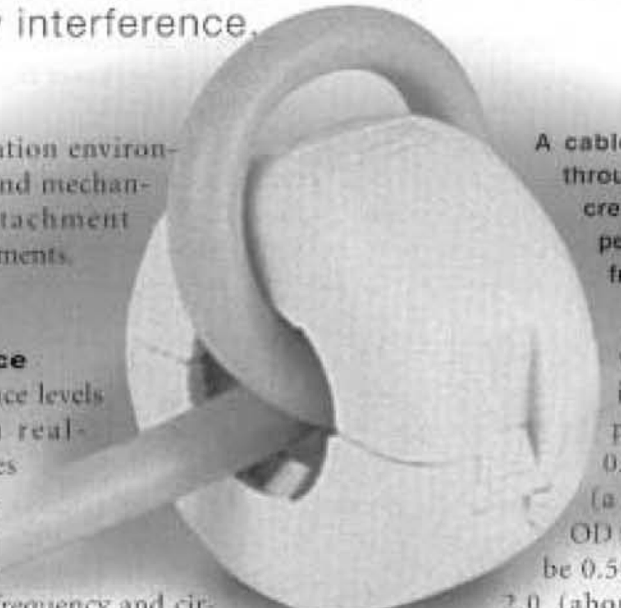
Jim May

Filtering Out Interference Signals with Cable Ferrites

Attaching a ferrite to a cable or looping a cable through a ferrite can help reduce unwanted high-frequency interference.



A cable can be looped through a ferrite to increase the ferrite impedance at a specific frequency.

Electronic cabling and wires, by virtue of their length-to-width ratios, are perfect natural antennas. In the presence of high-speed microprocessor signals, cables will conduct, radiate, and receive unwanted high-frequency interfering signals. Control of radio-frequency (RF) interference can be ensured by the proper placement of an insertion-loss device, such as a ferrite suppressor. Compared with alternatives such as in-line filters, onboard suppression circuits, shielded cables, and expensive filtering circuits, the high resistivity per cubic volume of ferrites stands out as the most important advantage. Ferrites have a concentrated, homogeneous magnetic structure with high permeability. They are consistently stable over time and over a wide temperature range, and provide RF suppression without high eddy-current losses.

The major application factors used for defining a specific ferrite solution for a particular interference problem include the following:

- Frequency at which maximum attenuation is required.
- Amount of attenuation needed.
- Ferrite permeability formulation characteristics as they relate to the frequency range in question, i.e., initial permeability.
- Ferrite formulation consistency, i.e., expected range of variation in attenuation performance.
- Installation environment and mechanical attachment requirements.

Cable Impedance

Impedance levels found on real-world cables and circuits vary widely as related to frequency and circuit length. For suppression modeling purposes, a 50-Ω source and load impedance combination is assumed. However, circuit and wire-cable geometries, especially circuit and cable length, can cause variation from as little as a few ohms to hundreds of ohms. Characterization of an actual circuit can be done with a simple impedance analyzer setup to refine any suppression modeling calculations at given frequencies.

Ferrite Impedance

Ferrite impedance varies linearly with changes in its overall length and with changes in the ratio of its outer diameter (OD) to its inner diameter (ID). One of the most effective techniques to increase ferrite effectiveness is to size the ID as closely to the wire size as possible. For a broadband ferrite with a 1.0-in. length and 0.50-in. OD attached to a 0.25-in.-diameter cable, a 0.25-in. ferrite ID would yield a 20% impedance improvement over a 0.30-in. ferrite ID (a looser fit). The OD to ID ratios would be 0.50 in./0.25 in., or 2.0 (about 200 Ω), and 0.50 in./0.30 in., or 1.66 (or about 166 Ω), respectively.

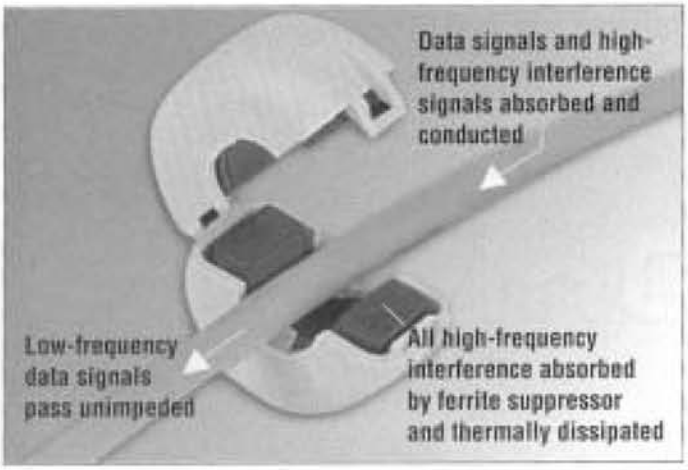
Insertion Loss

The modeling procedure to calculate impedance characteristics of the source and load coupled with the ferrite suppressor is developed as follows:

$$\text{Insertion loss (dB)} = 20 \log_{10} \frac{(Z_A + Z_B + Z_F)}{(Z_A + Z_B)},$$

where Z_A = source impedance, Z_B = load impedance, and Z_F = ferrite impedance. *Insertion loss* is defined as a measure of the effectiveness of a filter at a selected frequency. Insertion loss is expressed in decibels and is described as the ratio of voltage with, and without, the filter in the circuit.

For example, see the curve labeled as "one turn" at 44 MHz in Figure 1. If the circuit impedance $(Z_A + Z_B)$ is 50 Ω and the ferrite impedance is 70 Ω at 44 MHz,



Control of radio-frequency interference can be ensured by proper placement of an insertion-loss device such as a ferrite.

then the insertion loss will be $20 \log_{10} (50 + 70)/50 = 7.6$ dB.

Even if the same ferrite is used, the attenuation provided by the ferrite suppressor can change somewhat as the original circuit impedance varies. The ferrite is more effective when the circuit impedance is low. For example, by using the same ferrite performance of 70 Ω at 44 MHz in a 75-Ω circuit, the resulting insertion loss will be $20 \log_{10} (75 + 70)/75 = 5.7$ dB.

Increasing Ferrite Effectiveness

Ferrite Placement. For the most part, the impedance effect from the addition of a ferrite suppressor is constant regardless of where along the circuit the suppressor is applied. However, the overall success of the addition relates to the antennalike length-to-width structure ratio of the cable and its tendency to receive or emit radio signals. For a cable, it is best to locate the suppressor close to the cable termination where it exits the electronic enclosure, thereby negating the cable's antenna-length effect. This is effective for both emissions and susceptibility. A suppressor may also be needed on each end where a cable connects two enclosures containing RF sources. For circuits within an enclosure, a position close to the RF source is best; however, other locations along these relatively short runs are usually just as effective.

Ferrite Size. In applications with high circuit impedance, it may be possible to increase the effectiveness of the ferrite by increasing its impedance Z_F. A larger-size ferrite will increase Z_F almost on a direct percentage basis. However, larger ferrites, especially longer ferrites, are sometimes not an option because of space allowances, weight, aesthetics, and other packaging considerations.

Multiple Looping. An effective alternative is to pass the cable through the ferrite opening multiple times by looping the cable back through the ferrite. This increases the effective magnetic path—Z_F increases geometrically by the square of the number of turns (N^2) through the ferrite opening.

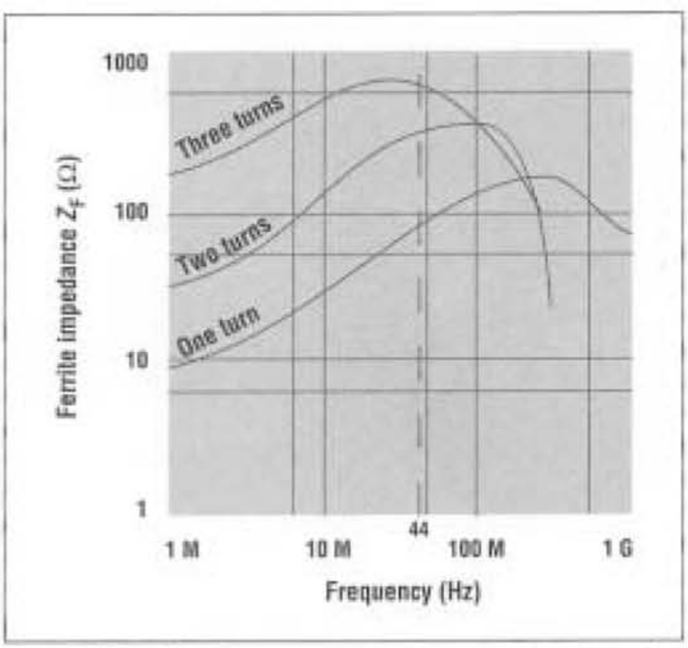
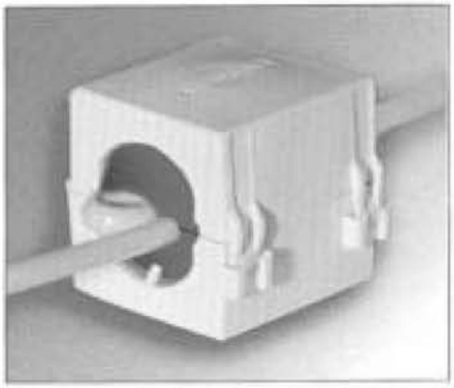
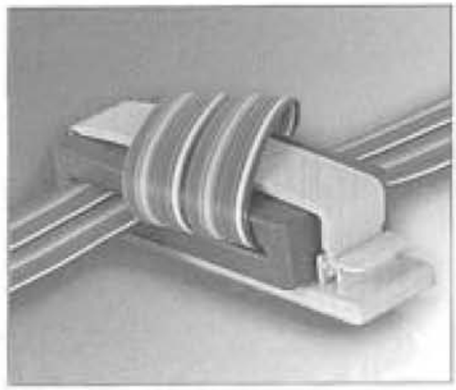


Figure 1. Typical performance at one, two, and three turns for the same ferrite configuration.



A multihole ferrite core. A cable is threaded through openings in the core without passing around the exterior dimensions.



Multiconductor flat cables can be accommodated by using a side-by-side method.

For example, two turns provide ($2^2 = 4$) four times the Z_F at a given frequency.

The drawback to multiple looping is that the characteristic frequency performance band will become narrower and the frequency at which maximum impedance is attained will be lower. However, this is not an operational restriction because Z_F increases so much throughout the (narrower) band that it is not necessary to be concerned with where the peak of the performance curve moves. At three or more turns, there are commensurate (N^2) results. Although the performance band compression and resonant-frequency effects may differ from one core geometry to another, the Z_F increase from multiple turns around the ferrite should follow the N^2 rule.

Figure 1 shows that two turns through the same ferrite will yield 280 Ω at 44 MHz. The Z_F of 280 Ω is the same as the theoretical value of $70\ \Omega \times 2^2$. The resulting attenuation with a 50-Ω circuit at the same frequency is calculated as

$$20 \log_{10} \frac{50 + 280}{50} = 16.4 \text{ dB for 2 turns.}$$

Checking Figure 1 again for three turns ($N = 3$) yields a Z_F of 604 Ω. The Z_F of 604 Ω is close to the theoretical value of $70\ \Omega \times 3^2 = 630\ \Omega$. The attenuation with a 50-Ω circuit is

$$20 \log_{10} \frac{50 + 604}{50} = 22.4 \text{ dB for 3 turns.}$$

Both round- and flat-cable circuits lend themselves to the multiple-looping technique. Ferrite cores for round cables are typically available with an ID up to 1.00 in., and cores for flat cables are available in widths up to 3.25 in. or 64 conductors. One variation is a multihole ferrite core that allows the cable to be threaded through the openings without passing around the exterior dimensions of the ferrite. Multiple looping with flat cables can be accommodated by using a side-by-side method.

Conclusion

The performance of a ferrite suppressor is consistent over time and over a wide range of temperatures. With the proper matching, placement, fit, and sizing, ferrites can provide an effective solution to unwanted RF interference. If more suppression is required, looping

The increase of ferrite impedance from multiple turns follows the N^2 rule.

the cable through the ferrite can increase the effectiveness of a ferrite without increasing cost. In addition, multiple looping locks the ferrite into position along the longitudinal axis of the cable. In some cases, it can serve as the mounting location mechanism for ferrite positioning. The resulting increase in packaging integrity is an ancillary benefit. Furthermore, packaging with the smallest, most cost-effective component to accomplish the task is certainly an option with this simple technique.

Jim May is the vice president of FerriShield Inc. (New York City). He has been an electromagnetic compatibility market participant for the past 23 years and holds many related patents. He can be reached at info@market-shareinc.com. ■