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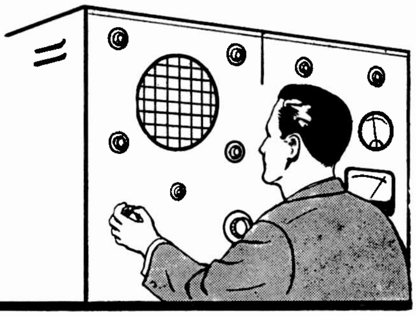

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Inductive and Reactive Effects In Straight Wires

By the Engineering Department, Aerovox Corporation

THE inductance of a short, straight wire is so low as to be inconsequential at low frequencies. This is especially true when the wire is relatively large in diameter or, more correctly, when its ratio of length to diameter of the cross sections is small. The effect of this inductance becomes increasingly important, however, as electronic practice moves into ever higher frequency applications. As an example, consider a straight 1 inch length of No. 20 copper wire. Suppose this lead has an inductance of 0.021 microhenry. At 100 kc, its inductive reactance, X_L, is only 0.013 ohm and is therefore negligible. But at 10 Gc (10 kMc), on the other hand, this same length of wire has an inductive reactance of 1319 ohms, neglecting skin effect and standing wave phenomena. Thus, at higher frequencies the very small inductance of the short pigtail leads of capacitors, resistors, diodes, transistors, and other components must be taken into account.

Calculation of Straight-Wire Self-Inductance

The standard equations for the self-inductance of straight wires are given by **Circular C74** of the National Bureau of Standards and assume that there is no iron in the vicinity of the conductor or circuit of which the inductance is to be calculated. A more complete collection of inductance formulae with numerical examples may be found in the **Bulletin of the National Bureau of Standards,** 8, pages 1-237; 1912; also known as **Scientific Paper No. 169.**

The equation for the self-inductance of a straight, round wire may be re-written in terms of inches and the common logarithm (rather than centimeters and the natural loga-

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rithm called for in the Bureau of Standards formula):

(1) $L_0 =$

$$0.00508\ell\left[2.303\log_{10}\frac{4\ell}{d}-1+\frac{\mu}{4}\right]$$

microhenry

Where d is the diameter of the cross section (inches) and ℓ the length of the wire (inches). L_0, the self-inductance at low frequencies, is in microhenry (μH. The term μ is the permeability of the wire metal (for copper, $\mu = 1$). Some diodes employ ferrous pigtails, and μ must then be taken into consideration when computing the inductance of such leads. In those instances, however, where copper leads are attached to components, the self-inductance equation may be simplified as follows:

(2) $L_0 =$

$$0.00508\ell\left[2.303\log_{10}\frac{4\ell}{d}-0.75\right]$$

microhenry

Illustrative Example: Calculate the inductance of a straight 2-inch length of No. 20 copper wire:

Here, $\ell = 2''$, and $d = 0.032''$ (from wire tables).

Substituting in Equation (2)

$L_0 =$

$$0.00508(2)\left[2.303\log_{10}\frac{4\ (2)}{0.032}-0.75\right]=$$

$$0.0102\left[2.303\log_{10}\frac{8}{0.032}-0.75\right]=$$

$$0.0102\left[(2.303\log_{10}250)-0.75\right]=$$

$$0.0102\left[2.303\ (2.3979)\ -0.75\right]=$$

$$0.0102\ [\ 5.522 - 0.75\ ] =$$

$$0.0102\ [\ 4.772\ ] = 0.0487\ \mu H$$

The inductance tends to decrease with increasing frequency, and approaches an infinite-frequency value equal to

$$0.00508\ell\left[2.303\log_{10}\frac{4\ell}{d}-1\right]$$

which is the limiting value. With this in mind, a general equation for straight-wire self-inductance at any frequency may be written:

(3) $L =$

$$0.00508\ell\left[2.303\log_{10}\frac{4\ell}{d}-1+\mu\delta\right]$$

microhenry

Where μ = permeability of the wire metal, and is 1 for all materials except iron wires

δ = skin-effect factor, and is a function of x.

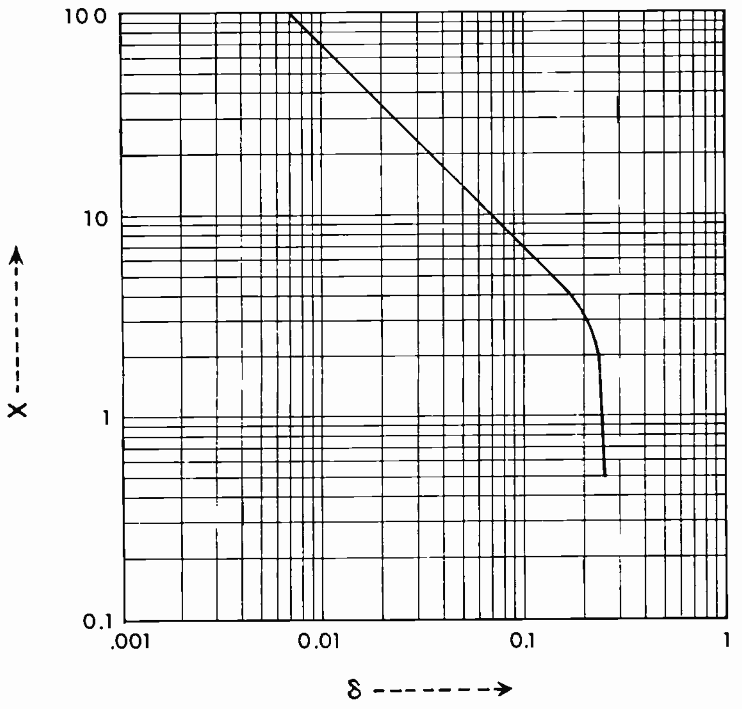
where $x = 0.3569\ d\ \sqrt{(\mu f)\ /\rho}$,

for d = diameter of cross section in inches

f = frequency in cycles per second

ρ = volume resistivity of the wire in μohm-cm (ρ_c = 1.724 for annealed copper and 1.771 for hard-drawn copper).

To determine the value of δ for use in Equation (3), first calculate x, then use this calculated value to find δ by use of the curve in Figure 1. The 20°C value of x_c for copper wire is equal to $0.272\ d\sqrt{f}$.



GRAPH OF δ VS X

FIG. 1

Equations (1), (2), and (3) are also based on the assumption that the length (ℓ) of the wire greatly exceeds the diameter (d). But if ℓ is less than 500 times d, the term

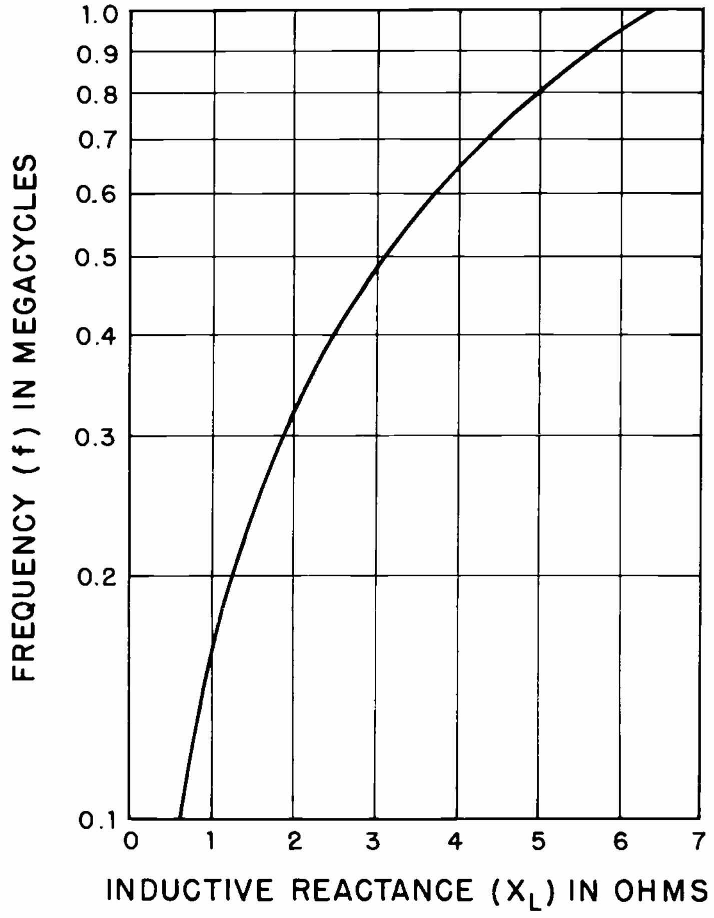
$$\left[\frac{d}{2\ell}\right]$$

must be added arithmetically to the expression inside the brackets of each equation.

The above relationships give merely the value of the self-inductance of one conductor. In many problems the self-inductance of the return conductor and, if the latter is reasonably close by, the mutual inductance of the two conductors must also be considered.

Calculation of Lead Reactance

The inductive reactance, X_L, of a straight, round wire may be determined by multiplying Equation (1), (2), or (3) by 6.28f; if f is in megacycles, the reactance will be in ohms. At relatively low frequencies, X_L will be the dominant component of the impedance, ($Z = R+jX_L$), of a straight wire, since its ohmic resistance, R, is negligible. At very high frequencies, however, the effective resistance, R, increases to a significant level due to a combination of in-phase components such as skin effect. These components are difficult to determine and to account for completely in a theoretical analysis; therefore, a measurement of the impedance of the wire at the high frequency is recommended when a true value of Z is required.



UNIVERSAL REACTANCE CURVE

FIG. 2

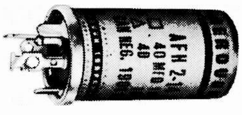
For time saving in the determination of reactance, a universal reactance curve is given in Figure 2. This curve has been plotted for an inductance of 1 μh and for frequencies from 0.1 to 1.0 Mc. For use at other frequencies and inductances, follow this procedure: (1) Let L_0 = 1 μh, L_X = the calculated inductance of the wire sample, f_0 = a frequency on the ordinate scale of Figure 2, and f_X = frequency of interest. (2) When L_X is higher or lower than L_0, and f_X is higher or lower than f_0, shift the decimal point in f_0 (in Figure 2) to the right or left as required to give f_X, locate the nominal reactance (X_L) on the curve, and multiply this X_L value by $(L_X f_X)/f_0$.

The practical significance of inductance and reactance in straight wires is evident. And while it is a good rule of thumb simply to keep all component leads and circuit wiring as straight and as short as practicable, the designer and technician should also be well aware of the magnitude of reactive components and the side effects they produce in a very-high-frequency circuit. In this way, the frequencies at which capacitors of low internal inductance show self-resonance effects can be known, as well as the high-frequency series impedance of the pigtails of diodes, varactors, transistors, thermistors, and similar components, and the circuitry may be compensated accordingly.

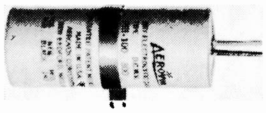
PRODUCT NEWS FROM AEROVOX

AEROVOX ELECTROLYTIC CAPACITORS PROVIDE TOP QUALITY IN EVERY EXACT REPLACEMENT TYPE YOU NEED

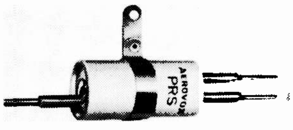
Continuous research and product development by Aerovox engineers, coupled with advanced manufacturing techniques, has produced the most dependable and complete line of 'lytics in the electronics industry. Some of the most widely used types are featured here.



AFH twist-prong 'lytics feature 85°C operation, improved sealing, high-purity aluminum foil construction throughout, ruggedized prongs and mounting terminals. Tops for filter audio bypass in TV-radio and amplifiers.



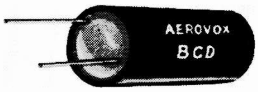
PR wax-filled tubulars manufactured to same high standards as more expensive metal-cased units. Made for exact replacements in TV receivers and antenna rotating devices. Available in singles, duals, triples, quads, and quints for 0-65°C operation



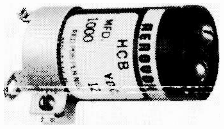
PRS compact "Dandee" units for trouble-free repair of series-string TV and AC-DC table radios. Aluminum cans with cardboard insulating sleeves. Made in singles, duals, and triples, as well as AC rated and non-polarized units.

SRE ..."Bantam" metal tubular 'lytics hermetically-sealed in aluminum cans with cardboard insulating sleeves. Smaller than the PRS but capable of handling full size loads to 85°C.

PTT-PWE miniaturized tubular 'lytics for repair of personal transistor radios, portable TV sets, and all space-tight requirements. Feature "Polycap"® plastic cases with exceptional humidity resistance.



BCD upright mounting 'lytics for replacement in printed circuits, transistorized and auto radios. "Polycap" case and epoxy seal offer excellent moisture barrier to protect against drying out or leakage.



HCB...high-capacity-low voltage 'lytics designed especially for applications such as motion picture sound equipment, electric fence controls and other low voltage applications. Feature bakelite case which eliminates need for cardboard outer insulating tubes.

Ask your local Aerovox Distributor for a free copy of the TV Electrolytic Capacitor Replacement Guide AFG-370 and AFH Twist-Prong 'Lytic Booklet AFH-461.

Remember—it pays to use Aerovox!

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