Non-permeable Cable Magnetic Shielding Properties

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Magnetic Fields in Shields

The only way a non-permeable metal cable shield can prevent penetration of an external H-field into the shielded volume is by generating an opposing magnetic field of the same strength but opposite in direction. This situation exists when the shield forms part of a closed loop, as shown in Figure 1, allowing the induced current to flow.

The induced current created its own magnetic field, which opposes the incident field and creates a null inside the cable. Lenz's Law states that the field produced the loop will oppose any change in the external field. The issue here is nulling a sine wave with another sine wave 90 degrees out of phase, which is impossible. The solution is to shift the phase of the second sine wave until cancellation occurs. This can be done by making the loop resistance very low. If loop resistance is high, the induced current is small (equal to induced EMF divided by R) and also proportional to the rate of change of the incident magnetic field (from Faraday's Law of Induction). That would produce a null. If resistance is low, the loop current is larger, and the induced magnetic field may be nearly proportional to the incident magnetic field so that nulling can occur.

The response of a closed inductive loop to an external sinusoidal flux passing through the loop results in the EMF due to the external field being diminished by the amount of EMF caused by the loop current, to arrive at a resultant EMF which would drive current around the loop. The resultant equation is:

$$\frac{d\phi}{dt} - L\,\frac{di}{dt} = iR$$

The first term is induced EMF from the external field (Faraday's Law of Induction). The second term is the EMF due to loop self-inductance. The iR quantity is the resultant voltage developed across the loop resistance. Loop resistance could be distributed around the loop, or it could be a discrete localized resistor for ease of measurement. For the purpose of this analysis, knowledge of flux direction is unimportant, so other combinations of algebraic signs would also work.

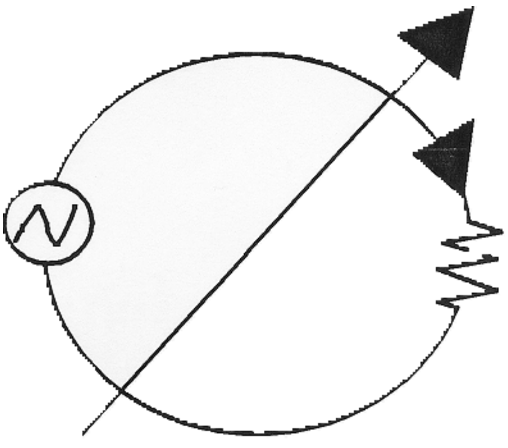

Figure 1 - Closed Loop Exposed to a Magnetic Field

Now let R go to zero and assume that the excitation is sinusoidal. For this condition, the first equation simplifies to:

$$i'(t) = \phi'/L$$

Rewriting for phase shows that loop current is in phase with the impinging magnetic flux.

$$\Phi' = i'(t)$$

The flux produced by the loop current also happens to be $\Phi' = iL$

and the two equal fluxes are in opposite directions, so that the total flux passing through the loop is zero. The cancellation of fluxes through a hypothetical closed loop goes a long way toward reducing fields very near the loop, and explains the shielding process of magnetic fields in cables.

Now suppose in the first equation, resistance R is non-zero, and that phase and current are sinusoidal functions with frequency $\omega = 2\pi f$ (f is in hertz). It can be shown that the amount of flux cancellation will depend on both Rand L.

If R<<wL, then induced EMF is drastically reduced. If >>wL, then induced EMF is not significantly reduced. In terms of shielding effectiveness, as the frequency of the impinging noise field is increased through the RF range, the requirement for a low R is gradually relaxed and magnetic shielding becomes easier. As frequency is decreased into the audio range, R may have to be so low as to be unattainable and shielding effectiveness disappears.

This analysis is applied to the loop formed by a cable braid and a ground plane. EMF on the coax inner conductor will track the braid EMF. As the EMF on both is reduced, the desired shielding is achieved.

For the real world case of non-uniform magnetic fields near a cable shield, the non-zero fields integrate out to a total of zero over segments of a coax, so that the total EMF can be zero. The whole shielding concept works only if all loop inductance is coincident with the portion of the loop where the total EMF is to be zero. (the shielded cable from end to end). Any other inductance, such as the inductance of a pigtail termination at the end of the cable braid, will degrade shielding effectiveness.

Flux in Mu-Metal Shields

Lines of flux are not attenuated in Mu-metal. What really happens is the Mu-metal looks like a lower impedance path for lines of flux then air. The Mu-metal divests the flux lines and tends to concentrate more of them into the metal then in the air. The process is called flux diversion. Figure 2 shows the path of flux lines traveling around a Mu-metal box.

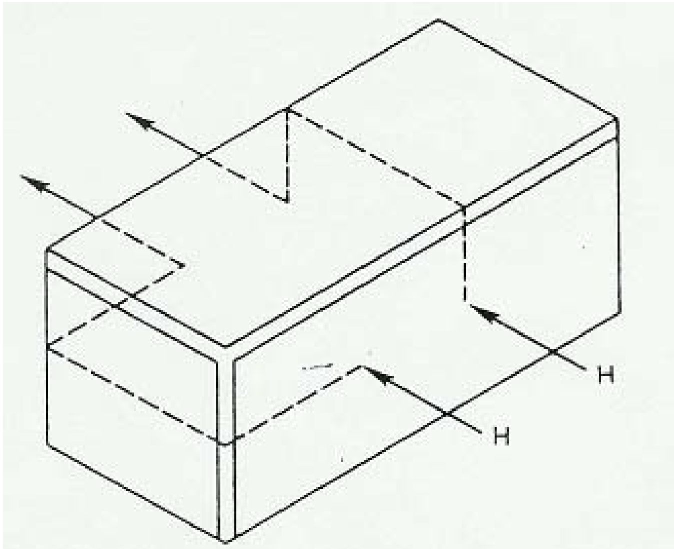

Figure 2 - 2 Flux Patterns Through Mu-Metal

$$B = \frac{\mu_o H_o A_e}{a_T} = \frac{\mu_o H_o A_e}{4\Delta(h + l)}$$

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where,

- μ_o = permeability of air ($4\pi 10^{-7}$)
- H_o = H-field exterior of enclosure (oersted)
- A_e = effective flux capture area ($A_e = 2A$)
- a_T = total cross-sectional area of four panels
- Δ = material thickness
- h = enclosure height
- l = enclosure length
- B = flux density (gauss)
- A = physical flux intercept cross-section area of enclosure perpendicular to magnetic flux lines (four side panels)