HOW THE "MYSTERY MATERIAL" WORKS: USING FERRITES FOR EMI SUPPRESSION

Once understood, ferrite shielding materials can be engineered to provide a simple, convenient and cost-effective solution for RFI problems in cables and connectors.

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Ferrite shielding materials are now widely accepted as providing the simplest, most convenient and most cost-effective solution for radio frequency interference problems in cables and connectors. Further, they accomplish both RF attenuation and suppression of unwanted high frequency oscillations with no loss in dc or low-frequency signal strength. Ferrite is by no means a "new material" in the high-tech sense. It has been used for its magnetic properties for decades; but its capabilities and application in interference control have become widespread only during the second half of this decade.

Figure 1. Ferrite Clamp Configured to Surround a Cable.

Attesting to the popularity of this versatile material, annual production levels have grown by more than 30 percent for each of the past three years. This rate of increase far exceeds the RFI market as a whole; in fact, ferrite may be the leading growth segment in that market. Yet many electronic engineers, even those who work regularly with ferrite, still consider it an enigma, effective but mysterious.

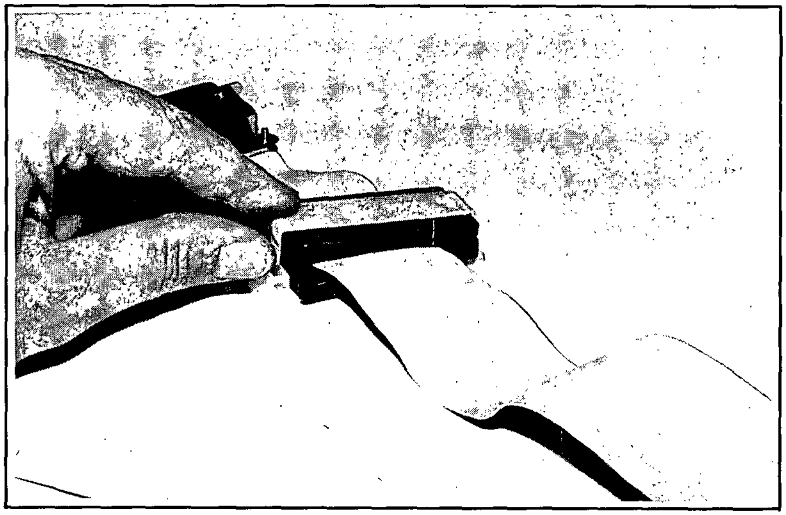


Figure 2. Ferrite Clamp.

The basic composition of ferrite materials is a combination of ferrous oxide and one or more other powdered metals — most often manganese, zinc, cobalt or nickel. The powder is pressed and then sintered into a crystalline ceramic by kiln firing at a nominal 2000° F for prescribed durations. An extensive selection of shapes and sizes is already available, and custom geometries may be manufactured for special situations.

There are an infinite variety of mixtures and performance levels possible, and each discrete ferrite formulation has an individual combination of electrical, magnetic and mechanical characteristics. The most common expression of ferrites' performance capabilities is in terms of their permeability (μ), a property that determines the ratio of the mag-

*See advertisement on page 381.

nitude of magnetic induction (B) to magnetizing force (H). The materials are normally categorized according to their initial permeability (μ_i).

Most ferrite geometries are configured to surround the cable or wire affected by interference (Figures 1 and 2). Ferrites are frequency sensitive with respect to permeability. If a ferrite component is used in an application where a signal has elements that exceed its optimal frequency range, the result is increased core loss and decreased permeability. The circuit which incorporates the ferrite then displays a substantially higher series resistance and a lower inductance reactance; and an impedance damping of the unwanted signal frequencies results.

Stated most simply, the operative characteristic which makes ferrites effective in EMI suppression is their variable sensitivity to frequency. With a ferrite installed as a suppressor, lower frequencies will pass with no significant loss. But above the frequency where ($\tan \delta/\mu$) climbs sharply (see Figure 3), the signal couples with the ferrite to create an impedance which is quite high compared with the rest of the circuit. The offending RFI is thus immediately and consistently blocked out.

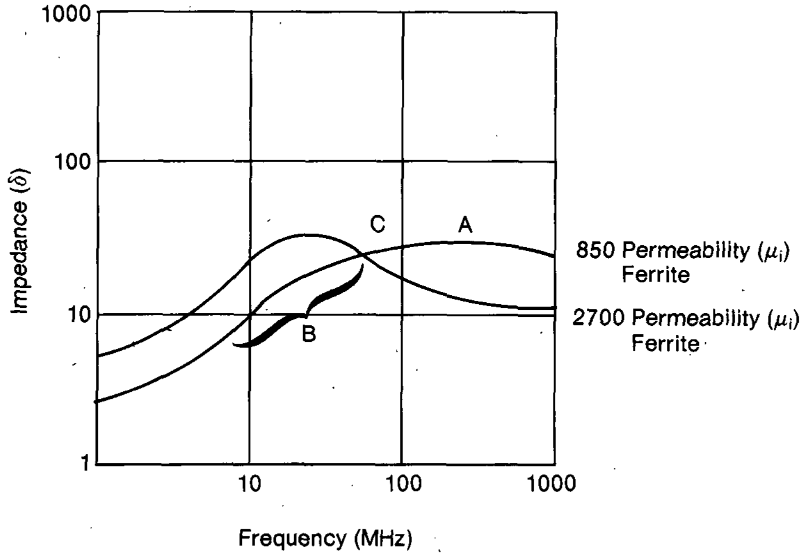


Figure 3. Typical Attenuation Profiles.

Expressed somewhat differently, ferrites function by adding greater resistive impedance at high frequencies which are beyond the ferrites' inherent ferromagnetic resonant frequencies. The ferromagnetic resonant frequency is that frequency where a decrease in initial permeabil-

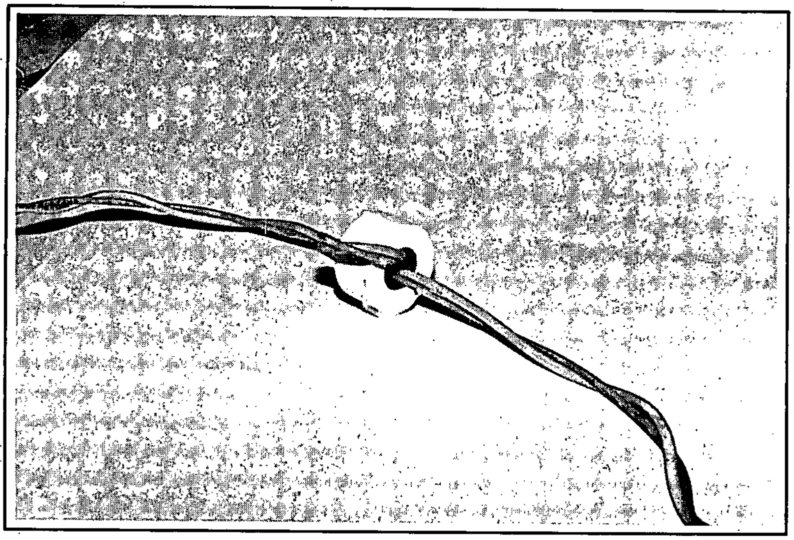


Figure 4. Circular Ferrite Snap.

ity and a rapid increase in high frequency losses become quite evident.

It is this greater resistive impedance which allows this basically passive, apparently simple material to suppress multiple signals in a variety of application situations without adjusting or tuning. It is only a lack of this knowledge which has earned ferrites the reputation of being "magic" or "mysterious".

Alternate suppression solutions, such as different types of filters or cable shielding, are often significantly more expensive, awkward to use, and in many cases, considerably less effective. When compared to laminated or powdered iron cores, the most important advantage of ferrite is its high resistivity. Ferrite has a concentrated, homogenous magnetic structure with high permeability, is consistently stable versus time and temperature, and has no high eddy current losses.

Understanding the various practical modeling techniques employing ferrite sheds further light on the ferrite "mystery". As indicated above, a wide range of formulations is possible. The major application factors to be used when defining a specific ferrite solution for a particular interference problem include the following.

- Frequency where 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 requirements

The frequency range requiring attenuation must be matched to the performance profile of a given ferrite composition (Figure 3). The optimum profile would be a ferrite in which the highest attenuation level coincides with the disruptive frequency (A). That same ferrite could be used even if the frequency falls in a lower area of its impedance curve (B) but there would be correspondingly reduced attenuation. Conversely, a different ferrite formulation could be employed in the same frequency situation with the intent of using a lower part of its performance curve (C). Space and weight considerations are not normally a concern since good quality ferrites provide high performance for a given cubic volume.

Interference control standards are mandated by various regulatory agencies in this and other industrialized markets; either they are expressed in, or they can be converted to, decibels insertion loss (dB). Insertion loss, a measure of the effectiveness of a filter, is described as the ratio of voltages with, and without, the filter in the circuit. The voltage ratio is then converted to dB by dividing the circuit impedance with the filter by the circuit impedance without the filter, converting the result of $\log_{10}$, and then multiplying by 20.

The modeling procedure to calculate impedance characteristics of the source and load may be coupled with the ferrite attenuator and developed as follows:

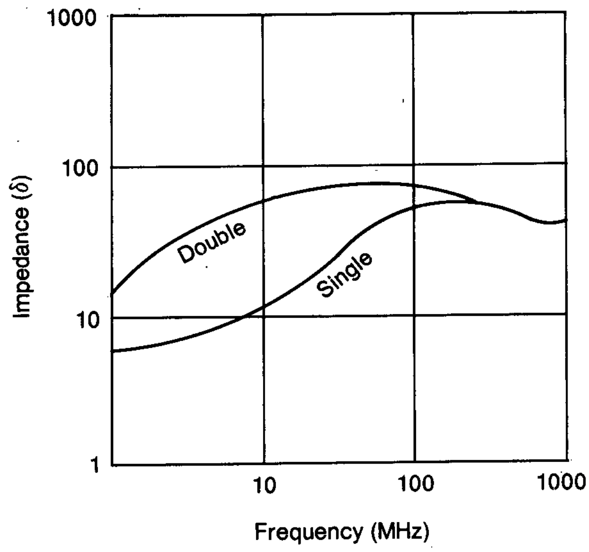


Figure 5. Attenuation vs. Single or Double Passes Through Ferrite.

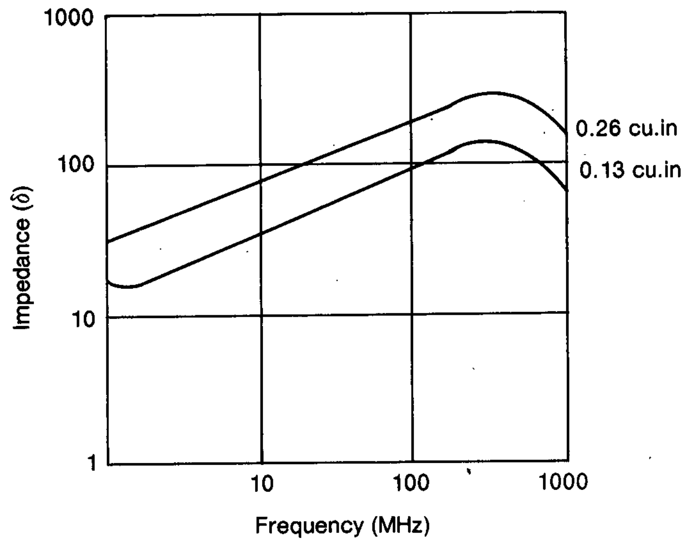
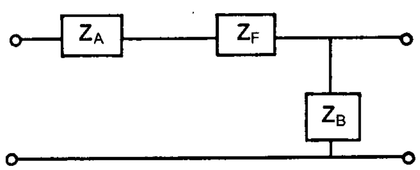


Figure 6. 850 μ_i Material Comparison of Impedance as Related to Cubic Volume.

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



Where

Z_A = Source Impedance

Z_B = Load Impedance

Z_F = Ferrite Impedance

If the circuit impedance ($Z_A + Z_B$) is 1 ohm and the ferrite is 500 ohms, then the insertion loss will be:

$20 \text{ Log}_{10} (1 + 500)/1 = 54 \text{ dB}$

Even though the same unit of ferrite is used, the attenuation provided by a ferrite filter can differ substantially as the original circuit impedance varies. The ferrite is more effective when the circuit impedance is low. For example, by using the same 500 ohm ferrite in a 50 ohm circuit, the results will be:

$20 \log_{10} (50 + 500)/50 = 21 \text{ dB}$

With a high circuit impedance, it becomes necessary to increase the number of turns or passes through the ferrite (Figures 4 and 5) or to use a larger amount of ferrite (cubic volume) in the circuit in order to achieve the same level of insertion loss. When additional ferrite volume is added, impedance increases on almost a direct percentage basis; i.e., a 50 percent increase in volume will provide about 50 percent increase in attenuation (Figure 6).

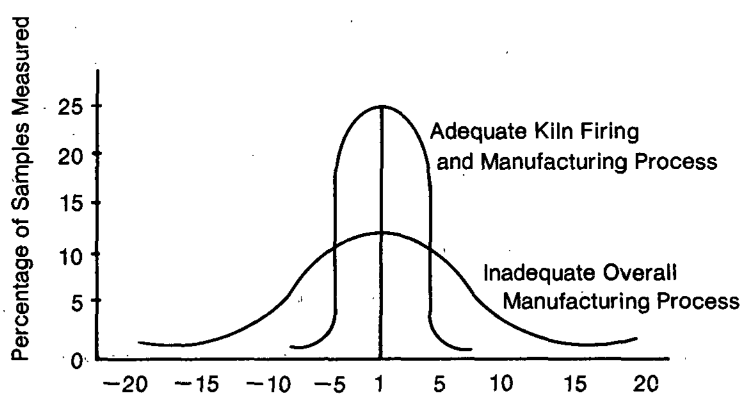


Figure 7. Percentage Variation of Impedance Measurement at 100 MHz (850 μ_i Material).

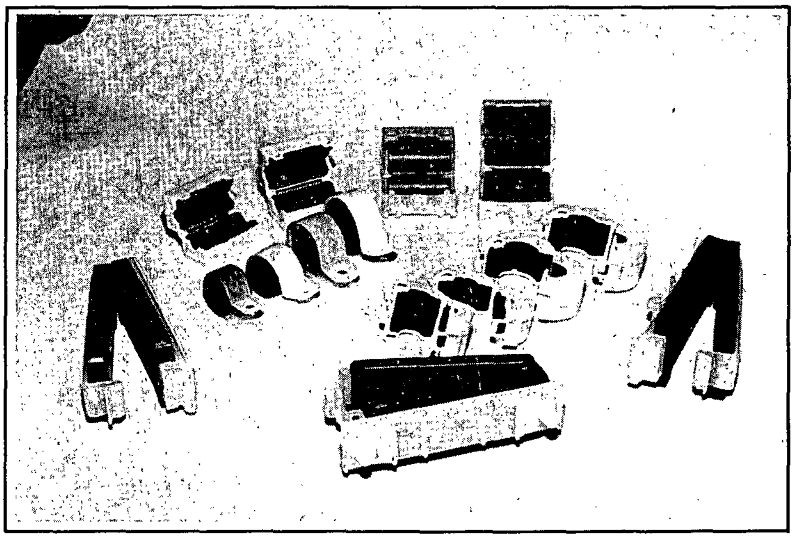


Figure 8. Ferrite Clamps Configured to Surround a Wire.

Consistent ferrite performance is necessary if the limitations and requirements of regulatory agencies are to be met successfully and reliably. However, no two manufacturers' products are the same, and there are significant variations in performance standards among the brands currently on the market. In most cases, an attenuation safety factor can be prescribed, but it is recommended that the permeability variation from the mean be kept to a minimum.

By controlling the formulation recipe, the manufacturing process, and finishing operations, consistent ferrite performance can be expected both within a batch and from batch-to-batch. The major factor in performance variations is usually the kiln firing process. Inferior products frequently come from markets where fuel is at a premium, and kiln firing time is reduced accordingly, sometimes by as much as 60 percent (8 hours compared to the normal 21-hour firing schedule). Without adequate firing, ferrite may easily fail to develop the homogenous spinel structure required for quality ferrite performance. It is not uncommon to find products on the market today with variations as high as 30 percent above or below the mean (Figure 7). These variations mean a consequent reduction in performance by the same cubic volume.

Installation has, at least until recently, presented some problems in ferrite usage. Initially, ferrites had to be strung onto a wire or cable before termination; post-production applications required dismantling and reassembly. Split geometries later became available, but methods for holding the segments together, including tape and shrink tubing have often been makeshift and costly. Other problems facing engineers using ferrites have been the need for securing mounting and sometimes the need for insulating ferrites from other components in an assembly.

Improved configurations have recently come to the market. Some have split geometries inside an integral mounting case which can be snapped around a wire or cable with no loss in performance (Figure 8); some feature adhesive strips, hardware holes or tabs for secure mounting.

Once understood, ferrites are easily engineered. They should no longer be an enigma in RFI control. ■