Current Applications of Ferrites for Interference Suppression

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TODAY'S ELECTRONIC ENVIRONMENT

Almost fifty years have passed since the need for interference control was first discovered. Although the early stimulus to develop solutions to interference problems was from military sources, the commercial community was not long in joining the clamor for electromagnetic compatibility. In the last years of the twentieth century the requirement for interference-free systems has become exceedingly crucial. The consequences of the loss of signal integrity can be literally devastating.

In order to ensure that systems operate in trouble-free environments, major regulating authorities have placed stringent requirements on manufacturers of devices and systems which are susceptible to, or which may emit, electromagnetic radiation. Most, but not all, involve digital systems. In order to sell the products in all parts of the world, marketers of these devices are required to supply certification that the device complies with the appropriate governing body.

HOW FERRITES FIT INTO THIS PICTURE

While ferrite components are not the electronic device designer's sole available tool for dealing with interference, they do fit very well into comprehensive plans for achieving compliance. Reasons include:

Ferrite components and ferrite absorbers are likely to play an expanded role in interference control.

- Effective over a broad frequency band
- Low utilization cost
- Capability of being applied to various types of components
- Ease of availability

Considerations of the application objectives must drive the strategy of the designer. Design and EMI engineers must determine the most effective solutions with respect to performance and cost to meet the regulatory requirements for emissions and immunity. In utilizing ferrite components the primary factors to be considered are:

- Frequency range to be suppressed
- Mode of conductive interference—differential or common
- Level of attenuation required
- Optimum location of the component
- Application for the ferrite

There are three distinct types of applications of ferrite components for interference control. These include:

- In-circuit applications where the ferrite's frequency-sensitive loss characteristics provide high frequency interference suppression
- Applications utilizing purely inductive reactance for impedance mismatch, as in low-pass filters
- Out-of-circuit applications where the ferrite serves as an absorber of radiated electromagnetic energy

Ferrite beads are examples of the first type of application, and are the most well-known in the area of electromagnetic compatibility. The other two application areas are also vital, and it is important to examine them as well.

FERRITES IN INDUCTIVE APPLICATIONS

Probably the two most common uses of ferrites in inductive applications are in wound chokes and filters. In common-mode chokes or power-line chokes, multiple turns of wire are applied to a ferrite core to provide high reactive impedance over a relatively narrow bandwidth. Characteristics which the ferrite should exhibit are high permeability and high saturation flux density. Shapes include toroids, E cores, PQ cores, and bobbins. Multilayer chip inductors and small wound rod inductors are also available for use on printed circuit boards.

Ferrites may also function as the inductive element of an EMI filter. In this case the interference energy is reflected instead of being absorbed. Ferrites used in line filters (low frequency) employ a common-mode inductor,

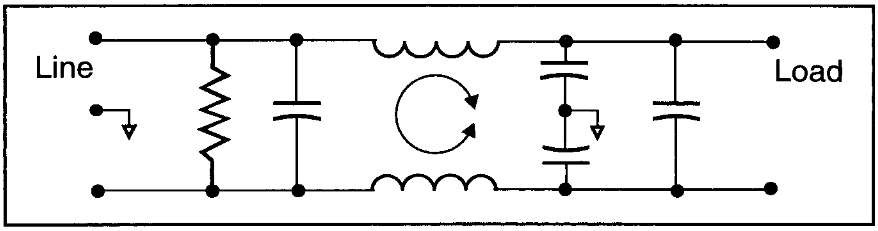

Figure 1. *Typical Power-line Filter.*

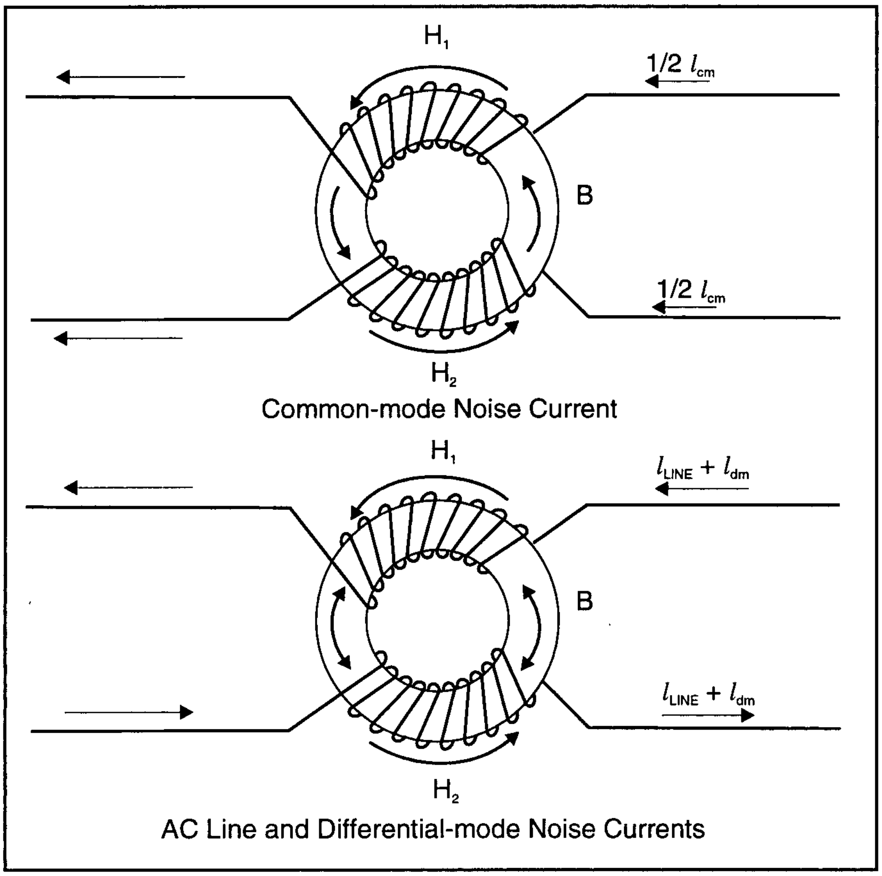

Figure 2. *Common-mode Inductor.*

generally a toroid. This component operates with a high level of common-mode inductance and operating current at the expense of differential-mode inductance. By providing identical windings on a common core for all current-carrying lines to be filtered, the flux developed in the core cancels when currents in the windings are equal but of opposite phases. Such currents are differential mode and include the ac power current. The common-mode currents, which are in phase on the line, and the neutral windings generate additional flux. The filter is designed to reflect the energy provided on the common-mode side. Figure 1 is a typical circuit schematic of a power-line filter. Figure 2 illustrates the effect of the windings on line and differential-mode noise currents.

SUPPRESSION USING FERRITE FREQUENCY RESPONSE CHARACTERISTICS

Ferrites used in EMI suppression to provide high impedance to unwanted noise typically exhibit relatively high permeability at low frequency levels, possess high volume resistivity and have loss characteristics which are frequency-dependent. It is this latter property which enables them to act as attenuators of higher frequency. Usually nickel zinc combinations, they are used as two-terminal elements or in groups of two-terminal elements. At low frequencies, for example less than 10 MHz, the ferrite represents a small, predominately inductive impedance. At higher frequencies the impedance becomes very much greater, the lossy component of the complex permeability increases rapidly, and a selective filtering action results at the higher frequencies. This impedance is comprised of both reactive and resistive components. Whereas the impedance at low frequencies is predominately reactive, above 100 MHz it becomes essentially resistive. Figure 3 illustrates the effect of frequency versus impedance on a typical ferrite component.

The high frequency energy loss is generally expressed in terms of the complex permeability of the core. Figure 4 illustrates the vector relationship between the real and imaginary permeabilities and the magnetic loss angle (δ), such that $\tan \delta = \mu''/\mu'$ where μ' is the real component of the series complex permeability,where μ'' is the imaginary component of the series complex permeability and μ_r, is the relative permeability. As the ferrite core is excited and oscillates with each cycle, its domains continually reverse. Since the domain cannot switch as fast as the applied signal, there is a finite lag of B, the inductance level in the core, with respect to H, the applied field. As the frequency continues to rise, this difference increases. The loss angle, or its tangent, is the measure of this phase difference.

The frequency-loss tangent effect is dependent upon the ferrite composition, and the user may select the optimum ferrite type for the range of frequency to be attenuated. The imaginary

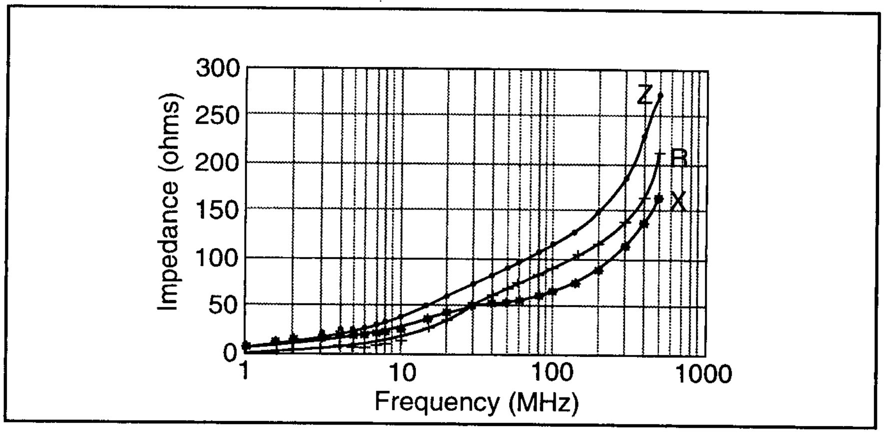

Figure 3. *Complex Impedance vs. Frequency for a Typical Ferrite.*

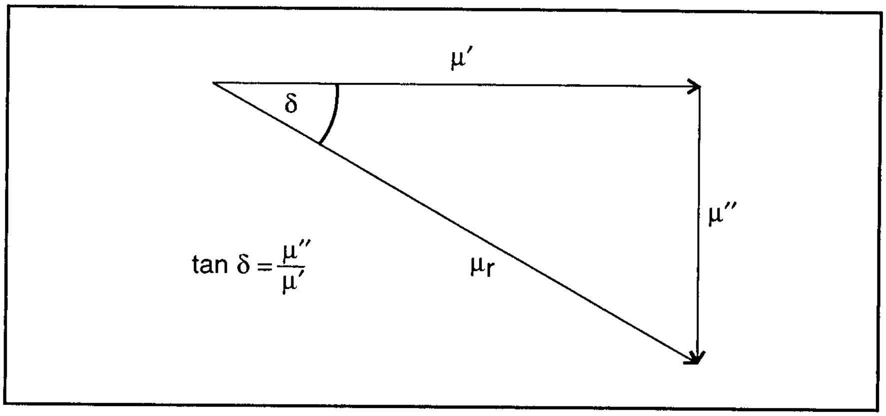

Figure 4. *Graphical Expression of the Magnetic Loss Tangent for a Typical Ferrite.*

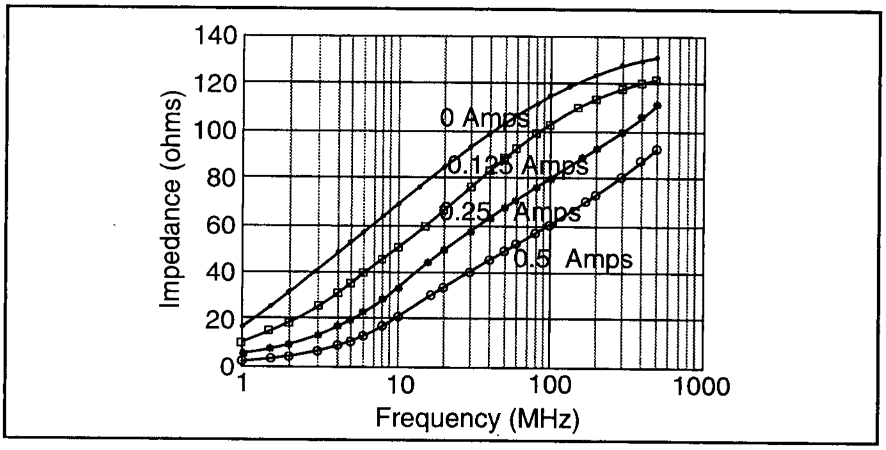

Figure 5. *Impedance vs. Frequency under Various Levels of Bias for a Single-turn Ferrite.*

portion of this relationship is the resistive or lossy component. The energy consumed in this loss mechanism, albeit small, is dissipated in the ferrite.

In differential two-port connections, another consideration is the reactive behavior of the ferrite under bias. As the flux density in the ferrite is driven higher (through higher current in the conductor), the permeability of the core falls, yielding a lower impedance than with the unbiased ferrite, so that the core size of the ferrite may need to be adjusted to provide lower flux density. Figure 5 illustrates the effect of bias and frequency on the impedance of a specific ferrite core.

Another means of suppressing noise with ferrites is to combine a sleeve or sleeves with one or more bypass capacitors forming L, T, or π filters. Whereas the ferrite, by itself, may offer an insertion loss of 10 dB at 100 MHz, the combination may run as high as 50 to 60 dB at the same frequency. Since the ferrite is still functioning as a two-port connection, current must be considered. Figure 6 shows the performance of a filter of this type.

Suppression of common-mode interference from both internal and external cables is important. A ferrite sleeve on the cable conveniently handles most of this noise. Common-mode filtering on circuit boards is also vital, and for this case special ferrite configurations are available which may be easily applied to the board in the assembly operation. This is particularly true for dc power supplies. The same common-mode filter is effective in those cases where it is exceedingly important to maintain high frequency signal integrity, such as connections to 10 Base T, Ethernet and some SCSI storage subsystems. The need to apply common-mode suppression on the circuit board has been realized and low-profile, slotted ferrite chips have been developed to meet it.

FERRITES AS ABSORBERS

The use of ferrites as freestanding absorbers has become a significant part of the electromagnetic compatibility industry. Ferrites in the form of tiles are used extensively to line anechoic chambers. The tiles absorb radiated energy which is applied to or which emanates from equipment undergoing compliance tests. The tile effectively pre-

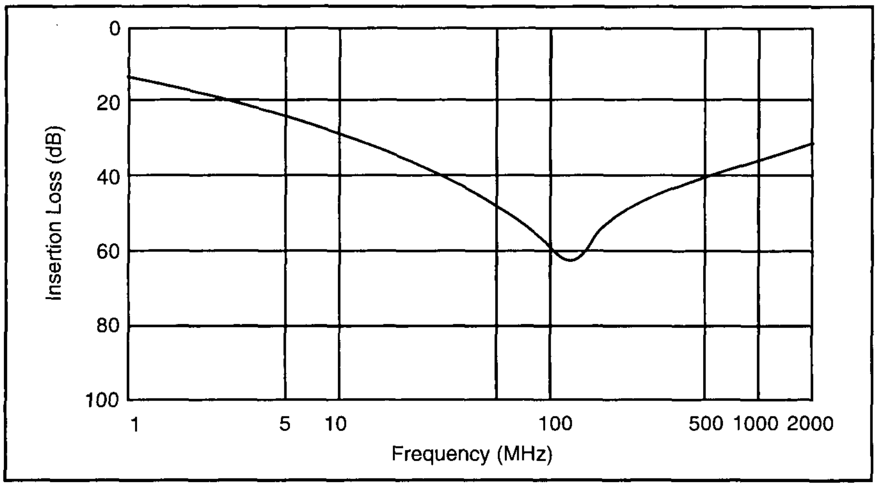

Figure 6. *Insertion Loss vs. Frequency Characteristics.*

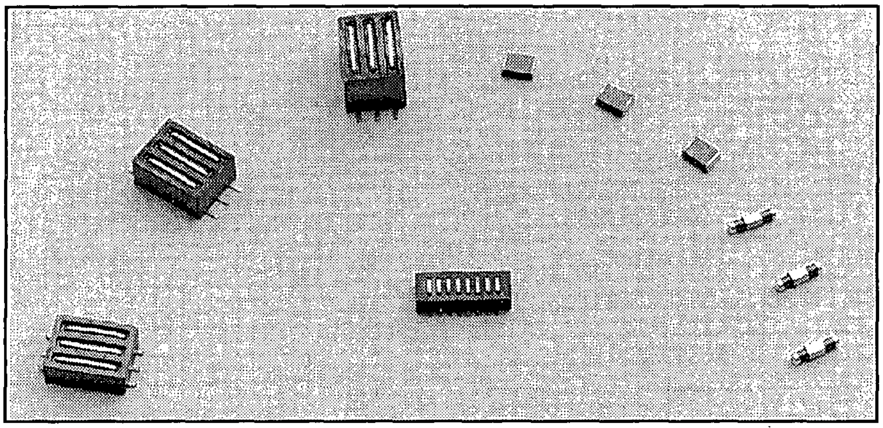

Figure 7. *Surface-mountable Suppressors and Filters.*

vents reflections or reverberations which would otherwise preclude accurate measurements of the performance of the equipment.

As EMC testing is now a primary requirement for marketing products which must be limited in emissions as well as immune to radiation, chambers containing ferrite tiles are a necessity to ensure "quiet" environments. The tiles, in conjunction with tipped polyurethane pyramids, allow the chamber to function in the range of 30 MHz through 1 GHz to simulate the conditions of an open air test site.

A second, somewhat similar use of ferrite materials is in the absorption of energy in shielding applications to prevent background reverberations from entering microwave equipment. Examples of this function include shielding ignition wires in automotive systems, and covering structures with materials coated or loaded with ferrite powders without which the structure might interfere with intended transmission or reception of microwaves. In these cases an elastomer is generally densely loaded with either a nickel zinc or manganese zinc ferrite powder and applied as a shield to a potential reflector. Here the loss mechanisms to achieve optional absorption become complex. These include not only domain resonance, which is predominant in the ferrite bead applications, but ferromagnetic and eddy current resonances as well. Further, since the dielectric characteristics of the ferrite play an important role in attenuation and the reflection coefficient is a function of the permittivity and permeability of the absorber, the type of ferrite or composite selection is exceedingly important.

THE FUTURE OF FERRITES

The two most significant factors which influence designs using lossy ferrite components are faster system speeds and the need to economically package components in smaller configurations. Accordingly, ferrite manufacturers need to provide materials and shapes which handle higher interference frequencies and which are suitable for surface mounting. In short, surface-mount chips and planar components will be prevalent in many component designs (Figure 7).

Ferrites for reflective filtering will also be influenced to a great extent by the need for more compact, less costly designs. Higher permeability ferrites and smaller packages seem to be the trend. Absorber materials for test chamber applications will address lower reflectivity in the lower frequency range. Another requirement will be to produce lower cost chambers through the use of more effective composite materials, with ferrites replacing the more fragile polyurethanes.

Most suppliers of ferrites for the suppression of EMI provide catalog data to assist the designer. Tools for troubleshooting in the form of kits and application guidelines are also very helpful.

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