



Note the series resistance,  $R_s$ , is not affected if this capacitance is lumped. This is usually a small effect but can be important for physically-large, high-valued resistors.

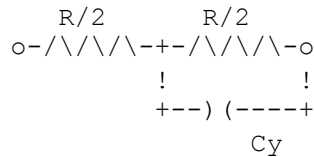
**Dielectric Loss in the Capacitance to Guard**

If the capacitance to guard has losses, it effectively causes an increase in both  $R_p$  and  $R_s$ . If we let  $D_g$  be the dissipation factor of the stray capacitance  $C_g$ , we get a conductance  $G_g = \omega D_g C_g$  from the middle of the resistor to guard (if we assume that simple model). This causes an increase in both  $R_p$  and  $R_s$ .

$$R_{ac} \cong R[1 + \omega D_g R C_g / 8] \tag{9}$$

**Distributed Capacitance Along Resistor**

Resistors also have distributed capacitance between all points along its body to all other points. Modeling this can be difficult, but the first-order effect will be that of a single capacitance,  $C_y$ , shunting part of the resistor as shown. The value of  $C_y$  is hard to determine.



$$R_p \cong R / (1 + (\omega R C_y)^2 / 16) \tag{10}$$

$$Q \cong - \omega R C_y / 4 \tag{11}$$

This is the classic cause of the decrease of  $R_p$  with frequency of high-valued resistors. This affects  $R_s$  as well but that would be more affected by the lumped shunt capacitance.

If there is loss in this distributed capacitance it would reduce  $R_p$  slightly. Note also that, if equal capacitances are in series shunting equal parts of the resistance, then these capacitances are equivalent to a very small lumped capacitance across the whole resistance.

The effect of distributed capacitance is particularly important in shielded resistors when the shield is tied to one end of the resistor as in the case of the coaxial GR 1442 resistors when one end is shorted to make the resistor two-terminal.

These distributed capacitances can be internal to the resistor. High-valued, carbon-composition resistors are subject to the "Boella Effect", the error caused by internal capacitances between the granules of carbon.

**Eddy Current Loss**

If a wire-wound resistor is wound on a conducting form or if a conducting material is nearby, eddy currents will cause power loss that can be represented by resistance shunting the series inductance. This might be the case in some power resistors with metal heat sinks. An extreme case is the resistance of iron-cored coils or transformers which varies widely with frequency due to eddy-current and hysteresis losses.

"Skin Effect" is due to eddy currents in the resistor itself. It causes an increase in resistance and inductance in thick, low-resistance conductors at high frequencies. It is usually negligible compared to other errors except in resistors made of thick, low-resistance wire.

**Combining Errors**

The errors for each effect was considered separately in the above discussion. Generally speaking, these effects may simply be added. An expression for an equivalent circuit that represents all sources of error would have many more, second-order error terms that would be negligible compared to the largest terms.