet and panel, which completely enclose both the resistance units and switch contacts. The resistance elements have no electrical connection to the cabinet and panel, for which a separate shield terminal is provided.

Three-, four-, and five-dial decade assemblies are available. Each decade has eleven contact studs and ten resistance units, so that the dial values overlap. Positive detent mechanisms in conjunction with bar-type knobs permit the operator to sense the position of the switches without looking at the panel.

FEATURES: ➤ Low zero resistance — less than 0.003 ohm per decade.

➤ High accuracy — 0.05% for most decades.

➤ Low temperature coefficient of resistance.

➤ Negligible thermal emf to copper.

➤ Resistors are adjusted to specified values at their own terminals rather than at the box terminals, so that resistance *increments* are always correctly indicated.

➤ Residual impedances are small and are given in the specifications so that approximate frequency characteristics can be computed.

➤ Maximum current for each decade based on 40° C temperature rise is engraved on panel.

SPECIFICATIONS

Frequency Characteristics: Similar to those of individual TYPE 510 Decade Resistance Units, modified by the increased series inductance, L_0, and shunt capacitance, C, due to the wiring and the presence of more than one decade in the assembly. At total resistance settings of approximately 1000 ohms or less, the frequency characteristic of any of these decade resistors is substantially the same as those shown for the TYPE 510 Decade-Resistance Units in the plot on page 4. At higher settings, shunt capacitance becomes the controlling factor, and the effective value of this capacitance depends upon the settings of the individual decades. See *Residual Impedances* below.

Residual Impedances:

Zero Resistance (R_0)**:** 0.002 to 0.003 ohms per dial at dc; 0.04 ohms per dial at 1 Mc; proportional to square root of frequency at all frequencies above 100 kc.

Zero Inductance (L_0)**:** 0.10 μh per dial.

Effective Shunt Capacitance (C)**:** This value is determined largely by the highest decade in use. With the LOW terminal connected to shield, a value of 15 to 10 $\mu\mu$f 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 $\mu\mu$f. If the highest decade in the assembly is in use, the effective capacitance is 15 to 10 $\mu\mu$f, regardless of the settings of the lower-resistance decades.

Temperature Coefficient of Resistance: Less than ±0.002% per degree Centigrade at room temperatures, except for the 0.1 Ω decade, where the box wiring will increase the over-all temperature coefficient.

Type of Winding: See specifications for TYPE 510 Decade-Resistance Units, page 4.

Accuracy of Adjustment: All cards are adjusted within ±0.05% of the stated value between card terminals, except the 1-ohm cards, which are adjusted within ±0.15%, and the 0.1-ohm units which are adjusted within ±0.5%.

Maximum Current: See specifications for TYPE 510 Decade-Resistance Units, page 4. Values for 40° C rise are engraved on panels directly above switch knobs.

Terminals: Jack-top binding posts set on General Radio standard ¾-inch spacing. Shield terminal is provided.

Mounting: Aluminum panel and cabinet.

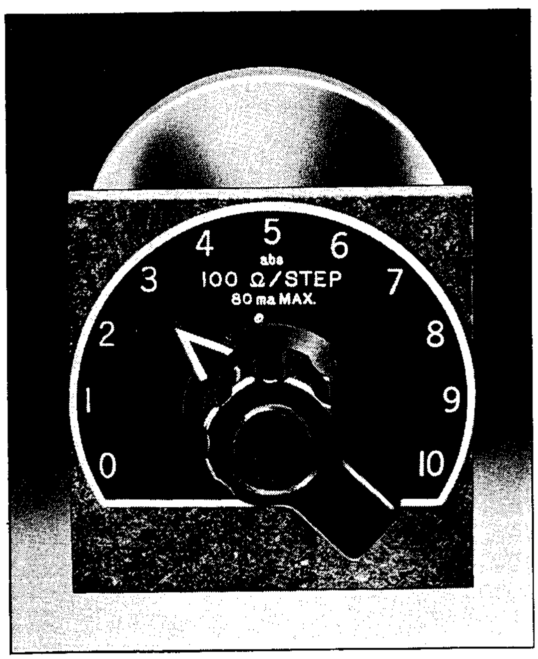
Dimensions: Width, $4\frac{5}{16}$ inches; height, $4\frac{11}{16}$ inches: length, $10\frac{5}{16}$ inches for 3-dial, 13 inches for 4-dial, and $15\frac{3}{4}$ inches for 5-dial box.

Net Weight: Type 1432 — A, C, F, 4 pounds, 2 ounces; Type 1432 — J, K, L, Q, 5 pounds, 4 ounces; Type 1432 — M, N, P, 6 pounds, 5 ounces.

Type	*Resistance*			*No. of Dials*	*Type 510 Decades Used*	*Code Word*
1432-F	**111 ohms, total, in steps of**	**0.1**	**ohm**	**3**	**A, B, C**	DELTA
1432-K	**1,111 ohms, total, in steps of**	**0.1**	**ohm**	**4**	**A, B, C, D**	DEFER
1432-C	**11,100 ohms, total, in steps of**	**10**	**ohms**	**3**	**C, D, E**	DEBAR
1432-J	**11,110 ohms, total, in steps of**	**1**	**ohm**	**4**	**B, C, D, E**	DEBIT
1432-N	**11,111 ohms, total, in steps of**	**0.1**	**ohm**	**5**	**A, B, C, D, E**	DEMON
1432-L	**111,100 ohms, total, in steps of**	**10**	**ohms**	**4**	**C, D, E, F**	DECAY
1432-M	**111,110 ohms, total, in steps of**	**1**	**ohm**	**5**	**B, C, D, E, F**	DEMIT
1432-A	**1,110,000 ohms, total, in steps of**	**1000**	**ohms**	**3**	**E, F, G**	DEMUR
1432-Q	**1,111,000 ohms, total, in steps of**	**100**	**ohms**	**4**	**D, E, F, G**	DEPOT
1432-P	**1,111,100 ohms, total, in steps of**	**10**	**ohms**	**5**	**C, D, E, F, G**	DETER

TYPE 510 DECADE-RESISTANCE UNIT

USES: Because of their accuracy, compactness, and sturdy construction the Type 510 Decade-Resistance Units are ideal for assembly into production test instruments, bridges, and other experimental and permanent equipment. They are particularly useful in applications where only one or two decades are needed, or where a Type 1432 Decade Resistor cannot be mounted conveniently. In many cases the use of these units will release for general laboratory work relatively more expensive decade resistors, that would otherwise be tied up for long periods of time in experimental equipment.



DESCRIPTION: Winding methods are chosen to reduce the effects of residual impedances. The 1-, 10-, and 100-ohm steps are Ayrton-Perry wound on molded phenolic forms especially shaped and heat treated to minimize aging effects. The 0.1-ohm steps are bifilar wound with ribbon, while the 1000-, 10,000-, and 100,000-ohm steps are wound on thin mica cards.

Each decade is enclosed in an aluminum shield, and a knob and etched-metal dial plate are supplied. The mechanical assembly is also available complete with shield, blank dial plate, switch stops, and knob, but without resistors, as the Type 510-P3 Switch.

FEATURES: ➤ High accuracy — ±0.05% for most units.

➤ Excellent stability — newly developed stable resistance alloys, with final resistance adjustment after artificial aging at high temperatures.

➤ Good frequency characteristics — most Type 510 Decades can be used at frequencies as high as several hundred kilocycles, as well as at dc.

➤ Low temperature coefficient.

➤ Negligible thermal emf to copper.

➤ Unaffected by high humidity — even the high resistance units can be exposed to high humidity for long periods of time without significant change in resistance.

SPECIFICATIONS

Accuracy of Adjustment: Resistors are adjusted to be accurate at card terminals within the tolerances given in Table I.

Maximum Current: See Table I below.

Frequency Characteristics: The equivalent circuit of a decade resistance unit is shown on page 6. The values of the residual impedances are listed in Table I.

The accompanying plot shows the maximum percentage change in effective series resistance of all seven decades as a function of frequency. For TYPES 510-A and 510-B the error is due almost entirely to skin effect and is independent of switch setting. For TYPE 510-C the error changes slowly with dial setting and is a maximum at maximum resistance setting, while for TYPE 510-D a broad maximum occurs at the 600-ohm setting. For all the higher resistance units, the error is due almost entirely to the shunt capacitance and its losses and is approximately proportional to the square of the resistance setting.

The high-resistance decades (TYPES 510-E, 510-F, and 510-G) 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 amount indicated in the plot as the series-resistance change, depending on frequency and the insulating material in the switch.

Switches: Quadruple-leaf, phosphor-bronze brushes bear on lubricated bronze contact studs 3/8 inch in diameter. These brushes are bent so as not to be tangent to the arc of travel, thus avoiding cutting and affording a good wiping action. A cam-type detent is provided. There are eleven contact points (0 to 10 inclusive). The switch resistance is between 0.002 and 0.003 ohm. The effective capacitance of the switch is of the order of 5 $\mu\mu f$, with a dissipation factor of 0.06 at 1 kc for the standard cellulose-filled molded phenolic switch form, and 0.01 for the mica-filled phenolic form used in the TYPE 510-G Unit.

Temperature Coefficient of Resistance: Less than ±0.002% per degree Centigrade at room temperature.

Terminals: Soldering lugs are provided.

Mounting: Each decade is complete with dial plate and knob and can be mounted on any panel between 1/4 inch and 3/8 inch in thickness. A template is furnished with each unit.

Dimensions: Over-all diameter, 3 1/16 inches; depth behind panel, 3 1/16 inches; template and dimension sketch mailed on request.

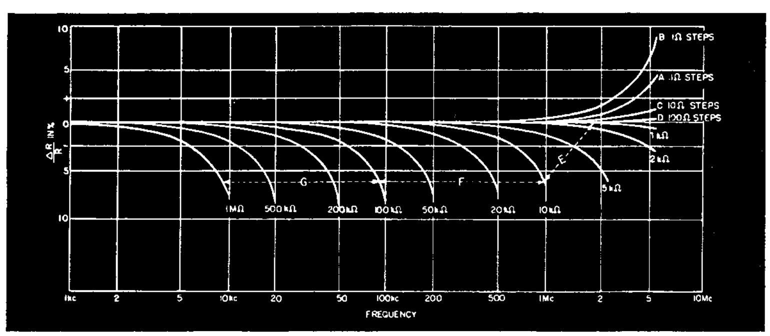
Net Weight: TYPE 510 Units, 11 ounces; TYPE 510-P3, 9 1/2 ounces.

TABLE I

Type	*Resistance per Step (ΔR) Ohms*	*Accuracy*	*Maximum Current 40° C Rise*	*Power per Step watts*	*ΔL μh*	*C* μμf*	*L_0 μh*
510-A	0.1	±0.5%	1.6 a	.25	0.014	7.7-4.5	0.023
510-B	1	±0.15%	800 ma	.6	0.056	7.7-4.5	0.023
510-C	10	±0.05%	250 ma	.6	0.11	7.7-4.5	0.023
510-D	100	±0.05%	80 ma	.6	0.29	7.7-4.5	0.023
510-E	1,000	±0.05%	23 ma	.5	3.3	7.7-4.5	0.023
510-F	10,000	±0.05%	7 ma	.5	9.5	7.7-4.5	0.023
510-G	100,000	±0.05%	2.3 ma	.5	—	7.7-4.5	0.023

*The larger capacitance occurs at the lowest 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 10 to 20 $\mu\mu f$ greater than indicated here, depending on whether the shield is tied to the switch or to the zero end of the decade.

Type	*Resistance* Total	*Resistance* Per Step	*Code Word*
510-A	**1 ohm**	**0.1 ohm**	ELATE
510-B	**10 ohms**	**1 ohm**	ELDER
510-C	**100 ohms**	**10 ohms**	ELEGY
510-D	**1,000 ohms**	**100 ohms**	ELBOW
510-E	**10,000 ohms**	**1,000 ohms**	ELECT
510-F	**100,000 ohms**	**10,000 ohms**	ELVAN
510-G	**1,000,000 ohms**	**100,000 ohms**	ENTER
510-R	**100,000 ohms**	**Decade Steps, i.e., 0.1, 1, 10, 100, 1,000, 10,000, 100,000 ohms**	EAGER
510-P3 Switch only (Black Phenolic Frame)			ENVOY
510-P3L Switch only (Low-Loss Phenolic Frame)			ESTOP



Maximum percentage change in resistance as a function of frequency for TYPE 510 Decade-Resistance Units.

RESISTORS

Resistors designed for use at electrical communication frequencies differ from those intended for use only at direct current in that low reactance and constancy of resistance as the frequency is varied are of considerably more importance than extreme accuracy of adjustment. Inevitably, resistors have capacitance and inductance associated with them, and these residual impedances become increasingly important as the frequency is raised, acting to change the terminal resistance from its low-frequency value.

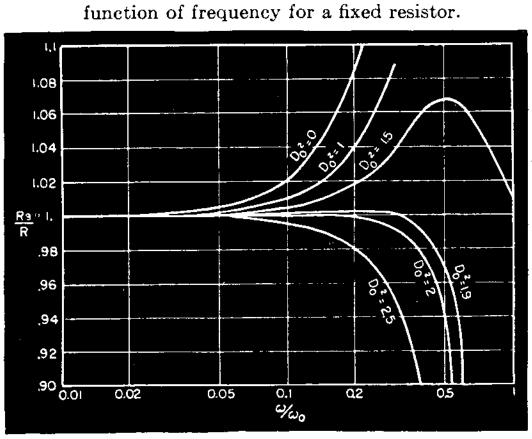
For frequencies where the resistance and its associated residual impedances behave as lumped parameters, the equivalent circuit of a resistor can be represented as shown in Figure 1. The inductance L is the equivalent inductance in series with the resistance, while the capacitance C is the equivalent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

To analyze the behavior of the equivalent circuit as frequency is varied, 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, $G + jB\left(=\frac{1}{R_p} + \frac{1}{jX_p}\right)$, wherein the parameters are a function of frequency. This distinction between series and parallel components is more than a mathematical exercise — the use to which the resistor is put will frequently determine which component is of principal interest.

The expressions for the effective series resistance (R_s) and the effective series reactance (X_s) of Figure 1 are:

$$R_s = \frac{R}{\left[1 - \left(\frac{\omega}{\omega_0}\right)^2\right]^2 + (R\omega C)^2} \qquad (1)$$

Figure 2. General normalized curves of resistance as a function of frequency for a fixed resistor.



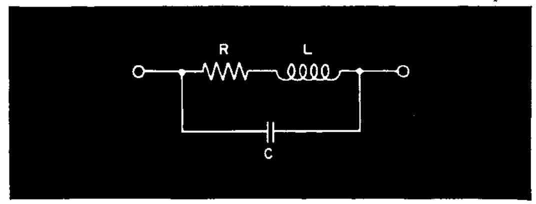


Figure 1. Equivalent circuit of a resistor showing the residual impedances associated with the resistance.

$$X_s = \frac{\omega\left\{L\left[1 - \left(\frac{\omega}{\omega_0}\right)^2\right] - R^2C\right\}}{\left[1 - \left(\frac{\omega}{\omega_0}\right)^2\right]^2 + (R\omega C)^2} \qquad (2)$$

where

$$\omega_0 = \frac{1}{\sqrt{LC}} \quad \text{and} \quad \left(\frac{\omega}{\omega_0}\right)^2 = \omega^2 LC \qquad (3)$$

The effective parallel components are given by:

$$G = \frac{1}{R_p} = \frac{1}{R\left[1 + \omega^2\left(\frac{L}{R}\right)^2\right]} \qquad (4)$$

$$B = -\frac{1}{X_p} = \omega C - \frac{1}{\omega L\left[1 + \frac{1}{\omega^2}\left(\frac{R}{L}\right)^2\right]} \qquad (5)$$

At frequencies sufficiently low so that the terms in ω^2 may be neglected, the network behaves like a resistance, R, in series with an inductance, $L - R^2C$, or in parallel with a capacitance, $C - \frac{L}{R^2}$. It is apparent that for high values of resistance the *capacitance* dominates, while for low values of resistance *inductance* is the controlling effect.

At higher frequencies the behavior can best be demonstrated by normalizing the expressions and plotting against $\frac{\omega}{\omega_0}$ with the dissipation factor at resonance, $D_0 = \frac{R}{\sqrt{L/C}}$, as a parameter. This is done for R_s and X_s in Figures 2 and 3.

For values of D_0^2 less than 2, the resistance increases with frequency to a maximum and then decreases to zero. For values of D_0^2 of 2 or greater, the resistance never rises above unity. The same sort of behavior occurs for reactance, except that the value of D_0^2 is 1 for the monotonic condition.

Dielectric losses in the lumped portion of the shunt capacitance C of Figure 1 are equivalent to a resistance

$$R_0 = \frac{1}{D\omega C} \qquad (6)$$

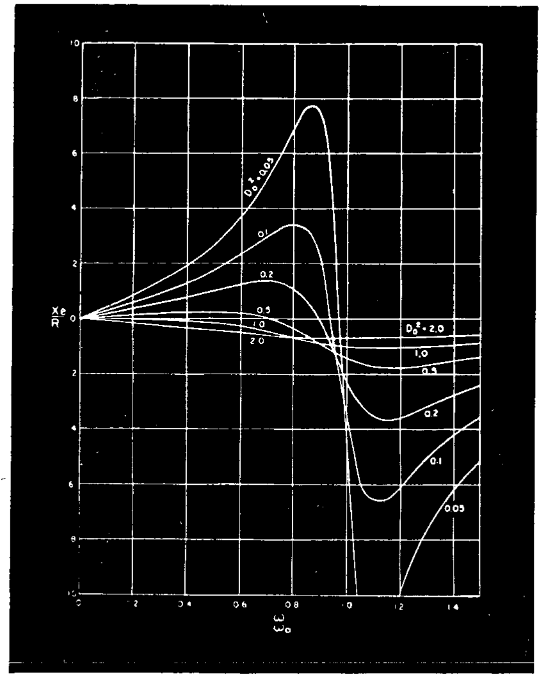


FIGURE 3. General normalized curves of reactance as a function of frequency for a fixed resistor.

which decreases with increasing frequency and causes even the parallel resistance to decrease rapidly beyond a certain frequency. That portion of the shunt capacitance C which is distributed causes a similar rapid decrease in resistance, even if its dielectric loss is negligible. These effects together are called the Boella effect. Its outstanding characteristic is that, when the ratio of a-c to d-c resistance (normalized parallel resistance) is plotted against the product fR of frequency and d-c resistance, all points for any one type of resistor fall approximately on the same curve, regardless of the resistance value. The decrease in resistance will amount to 1% for wire-wound resistors and the poorer composition-type resistors when the product fR is 0.01 (Mc, MΩ) and for the best composition-type resistor when fR is 10 (Mc, MΩ).

For any given resistance value there will be a combination of residual parameters that will give best performance over the widest frequency range. Proper proportioning of the residual parameters determined by the mechanical construction will lead to the best compromise design for a line of fixed resistors. An example of this kind of design is the TYPE 663 Resistor, in which a fine, straight wire is used as the resistive element in order to reduce skin effect. The inductance is held at a low value by clamping the wire to flat metal fins, which also aid in power dissipation. This produces a comparatively large shunt capacitance, and the element is so proportioned that $\sqrt{L/C}$ is of the same order of magnitude as the resistance, a condition which minimizes the changes of both inductance and capacitance with frequency. Resistors of this type exhibit only 1% change in resistance at frequencies as high as 30 megacycles.

Wire-wound resistors of the card type exhibit a negligible frequency error in resistance up to about 500 kc, for values of resistance up to 500 ohms, and only moderate errors at one megacycle.

When assembled into decades, these resistors have added to their own residual impedances those of the switches, wiring, and cabinet. The equivalent circuit is then that of Figure 4, which represents a single decade of the 510 type. For assemblies of such decades in the TYPE 1432 Decade Resistor the same circuit is still valid. The incremental inductances of the several decades in the circuit are additive, but the capacitance is approximately that of highest decade in use. Typical values of the residual impedances for the various types of General Radio resistors are given in the specifications for each type.

It should be noted that the effect of the residual reactance depends greatly upon the way the resistor is connected into a circuit. Reactances can often be tuned out, particularly in parallel circuits. This is a particularly important consideration with the higher valued resistors of 10,000 ohms and above. When the resistor is used as a parallel circuit element, the upper limit of frequency for a given error is some 10 times higher than for the series connection.

All General Radio precision resistors of 100 ohms and above are wound with wire of a newly developed alloy which has many desirable characteristics. Chief among these are a low and positive temperature coefficient of resistance, substantially constant over a wide range of operating temperature, and a negligible thermal emf to copper. Moisture has no appreciable effect on its resistance, and there is little, if any, drift in resistance as a result of strains put in the wire when it is wound on a card. Its greater tensile strength is an advantage in winding, making it possible to produce better and more uniform resistors than can be made with other alloys.

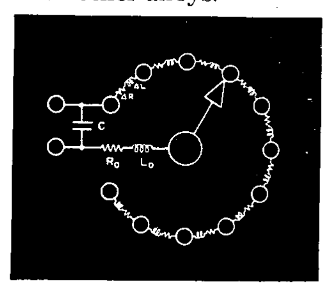


FIGURE 4. Equivalent circuit of a resistance decade, showing location and nature of residual impedances.