FERRITE BEADS

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 as shown in Figures 1 and 2. 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. Thus we have, in essence, a frequency-sensitive "resistor"–in actual operation an impedance consisting of a decreasing inductive reactance and increasing series resistance. Each material has a frequency at which it becomes effective as a suppressor of high frequencies (see Figs. 3 and 4).

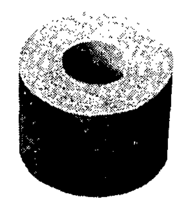


Figure 1: Ferrite bead inductor.

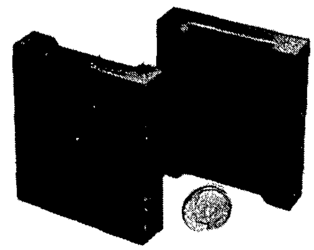


Figure 2: Two-part bead is used around flat ribbon cable to suppress computer transients.

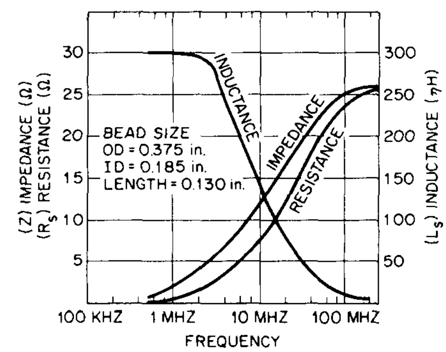


Figure 3: Effect of varying frequency on impedance, resistance and inductance of a typical bead material.

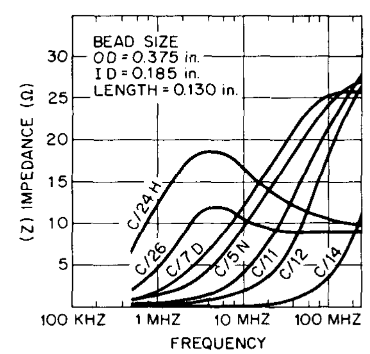


Figure 4: Frequency-impedance relationship of several materials.

Insertion Loss Determinations

It is possible for a single ferrite bead to provide considerable insertion loss over a wide frequency spectrum. For example, a bead can introduce 10 to 25 dB loss over a frequency range of 1 MHz to 1 GHz in a matched 1-ohm network. Figure 5 shows the topology of a circuit network with insertion-loss beads. Figure 6 is a graph of typical impedance changes of a single bead placed on a straight #22 gauge wire. The values of ΔR and ΔL depend heavily on the line frequency and bias current I. Gapping and dc bias effects will be considered in detail later.

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 a mutual inductance bridge to yield the impedance of the bead plus the line, or

$$\Delta Z_{TOTAL} = \Delta R + j\Delta X \sim \Delta Z_T \text{ (bead alone)} \quad .$$

As long as the line length through a bead (or an array of beads) does not become a significant portion of a quarter wavelength, line impedance can be neglected. The measurement, therefore, effectively determines the contributions to resistance and reactance due to the bead(s) alone. The resistance and reactance measurements are then plotted in graph form, similar to that shown in Figure 11.

The insertion loss ratio (ILR) of a circuit such as is shown in Figure 5, containing n identical ferrite beads, is defined as the ratio of load voltage with and without the beads' contribution, or

$$ILR = \frac{Z_G + Z_L}{Z_G + Z_L + n\Delta Z_T} \quad ,$$

by simple voltage division methods. Every ferrite bead introduces a series impedance. If n beads are strung together, and considering the quarter-wavelength limitations discussed earlier, the total

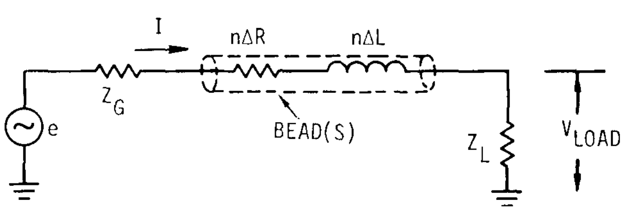


Figure 5: Equivalent line and load circuit with n ferrite beads. Impedances Z_G and Z_L are usually equal or matched for maximum power transfer.

series impedance must be nZ_T for beads of the same electrical characteristics. Of course, the beads need not be identical; in fact, judicious choice of different bead types and sizes can result in uniform impedances over a broad frequency range.

To illustrate the calculations used in predicting insertion losses when using ferrite beads, the following example is given. Consider a matched 50-ohm sytem with 30 beads of the kind shown in Figure 6. We wish to predict ILR at 10 MHz. The total length of the bead chain is (30) (0.118 inch) (0.0254 meter/inch), or 0.09 meter. With 10 MHz as the highest frequency under considera-tion, the corresponding wavelength* is 30 meters. Therefore, the bead length represents 0.09/30, or 0.003 wavelength, which is much less than a quarter wavelength. From Figure 6, at 10 MHz, $\Delta R \sim 12.2$ ohms and $\Delta X \sim 15.0$ ohms. Therefore,

$$n\Delta Z_T = (30)\,(12.2 + j15) = (366 + j450) \text{ ohms} .$$

With these numbers, a determination of the ILR magnitude can be made:

$$|ILR| = 20 \log_{10} \left| \left| \frac{50+50}{50+50+366+j450} \right| \right| \simeq -16.2 \text{ dB}$$

This yields one point on a curve of ILR versus frequency, which is plotted in Figure 7. Note that, at higher frequencies, line lengths become significant in relation to a quarter wavelength.

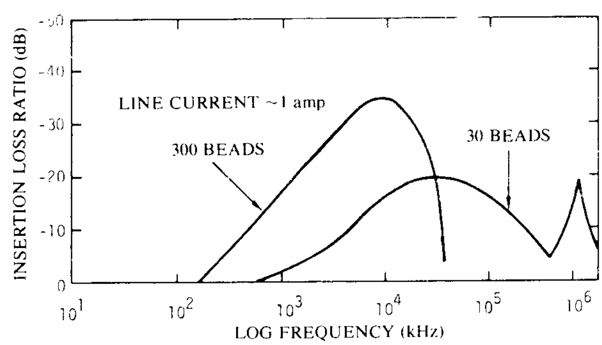


Figure 7. Measured insertion loss curves for various quantities of series-strung ferrite beads

The use of more beads for increased insertion loss has obvious limitations, as a quick estimate will show. Suppose the number of beads in the previous example is increased by a factor of 10. The insertion loss at 10 MHz then increases to -35.4 dB, as shown in Figure 7. However, the frequency of minimum attentuation has now decreased by the same factor of 5. Therefore, as a practical rule, ferrite strings are usually kept short. Long bead lengths cause severe insertion-loss degradation problems.

DC Bias Effects

Values of the effective impedance ΔZ_T will depend heavily on ther magnitude of the line current. In many applications, a disadvantage of ferrite beads is the loss of a considerable part of their effectiveness by bias caused by a direct current through the conductor on which the bead(s) is strung. This can be clearly recognized from reported data shown in Figure 8 for a string of two ferrite beads made of material 73 with an initial permeability of 2500 and nominal dimensions of 0.296 inch O.D., 0.094 inch I.D., and 0.297 inch average body length. The two beads were strung on a 1.5-inch #20 AWG tinned-copper wire.

The changes in ΔR and ΔL (and, therefore, ΔZ_T) with dc line current are caused by a variation in the permeability of the ferrite material. The variation plot of Figure 9 is typical of the nonlinear change of permeability with magnetic field intensity at the average radius of a ferrite bead. Referring back to the discussion of impedance calculations, this field intensity value must be

$$H = \frac{I}{P} = \frac{2}{\pi}\left(\frac{I}{D_0 + D_i}\right)$$

*The assumption is made here that, at the frequencies of interest, voltage waves on lines always travel with the speed of electgromagnetic waves in unbounded space, or 3 x 10^8 m/sec.

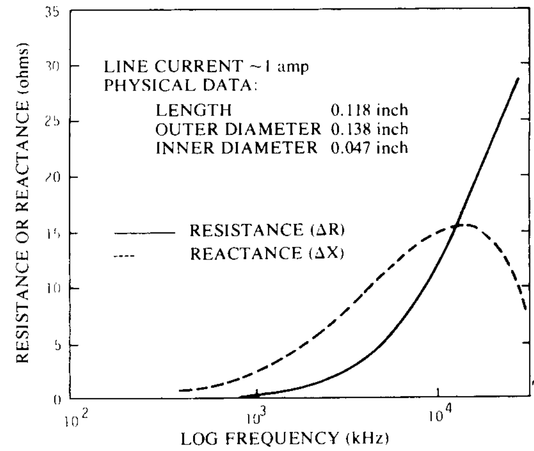


Figure 6: Measured resistance and reactance values for a typical ferrite bead

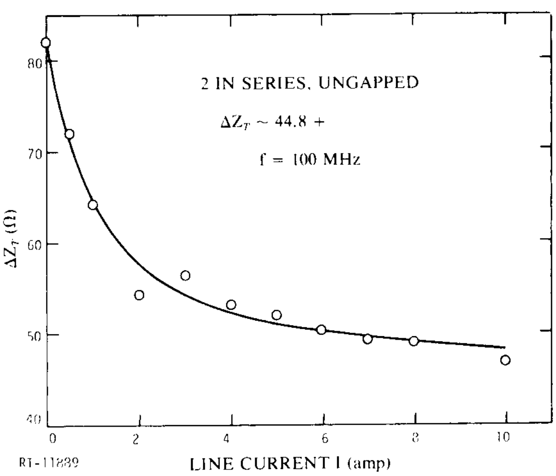
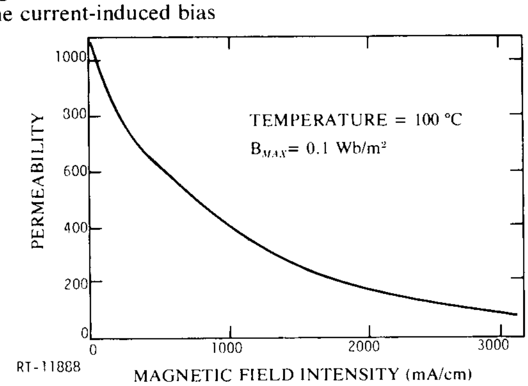


Figure 8. Changes in ΔZ_T for typical ferrite bead caused by line current-induced bias



where P is the average length around the periphery of the ferrite bead. To illustrate the impact of the change in permeability caused by a dc bias, consider the following examples. Using the physical data of Figure 6, path length P of a Ferroxcube type FXC-3B bead can be calculted as 0.738 cm. Assume that the manufacturer's data on relative permeabiity indicates that it should not be decreased beyond 530 for best performance. From Figure 9, the magnetic field intensity should, therefore, not be larger than ~713 mA/cm. The allowable line current cannot be greater than

$$I_{MAX} = H_{MAX}\, P = (713)(0.738) = 526.2 \text{ mA} .$$

For larger line currents, permeability falls rapidly. For I = 2 amp, H = I/P ~ 2710 mA/cm, and Figure 9 shows a large drop in permeability from 530 to ~125.

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