Cable Shielding to Minimize Electromagnetic Interference

Anke Fröbel
Cottbus University of Technology, Germany
Wrocław University of Technology, Poland

***Abstract* - A cable shield is necessary to prevent emission of electromagnetic waves from the cable respectively to protect data and signal conductors from external electromagnetic interference (EMI). The effectiveness of a cable shield installation depends on the kind of EMI to be shielded and the type of termination at both ends. This paper depicts the different types of cable shielding. Moreover shielding effectiveness is analyzed.**

I. INTRODUCTION

Electromagnetic shielding reduces, or rather prevents coupling of undesired radiated electromagnetic energy in electrical equipment. It is established over a large part of the electromagnetic spectrum from DC to microwave frequencies.

In general, shielding is produced by insertion of a metallic barrier in the path of electromagnetic waves between the source of the radiation and the device which is supposed to be protected. The shielding may be applied at the source (if the source is known) or at the susceptible equipment. Fig.1. illustrates the two modes of shielding.

Cable shielding is commonly used for data and signal cables. The design of cable shielding and grounding is important for the reduction of electromagnetic interference. Each application requires individual considerations given that parameters such as cable lengths, noise frequency, signal frequency and cable termination methodology impact the final result. Improperly cable shielding can actually increase noise coupling and thus make the problem worse.

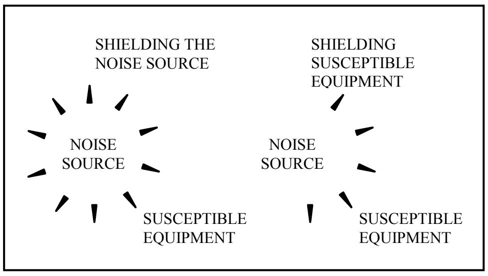

Figure 1. Modes of shielding: Shielding the source of noise or shielding the susceptible equipment.

II. TYPES OF SHIELDED CABLES

Since data or signal cables carry broadband signals, up to high frequency ranges, they need to be shielded to minimize radiated coupling. In addition, the impedance has to be controlled. The selection of a certain type of cable as well as the arrangement of signals and grounds rather shields in the cable determine the characteristic impedance of the transmission path.

In the following paragraphs the various versions of shielded cables are introduced.

A. *Coaxial cables*

A coaxial cable consists of an inner conductor, surrounded by an insulating layer which is then surrounded by another conductive layer, typically a fine woven braid for flexibility or a thin metallic foil, and than covered again with a thin insulating layer on the outside, shown in Fig. 2. The shield is grounded at multiple points at high frequencies and a single point at low frequencies. Coaxial cables are used in a frequency range of 20 kHz up to 50 GHz.

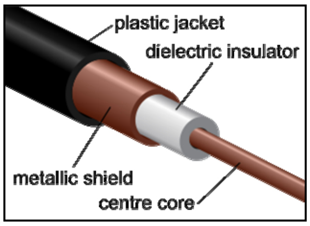

Figure 2. Coaxial cable cutaway

B. *Triaxial cables*

A triaxial cable is similar to coaxial cables but with another shield isolated from the signal return shield. The second shield is grounded, as shown in Fig. 3. Thus, triaxial cables provide a greater rejection of interference than coax.

C. *Twinaxial cables*

A twinaxial cable is a two-wire twisted balance line in a ground shielding braid, as shown in Fig. 4. The twisting provides cancellation of any induced noise voltage pickup caused by a leakage of the low-frequency magnetic field through the copper braid. Twinax are used up to 10 MHz.

D. *Quadraxial cables*

A quadraxial cable is a double-shielded twinax, as shown in Fig. 5. The outer shielding is grounded to the earth while the inner shielding is connected to the system ground. If there is no system ground available, both shields are earth grounded.

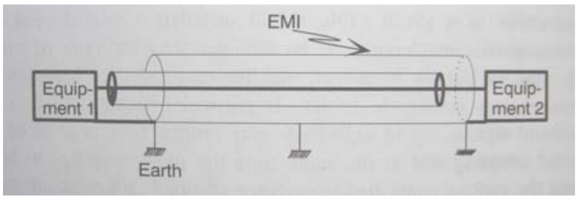

Figure 3. Shielded triaxial cable

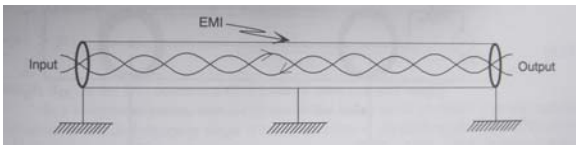

Figure 4. Shielded twinaxial cable

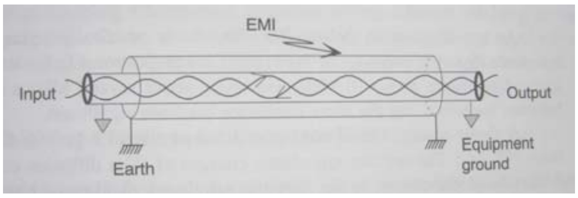

Figure 5. Shielded quadraxial cable

III. CABLE SHIELD GROUNDING

If a shielded cable is used to connect two systems, the shield has to be connected to a single ground reference. In order to prevent that electromagnetic energy penetrates through the shield, the outer surface of the shield has to be grounded, as shown in Fig. 6.

It is possible to ground the shield at one end (asymmetric), at both ends (symmetric) or in intervals along the length of the cable. The effectiveness of these different methods depends on the electromagnetic coupling mode and the length (l / λ) of the cable used for the interconnection.

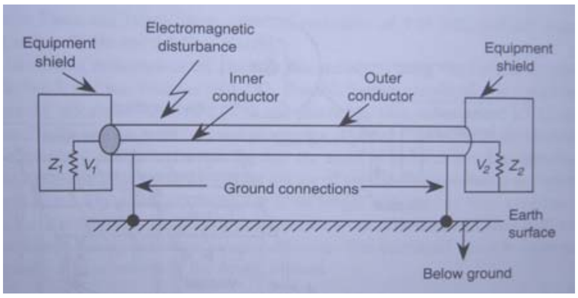

Figure 6. Cable grounding

There are two kinds of electromagnetic coupling in a cable:

1. Electric field coupling, the incident wave is polarized parallel to the conductor length, and
2. Magnetic field coupling, the incident wave is polarized normal to the loop formed by the cable and the ground plane.

The EMI voltage pickup in a cable increases with frequency. At high frequencies resonance phenomena produce maximum induced voltages for a certain cable length l such that

- both ends grounded + H-field excitation
  → no resonance
- both ends grounded + E-field excitation
  → resonance for $l = k\lambda / 2$
- one end grounded + H-field excitation
  → resonance for $l = (2k+1)\lambda / 4$
- one end grounded + E-field excitation
  → resonance for $l = (2k+1)\lambda / 4$

At low frequencies for E-field excitation it is more efficient to ground both ends, whereas for H-field excitation one end grounding has to be favored, since this eliminates the formation of a current loop by the cable and the ground plane.

At high frequencies both ends grounded configurations avoids resonances for E-field and H-field excitations.

In practice one ground connection is often preferred, since this avoids ground loops. However, for short cables, at low frequencies, the voltages induced by EMI at both ends of a coaxial cable become nearly equal and one end grounding is needed for E-field as well as for H-field excitations.

IV. TRANSFER IMPEDANCE OF CABLE SHIELD

The finite conductivity of shielding material as well as its small thickness and small openings in the braid allow electromagnetic fields to penetrate through the shield and induce currents in the line. Therefore it is necessary to evaluate the ultimately shielding effectiveness.

It is difficult to measure the field inside of a cable shield accurately. Moreover, the voltage measured at the end of the line depends on the type of termination. Therefore a definition of shielding effectiveness using the ratio of fields before and after the shield, or the ratio of voltage induced with and without a shield, is not adequate. An evaluation of the shielding effectiveness regarding the transfer impedance is more common.

The transfer impedance of a cable shield relates the current I_S flowing on the shield surface to the longitudinal induced voltage V_i per unit length on the outer side of this surface (see Fig. 7).

The sheath current I_S may result from an externally incident field or ground potential difference between the two ends of the cable.

Hence

$$V_i = I_S \times Z_t \tag{1}$$

where Z_t is the transfer impedance of the shielded cable.

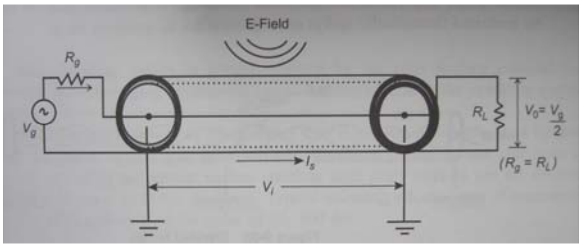

Figure 7. Model of transfer impedance coupling in coaxial cable

Z_t is expressed in ohms normalized to a one-meter shield length. The better the shielding the lower are the values of Z_t.

At frequencies below 100 kHz, Z_t is practically equal to the DC shield resistance R_{DC}. Above several MHz a capacitive coupling between the shield and the inner conductor has to be considered. At frequencies above 10 MHz, Z_t is proportional to the leakage inductance.

A single braided shield is a solid tube with rhombic or elliptical holes. The transfer impedance consists of three components. One of them is the diffusion impedance Z_r which expresses the relation between the shield current and the longitudinal electric field caused by the finite conductivity of the equivalent shield tube. The second component is the coupling inductance L_t term. It considers the magnetic field coupling through the openings in braided wire shields and the inductance between two interwoven parts of the braid. The third component is the so called skin inductance L_s, which results from magnetic fields penetrating the shield.

$$Z_t = Z_r + j\omega L_t + (1 + j)\omega L_s \qquad (2)$$

The transfer impedance of a single braided cable can be reduced by wrapping a metallic band (e.g. aluminum), or rather a conductive envelope (e.g. polycarbonate) over the braid. This way the coupling inductance L_t is reduced.

For thin-walled tubular shields the transfer impedance can be expressed as follows:

$$Z_t = \frac{1}{2\pi a\sigma t}\frac{(1 + j)t / \delta}{\sinh[(1 + j)t / \delta]} \qquad (3)$$

where a is the inner radius of the shield, t is its wall thickness, σ is the conductivity of the shield and δ is the skin depth of the shield.

At low frequencies and $t / \delta << 1$ the transfer impedance is

$$Z_t = \frac{1}{2\pi a\sigma t} = R_{DC} \qquad (4)$$

as mentioned above.

The transfer impedance and in order to that the shielding effectiveness differs significantly for the different types of shielded cables. Most common in use are solid semi-rigid coaxial, braided triaxial, braided coaxial, shielded quadraxial and shielded twinaxial cables (with descending order of effectiveness).

V. CONCLUSIONS

This paper presented analytical and practical aspects of cable shielding to mitigate electromagnetic interference. It was shown that the best shielding for any application depends on the application itself. The best solution for one situation may be bad for another set of conditions.

REFERENCES

[1] V.Prasad Kodali, *Engineering electromagnetic compatibility: principles, measurements, and technologies*, vol. I. New York: Institute of Electrical and Electronics Engineers, 1996, pp. 199-227.

[2] C.Sankran, *Power Quality*, vol. I Florida: CRC Press LLC, 2002, pp. 154-164.

[3] G. Vijayaraghavan, Mark Brown, and Malcom Barnes, *Practical Grounding, Bonding, Shielding and Surge Protection*, vol. I Oxford: Newnes, 2004

[4] http://en.wikipedia.org/wiki/Coax, February 7, 2009