# TYPE 1432 DECADE RESISTOR

# TYPE 510 DECADE-RESISTANCE UNIT

Form 843-B
November, 1956

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# RESISTORS

Because of accuracy of adjustment, long-time 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. In the resistance range from a fraction of an ohm to about one megohm such resistors have been developed to a high state of refinement through improvements in resistive alloys and in design and manufacturing techniques. The wire-wound resistors in the form of fixed elements, individual decades, and decade assemblies ("decade boxes") described on the following pages are designed for a-c use as well as for d-c.

Resistors designed for a-c use differ from those intended for use only at direct current in that low series reactance and constancy of resistance as frequency is varied are important design objectives. Inevitably, resistors have capacitance and inductance associated with them, and these residual reactances 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. 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:

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

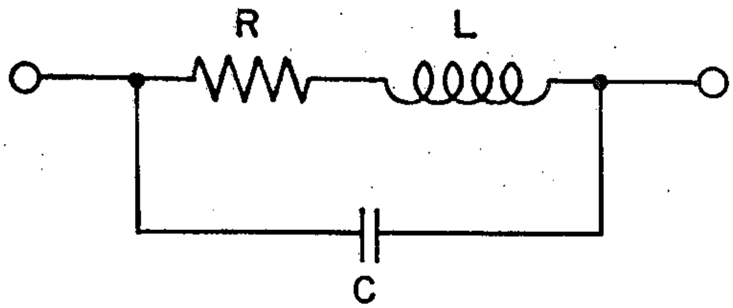



**Figure 1.** Equivalent circuit of a resistor showing the residual impedances associated with the resistance.

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

where

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

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 that terms involving the square of frequency are negligible, the resistor may be represented by a two-element network consisting of the d-c resistance, $R$, in series with an inductance equal to $L - R^2C$ or in parallel with a capacitance equal to $C - \frac{L}{R^2}$. 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 of resistance the series inductance invariably predominates. It is, in fact, a common fallacy to speak of "non-inductive" resistors in resistance values where shunt capacitance controls, and variations in inductance of the winding can have no significant effect on the reactive component.

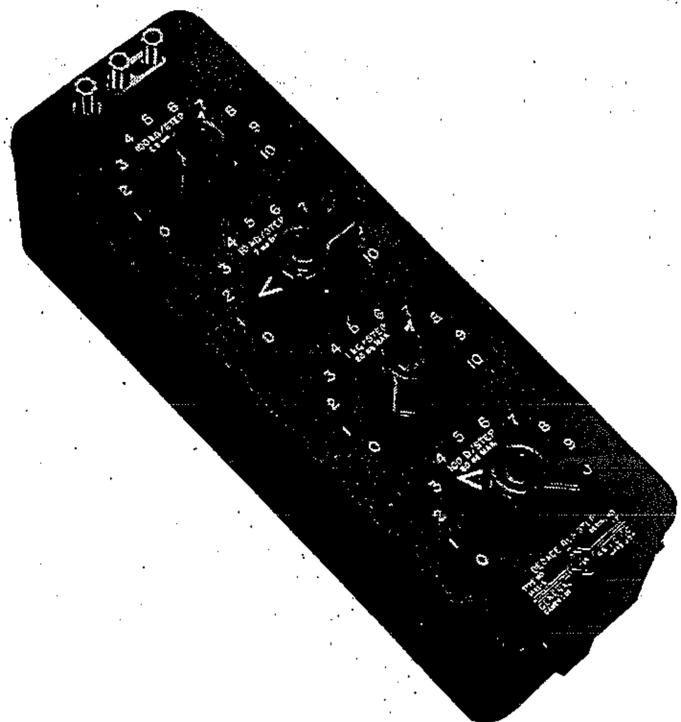
In the simplified circuit described above, the effective parallel resistance of a resistor in which shunt capacitance dominates would be independent of frequency. Actually, other effects may cause the parallel resistance to decrease with frequency. For example, dielec-

# TYPE 1432 DECADE RESISTOR

**USES:** Accurate decade resistors are necessary wherever electrical measurements are made. They are used in circuits where a wide range 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.

General Radio decade resistors are the standard of the industry. They have been manufactured continuously since 1915 and have been constantly improved in accuracy, stability, and appearance through the use of the finest available materials and manufacturing techniques.



**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 provided by the attractive 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 reactances are small and are given in the specifications so that approximate frequency characteristics can be computed.

## 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 171. 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, and Figure 3, page 168.

**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 $\mu$h 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 171.

**Accuracy of Adjustment:** All cards are adjusted at dc within ±0.05% of the stated value at their terminals, except the 1-ohm units, 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 171. 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.

...change in effective series resistance of 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 ⅜ 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 23° C.

**Terminals:** Soldering lugs are provided.

**Mounting:** Each decade is complete with dial plate and knob and can be mounted on any panel between ¼ inch and ⅜ inch in thickness. A template is furnished with each unit.

**Dimensions:** Over-all diameter, 3$\frac{1}{16}$ inches; depth behind panel, 3$\frac{3}{16}$ inches; template and dimension sketch mailed on request.

**Net Weight:** TYPE 510 Units, 11 ounces; TYPE 510-P3, 9½ ounces.

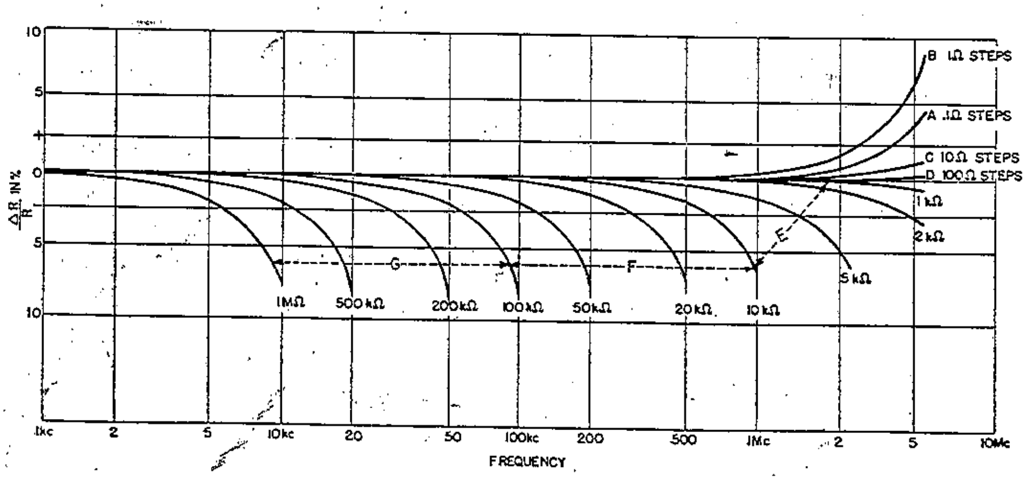
TABLE I

| *Type* | *Resistance per Step (ΔR) Ohms* | *Accuracy* | *Maximum Current 40° C Rise* | *Power per Step watts* | *ΔL μh* | *C* μμf* | *$L_0$ μh* |
|---|---|---|---|---|---|---|---|
| 510-AA | 0.01 | ±2% | 4 a | .16 | 0.01 | 7.7-4.5 | 0.023 |
| 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 |

* 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-AA** | **0.1 ohm** | **0.01 ohm** | EASEL |
| **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 series resistance as a function of frequency for TYPE 510 Decade-Resistance Units.



**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 reactances. The 1- and 10-ohm steps are Ayrton-Perry wound on molded phenolic forms especially shaped and heat treated to minimize aging effects. The 100-ohm steps are Ayrton-Perry wound on a form of silicone-fiberglas laminate. The 0.01- and 0.1-ohm steps are hairpin-shaped ribbon, while the 1000-, 10,000-, and 100,000-ohm steps are unifilar 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 and -P3L Switches.

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

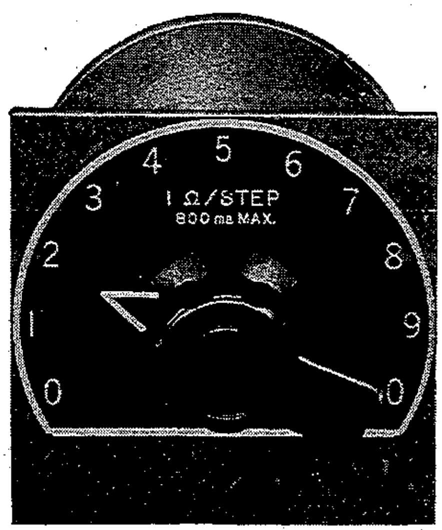
➤ Excellent stability — newly developed stable resistance alloys, with final resistance adjustment after artificial aging at high temperatures above normal operating temperatures.

➤ 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 permanent 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. Maximum current is engraved on the dial plate supplied with each decade.

**Frequency Characteristics:** The equivalent circuit decade resistance unit is shown on page 168. The of the residual impedances are listed in Table I.

The accompanying plot shows the maxim

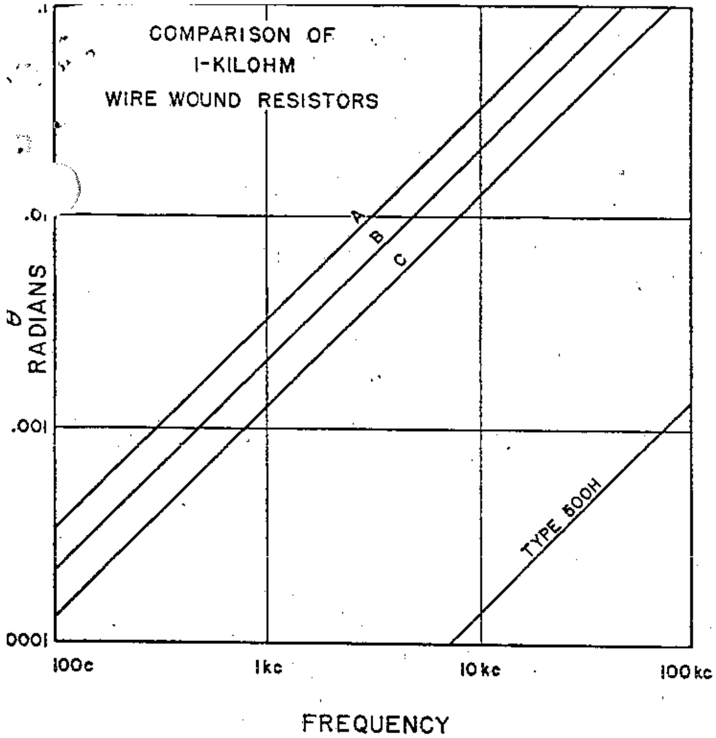



**FIGURE 2. Phase angle as a function of frequency for a General Radio mica-card resistor and for three commercial wire-wound types.**

tric losses in the shunt capacitance, $C$, of Figure 1 are equivalent to a resistance

$$R_o = \frac{1}{D\omega C}$$

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.

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 100 ohms utilize a so-called Ayrton-Perry winding, in which each resistor consists of two parallel windings of opposed direction, so that the current flow in the two windings is in opposite directions. The external magnetic field, as a result, is effectively canceled so that, typically, the residual inductance of such a winding is of the order of 1% of the inductance of a corresponding single winding.

Elements having 200 ohms resistance or higher are unifilar-wound on their flat rectangular "cards". The inherent phase angle of these resistors is substantially lower than that obtained with so-called "non-inductive" spool-wound resistors commonly used commercially.

Wire-wound resistors of these types 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 3, 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.

Probably the best known resistance alloy is manganin, used for over half a century in the manufacture of precision resistors. This old established alloy is still the most suitable for low values of resistance. For higher values, where small-diameter wire is required, more modern, proprietary alloys have been demonstrated to be superior. Such alloys are characterized by low, positive temperature coefficients, substantially constant over a wide range of temperature. They have, in addition, negligible thermal emf against copper, high tensile strength, relative immunity to the effects of humidity and atmosphere, and are relatively insensitive to strain. These newer alloys are used in all GR precision resistors of 40 ohms and above.

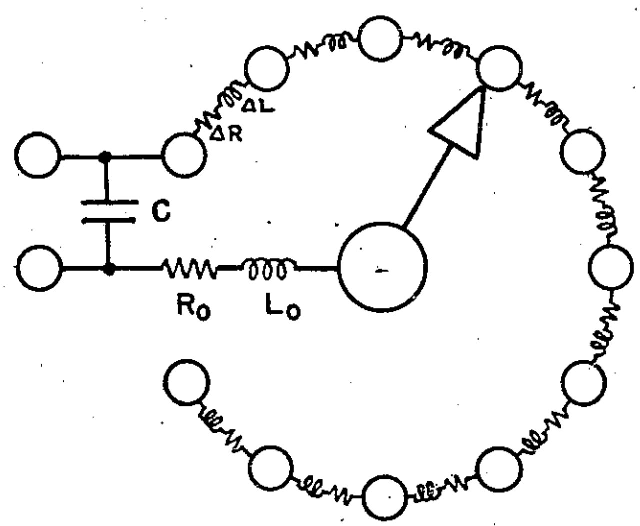



**FIGURE 3. Equivalent circuit of a resistance decade, showing location and nature of residual impedances.**