The use of ferrite beads provides many designers a convenient way of adding high frequency noise rejection in a circuit. They are generally small, do not add any dc resistance or loss to the circuit, and are installed by simply slipping them on to component leads and wires.

It was in the early 1960's when ferrites formed into a small sleeve configuration became known as a "bead"; and were found to be effective in suppressing transient spikes. Ferrite beads can be small (0.038 in on up) or large enough to encase a flat ribbon cable. They are relatively inexpensive (in large quantities some are less than a penny), and are produced in a wide variety of materials. Millions are now in use suppressing all types of transients and interfering signals containing frequencies of approximately 1 MHz and above.

Basically, ferrites are electromagnetic materials consisting of mixtures of iron oxide and metallic oxides of nickel, zinc, manganese (or combinations thereof), which are calcined, milled, spray-dryed, molded or extruded and sintered at temperatures of 1100°C or higher. The resultant ferrite is a polycrystalline, ceramic material with a spinel structure. It is very hard and, if machined, requires diamond wheel grinding.

All ferrites have a permeability and quality factor ($Q = X_L/R_s$) which are frequency sensitive. Over the specific frequency range for which the material is designed, this permeability (directly proportional to inductance) and the series losses of the material R_s are relatively constant. But as frequency increases above the operational range, permeability decreases while losses increase rather drastically. Both characteristics continue in this manner until, respectively, a minima and maxima are reached.

Ferrite beads can provide up to 10 dB of insertion loss over the frequency range of 1 MHz to 1 GHz. When inserted on a line, a bead has an equivalent circuit of a resistance in series with an inductance (Fig. 1). The values of both R and L depend heavily on the line frequency and current. The line current is the lesser of these two considerations, since it must be kept below about 5 A to avoid saturation of the bead.

The equivalent resistance and inductance of a ferrite bead can be measured by winding a single coil turn around the bead. The lumped impedances are then determined with either a Maxwell-Schering bridge or a mutual inductance bridge to yield the impedance of the bead plus the line, or $Z = R + jX$.

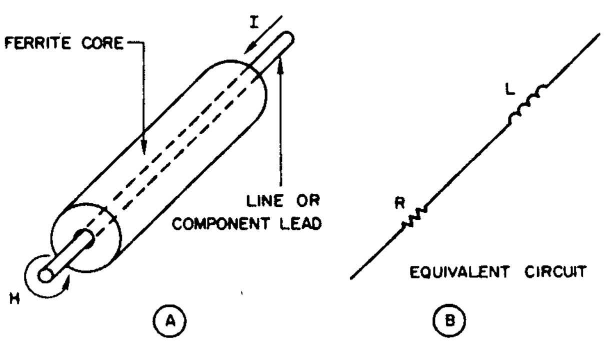

Figure 1. Ferrite bead inductors (A) have the simple equivalent circuit showin in (B).

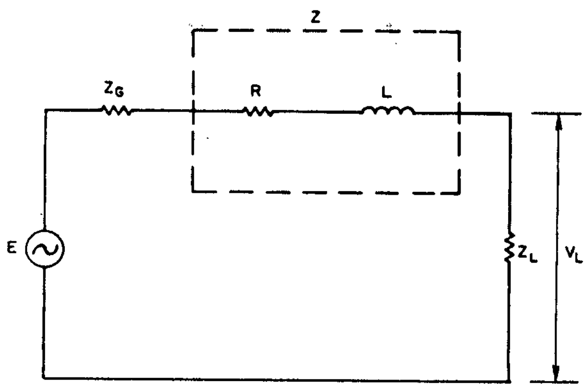

Figure 2. When a bead is placed on a line, the impedance, Z, of the bead and line adds to the existing circuit impedances, Z_G, and Z_L.

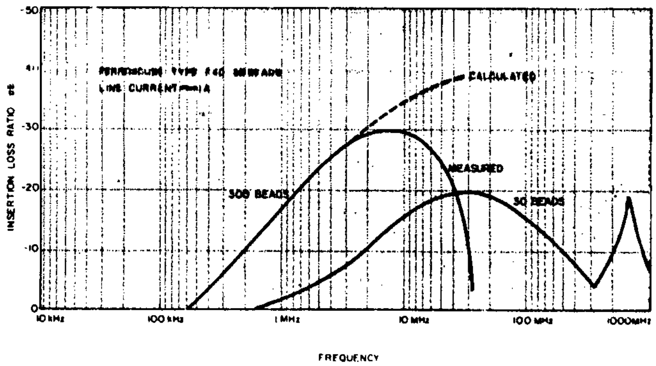

Figure 3. Typical comparison of IL with 30 beads vs 300 beads.

Every ferrite bead strung on a wire introduces a series impedance $\Delta Z = \Delta R - j\Delta X$. If n beads are used, and if the highest frequency is low enough to keep the electrical line length below a significant fraction of a quarter wavelength, then the total series impedance of the n beads is $n\Delta Z = n(\Delta R - j\Delta X)$.

INSERTION LOSS CALCULATION

The insertion loss (IL) in dB of a circuit containing ferrite beads is the ratio of load voltage with (v_o) and without (v_L) the inserted circuit (Fig. 2):

$$IL = 20\, LOG_{10} (E/v_o) / (E/v_l) = v_o/v_l$$
$$IL = 20\, LOG_{10} (Z_G + Z_L) / (Z_G + Z_L + Z)$$

HOW MANY BEADS SHOULD BE USED

The use of ferrite beads for increased insertion loss has obvious limitations, as can be seen in Figure 3. Increasing the bead count improves low frequency insertion loss, but at the expense of high frequency performance.

As a practical rule, ferrite bead strings should be kept short, and should be limited approximately to the 1 to 100 MHz frequency range. Long bead lengths cause severe insertion-loss degradation.