



Design Tips

Bruce Archambeault, Associate Editor

Welcome to Design Tips! This issue, Colin Brech will discuss shielded cables and how they work! This topic is not as straightforward in many practical applications as many might think (or wish).

Please send me your most useful design tip for consideration in this section. Ideas should not be limited by anything other than your imagination! Please send these submissions to bruce.arch@ieee.org. I'll look forward to receiving many

"Design Tips!" Please also let me know if you have any comments or suggestions for this section, or comments on the Design Tips articles.

You will also find "Design Tid-Bits" at the end of the Design Tips Article. These Tid-Bits are intended to be a very short description of EMC design best practices and cover a wide range of EMC design issues. Please send me your contributions to bruce.arch@ieee.org.

Design Tip: A Detailed Look at Shielded Cable Terminations

By Colin E. Brech, Southwest Research Institute, San Antonio

To best understand and implement the termination of an EMI shielded cable, it is essential to understand exactly what connections must be made. There is no value in simply saying, "ground the shield" because, whatever this may actually mean, it is usually left undefined. This design tip will clarify the current paths that must be properly connected, from the most basic case to more complex ones where the cable shield may have multiple functions. When the requirements for the different current paths can be separated and made clear, the design of the cable termination can proceed with confidence.

The most basic cable shield termination is the connection of the full circumference of the cable shield to the outside of the shielded enclosure. Physically this is comprised of the connection of the cable shield to the connector back shell, and the connector back shell to the enclosure. However, even in this case there are two independent current paths to consider, that on the inside of the shield and that on the outside.

To better understand these two paths, consider the following two situations: an immunity case, where all current that is induced on any part of the outer surface must stay on the outer surface; and an emissions case, where all energy is required to stay contained within the shield. This is hopefully an obvious point but it highlights a concept that is frequently missed: over most frequencies, all EMI shields are effectively formed of two independent conductors, the inner and outer surfaces, as shown in Figure 1. This is due to the skin effect that forces the current to flow in an extremely thin layer at the surface of a conductor. Therefore, providing the shield conductors are thick compared to 5 or more skin depths, there is no coupling between currents on the inner and outer surfaces of the conductor.

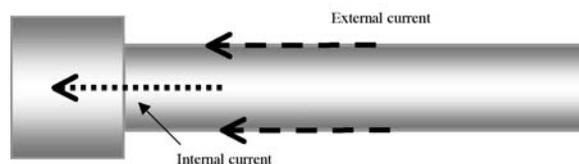


Figure 1. EMI Shield Cross-section Showing the Independent Current Paths

To maintain a high level of EMI control it is essential that the outer surface of the cable shield be well bonded to the outer surface of the enclosure. However, an EMI shield is often required to provide part of or the entire path of the current return for the signals within the shield. Confusion concerning cable termination usually arises when the requirements for these signal paths are considered. The basic EMI shield bonding requirement then becomes clouded, which can lead to endless discussions on where a shield and other 'ground' conductors should be terminated. In addition to providing a return path for various signals, the cable shield can also provide other functions. Following are five examples of current paths that an EMI shield may provide:

- Return path for single ended signals
- Return path for imperfectly balanced differential signals
- Return path for the power distribution
- ESD protection
- Equi-potential bonding between enclosures

Return Path for Single Ended Signals

When a single conductor is used to carry data within an EMI shielded cable, the data return current must pass along the cable shield. It is important to repeat that the return current

will be passed along the inside of the cable shield and not the outside of the shield. Therefore, for the circuit to be terminated and operate correctly there must be a path to complete the circuit from the shield to the enclosure to the connected port. This is shown in Figure 2.

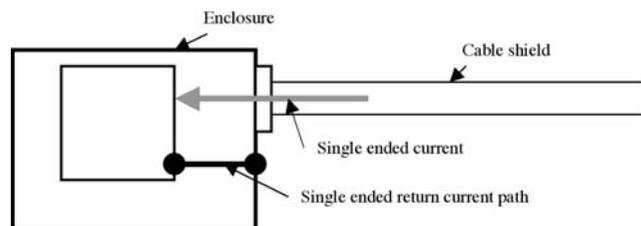


Figure 2. Single Ended Data Line Termination

The return current path termination at the enclosure is a required functional termination but it is not equivalent nor does it replace the shield termination to the enclosure. A common mistake is to provide only the termination to the circuit board and leave off the critical enclosure connection.

Return Path for Imperfectly Balanced Differential Signals

Unless a tremendous amount of care is taken, differential lines are usually imperfectly balanced, and even a well-balanced pair will be unbalanced to some extent when placed within an overall shield. Any imbalance results in a common mode current on the differential pair that again returns on the inside surface of the overall shield, just as it does for the single ended case. A path must be provided for this common mode return current to follow that of the data pair as shown in Figure 3.

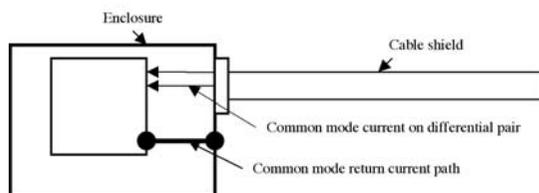


Figure 3. Common Mode Current Termination for a Differential Pair

When the differential pair has its own inner shield to isolate it from other pairs, which is usually done to minimize cross talk, the common mode current created by the imperfect balance in the differential signals is returned along this inner shield. In this situation it is essential that the common mode current follows the path of the pair from the source location to the load. The correct termination method is to connect the inner shield to the reference of the load as is shown in Figure 4.

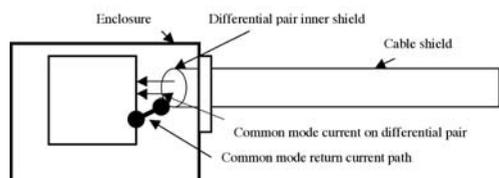


Figure 4. Common Mode Current Termination for a Shielded Differential Pair

The connection of the differential pair inner shield is in addition to the EMI shield connection to the enclosure, and is primarily for maintaining signal integrity rather than EMI control. In this specific case it is not essential to connect the board reference to the enclosure.

Return Path for Power Distribution

Since an EMI shield is frequently simply seen as “ground”, in many people’s perspective this can be translated to 0V or power return. While the merits of this are debatable, it should be realized that at DC the current is uniformly distributed across the entire conductor and that a suitable low resistance connection will be required. More importantly it should be realized that using the shield in this way has no EMI benefits, as there is nothing special about the power return. The RF currents associated with the signals will travel where they must, and can/will be along a different route than any DC power. Since power distribution is almost always single ended, the termination scheme shown in Figure 2 is applicable.

ESD Protection

A frequently required function of an EMI shield is to prevent ESD induced current from upsetting or damaging a device. In this situation it is imperative that the integrity of the shield bonding is high so that the high frequency components of the ESD pulse are not able to penetrate due to any common impedance between the shields inner and outer surfaces. Due to the high current and voltages involved in an ESD event, particularly low impedance terminations must be used to ensure adequate protection is achieved. As for other immunity cases, the requirement is to keep all the induced current on the outside of the EMI shield.

Equipotential Bonding Between Enclosures

The means of maintaining an equal potential between enclosures is unrelated to EMC emission or immunity issues and is a very poor intended use for an EMI shield. However, when multiple pieces of equipment are connected it is often found that the shielding has a lower resistance than safety ground straps, so if a strap is missing there can be AC line current passing along the shield. For single ended signals it is essential that the common mode range of the receivers is not exceed, either by an offset caused by excessive line current or from the net effect of many single ended signals within a shielded cable. A separate, heavy-duty ground strap can mitigate the effects of line current. While excessive signal return current within the shield can only be mitigated by lowering the impedance of the shield.

Now that the current paths have been identified, they should be incorporated into a schematic. The presence of an EMI shield on a schematic diagram is rarely shown in full; at best it may be identified simply with a ground symbol. If time is taken to draw out the conductors that comprise the shield, the different paths that must be properly terminated become apparent. Following are schematics for an ideal shield, a leaky shield, and a poorly terminated shield. Adding these elements appropriately into the interface schematics is an excellent way to address the termination of an EMI shielded cable.

The circuit schematic of a perfectly bonded, impenetrable shield is shown in Figure 5. As can be seen it is far from complex, but emphasizes the separation of the internal and external current paths. This is only valid when the connection of cable shield to connector back shell, and connector back shell to enclosure can be considered perfect over the frequency range of interest.

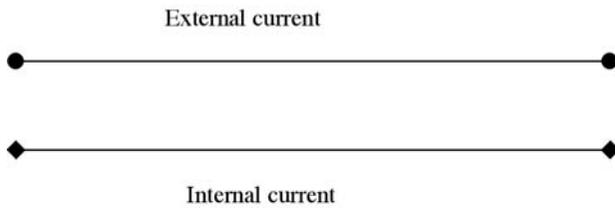


Figure 5. Schematic of a Perfectly Bonded, Impenetrable Shield

In reality, there are impedances that link the internal and external current paths. A leakage path can exist through the shield if either it is a very thin shield (less than a few skin depths) or it is comprised of a very open-weave braid. The schematic for this case is shown in Figure 6.

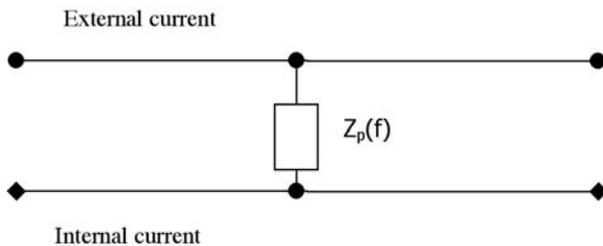


Figure 6. Schematic of a Perfectly Bonded Penetrable Shield

When a good shield is connected imperfectly, such as in the case of a pigtail connection, there is an impedance in series, common to both the external and internal currents as shown in Figure 7.

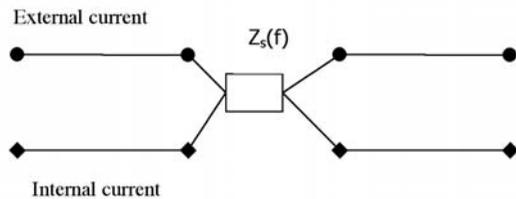


Figure 7. Schematic of a Poorly Bonded, Impenetrable Shield

In the case of a pigtail $Z_s(f)$ will be inductive. If the shield is connected via capacitors to provide DC isolation the impedance will be more complex, capacitive at low frequencies and inductive at higher ones. As this impedance is in the signal return path it has the potential to impair the signal integrity as well increase EMI risks. While in practice a pigtail connection may not be used, it is quite possible that a connector back shell is bonded at only a few points to the enclosure, such as with a pair of jack screws. This is a similar though less severe case but may require evaluation.

The combination of the shield leakage $Z_p(f)$ and the common termination impedance $Z_s(f)$ provides a more complete description of the cable shield. As can be seen, this is far more informative than a single 'ground' point drawn in the corner of a schematic.

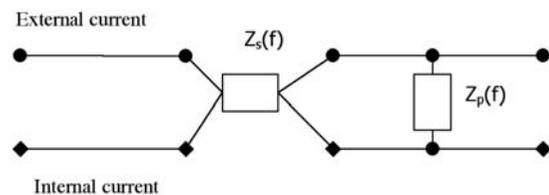


Figure 8. Schematic of a Poorly Bonded, Penetrable Shield

This design tip has opened up some of the buried details of an apparently simple structure: the correct termination choices for an EMI shielded cable. Once the physical current paths are understood, an appropriate schematic can be developed and much of the confusion that frequently surrounds this topic can be dispelled. Application of these schematic elements into a more complete functional schematic can ensure that all the expected functions of the EMI shield are properly fulfilled.

EMC

Design Tid-Bit

The usefulness of decoupling capacitors on printed circuit boards is limited by the connection inductance plus the equivalent series inductance (ESL) of the capacitor. The connection is usually much higher than the ESL (typically about 0.3 to 0.5 nH). Connection inductance takes into account the distance between the capacitor vias and the distance down to the planes to which the capacitor is connected. Often simple rectangular loop inductance formulas will give a value of this inductance within about 20% of the result from more complex calculations.

--- Bruce Archambeault