Cable Shielding With Ferrites

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Ferrites can be used to block the transmission of interference along cable lines.

INTRODUCTION

Electromagnetic interference problems can arise anywhere and the coupling of electromagnetic energy is unpredictable. The effects are always unwanted. Electromagnetic interference occurs when three elements come together: a source of interference, a receiver of the interference, and a way of transfer. According to this simple scheme, minimizing the electromagnetic interference can be attained by eliminating one of the three elements: by suppressing the source, protecting the receiver against noise , or reducing the interference transmission. This article will concentrate on the transmission of interference.

Any device which suppresses noise between the source and the receiver is an EMI shield. Interference can propagate in different ways:

- By *radiation* as an electromagnetic wave in free space. Suppression requires shielding with conductive or absorbing materials.
- By *conduction* via a conductive path. One suppression solution is ferrites in the form of beads or cable shields.

Conductive coupling is the most common way an interference signal is transmitted into a system. When studying an interference problem, attention is very often focused on critical components, while system cables are overlooked. A cable can pick up noise and bring it to other areas traversed by the cable.

With today's regulations, all electric and electronic products, no matter how trivial they seem to be, have to comply with certain limits, both emitting and receiving. There is a need to suppress common-mode EMI not only on internal cables but also on external cables of electronic equipment. Ferrite cable shields are cost-effective as they suppress any electromagnetic noise and reduce the need for other, more complicated shielding measures.

CABLE SHIELDING WITH FERRITES

When a ferrite cable shield is used, low frequency signals are not affected by the shield. At low frequency, a ferrite inductor is a low-loss, constant self-inductance, causing only a minor increase in impedance. Interferences normally occur at elevated frequencies and there the picture changes. Magnetic losses start to increase and at the frequency of the *ferromagnetic resonance,* permeability drops rapidly to zero while the impedance reaches a maximum. This impedance, the most important parameter for suppression, becomes completely resistive and at higher frequencies, even capacitive with losses. While for inductor applications the operating frequency should stay well below the resonance, effective interference suppression is achieved up to much higher frequencies. The impedance peaks at the resonance frequency and the ferrite is effective in a wide frequency band around it.

Around its ferromagnetic resonance, the impedance of a ferrite is largely resistive, which is a favorable characteristic for several reasons:

- A low-loss inductor can resonate with a capacitance in series, leading to almost zero impedance and interference amplification. A more resistive impedance cannot resonate and is reliable independent of source and load impedances.
- A resistance dissipates interfering signals rather than reflecting them to the source. Small oscillations of high frequency can damage semiconductors or negatively affect circuit operation. Therefore, it is better to absorb them.
- The shape of the impedance curve changes with material losses. A lossy material will show smooth variation of impedance with frequency and a real wideband attenuation. Interference signals often occur in a broad spectrum.

Very often EMI suppression is required on cables carrying dc or ac power. In these cases *current compensation* is needed to avoid a saturation of the ferrite and, consequently, loss of impedance. Current compensation is based on the principle that in cables passing through a ferrite core, the carried load and signal currents are generally balanced. The net current is zero and no saturation occurs. In other words, the currents generate opposed fluxes of equal magnitude that cancel each other. EMI noise, however, usually travels in the same direction on all conductors (common mode), causes flux in the ferrite and will be suppressed by the increased impedance.

For high frequency signals, current compensation is a beneficial effect for reasons other that saturation. In an I/O cable, the regular RF signal could be suppressed together with the interference. Since the actual signal is differential mode, current compensation avoids this unwanted damping effect on the actual signal. A cable shield is mainly active against common-mode interference, although its small stray inductance will also have some effect against differential-mode interference.

Ferrite products for cable shielding are available in different shapes and can be:

- Entire, for mounting during manufacturing. Ferrite cores can, for instance, be embedded in the plastic cover of the cable or shifted on before mounting the connectors.
- Split, for mounting on existing cables. This type of product was developed for easy installation when the interference problem is detected after final design. The gap between halves has only little influence on the magnetic performance. Impedance is hardly affected, while current handling capability increases. The two halves are mounted with special clips.

FERRITE SELECTION

When selecting a ferrite shield to solve an interference problem, it is necessary to consider some important application aspects:

- The frequency where maximum attenuation is needed. The most suitable ferrite would offer the highest impedance levels at the interference frequencies, which usually cover a broad spectrum.
- Core shape, which is usually defined by the cable type.
- Installation requirements to decide on an entire or a split core type.
- Attenuation and impedance level for maximum suppression.
- Ferrite characteristics as a function of operating conditions. Impedance can vary with temperature or dc current.

FERRITE CORE AND ITS IMPEDANCE BEHAVIOR

The selection of the core type is based on optimizing the suppression performance. The inside diameter is fixed by the cable dimensions. The ferrite should fit closely to the cable. If not, loss of impedance and stray flux result, which convert into mutual inductance if other circuit parts are close. Impedance is adjusted mainly by the length and/or number of shields. Impedance depends linearly on length and only logarithmically on the outer dimensions.

Accordingly, the most suitable ferrite core would be the largest type with an inner diameter matching the cable outer dimensions. But this only applies if a large size and weight are no problem! For cost reasons, a minimum size with optimum properties is preferred.

A simple solution for flexible cable is to wind a few turns on a ring core with a large diameter. The large inner diameter (not fitting the cable) and short length (small impedance) are compensated by using more than one turn:

$$Z \propto N^2$$

where N is the number of turns (Figure 1).

The use of more than two turns on a ferrite core is not recommended. Although the number of turns results in more impedance, the parasitic interwinding capacitance, which is also proportional to the number of turns, decreases the frequency where peak inductance occurs. This results in a worse performance at higher frequencies.

FERRITE LOCATION

Ferrite position along the cable is also an important issue for the best performance of the application. For filtering purposes, the placement of the ferrite suppressor should be as close as possible to the source of interference in order to achieve the most effective noise suppression.

When applied on an I/O cable which passes through a connector of an enclosure, the ferrite shield should be very near the enclosure output. If the two connected systems are completely enclosed, the location of the ferrite core is not that critical; it may be anywhere along the cable. In the case of a cable connecting two EMI interference sources, both systems must be protected and shielded with ferrite cable shields.

THE IMPEDANCE CONCEPT

MATERIAL AND SIZE

The impedance curve can be derived from a pure material curve, the complex permeability curve. As impedance consists of a reactive and a resistive part, permeability should also have

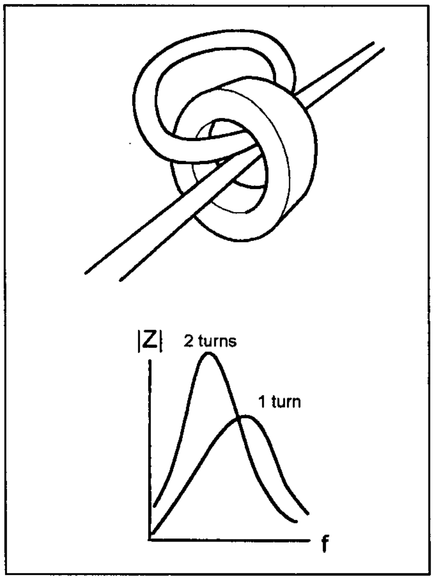

***Figure 1.** Two Turns of a Cable through a Ferrite Cable Shield.*

two parts to be representative. The real part (μ') corresponds to the reactance, and the imaginary part (μ'') to the losses.

$$\begin{aligned} Z &= j\omega \cdot (\mu' - j\mu'') \cdot L_0 \\ &= \omega\mu'' \cdot L_0 + j\omega\mu' \cdot L_0 \\ Z &= R + jX \rightarrow R = \omega\mu'' \cdot L_0 \\ X &= \omega\mu' \cdot L_0 \end{aligned}$$

$$|Z| = \sqrt{(R^2+X^2)} = \omega \cdot L_0\sqrt{(\mu'^2+\mu''^2)}$$

where:

$\omega = 2\pi f$

$L_0 = \mu_0 \cdot N^2 \cdot A_e/l_e$

$\mu_0 = 4\pi \cdot 10^{-7}$

N = number of turns

A_e = effective area

l_e = effective length

The simplest way to estimate the impedance of a product with different dimensions is to take the impedance curve of a reference core. Two factors have to be corrected: effective magnetic dimensions and number of turns.

$$Z \propto N^2 \cdot A_e/l_e$$
$$Z = Z_0 \cdot (N^2/N_0^2) \cdot (A_e/A_{e0}) \cdot (l_{e0}/l_e)$$

where the parameters with index 0 correspond to the reference core. The number of turns N is always an integer number. Half a turn geometrically is 1 turn magnetically. The effective magnetic dimensions A_e and l_e are calculated from geometric dimensions according to IEC Norm 205. In the case of cylindrical symmetry an analytical formula exists:

$$A_e/l_e = L/(2\pi) \cdot \ln(D/d)$$

where:
D = outer diameter
d = inner diameter
L = height (length)

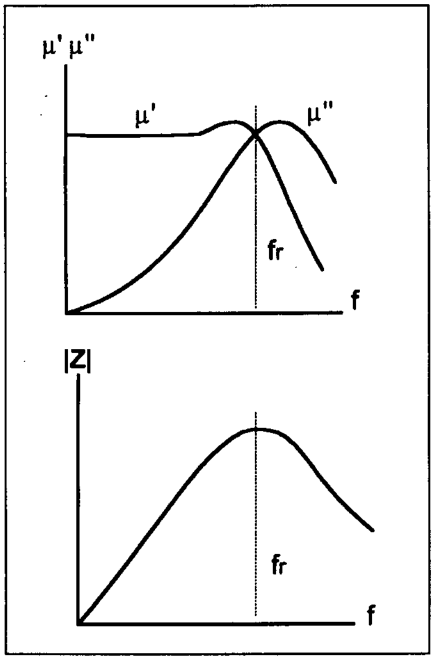

Figure 2. *Complex Permeability and Impedance.*

BIAS CURRENT

Often a dc supply or ac power current is passing through the inductor to facilitate the regular operation of the connected equipment. This current induces a high field strength in the ferrite core, which can lead to saturation. When current compensation is not possible, the effects of the current have to be taken into account. Impedance then decreases along with permeability, especially in the low frequency region.

A solution is to compensate for the loss of impedance by increasing the length of core (the longer the core, the higher the impedance). Another way to reduce the negative effect is to introduce a small gap in the ferrite core, but this is only feasible in the bisected types.

The influence of bias current can be calculated rapidly. The induced field strength is directly proportional to the current:

$$H = N \cdot I/l_e$$

Whether this field causes a significant saturation or not can be seen in a curve of inductance versus bias field. However, this only indicates the decrease of impedance at low frequency. Impedance at high frequency decreases less.

Again, impedance can be calculated from reference curves if they show impedance versus frequency with bias current as a parameter. First, the bias current is translated into the current that would induce the same field strength in the reference core, thus the same amount of core saturation:

$$I_0 = I \cdot (N/N_0) \cdot (l_{e0}/l_e)$$

For a ring core, tube, or bead, the effective length is:

$$l_e = \pi \cdot \ln(D/d) / (1/d - 1/D)$$

Now the relative impedance decrease must be the same:

$$Z_{bias} = Z \cdot (Z_{0bias}/Z_0)$$

with Z again equal to:

$$Z = Z_0 \cdot (N^2/N_0^2) \cdot (A_e/A_{e0}) \cdot (l_{e0}/l_e)$$

Curves of typical impedance with and without a dc current are presented (Figures 3a and 3b).

TEMPERATURE

Since impedance is directly dependent on permeability and losses, it is also important to evaluate the effects of temperature on the intrinsic material

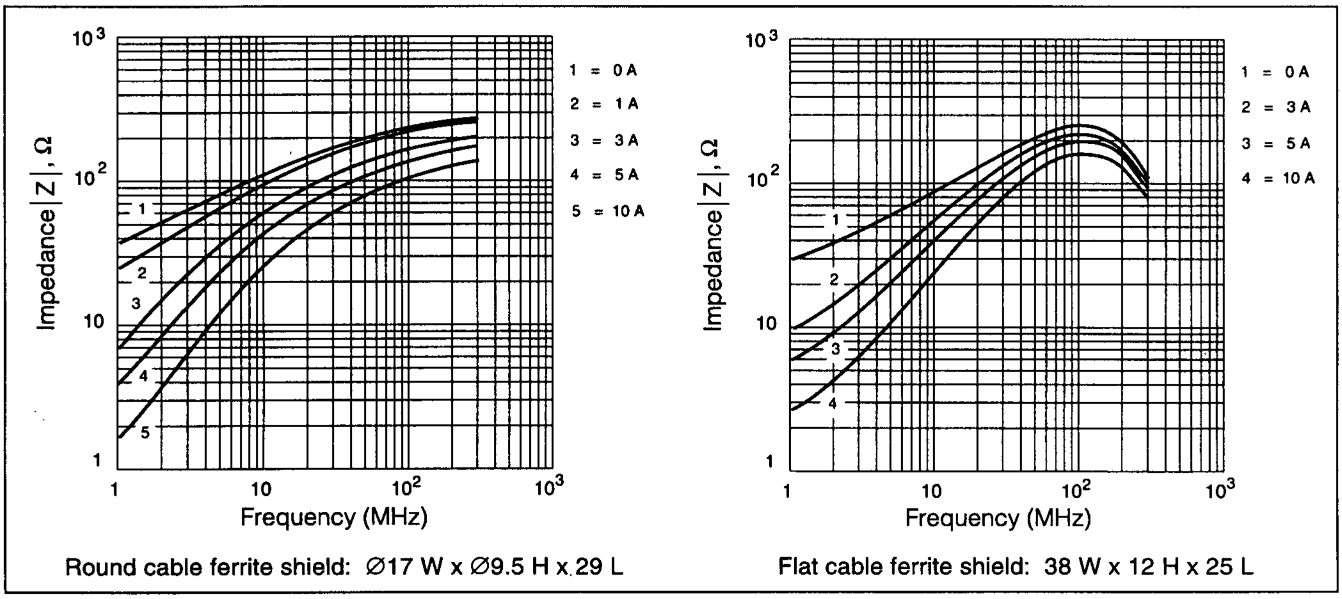

Figure 3. *Impedance under Bias Conditions for Selected Ferrites.*

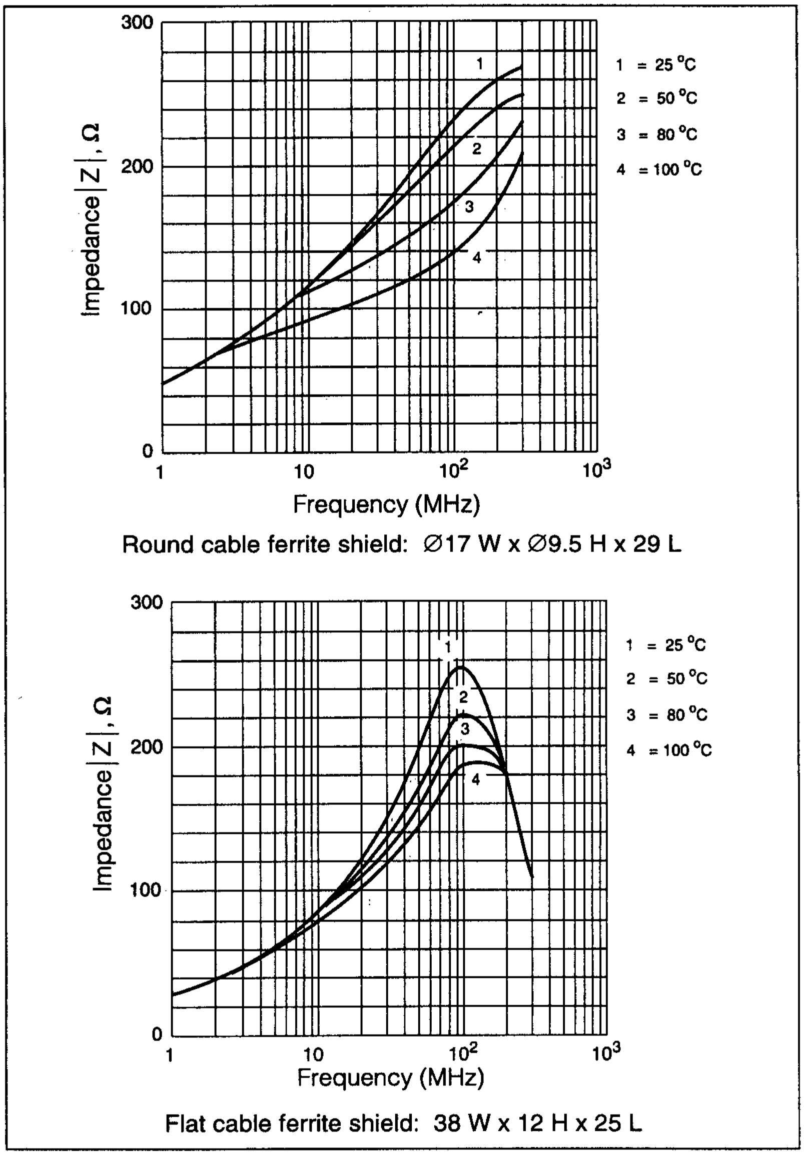

Figure 4. *Impedance Curves at Several Temperatures for Selected Cable Shields.*

parameters. The behavior of permeability versus temperature is shown. Figure 4 shows how this affects the impedance behavior of some typical cable shields.

ATTENUATION CONCEPT

When it is necessary to express the effectiveness of a suppressor in decibels (dB), impedance should be converted to insertion loss. Insertion loss is the ratio of the resulting voltage over the load impedance without and with a suppression component:

$$IL = 20 \cdot \log (E_0/E)$$
$$IL = 20 \cdot \log |Z_G + Z_L + Z_S| / |Z_G + Z_L|$$

where:

E = load voltage with inductor
E_0 = load voltage without inductor
Z_G = generator impedance
Z_S = suppression impedance
Z_L = load impedance (Figure 5)

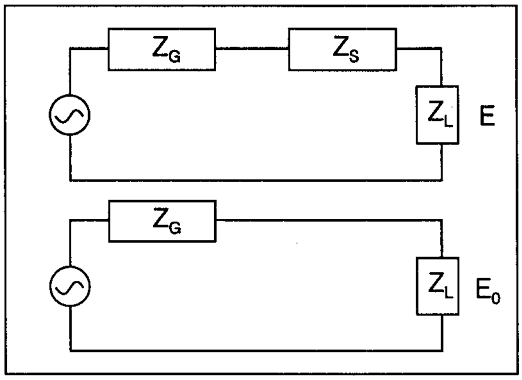

Figure 5. *Voltage With and Without Inductor.*

For a 50-ohm/50-ohm system:

$$IL = 20 \cdot \log (1 + Z/100) \text{ dB}$$

The decibel seems a practical unit because interference levels are usually expressed in it, but designers should be aware that insertion loss depends on source and load impedance. Thus the decibel is not a pure product parameter like impedance. In the application, source and load will not normally be a 50-ohm fixed resistor. They might be reactive, frequency dependent, and quite different from 50 ohms.

Insertion loss is a standardized parameter for comparison, but it will not directly predict the attenuation in the application since it is not a pure product parameter. It is advisable to check the attenuation values by testing the real circuit to find deviations caused by actual system impedances. The lower the circuit impedance, the higher the attenuation with the same ferrite core will be.

CONCLUSION

Ferrite devices offer a cost-effective means of providing EMI suppression on cables by presenting a high impedance to the high frequency interference. Ferrite cable shields are available in various shapes and materials to match the user's needs.

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