Impedance termination of cable shields to reduce EMI coupling

Surge damage as a result of long cables connected to low voltage data systems can be prevented.

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This article proposes a solution to the problems encountered when long cables are used to connect low voltage data systems, and either data interference or lightning surge damage is encountered. Three separate interference regimes are addressed: the low frequency data interference caused by shield current coupling to the signal lines; the surge potentials, due to lightning, encountered when a remotely grounded conductor is isolated from a local ground; and the high frequency interference that can propagate along a shield and cause high frequency electromagnetic interference to electronics at the ends of the shielded cables. This article focuses on shielded multi-conductor cables where problems are most frequently encountered. However, these issues also apply to coaxial cables that are used for data transmission at spectral frequencies below 300 kHz. The proposed solution is to use a termination device that provides optimal termination at both low and high frequencies, while also providing a safe bleed path for the induced surge voltage.

GROUNDING CABLE SHIELD

Early experience with running long data lines for systems such as an RS232 interface or a modem quickly revealed that grounding the shield at each end would cause considerable data interference. The rule quickly evolved to ground the shield only at one end. However, this often did not work if the cables were much longer than 500 feet.

If lightning activity was significant, the location at the end of the cable where the shield was ungrounded frequently suffered component failures due to lightning induced surges. The solutions for this problem were varied, ranging from looking for a better ground to drain the surge current away from the electronics, to simply installing surge protection on all the circuits at the affected location. The purist insisted that the shield be grounded at each end to provide induced magnetic field cancellation and to provide voltage equalization to prevent surges. The surge immunity test provided a way to test systems, focusing on the grounds and power input.

As electronics operating frequencies have increased and operating voltage levels have decreased, a new problem has emerged; namely, fast transient interference occurs that upsets a microprocessor or activate alarms and protection circuits. In that case, the interference pattern is well known. The fast transients readily propagate along a conductor inadvertently acting as a radio frequency transmission line and radiate or couple to sensitive elec-

	1 kHz	10 kHz	20 kHz	40 kHz	80 kHz	120 kHz	200 kHz
Aggressor: Shield/Drain Wire with Ground Plane Return 2Vp-p (2mA/mV) into 4 Ω Load	4 A	4 A	4 A	4 A	4 A	4 A	4 A
Victim: Black Twisted Conductor, O.C., Common Mode Voltage V_1	36.0 mV	348 mV	708 mV	1.37 V	2.78 V	4.00 V	6.56 V
Victim: White Twisted Conductor, O.C., Common Mode Voltage V_2	38.0 mV	370 mV	748 mV	1.47 V	2.94 V	4.36 V	7.04 V
Victim: Twisted Conductor Loop, S.C. Current I (Normal Mode)	25 mA	154 mA	184 mA	204 mA	216 mA	232 mA	240 mA

Table 1. Twisted shielded pair cable interference levels.
The shielded twisted pair cable used for the experiment is 2 m in length and contains two twisted conductors, each having a 1.52 mm dia. and a twisted lay of 40 twists/meter. The mylar shield is 0.06 mm thick and is conductive on the outer surface only. The drain wire appears twisted synchronously with the pair and has a diameter of 1.52 mm.

tronics at the end of the conductor. The solution is to provide a shield around the sensitive electronics and *never* bring a conductor directly into the shielded environment. All conductors should be bonded directly or through a filter to the external surface of the shield boundary. The fast transient immunity test provided a way to test systems, focusing on the shielded cables and the power input.

SHIELD CURRENT AT LOW FREQUENCIES

Current flow on the shield of a cable always links magnetically with all internal conductors. If the cable shield is cylindrical and current flow is uniform, an equal voltage will be induced on all internal conductors. In this case, a circuit with reasonable common-mode rejection ignores the induced interference voltage.

A more serious interference problem results if the shield is not cylindrical or if the current flow is not uniform around the shield. A commonly-used cable is a twisted shielded pair cable constructed with a conductive mylar shield and "drain" wire in contact with the shield to facilitate shield termination. The drain wire appears to be twisted synchronously with the circuit conductors, yielding an apparent symmetrical construction. At low frequencies, the current flow, thought to be uniform around the shield, is shared with the drain wire. At very low frequencies, most of the current flows on the drain wire. This causes asymmetrical magnetic coupling to the signal conductors and results in normal-mode interference that is not easily eliminated. As frequencies increase, skin effect causes the current to flow on the surface of the shield and coupling reverts to common mode coupling.

TWISTED SHIELDED PAIR CABLE INTERFERENCE DATA

Experimental data demonstrates that current flow in the drain wire of a shielded twisted pair cable induces a differential mode voltage in the shielded conductors (Figure 1).

Open circuit voltage induced on each twisted pair conductor is measured in a manner similar to measurement of shield transfer impedance. This experiment is limited to low frequencies because the measurement leads become a problem at high frequencies. Simulated "noise" current of various frequencies is forced onto the cable shield/drain wire and returned via the ground plane. As a second test, the twisted shielded pair conductors are terminated in low impedance (4 ohms) to form a loop and the resultant current flow is measured via current probe to quantify the normal-mode interference. The tabulated data acquired during the experiment is given in Table 1.

The experimental data confirms that time varying current flow in the shield/drain wire induces a voltage in each shielded conductor consistent with the principle of mutual in-

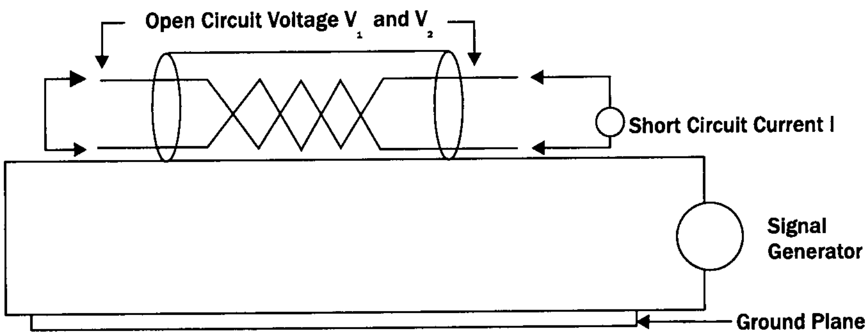

Figure 1. Measuring induced voltage due to shield current.

ductance. However, the data also indicates asymmetrical mutual inductance between the shield/drain wire combination and shielded conductors, resulting in an induced differential-mode voltage in the shielded conductors.

SHIELD CURRENT AT HIGH FREQUENCIES

As the frequency of shield current increases, a point is reached where the current is traveling on the surface of the shield, a current component of a traveling wave. This creates a totally new interference model, fundamentally based on the coaxial cable design. The skin depth of the interfering shield current decreases with increasing frequency and will reach a point where the interfering current and internal signal currents are electrically isolated. Many authors refer to this phenomenon with respect to coaxial cables by stating that the coaxial cable appears to be a triaxial cable at high frequencies.

This triaxial cable model can also be created by increasing the thickness of the shield, thus getting more effective isolation at a lower frequency. Experimental data suggests that most shielded cables begin exhibiting improved isolation between shield current and internal signal circuits at about 300 kHz. In practice, the most troublesome frequencies are from 1 kHz to 20 kHz.

INDUSTRY EXPERIENCE

Currently, the braided shield or thick foil shield is considered superior to a mylar shield with drain wire. The above model and data supports this argument, at least for frequencies up to approximately 300 kHz.

USING EXISTING CABLES FOR EQUIPMENT UPGRADES

Many times, existing twisted shielded pair type interface cables can still be used in equipment upgrades by properly terminating the shields to prevent current flow at low frequencies, charge build-up due to lightning, and RF transmission of interference into a shielded or protected area. This can be accomplished by properly terminating the cable shields for both low and high frequencies, while insuring that a bleed path exists for the induced voltage due to lightning that creates damaging surges.

At one end of the cable, bonding the shield to the surface that best represents the protective shield for the connecting electronics is recommended. This can be a bonding strap or a circumferential connection from the shield to the surface. If a bonding strap is used, the impedance should be less than 5 ohms at the interfering frequency. This will adequately reflect high frequency transients and will also eliminate lightning surge problems.

At the other end of the cable, a shield termination should be placed between the cable shield and the corresponding protective shield, and a low inductance capacitor with less than 5 ohms impedance at 1 MHz (0.01 to 0.03 µF) should be used. In parallel with this high frequency termination, a bleed resistor that is approximately 10 times the shield impedance at 1 kHz (e.g., a 500-ohm, 2-W resistor) is placed to minimize shield current while minimizing induced potential difference between the grounds. A surge protective device is also placed across both the resistor and capacitor, in parallel, to prevent surge damage to the resistor or capacitor in the event of very high level lightning activity. This surge protective device should clamp at 250 to 300 V.

Which end of the shield bonds directly and which end bonds with the terminating impedance is a decision which must be made based on the EMI of all the electronics in the immediate area. This may require evaluation by an expert.

BONDING

In many cases, the shielded cable is run directly into an electronics enclosure and it is not possible to terminate the shield ideally at the external surface of the enclosure. In these cases the shield termination should be placed as close to the cable entrance as possible, making certain that the shield termination is bonded directly to the cabinet or to the point at which the cable carrying conduit or cable tray is bonded. Any pigtails for this bonding should be routed at 90° to and away from any signal carrying conductors.

JUSTIFICATION FOR SHIELD TERMINATING IMPEDANCE

The IEEE 1050-1996 provides guidance in the termination of twisted pair cable shields for EMI immunity with respect to frequency. Included in this discussion is Figure 21, an illustration of multi-point shield grounding with optional impedance (resistance and capacitance) installed in the shield-to-ground connection. Similar terminations are frequently used between isolated circuitry, where a bleed resistor and coupling capacitor are connected between the grounds of the circuits.

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