The Role of Ground Bonding in Cable Assembly Shielding

Electronic systems can fail to meet shielding performance requirements as a result of faulty RF grounds.

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INTRODUCTION

Shielding cable assemblies is usually one of the last steps in the design of an electronic system which must meet susceptibility and radiation requirements. Normally, the system has had all of the printed circuit boards and cabinets optimized for the shielding necessary to meet whatever specification will be imposed on the system. However, when testing a well-designed system and a well-designed shielded cable assembly, the radiation or susceptibility signature is often not near the amount predicted by the combination of those elements. Why do the various subcomponents of the fully integrated system not comply with the expected? One reason that the system does not meet the expected shielding requirements is that the RF ground is faulty. Since many electrical engineers today have had most of their education and experience in digital electronics, and very little in analog or RF engineering, the specter of a faulty RF ground is a real possibility and may be nearly impossible to detect.

This article addresses the subject of RF grounds and the effect of proper and improper RF grounds on the total system performance and its response to susceptibility and radiation. Also discussed are methods to determine if the loss of shielding is due to poor RF grounding or to other factors.

Signal grounds are necessary for systems to work; however, poor grounds in signal paths often do not lead to a catastrophic failure of the system. In fact, the common practice of single point grounding, a vital necessity in analog and high frequency systems, is often violated without penalty in low clock rate digital systems. This lack of penalty in the digital system will often lead the digital engineer into a false sense of security concerning

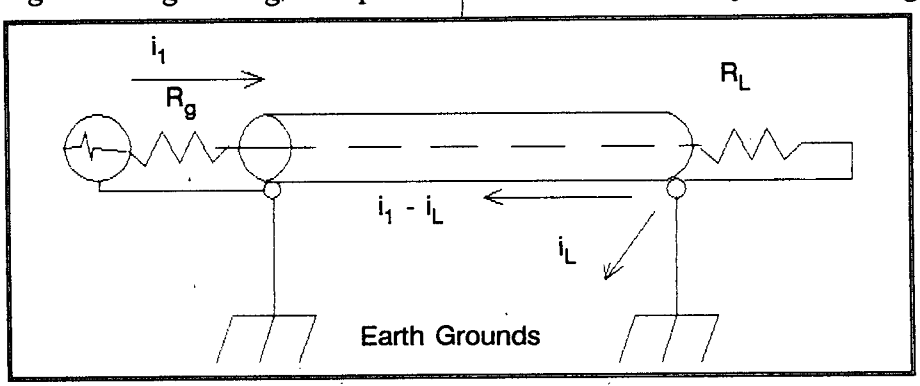

FIGURE 1. Shielded Terminated Wire.

grounds and will lead to catastrophic failure in the shielding of the system.

What, then, are the symptoms of an RF ground problem and what are the effects?

GROUND BONDING

To understand the effects of poor grounding, one must first understand how a shield on a wire works. The relationship of the current to the shield can be investigated by visualizing a shielded wire that has its shield terminated to ground (Figure 1).

If the shield is to be effective, then the ground current, i_L, must be much less than the shield return current, $i_1 - i_L$. But why should it be if the ground resistance is much less than the shield resistance?

In order to understand how this is possible, the equivalent circuit of the shielded line must be considered and the mesh equation that describes the shield-ground plane loop must be developed. Figure 2 shows the equivalent circuit for the shielded terminated wire in Figure 1.

In this circuit the following hold:

L_1 = the inductance of the center conductor over the ground

L_s = the inductance of the shield over the ground

M = the mutual inductance between the shield and the wire ($M = L_s$)

R_s = the shield resistance (also known as the transfer impedance at high frequencies)

From these parameters the mesh equation for the shield-ground loop is developed:

$$i_1\,[-R_s + j\omega\ell\,(M - L_s) + i_L\ell\,(R_s + j\omega L_s) = 0$$

Rearranging terms and dividing gives:

$$i_L / i_1 = \frac{R_s + j\omega(L_s - M)}{R_s + j\omega L_s}$$

But: $M = L_s$, therefore,

$$i_L / i_1 = \frac{1}{1 + j\,\dfrac{(\omega L_s)}{R_s}}$$

therefore,

$$i_L << i_1 \text{ for } \omega L_s >> R_s$$

Thus, the ground resistance must be much smaller than the shield resistance if the shield is to operate effectively.

In an operating system the ground is normally made by the connector interfaces. Usually, this is accomplished by screw threads or by a bayonet coupling. The resistance of this coupling is normally in the neighborhood of milliohms, which for long lines can give rise to a ground current that is high enough to violate the parameters discussed above.

Once a significant ground current begins to flow, the shield of the cable begins to act like a radiating antenna and the shielding effectiveness can be totally destroyed.

REDUCTION OF GROUND CURRENT

In order to maintain a condition where $i_L << i_1$, the ground potential at the two ends of the shielded line must be kept as nearly the same as possible.

Three separate methods of assuring this are: a good ground connection from connector to connector at both ends of the cable assembly, thus assuring that both ends are relatively close in ground potential; connecting both pieces of equipment together using ground straps; and connecting both pieces of equipment to earth ground using ground straps.

When the most commonly used ground strap, that of braided construction, is used, it sometimes leads to less than acceptable ground referencing. How, if the resistance is low, can this be possible? The grounding bond always exhibits a finite impedance due to the material

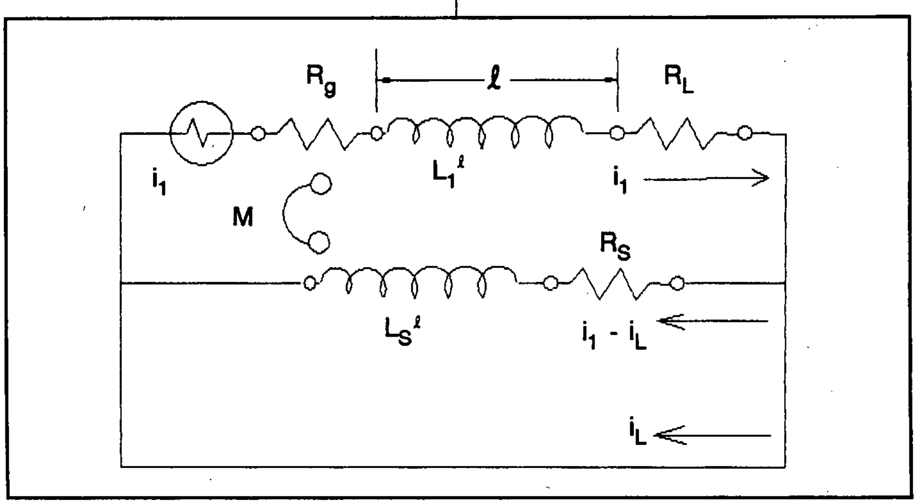

FIGURE 2. Equivalent Circuit of Shielded Wire.

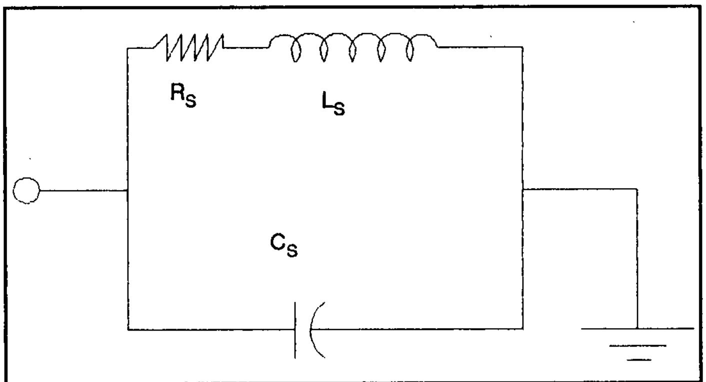

FIGURE 3. Ground Strap Equivalent Circuit.

of the ground strap and the geometry of the strap as well as the geometry of the grounded equipment. The effectiveness of the ground strap depends directly on this impedance.

The equivalent circuit of the ground strap illustrated in Figure 3 can be used to predict the effect of the grounding strap.

The elements of this circuit include a resistance, R_S, and an inductance, L_S, which are specific intrinsic properties of this ground strap alone. In addition, there is a capacitance, C, which is representative of the stray capacitance between the strap and the ground plane.

The DC and low frequency resistance of the ground strap is given by:

$$R = \frac{\epsilon \ell}{A}$$

where:

- ϵ = the resistivity of the material in ohm-meters
- ℓ = the length of the ground strap in meters
- A = the cross-section area of the ground strap in square meters

When the skin depth of the radiation decreases, which happens at higher frequencies, the depth of penetration of the current into the conductor decreases until the current no longer penetrates fully into the conductor, and the effective area of the ground strap decreases. At the same time, the resistance increases. Therefore the ground strap becomes less effective and the RF resistance of the ground strap must be calculated using a more complex equation.

For higher frequency applications, an RF resistance multiplier must be developed which allows for a correction due to the effective diameter of the individual wires at higher frequencies. The skin depth in meters is calculated from;

$$\delta = 50.33 \sqrt{\frac{\rho}{\mu_r \, \rho}}$$

where;

- f = frequency in Hz
- μ_r = relative permeability of the ground strap

Then, from the ratio of the effective diameter of the ground strap to the skin depth, an RF resistance multiplier is calculated. (See Table 1.)

Table 1. RF Resistance Multiplier.

d/δ	MULTIPLIER
1 < =	1
1 - 4	$1 + (d/\delta)^4/768$
4 - 10	$-5/9 + 7\,(d/\delta)/36$
= > 10	$d\,/\,(4\delta)$

The inductance of the ground strap, as shown in Figure 3, must also be taken into consideration. This formula is a function of the geometry of the strap. For example, a straight strap of circular cross section has an inductance given by:

$$L = 0.00508\, \ell(\ell_\eta \frac{4\ell}{d} - 1 + \mu_r K)$$

where:

- L = the inductance of the strap in microhenries (μH)
- ℓ = the length of the strap in inches
- d = the diameter of the circular strap in inches
- K = the skin effect correction factor

Finally the stray shunt capacitance is computed from:

$$C_s = \Sigma A/d$$

where:

- Σ = the permittivity (absolute) of the dielectric between the ground strap and the ground plane
- A = the effective area of the ground plane beneath the ground strap in square meters
- d = the effective separation between the ground strap and the ground plane in meters.

Since the ground strap is not used in isolation, there is a term for the inductance and the capacitance of the grounded equipment to the ground plane. However, in the normal case, the inductance and shunt capacitance of the ground strap are usually so much greater than that for the equipment that the terms relating to the equipment can be ignored.

Now armed with a method for computing the effective circuit parameters for the ground strap, first principles can be used to predict the expected radiation from the system coupled together with ground straps.

Simplistically, if the engineer assumes that the entire power consumed in the ground strap is converted to external RFI radiation, an envelope can be determined. Since the skin effect causes the effective resistance to decrease with frequency, radiation of the total power will be skewed toward the higher frequencies and should correlate with the measured system signature.

EMISSION REDUCTION

Since the factors determining radiated emissions are complex, the best method of reducing emissions is one of measurement and change, then re-measurement.

Once the engineer has determined that the system does not perform as originally predicted, a hierarchy of testing must be developed. Within this hierarchy, those items most likely to cause the measured problems should be placed at the top of the list. Once the list has been developed, the engineer can then set about determining the best solutions until the system falls within acceptable limits.

A sample system and its hierarchy is shown with the suggested steps to reduce the emissions (Figure 4). All components must be explored and treated if a proper cost-effective solution is to be found.

- Chassis 1 - minimum shielding effectiveness 60 dB
- Chassis 2 - minimum shielding effectiveness 60 dB
- Cable assembly - minimum shielding effectiveness 60 dB
- Total connected system - minimum shielding effectiveness 30 dB

HIERARCHY OF EMISSION POTENTIALS

1. Ground of chassis 1 and chassis 2
2. Connection of cable assembly to chassis 1 and chassis 2
3. Lay of cables
4. Orientation of system

As can be seen, the lay of the cables and orientation of the system have been given a lower position in the hierarchy of the emission potentials. This was done, not because of their low potential, but because these are areas that will not be addressed in this article.

A stepwise approach to the system grounding problem is as follows:

1. The two ground leads from the chassis 1 and chassis 2 to

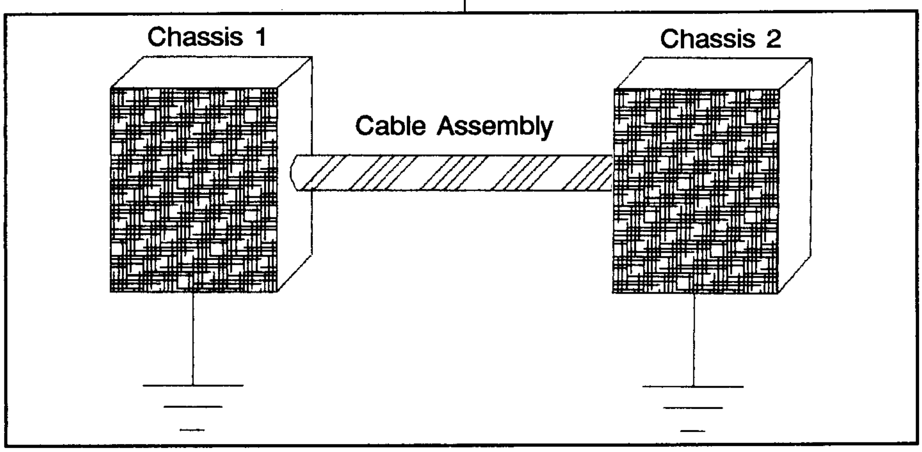

FIGURE 4. Sample System.

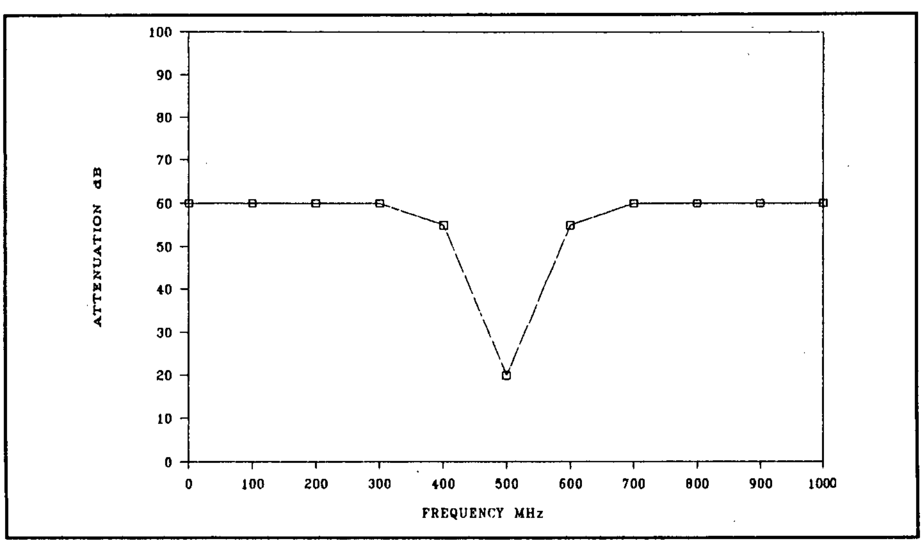

FIGURE 5 . Frequency Response of Resonant System.

ground are shortened.
2. The system RFI/EMI signature is measured.
3. If the signature has improved, the ground lead is shortened until no additional improvement is noted.
4. The ground strap is changed to a single heavy gauge wire.
5. The system RFI/EMI signature is re-measured. If improvement is noted, the ground braid inductance is the culprit and consideration should be given to using heavy gauge wire in place of braid for this system.
6. Both chassis are bolted to a single heavy gauge aluminum plate.
7. The system RFI/EMI signature is re-measured. If the system does not perform as originally expected, then the step of checking the attachment resistance of the connector-to-connector interface is indicated.

In order to check the connector-to-connector interface problem potential, the system is first restored to the original configuration. Then the following procedure is used:

1. With only one end of the cable assembly attached, the resistance between the connector on the cable end and the chassis connector to which it is connected is measured. This resistance should be no more than the equivalent resistance of the same length of connector.
2. If this resistance is as indicated, the resistance between the chassis connector and the chassis ground is measured. Once again, this resistance should be no more than the equivalent length of chassis.
3. The same test is performed with the other end of the cable assembly attached to the other chassis.
4. Should any of these resistances be higher than expected, the offending portion is wrapped with copper tape that has a highly conductive adhesive. Then the RFI/EMI signature test is performed once again. These resistances are more likely to be a good indicator of RF resistance than the ground strap resistance since the material configuration used does not give rise to the inductances of braided ground strap.

Once these tests have been performed, it will be possible to eliminate the ground as a source of deviation from a proper system RFI/EMI signature.

OTHER PROBLEM AREAS

If the system does not perform as expected after RF grounding has been eliminated as a possible source of system emission or susceptibility problems, other areas can be checked for sources to the problem. Most likely a system will only fall out of compliance at discrete frequencies, as shown in Figure 5. This frequency sensitivity is most likely caused by resonance effects on the surface of the cable shield. When the length of the cable assembly is an even multiple of the wavelength of the signal inside the cable, a standing wave is established on the surface of the shield that will couple to the external environment in such a manner as to give rise to excessive RFI. Such a system is shown in Figure 6.

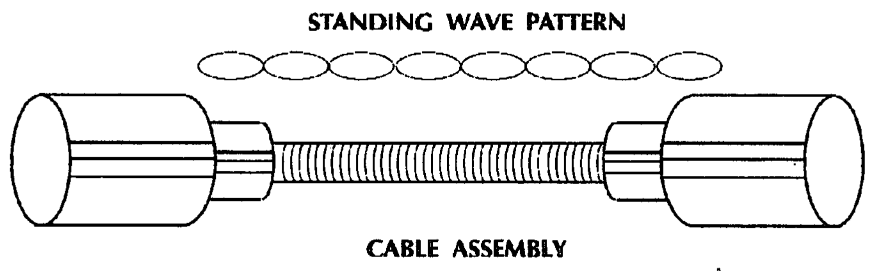

FIGURE 6. RFI Coupling of Resonant Cable Assembly.

CONCLUSION

When a system does not perform as expected under RFI/EMI testing, the possibility of poor RF grounding should be examined first. The solutions to poor RF grounding may not seem easy; however, they will become easier as one gains experience. Solutions are normally gained through empirical cut and try methods; however knowledge of the mechanisms of RFI/EMI from a poor RF ground will give specific clues that will lead to a properly operating system.

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